Improving Feed-in Tariff policy design for solar PV

Learning lessons from the experiences of Greece, Spain and Germany

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General Information

Improving Feed-in Tariff policy design for solar PV : Learning lessons from the experiences of Greece, Spain and Germany

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The present document constitutes the final report of my Master Thesis project for the MSc Programme of Sustainable Energy Technology (SET) in the Technical University of Delft. Therefore, I believe this is the appropriate time to talk about my experiences and express my gratitude to the people that have supported me during the conduction of this Thesis.

This project started almost a year ago, as the final part of my Master studies. Although it was not the first time I had to work on a Thesis Report, I have to admit that it was one of the most demanding but simultaneously inspiring periods of my life. More specifically, the main challenge I have encountered was that, given my engineering background and the renewable policy related topic of the Thesis, I had to obtain a deep knowledge on aspects unfamiliar to me. Nevertheless, it is my belief that, except the high level of academic education I gained, I have also obtained valuable lessons. Completing a Master Thesis in an international Technical University with high esteem among the rest technical universities of Europe, helped me become more systematic, setting high goals and achieving them; I have realized the importance of collecting and elaborating data and information using the international literature and databases, having a more complete view of problems outside the national borders of my country. Moreover, I have learned to receive comments and feedback from people coming from different scientific backgrounds, which enabled me to become more critical.

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Summary

In Directive 2001/77/EC of 2001, the European Union officially recognized the significance of promoting Renewable Energy Sources (RES) as a priority measure. The main reason for this action is the excess in which RES utilization helps in environmental protection, as well as in the sustainable development of the European countries. At the same time, the exploitation of RES also helps in meeting the targets of Kyoto faster.

In 2007, under this Directive, the European countries decided to reinforce the use of RES by setting a target of 20% RES contribution on the total European production of energy by 2020 (European Council Act 7224/1/07, 2007). However, such a target cannot be easily achieved. It needs the implementation of effective policies and support schemes for RES, with feed-in tariffs (FiT) being the most commonly referenced incentive mechanism used by EU countries, together with a serious effort and research in order to improve the energetic efficiency of each source.

A series of environmental and socio-economic benefits result from the use of RES, thus contributing to the formation of a sustainable energy sector. Lower emissions compared to fossil fuels, limited environmental damage and diversification and security of energy supply are only some of these benefits. Among the abovementioned environmental and socio-economic benefits, there are some certain characteristics which make RES a perfect fit into the scopes of the European energy policy and more specifically, to securing the energy supply and the establishment of competitive energy costs and prices, once the security in supply is achieved.

However, in their effort to enter the domestic electricity markets, renewable energies are facing two obstacles: firstly, due to their immaturity, it is very difficult for RETs to enter the market and directly compete with the mature fossil fuel technologies. Secondly, electricity wholesale prices do not take into account the cost of the pollution caused by the use of fossil fuels. As a result, they are not representative of the real cost of electricity production, thus eliminating the environmental benefits occurring from the use of RES instead of fossil fuels. These two reasons, the stimulation of technological change and the environmental externalities, consist the two main rationales for supporting RES through public intervention.

This support, in the case of RES-E, includes financial or other forms of help which beneficiaries which meet certain criteria can receive for providing renewable power (Verbruggen and Lauber, 2012). Support is provided to installed or actually available production capacity (kW) or generated electricity (kWh) and both can be qualified by RE source, technology, ownership or any other feature that can be measured and meet the terms of support. The costs of the support can be charged either to the public budget, with the risk of the latter running dry due to its dependence on political fortune, or to end-users of electricity through electricity suppliers, network companies or electricity generators.

Among the countries contributing in the effort of reaching the target described above are Greece, Spain and Germany. All of them have implemented the FiT policy for supporting

solar PV deployment and each of them ended up with different results of the policy. The main objective of this Thesis is to suggest improvements in the FiT policy design for promoting solar PV based on lessons learned by the experiences of the three countries that have implemented FiTs for achieving such support. This will be achieved by answering the question:

"Which lessons for policy design and implementation can be learned from experiences with FiT policies in Germany, Greece and Spain in order to improve the promotion of solar PV systems without causing undue burdens on their citizens and public finance?"

In order to answer this question, this Thesis starts by setting the agenda, meaning by identifying the problems that require the government's attention and intervention in the promotion of renewable energy technologies in general and more specifically, of solar PV. Moreover, the Thesis formulates the policy, by choosing the policy instrument to be used from a list of solutions, based on the goals set, the identification of the costs and the estimation of the effects of this solution. In order this objective to be achieved, the different supporting measures for electricity production by solar PV systems used in Europe are investigated together with the solar PV technologies currently used, their efficiencies and their costs. Thus, a theoretical policy evaluation framework will be provided.

The tools used for supporting the FiT policy in the chosen countries are also presented, by carrying out three case studies and having first examined whether there is a pattern between the adoption of a solar PV FiT support policy and the learning effects of the technology, in order to justify the choice of the tools. Through the case studies, an investigation of the implementation part of the policy will be carried out, by investigating whether the policy decisions have been carried out as planned and if not, which reasons led to this deflection.

Finally, the evaluation of the use of FiTs for promoting solar PV takes place, by assessing the extent to which the policy has been successful, based on certain criteria found in the literature. Based on this evaluation, the main objective of this Thesis will be achieved, since the lessons learned by the experiences of the three countries will help improve the design of the FiT policy through suggestion of which aspects of the policy should continue, be modified or stop being used.

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1. Introduction

1.1 Background and research problem

In Directive 2001/77/EC of 2001, the European Union officially recognized the significance of promoting Renewable Energy Sources (RES) as a priority measure. The main reason for this action is the excess in which RES utilization helps in environmental protection, as well as in the sustainable development of the European countries. At the same time, the exploitation of RES also helps in meeting the targets of Kyoto faster.

In 2007, under this Directive, the European countries decided to reinforce the use of RES by setting a target of 20% RES contribution on the total European production of energy by 2020 (European Council Act 7224/1/07, 2007). However, such a target cannot be easily achieved. It needs the implementation of effective policies and support schemes for RES, with feed-in tariffs (FiT) being the most commonly referenced incentive mechanism used by EU countries, together with a serious effort and research in order to improve the energetic efficiency of each source.

One of the European countries contributing in the effort of reaching the target described above is Greece. Greece has a considerable potential of renewable energy sources, which can offer a real alternative in order to cover part of the country's energy needs, contribute to the reduction of dependence on fossil fuels, reduce greenhouse gas (GHG) emissions, create new jobs and develop decentralized areas. Furthermore, Greece has a particularly high solar potential of about $1400 - 1800 \text{ kWh/m}^2$ annually in horizontal plane, depending on the latitude and the topology of each area (Technical Chamber of Greece, 2010).

With such high solar potential, one would expect Greece to be one of the leading countries in PV systems installations in Europe. However, this is not happening. Despite the prerequisites of the country for the development and implementation of PV systems, only a small number of installed PV systems existed in 2001, with a total capacity of about 1400 kWp (CRES, 2001). In order to improve the situation, the Ministry of Environment and Climate Change issued a series of measures as part of the long-term energy planning of the country. These measures involved financial strategies for PV systems, like feed-in tariffs and capital subsidies, grants or rebates.

From a technical point of view, these measures could be described as successful, as a remarkable increase was noted in PV systems installed across the country, reaching the impressive number of 2578,8 MWp of total installed capacity in 2013 (Helapco, 2014). However, this number does not reveal the whole truth. During the last years, the Ministry of Environment and Climate Change changed the legislation concerning PV systems installations four times in four years, the last time being in March 2012. But every time, including the last one, the chosen measures failed in successfully promoting RES and achieving energy security and environmental objectives *without* causing undue burdens on the citizens and on public finances. A second reason why the abovementioned measures

failed is the lack of the stakeholders to offer terms of connection, due to network failure and lack of transparent procedures by the Network Operator. The recent financial crisis and the recession that followed only made things worse.

A similar pattern was followed by Spain, but in this case the reasons were slightly different. In 2007 and 2008, Spain experienced an unprecedented boom in the deployment of solar PV modules, due in large part to a generous FiT (del Rio and Mir-Artigues, 2014). This was followed by a spectacular bust, as the government stepped in to reduce the unsustainable costs of the FiT. Eventually, policy changes that were considered retroactive were made, angering investors and becoming the focus of much analysis and criticism among the international policy community.

The principle objective of the FiT was to increase the deployment of solar PV. In the short term, this was indeed achieved. But failing to control costs ultimately damaged the future prospects of rate-payer funded solar PV deployment in Spain and damaged the country's small domestic industry. Spain has completely suspended FiT incentives for renewable electricity and the retroactive incentive reduction policies that have been implemented have affected revenue, cash flow and investment returns for existing operational projects.

On the contrary, Germany seems to have successfully implemented a FiT policy, by setting the right FiTs, having absolute control of the costs and keeping more or less the same policy since 2000, when it was first introduced. But even in this case, a viable and cost-effective introduction of solar energy into Germany's energy portfolio was not succeeded. On the contrary, the government's support mechanisms have in many respects subverted these incentives, resulting in massive expenditures that show little long-term promise for stimulating the economy, protecting the environment or increasing energy security (Frondel et al., 2010). In order to control escalating surcharges on consumer electricity bills, Germany has been rapidly reducing financial incentives for solar PV and has instituted a solar PV financial support limit of 52 GW, at which point incentives will no longer be available for new projects (Brown, 2013).

All three abovementioned countries have used FiTs as the main support policy for the deployment of solar PV systems and the implementation of this policy has been characterized as either successful or not. But the criteria for judging the success of FiTs depend on the policy goals of each country. So, in order to characterize the FiT policy as successful or not, a thorough analysis needs to be carried out, taking into account the performance of FiTs in each country, secondary factors that have either enhanced or undermined it and also, for the cases examined in this Thesis, the possible impact of an economic crisis. Based on this analysis and by learning from the experiences of the selected countries, the policy design of FiTs for promoting solar PV systems can be improved.

1.2 Research objectives – questions

1.2.1 Research objectives

As it has already been mentioned above, the main objective of this Thesis is to suggest improvements in the FiT policy design for promoting solar PV based on lessons learned by the experiences of three countries that have implemented FiTs for achieving such support: Spain, Greece and Germany. In order to achieve this objective, several sub-objectives need to also be achieved and an analysis will be carried out based on the stages of the policy cycle.

The first stage, and thus the first objective of this Thesis, is to set the agenda, meaning to identify the problems that require the government attention and intervention in the promotion of renewable energy technologies in general and more specifically, of solar PV. Moreover, it is a second objective of this Thesis to formulate the policy, meaning to choose the policy instrument to be used from a list of solutions, based on the goals set, the identification of the costs and the estimation of the effects of this solution. In order this objective to be achieved, the different supporting measures for electricity production by solar PV systems used in Europe are going to be investigated together with the solar PV technologies currently used, their efficiencies and their costs. Thus, a theoretical policy evaluation framework will be provided.

The third objective of this Thesis is to present the tools used for supporting the FiT policy in the chosen countries, by carrying out three case studies and having first examined whether there is a pattern between the adoption of a solar PV FiT support policy and the learning effects of the technology, in order to justify the choice of the tools. Through the case studies, a fourth objective of this Thesis will be made clear, which is the investigation of the implementation part of the policy, by investigating whether the policy decisions have been carried out as planned and if not, which reasons led to this deflection.

The fifth objective of this Thesis is the evaluation of the use of FiTs for promoting solar PV, by assessing the extent to which the policy was successful, based on certain criteria found in the literature. Based on this evaluation, the main objective of this Thesis will be achieved, since the lessons learned by the experiences of the three countries will help improve the design of the FiT policy through suggestion of which aspects of the policy should continue, be modified or stop being used.

1.2.2 Research questions

Based on the research problem and objectives of this Thesis, as these have been set above, the main research questions can be classified as shown next, with the main question being: *"Which lessons for policy design and implementation can be learned from experiences with*

FiT policies in Germany, Greece and Spain in order to improve the promotion of solar PV systems without causing undue burdens on their citizens and public finance?"

In order to answer the main research question, several sub-questions have to be answered first. And the best way to start unraveling the story of the support policies for solar PV is to understand why there is so much fuss for RES in general. This will be understood after answering the first sub-question:

SQ1: What is the rationale for RES support policies?

A starting point for the survey concerns the existence or not of a policy, which can provide successful implementation of solar PV systems. Of course, the policy chosen has to be focused on the special needs and specificities of a country. However, there are some general trends in Europe and a number of different forms of financing PV systems which should be taken under consideration. Such trends are capital subsidies, feed-in tariffs, green certificates, net metering, VAT reduction and tax credits. So, the second sub-question concerns the general agenda in Europe:

SQ2: Which are the different supporting measures for electricity production by solar PV systems in Europe?

Another important aspect that should be taken into consideration when designing a support policy is the efficiency of the technology used, as there is a specific energy demand that has to be covered, so, choosing the most efficient technology, based always on the specific needs of the country, is of utmost importance. This choice also determines the economic output of each policy. This field is covered by the next sub-question:

SQ3: Which are the solar PV technologies currently used and which are their costs and efficiencies?

Also, the relationship between the learning effect of the system's cost and a negative network externality effect inherent in the FiT policy will be examined. This will be achieved by answering the fourth sub-question:

SQ4: Is there a pattern between the adoption of a solar PV FiT support policy and the learning effects of the technology?

Finally, there are some key common factors in the policies the three abovementioned countries chose. As it has already been mentioned, Germany is probably the most successful country in Europe to implement solar PV systems, at least until now. Despite its low solar potential, in 2013, the PV-generated power in Germany totaled 30 TWh (Wirth, 2014), covering approximately 5,7% of the country's net electricity consumption. On the other hand, Spain experienced a remarkable increase in PV systems installation in 2007 – 2008, which was followed by an equally remarkable bust, due to changes in the government's policy (del Rio and Mir-Artigues, 2014), while a similar situation occurred in Greece. Therefore, the fifth and final sub-question concerns the similarities and differences between the three countries on the base of the policy chosen and what lessons can be learned by these countries.

SQ5: Regarding the issues raised from the answers of sub-questions 1 to 4, what lessons can be learned from the experiences of promoting energy production by solar PV systems in the following countries: Germany, Spain and Greece?

1.2.3 Research boundaries

By this point, the research objectives of this Thesis have been clarified together with the subjects that are going to be discussed. However, the question arises of to which extent this research goes together with the need to justify some of the choices made. Although some of these matters have already been briefly discussed, it is necessary to present them in a more clear and aggregated way.

Starting with the question regarding *who is the problem owner*, the current Thesis is in the field of policy analysis regarding renewable energy sources and sustainable energy technologies. As a result, all the actors involved in this area are interested in the promotion of renewable energy technologies, however from different perspectives. The RES producers have the goal of maximizing their profits while governments and public policy makers aim to the promotion of new, innovative technologies at the lowest prices for the consumers. As a result, this Thesis has the viewpoint of the government or public policy makers and aims to understand in depth the development of the solar PV sector in Europe through the last years.

Concerning the reasons *why the focus is on solar PV*, these are because this technology seems to be one of the most promising RETs, due to the room for improvement that still exists, together with the fact that solar PVs can be used anywhere the sun shines, thus making them a desirable sector for investments. There is no intention in this Thesis to compare different RES technologies or present solar PV as a superior technology; solar PV was selected based on the interesting current situation which is worth examining.

Regarding the question of the *choice of the FiT support policy for investigation*, this is because several EU countries have supported renewable electricity development through the use of FiT incentives, despite the key challenge of setting a tariff rate high enough to incentivize development and investment in the renewable electricity sector, but not so high as to create windfall profits or stimulate capacity installations that result in power system operational issues and/or cost concerns.

Concerning the *choice of the countries to be studied*, this was based on the different results achieved using the same policy (FiT) for supporting the same technology (solar PV) between countries of similar or completely different potential (solar irradiation). It was of particular interest the fact that, although Germany had the lowest potential of all three countries, it was the country which managed to implement most successfully solar PV systems.

Finally, concerning the *examined period*, this was chosen to be the period from 2006 onwards, since a more systemic way of promoting solar PV was established in all three countries during this period.

1.3 Research relevance - contribution

The solar PV industry would not exist without government policies. Governments around the world have implemented policies to support consumption of solar energy and production of solar PV products. However, these policies vary from time to time and from country to country, providing different results in each case. Moreover, much research has been conducted in order to define the ideal form of such a policy and why the implementation of a policy resulted in unexpected and undesired consequences, with the focus being on certain aspects of the problem each time.

The focus of this Thesis, however, is not on specific flaws of the policy, but rather on the problems occurring when implementing a policy as a whole, in this case, a FiT support policy for solar PV. Unlike other projects, where the focus is on specific aspects of the policy which yielded a series of problems for a certain country, this Thesis aims to investigate the reasons why the FiT support policy faced a number of problems as a whole, even in cases such as Germany, where every aspect had been taken into consideration when designing the policy but still problems occurred, thus providing a useful insight in designing a FiT support policy from an academic point of view. Also, an attempt will be made to provide a conceptual model for the adoption decision of a FiT policy, where both the learning effect and the network effect will be included; a field in which not much research has been done yet.

Moreover, a policy is more than a scientific approach to a problem. It also has a societal aspect. In the case of the FiT support policy for solar PV, this societal aspect is the effort to promote the use of RES for energy production through reaching grid parity. The technical potential of solar PV is large enough to make a significant contribution to greenhouse gas mitigation goals, but the technology itself still requires research, innovation and in some cases still, market deployment. Although the costs of solar PV have decreased substantially, mainly due to government policies, they still have to decrease further in order them to become competitive with conventional energy sources. Various policy approaches have been used all over the world in order to achieve this goal, with varied success. Since the focus of this Thesis is on the results from the application of the FiT support policy in three different cases and the interpretation of the results that occurred in each case, the result of the research can provide policy makers with some lessons and a new framework concerning how a FiT support policy could be improved based on the certain needs of each country.

Summing up, this Thesis thoroughly deals with the main policy instruments for the promotion of RES, stressing the basic features for policy shaping and providing an extensive analysis of the support policy framework. As such, it is addressed to public policymakers, by evaluating the current support policy scheme and more specifically, it presents policy examples and approaches that should be followed or avoided and, in some extent, it can provide directly policy recommendations for the future deployment of solar PV in the three examined countries.

All things considered, the potential contributions of this Thesis can be distinguished in the following categories: first, for the academic community, it proposes a policy support

instruments evaluation framework and second, for the governments and the public policymakers, it provides an evaluation of the existing support scheme and policy recommendations for the future.

1.4 Research methodology and research design

Having described the research problem, as well as the objectives and the research questions, the next step to be taken is the formulation of a design that will guide the research. The first step will be to describe the theoretical framework of the research, defining the main concepts and quoting the theories and frameworks that will be used. The second step will be the methodological framework, where the research strategies and the data collection methods will be presented.

1.4.1 Theoretical framework

In this part, the theoretical framework that will be used for carrying out the analysis is presented, with the development of an organized and scientific way to approach the research questions as its main purpose. The fundamental component of each important political process is the establishment of specific targets for the future on which policies rely upon (Verbruggen and Lauber, 2009). Therefore, an important part of this Thesis is the performance evaluation of the support instruments measuring the distance between the targets set and the results achieved. Such an evaluation may enhance the effectiveness and efficiency of already applied policies and prevent the implementation of ineffective and inefficient ones. Hence, since one of the targets of this Thesis is to understand the wider policy environment, the performance evaluation of the support instruments is justified.

Concerning the evaluation criteria, it can be argued that they cannot be treated in a uniform way. They may vary, depending on the applied instrument, the examined country or the technology. The major complexity is detected on the fact that common criteria, such as effectiveness and efficiency, cannot be defined on a single manner and they often possess multi-layer descriptions. Furthermore, differences on the aspects and the general prism under which authors on the existing literature examine support instruments are noticed. All things together, all available literature in the field of evaluation of RES support schemes can be said that consists of two features: firstly, the viewpoint of the evaluation which is determined in a large degree by the chosen criteria and secondly, the nature of the criteria, which can be either qualitative or quantitative, aiming to a credible and trustworthy assessment. Based on the relevant literature, the most widely applied criteria are effectiveness, cost-effectiveness, dynamic efficiency and certainty. In the context of this Thesis, a combination of both qualitative and quantitative criteria is chosen.

Finally, in this evaluation, apart from the support scheme, other technical, administrative and social aspects will also be taken into account, as policies are implemented in a unique environment, totally different from the ideal circumstances. Therefore, despite the fact that this analysis is positioned within the boundaries of a theoretical debate, it is important that other aspects, closer to institutional economics, should be taken into account with the goal of identifying the influence that political, social and technical factors have on the policy outcome. Such an approach will help obtaining a better explanation and understanding of the policy outcome.

1.4.2 Research framework

Two main research methods are used for the conduction of this Thesis. The first method used is the literature research. Through the collection of existing, relevant and recent information on the topic, the necessary knowledge concerning the function and design of the policy instruments, the regulatory and the surrounding environment on which these operate as well as general aspects regarding solar PV technology, the current state of scientific knowledge on the field will be acquired.

The second method used is the case study, for carrying out the evaluation of the performance of FiT for the promotion of solar PV in the three countries chosen. Through the case study, valuable insights can be provided concerning the regulatory framework of solar PV in the chosen countries, the main actors involved and their main interests. Moreover, the case study portrays the primary and secondary design elements of the support policy instrument used and the overall results of the aforementioned regulatory framework and the support policy instrument.

1.4.3 Data collection

Concerning the data collection, the method used is the collection and analysis of already existing data. The necessary material for this research will be gathered from primary and secondary publications, as well as national and international databases and websites of national and international organizations and associations of photovoltaic companies.

1.5 Outline of Thesis

The thesis consists of 11 chapters. In Chapter 1, an introduction to the research topic and the main questions that will be answered is made. Chapter 2 investigates the rationale for RES support policies, where the main drivers for using and supporting RES are presented and shortly analyzed. Chapter 3 presents and briefly analyzes the policies applied in the EU for supporting RES-E, with the focus being on the support policies concerning RES-E by solar PV. In Chapter 4, the PV technologies currently used in solar PV applications are presented and their technology status and performance are analyzed. The various solar PV applications are also presented and shortly discussed, as well as the current costs and costs projections of the solar PV systems using various PV technologies. Moreover, the Levelised Cost of

Electricity (LCOE) for solar PV is discussed. In Chapter 5, a general technology adoption model of solar PV under FiT policy incorporating learning and network effects is discussed, as well as the results of applying this model in the three case studies and the reasons of the differentiated results are analyzed. In Chapters 6, 7 and 8, the case studies for the cases of Greece, Spain and Germany are carried out and in Chapter 9, a comparative analysis on the results of the case studies provides the main conclusions occurring for the FiT support policy for solar PV systems. Chapter 10 delivers the conclusions of the Thesis, with answers to the research questions. Finally, Chapter 11 delivers the reflection on the research boundaries, the methods and approaches used for the research and on the results.

2. Rationale for RES support policies

Fostering the use of RES is a key issue for achieving the long-run objectives of the European energy policy. However, despite the considerable progress that has been achieved in several renewable energy technologies, others are still immature or have not yet reached an adequate level of economic performance and therefore, they cannot yet compete directly with the existing fossil-fuel technologies. As a result, a public intervention in the renewable energy policy is justified and this intervention is achieved through support policies for RES. Prior to presenting the major support policies for the promotion of RES-E in Europe, a brief analysis on the need for such support policies and why this need is so urgent needs to be carried out in order to give an overview of the issues that deserve the most attention and define the nature of the problem. It is the object of this chapter to present the main drivers for using RES and the rationale for their support.

2.1 Main drivers for using RES

Renewable energy sources provide a series of environmental and socio-economic benefits, thus contributing to the sustainability of the energy sector. Concerning the environmental benefits, RES have lower emissions of several pollutants compared to fossil fuels, both locally and globally (del Rio, 2008). As a result, the deployment of RES can help the OECD countries meet their Kyoto Protocol targets, among which the climate change mitigation consists the major policy goal. Furthermore, RES can substitute conventional energy sources, thus limiting the environmental damage caused by the conventional electricity generation techniques, as it can provide better results than the "inefficient end-of-pipe solutions" currently used for the control of greenhouse gas (GHG) emissions (Menanteau, 2003). On top of this, RES can help in the efforts for the mitigation or even the avoidance of a number of health problems and impacts on the ecosystems caused by the extraction, the transportation, the processing and the use of many fossil fuels (van Dril, 2011).

Despite the low attention that they have received compared to the environmental benefits, the socio-economic benefits of RES are also important. Diversification and security of energy supply, improved opportunities for development both in a rural and a regional level, formation of a domestic industry with an export potential and employment options are some of the benefits which have already been proven important in countries where high levels of renewable development have been realized (del Rio, 2008). In certain cases of developed countries, these benefits were used for the political justification of implementing RES support policies. One characteristic motivation for supporting RES development in developing countries is the option they offer for decentralized energy by enabling the access to energy and electricity supply for isolated and distanced areas which otherwise cannot be reached by the electricity grid at a reasonable cost. As a result of this, the migration from

rural to urban areas reduces and chances for employment and capacity building locally occur.

Finally, RES can play an important role in a comprehensive global strategy aiming to the elimination of energy poverty (van Dril, 2011). On top of the current energy system being environmentally unsustainable, it is also highly unequal, with 1.4 billion people without access to electricity and 2.7 billion people dependent on traditional biomass for cooking.

Among the abovementioned environmental and socio-economic benefits, there are some certain characteristics which make RES a perfect fit into the scopes of the European energy policy. The fundamental aim of most EU member countries is the security of energy supply. A sustainable energy supply is required for the EU citizens, which has been traditionally interpreted in an "interior dimension", namely by avoiding "black- and brownouts in the provision of electricity in a national, as well as in a regional level" (Ringel, 2006). An exterior dimension has also been ascribed to this aim after the oil crisis of the '70s, as a reduced dependence on imported primary energy sources is required for protecting the domestic supply. In addition, the current highly carbon-intensive energy systems depend on a finite supply of fossil fuels, the extraction of which is getting more difficult and more expensive and leads to further concerns about the national security of a number of countries (van Dril, 2011). RES on the other hand, are domestic energy sources that are not finite, thus supporting the goal of import independence (Ringel, 2006).

The second, probably, most important goal of the energy policy in the EU is the establishment of competitive energy costs and prices, once the security in supply is achieved. In the EU, as well as in all industrialized countries, competitive energy prices are defined as cost-oriented, thus leading to a transition from state-owned monopolies to liberalized energy markets (Ringel, 2006). This liberalization of the energy supply market was triggered by the comparisons between the prices in the regulated markets of Europe and those in the liberalized markets in England, Wales and several US states, which revealed that the liberalized markets reached the target of cost-orientation far better compared to the regulated systems. A short term and a medium/long term perspective need to be taken when investigating the contribution of RES to this target. In the short run, RES can compete with neither the investment cost and the amortized period of traditional power plants nor the variable power production costs of fossil fuels and nuclear energy. However, in the long run, a return to domestic energy sources might contribute in achieving low-price electricity supply, especially in the case where the energy needs of Europe increase and the continent continues to be under import dependence, thus vulnerable to the fluctuations in prices.

Concerning the deployment status of RET markets, the following general categorization can be used (Steinhilber, 2011), which is also illustrated in Figure 1:

• <u>Immature RET markets</u>: These markets are characterized by small sizes, few market players and low growth rates. The local, regional and national administrations have little experience on the use and promotion of the RET in question, and so do the energy companies and the local project developers, while local banks are also needed for financing. Moreover, typical barriers exist preventing the entrance of the

RET in the market, e.g. long and non-transparent permitting procedures, grid access barriers, etc.

- Intermediate RET markets: These markets have increased sizes and are usually accompanied by strong market growth and the interest of many players. The energy sector, the administration and the parties involved in the financing of the technology have gained experience, as the increased size of the market proves. However, if the market growth is fast, then growth-related market barriers might occur, like infrastructural and supply chain bottlenecks.
- <u>Advanced RET markets</u>: These markets are characterized by established market players and fully mature technology. At this stage, the market growth may start to slow down and the market players may face typical high-end barriers, like competition for scarce sites and resources, since the most cost-effective RES potential will have been increasingly exploited.

2.2 Rationale for supporting RES

In their effort to enter the domestic electricity markets, renewable energies are facing two obstacles: firstly, due to their immaturity, it is very difficult for RETs to enter the market and directly compete with the mature fossil fuel technologies. Secondly, electricity wholesale prices do not take into account the cost of the pollution cost caused by the use of fossil fuels. As a result, they are not representative of the real cost of electricity production, thus eliminating the environmental benefits occurring from the use of RES instead of fossil fuels. Based on these, there are two main rationales for supporting RES through public intervention: the stimulation of technological change and the environmental externalities.

2.2.1 Stimulation of technological change

"A transition is the result of developments in different domains and can be described as a set of connected changes, which reinforce each other, but take place in several different areas, such as technology, the economy, institutions, behavior, culture, ecology and belief systems" (Rotmans, 2001). A successful transition is caused by independent developments, but even if this transition is multi-dimensional, with different dynamic layers, it is still necessary for several developments in different domains to come together to reinforce each other. Four different transition phases can be distinguished (Figure 1):

- 1. A *pre-development phase* of dynamic equilibrium, where there is no visible change of the status quo.
- 2. A *takeoff phase*, where the state of the system begins to shift.
- 3. An *acceleration phase*, where "visible structural changes take place through an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other". During this phase, collective learning processes, diffusion and embedding processes arise.

4. A *stabilization phase*, where the speed of social change decreases and a new dynamic equilibrium is reached.

This scheme is used in this sub-chapter in order to analyze the steps that need to be taken for a transition from fossil fuels to RES.

For the accomplishment of a transition from a conventional fossil fuel energy sector to a renewable energy one, it is essential to promote the diffusion of sustainable energy technologies on a global scale (Gallagher, 2014). However, in order to secure the development of sustainable energy technologies, the involvement of the government is crucial in the emergence phase, in order to protect them from directly competing with the conventional technologies (Menanteau, 2003). Other barriers also exist for the diffusion of RES, resulting from their economic and technical characteristics. Such barriers include their capital-intensive profile, their size limitations which cause the mobilization of mass production effects instead of scale effects and, in certain cases, their inability to continuously generate energy (Menanteau, 2003). Furthermore, in the new liberalized electricity markets, generation technologies which are the least capital-intensive and have continuous and stable energy supply are favored, while the technological culture of the established electric utilities favors large systems, thus causing RES-E technologies to have a lower value for the market actors compared to e.g. a gas turbine, which can continuously generate power. As a result, public support is needed for fostering the technological progress in RES and ultimately achieving optimum performance.



Note: The figure includes generalised technology classifications. In most cases, technology will fall in more than one category for any given time.

Figure 1 Policies for supporting RETs (van Dril, 2011)

Without such support and based only on the forces of the market, the diffusion of RES would be narrowed to a small number of market niches, thus making it difficult for them to benefit from dynamic learning effects and become competitive. For succeeding in this, a process of cumulative industrial learning is needed (Gallagher, 2014). "In the energy industry, the diffusion of a technology depends on the absorptive capacity of the receiving country, which, in turn, is understood as a set of different abilities ranging from production to innovation capabilities". The under-deployment of sustainable energy technologies by markets makes the formation of market policies essential for accelerating their diffusion and correcting their improper valuation. For executing such policies, various means and tools exist and are used for stimulating the innovation process, having as a starting point the research, development and demonstration (RD&D). Such policy tools are feed-in tariffs (FiTs), carbon taxes, cap-and-trade schemes, performance standards and the creation of niche markets through supply. So, the governmental support of RES can be summarily justified as "a way of correcting the negative externalities resulting from using fossil fuels and achieving dynamic efficiency by stimulating the technological change" (Menanteau, 2003).

More specifically, despite the considerable progress that has been recorded in a number of sustainable energy technologies, a large number of them is still in an immature level or have not reached a sufficient level of economic importance (Menanteau, 2003). Even creating the conditions for competition between fossil fuels and RES cannot guarantee a dynamic diffusion of the latter, despite them reflecting the private and social costs. This is because renewable energy technologies, as they are still new technologies, have to compete with the established, technologically superior and long-lasting used fossil fuel technologies, which are mature and have reached their optimum performance in terms of both cost and reliability, due to the mass production and the learning effects of their long-lasting use. This places SETs in an unfavorable position, as for them, optimum performance will be achieved through a process of learning by using or learning by doing.

The importance of the learning effects, which refer to "the tendency of the costs of new technologies to decline as cumulative production or cumulative investment in R&D and resulting in an increase of the experience and the know-how" (van Dril, 2011) is shown in

. According to this table, a decline in the range of the percentages concerning the investment costs of various technologies occurs when doubling the cumulative production capacity. For example, in the case of solar PV, the investment costs decline on average by 18 – 28% when the production capacity is doubled, while for advanced coal, the decline is lower (5 – 7%). Generally, the learning rates for less mature energy technologies like SETs, whose cumulative production capacity or knowledge stock are usually much smaller compared to those of conventional technologies, are higher resulting in a high possibility for the investment costs, and hence, the total production costs, to decline much faster over time.

Since a particular technology has to be adopted in order to become efficient, incentive systems are required in order SETs to be adopted in an extend larger than the narrow market niches and achieve progress on their learning curves. Taking a step further, larger producer surpluses should be permitted at the early stages of their introduction in the

Technology	Investment cost reduction (%)
Advanced coal	5-7
Natural gas combined cycle	10-15
New nuclear	4-7
Fuel cell	13-19
Wind power	8-15
Solar PV	18-28

Table 1 Learning rates of electricity-generating technologies (van Dril, 2011).

Furthermore, the support policies for RES are characterized by their efficiency (Menanteau, 2003). Considering that a coherent framework is implemented for the national support policies for RES, in which certain targets are set for each technology, depending on its cost function, the efficiency notion gains two meanings. On the one hand, it entails an effort of minimizing the total cost, so that the cost-effectiveness target can be reached, as it is not possible to use an environmental damage curve for defining the optimum level of environmental externalities reduction (*static efficiency*). On the other hand, it entails the creation of permanent incentives for cost reductions through technical progress, in order to achieve competitiveness (*dynamic efficiency*).

2.2.2 Environmental externalities

As external costs of the energy sector are characterized "those costs that the energy producers and consumers impose on others, without paying the consequences, including the impacts on air, waste and water pollution and of climate change" (European Environment Agency, 2005). These external costs are not included in the conventional market prices for electricity, causing the social costs to be higher than the private costs, thus contributing to inefficiencies in the decisions concerning the allocation of resources. Such negative externalities include both the current and future health impacts of various pollutants, as well as the costs needed for adapting to the climate change and the ocean acidification resulting from the CO₂ emissions (van Dril, 2011). Concerning the second rationale for RES support policies, this lies mainly on the positive externalities that RES generate and their role in stimulating the learning process. Starting with the first justification, the contribution of RES to the preservation of clean air and climate stability provides them with an important advantage over conventional energy generation (Menanteau, 2003).

However, these public goods have non-excludable and non-rival characteristics which cause private actors to be skeptical about investing on something that anyone could get for free, and resulting in an uncertainty concerning the spontaneous diffusion of RES in the market (Menanteau, 2003). The liberalization of the electricity market enabled the consumers who were willing to pay for RES-E to purchase green electricity directly by the supplier. However, most consumers are not yet willing to pay for a public good from which everyone will benefit, while the free-riding problem also exists. The proportion of green electricity buyers appears to be very low, around 2 - 3%, unless there are strong incentives, e.g. tax exemptions for green electricity consumers, without these numbers actually reflecting the real value that the public places on the protection of the environment through electricity generation using RES. This is a market failure, which could be solved by introducing regulations on fossil fuel emissions which would encourage the use of RES in a larger extent, since so far, the negative externalities resulting from the consumption of energy produced using fossil fuels are reflected imperfectly in the energy prices.

Traditional fossil fuel systems, such as coal, oil and, to a lesser degree, natural gas, demonstrate the highest external costs for electricity generating technologies, as shown in . These costs range from $1.1 \notin kWh$ for advanced gas technologies, when the lower bound estimate of damage costs in $\notin kWh$ is used, to $25.9 \notin kWh$ for traditional, coal-ignite plants when the higher bound estimate of damage costs is used (European Environment Agency, 2005). These external costs in most cases are internalized through environmental taxes and charges or tradable permits. However, internalization of all external costs for getting the full cost of pricing in the European energy sector would be difficult, given the range of existing energy subsidies acting to distort the energy prices, even before the consideration of externalities.

In Figure 3, the additional cost in US cents per kWh of energy produced by the most common renewable and fossil sources over facility lifecycles are presented, categorized into costs in terms of health impacts and costs due to climate change and the wide range of estimates available for both categories of external costs is shown. The differences between external costs from fossil-fuel electricity and RES-E on the graph appear smaller than they really are, due to the use of a logarithmic scale (van Dril, 2011). Furthermore, Table 2 is an example of how the economic competitiveness of RET in the EU could be increased by incorporating the external costs of CO₂ emissions. By providing a range of estimates for various technologies under a moderate fuel-price scenario, Table 2 illustrates the way some sources of RES-E, hydro and wind energy, can compete with fossil fuels and nuclear technologies in the EU. So, it can be concluded that public support to RES-E can be justified as a temporary compensation for avoiding negative externalities and should end when the taxes on the various forms of energy start reflecting the marginal cost of the damage caused by using fossil fuels (Menanteau, 2003).







External Costs [US\$ cent/kWh]

Figure 3 External costs of energy sources related to global health and climate change (logarithmic scale) (van Dril, 2011)

Energy	Power generat	ion			-					
source	e technology		Production cost of electricity (COE)				Lifecycle GHG emissions			
			State-of-the- art 2007 (€2005/MWh)	Projection for 2020 (€2005/MWh)	Projection for 2030 (€2005/MWh)	Net efficiency 2007	Direct (stack) emissions kgCO2/MWh	Indirect emissions kgCO2eq/MW h	Life cycle emissions kgCO2eq/ MWh	Fuel price sensitivity
Notural	Open cycle gas turbine (GT)	-	65-75 ^b	90-95 ^b	90-100 ^b	38%	530	110	640	very high
Gas	Combined cycle	-	50-60	65-75	70-80	58%	350	70	420	very high
Guo	gas turbine (CCGT)	CCS	n/a	85-95	80-90	49% ^c	60	85	145	very high
Oil	Internal combustion diesel engine	-	100-125 ^b	140-165 ^b	140-160 ^b	45%	595	95	690	very high
UII	Combined cycle oil- fired turbine	-	95-105 ^b	125-135 ^b	125-135 ^b	53%	505	80	585	very high
	Pulverised coal combustion (PCC)	-	40-50	65-80	65-80	47%	725	95	820	medium
		CCS	n/a	80-105	75-100	35% ^c	145	125	270	medium
Coal	Circulating fluidised bed combustion (CFBC)	-	45-55	75-85	75-85	40%	850	110	960	medium
	Integrated gasification combined cycle (IGCC)	-	45-55	70-80	70-80	45%	755	100	855	medium
		CCS	n/a	75-90	65-85	35% ^c	145	125	270	medium
Nuclear	Nuclear fission	-	50-85	45-80	45-80	35%	0	15	15	low
Riomass	Solid biomass	-	80-195	85-200	85-205	24%-29%	6	15-36	21-42	medium
DIOIIIdSS	Biogas	-	55-215	50-200	50-190	31%-34%	5	1-240	6-245	medium
Wind	On-shore farms	-	75-110	55-90	50-85	-	0	11	11	Nil
	Off-shore farms	-	85-140	65-115	50-95	-	0	14	14	
Hydro	Large	-	35-145	30-140	30-130	-	0	6	6	Nil
	Small	-	60-185	55-160	50-145	-	0	6	6	
	Photovoltaic	-	520-850	270-460	170-300	-	0	45	45	Nil
Solar	Concentrated solar power	-	170-250 ^d	110-160 ^d	100-140 ^d	-	120 ^d	15	135 ^d	low

Table 2 Energy technologies for power generation in the EU – moderate fuel-price scenario (van Dril, 2011).

^bCalculated assuming base load operation. ^cReported efficiencies for carbon capture plants refer to first-of-a-kind demonstration installation that will start operating in 2015. ^dAssuming the use of natural gas for back-up heat production.

2.3 Summary

A series of environmental and socio-economic benefits result from the use of RES, thus contributing to the formation of a sustainable energy sector. Lower emissions compared to fossil fuels, limited environmental damage and diversification and security of energy supply are only some of these benefits. Among the abovementioned environmental and socio-economic benefits, there are some certain characteristics which make RES a perfect fit into the scopes of the European energy policy and more specifically, to securing the energy supply and the establishment of competitive energy costs and prices, once the security in supply is achieved.

However, in their effort to enter the domestic electricity markets, renewable energies are facing two obstacles: firstly, due to their immaturity, it is very difficult for RETs to enter the market and directly compete with the mature fossil fuel technologies. Secondly, electricity wholesale prices do not take into account the cost of the pollution cost caused by the use of fossil fuels. As a result, they are not representative of the real cost of electricity production, thus eliminating the environmental benefits occurring from the use of RES instead of fossil fuels. These two obstacles, the stimulation of technological change and the environmental externalities, consist the two main rationales for supporting RES through public intervention.

This support, in the case of RES-E, includes financial or other forms of help which beneficiaries which meet certain criteria can receive for providing renewable power (Verbruggen, 2012). Support is provided to installed or actually available production capacity (kW) or generated electricity (kWh) and both can be qualified by RE source, technology, ownership or any other feature that can be measured and meet the terms of support. The costs of the support can be charged either to the public budget, with the risk of the latter running dry due to its dependence on political fortune, or to end-users of electricity through electricity suppliers, network companies or electricity generators.

3. Support policies for RES-E in the EU

3.1 Agenda of EU on RES

In line with the global trends of sustainable development and environmental protection, and in order to meet the Kyoto targets faster, the European Union set as a major target the increase in the share of renewable energy for electricity generation. With the Directive 2001/77/EC on renewable energies on the electricity sector in 2001, the EU set the goal of increasing the share of RES-E in the electricity mix of the European Union members from its 12% value in 1997 to a 21% by 2010, by issuing a series of challenging indicative national targets (Haas et al., 2011). In 2007, a new target (the European Council act 7224/1/07) was adopted according to which, 20% of the EU's energy consumption (electricity, heating/cooling and transportation) should be achieved by renewable energy by 2020 (EREC, 2008). In 2008, the Directive 2009/28/EC on the promotion of the use of energy from Renewable Energy Sources set the legislative framework to support this target. Furthermore, this Directive set mandatory national targets for the total share of RES in gross final consumption of energy, as well as a mandatory share of 10% RES in transport for each Member State (EREC website, 2015).

However, as it has already been mentioned, the cost disadvantage of RES compared to fossil fuels due to environmental externalities and technological immaturity of RES is causing constrictions. Moreover, in order such an ambitious goal as the abovementioned to be achieved, a number of support policies needs to be set and undertaken by the Member States; effective policies that will encourage the installation of energy generation systems based on RES by providing solid incentives, improve the energetic efficiency of the Member States and at the same time will be based on the potential and specific needs of each country.

A number of such support policies exist, with a first categorization of them being between direct and indirect promotion strategies. Direct promotion strategies target to the fast stimulation of RES, while the indirect focus on the diffusion of RES through the establishment and improvement of a long-term framework (Haas et al., 2011). A second categorization is between regulatory and voluntary promotion strategies. Direct promotion strategies are further divided into price or quantity driven and investment or generation focused promotion strategies.

Although the focus of this Thesis is on FiT support policy, as this is one of the dominant support policies for RES in EU, this chapter gives a brief description of the main support policies for RES in the EU in order to give a more complete view on the subject of RES policy. The chapter also focuses on the support policies used specifically for the support of solar PV technologies in the EU.

3.2 Main support policies for RES in the EU

In order to support and increase the penetration of Renewable Energy Technologies in the energy markets of the EU members, a number of policy schemes have been applied. All of them have the same objective: to substitute compatible forms of energy with their equivalent sustainable. As a result, their focus is to trigger investment in new, sustainable capacity (Haas et al., 2004). The various policy schemes that have been applied in the EU can be classified in a number of categories, based on specific characteristics. A first and fundamental distinction is between direct and indirect support policies (Haas et al., 2011).

3.2.1 Direct support policies

Direct support policies focus on the immediate stimulation of RES-E, while indirectly aim to improve the long-term framework (Haas et al., 2011). Direct policy measures can be further sub-categorized into price-driven and quantity-driven policies. Another classification can be between regulatory and voluntary policies, with the latter being based on the willingness of the consumers to pay premium rates for green electricity. In turn, these two categories can be sub-categorized into investment focused and generation based. The above policy classification is summarized in Table 3.

		Dir	Indirect	
		Price-driven	Quantity-driven	
		Investment incentives		Environmental taxes
	Investment focused	Tax credits	Tendering system for investment	Simplification of authorisation procedures
Regulatory		Low interest/soft Ioans	grant	Connection charges, balancing costs
	Generation . based	(Fixed) Feed-in tariffs	Tendering system for long- term contracts	
		Fixed premium system	Tradable green certificate system	
		Shareholder		
	Investment focused	programs	-	
Voluntary		Contribution		Voluntary
		programs	-	agreements
	Generation based	Green tariffs		

Table 3 Fundamental types of promotion strategies (Haal et al., 2011).

These policies are most of the times only a part of the support scheme, with their combination leading to the major support scheme of the various EU Members. Two main categories of policy types can be distinguished as shown in Table 4.

Table 4 Policy types used in the EU (I	Kitzing et al., 2012).
--	------------------------

Major support instruments
Feed-in tariffs (FiT)
Feed-in premiums (FiP)
Tenders (TND)
Quota obligations with tradable green certificates (TGC)
Supplementary support instruments
Investments grants (INV)
Fiscal measures (TAX)
Financing support (FIN)

3.2.1.1 Regulatory policies

As far as the regulatory price-driven policies are concerned, these refer to financial support for generators of electricity from RES. This financial support can be in the form of a subsidy per kW of capacity installed or a payment per kWh produced and sold. The major strategies in this category are investment focused strategies and generation based strategies (Haal et al., 2011). In the first case, the financial support is in the form of investment subsidies, soft loans or tax credits, most of the times per unit of generation capacity. In the case of generation based strategies, the financial support is a fixed regulated Feed-in-Tariff (FiT) or a fixed premium, meaning a payment per unit of generated energy, which is obliged by the law to be paid from a governmental institution, a utility or a supplier to the generators that meet specific standards.

FiTs, net metering and premiums

The difference between fixed FiTs and premiums lies in the fact that although for fixed FiTs the total feed-in price is fixed and nominal (without inflation correction) for every kWh of RE produced (Verbruggen and Lauber, 2012), for premiums the amount that is fixed is the one that will be added to the electricity price (Haal et al., 2011). So, FiT systems do not support the quantity of electricity which is fed into the grid, but rather the quantity of renewable power which is generated (Verbruggen and Lauber, 2012). This means that in the premium scheme, for the owner of a renewable plant, the total price received per kWh (electricity price plus the premium) is less predictable, compared to the FIT scheme, as it depends on the electricity price, which is unpredictable (Haal et al., 2011).

Moreover, in the FiT scheme, the price offered is not only fixed, but also differentiated to different forms of renewable energy generation. This price is usually combined with the requirement for grid operators or other incumbents to connect the renewable power generators and also purchase all the renewable electricity which they tender at this price (Verbruggen and Lauber, 2012). So, under a FIT, the generators are comfortable that they

will sell the electricity they produce (diminishing market risk for the producer), while in the case of premium policies, the only thing that is guaranteed is the add-on amounts over the electricity price, leaving the underlying risk unchanged (Kitzing et al., 2012). Furthermore, the FIT rates are set in a yearly base, for the year's new set of installations and do not change for a certain period. They also depend on the conditions of the resource, e.g. solar irradiation or wind availability, as well as on the socio-political situation of the countries (Campoccia et al., 2009). For each such set installed in subsequent years, new and usually lower rates are set in order to keep up with the technological progress and the price of the equipment needed for renewable energy generation (Verbruggen and Lauber, 2012).

On the other hand, in the case of renewable plants generating power for their own use, as well as in the case of "net metering", the difference between the quantity of electricity fed into the grid and the renewable power generated becomes of importance (Verbruggen and Lauber, 2012). This is because what net metering does is to measure the difference between the generated renewable power and the power used in site over a specific time-period, e.g. a month or a year. This is the net quantity that is exchanged with the grid, which, when positive, can be sold to the grid, most of the times at retail prices.

The reason why net metering was created was that a solution had to be found concerning the case where residential customers had installed RE systems at their houses, thus exchanging electric energy with the grid. With the standardized protocol of net metering, the customers are able to counterbalance their electricity consumption with electricity produced by small-scale RES over an entire period, which they can consume any time they wish and not only when this energy is produced and store the rest in the Utility's grid (Campoccia et al., 2009). In order this to be achieved, a bi-directional energy meter which measures the electricity flow in both directions is used, as it is shown in Figure 4. There, the energy E that is produced by the RES-based generators in injected into the grid at $t=t_0$ (Figure 4a) and an equal amount of energy is absorbed by the grid at $t=t_1$ (Figure 4b). So, the grid acts like an infinite energy storage system. Moreover, since the ingoing and outgoing energy flows have the same economical value, the electricity bill of the customer is not affected by the double exchange of energy. This system can also be of advantage to the utilities, since the system load factor can be increased as the customers are producing electricity during peak periods.



Figure 4 The net metering mechanism. (a) At $t=t_0$, the energy E produced by the RES-based generator is injected into the grid. (b) At $t=t_1$, an equal quantity E is absorbed by the grid. (Campoccia et al., 2009)
Furthermore, in theory, a mechanism based on a fixed premium or an environmental bonus could lead to fair trade and competition, as well as a competitive electricity market between RES and conventional power sources. However, in order to achieve this, this premium or bonus should reflect the external costs of conventional power generation. Using a market development perspective, this would allow a fast penetration of RES in the market, under the condition that their cost would fall below the electricity plus premium price. Setting the premium at the right level, probably equal to the external costs of conventional power, would allow the competition between RES and conventional energy sources without the existence of "artificial" quotas to be necessary (Haas et al., 2011). Together with taxes on conventional power sources, which will be based on their environmental impact, well-designed fixed premium policies are, in theory, the most effective way to internalize external costs.

However, the reality is different. Basing the policy on the environmental benefits that RES offer is a challenging task, as setting the exact costs is very complex. In practice, fixed premiums for renewable energy technologies are not the environmental benefits of RES, but rather a comparison between them and the electricity price and are based on the estimations concerning the production costs of renewable energy.

Tendering systems and TGCs

As far as the regulatory quantity-driven policies are concerned, in this case the quantity is set and the price is decided by the market (Haal et al., 2004). The quantity or desired level of generation or market penetration of RES (this is a quota or a Renewable Portfolio Standard) is defined by the government or other public authorities. Two sub-categories can be found: tendering systems for long term contracts and a tradable green certificate system, better known as a TGC system in Europe (Tradable Green Certificates system) and RPS (Renewable Portfolio Standards) in the US and Japan (Haal et el., 2011). In the first case, calls for tenders are launched for specific capacities. The winners of the contracts result from the competition between the bidders and they receive a guaranteed tariff for a specific period of time by the public authorities. As "attractive" are considered the bids which have a low request for support as well as other attractive specifications, e.g. small timing of the project, favorable position in the grid, etc. (Kitzing et al., 2012). The difference between the higher prices of the supply of renewable energy and the standard prices of conventional electricity is covered by the expenditures by the public budget or the contributions from electricity customers (Verbruggen and Lauber, 2012). This difference is theoretically kept at its lowest possible value under the condition that markets and auctions work well and as a result, so does the competitive process. Tendering systems, in most cases, are combined with another policy scheme, with the authority planning and the investor risk depending on the various combinations (Kitzing et al., 2012).

In the case of TGCs, a certain amount of electricity (the quota obligation) has to be supplied or purchased from RES by those involved in the electricity supply chain, e.g. generators, wholesalers, distribution companies or retailers. This renewable energy quota are translated into a number of certificates which are calculated as a percentage of the total MWh of sales or production and need to be submitted at the date of settlement. These certificates can be obtained by generating renewable energy and by purchasing renewable energy and/or certificates from other generators (Haal et al., 2011). Principally, one certificate is assigned to every RE MWh that is generated by a source on the EU list by a designated regulator (Verbruggen and Lauber, 2012). In the case where there are not sufficient certificates provided, the penalty must be higher than the expected market price of TGCs. The price of TGCs is set on a specific market, like NordPool (Haal et al., 2011) and is usually equal to the net marginal cost of the project that fulfills the certificates in order to meet the quota (Verbruggen and Lauber, 2012). In the case where the costs for certificates are much higher than the TGC market price or the penalty price, it is possible to be covered by the public budget. However, most of the times, these costs are charged to the grip operators or the suppliers who, in turn, incorporate it in the network tariffs, transferring them on the bills of their customers.

TGC schemes can either be uniform or differentiated concerning the certificates provided per unit of electricity generated (Kitzing et al., 2012). In a uniform scheme, the same number of certificates per unit of electricity generated is provided for all technologies (e.g. in Sweden, Belgium and Polland), while in a case of a differentiated scheme, specific technologies are provided with more certificates per unit of electricity generated, a process also called *banding* of certificates (e.g. in the UK, Romania and Italy).

The TGC support scheme assumes perfect competition among the standard electricity markets, justifying this assumption by pointing out that certificate prices should be on top of the prices the physical electricity traded in the power market (Verbruggen and Lauber, 2012). Based on this, the purpose of the scheme is to reward the green renewable electricity, by creating a liquid market for certificates in addition to the sales of physical power. However, in practice, the system did not work the way it was predicted to, as it performed well only under the condition that it was limited to only one technology in a limited area and was also based on additional funding mechanisms. On the other hand, there are cases like Sweden, where the use of *bankable* certificates, meaning certificates that under certain circumstances can be transferred from one compliance period to the next, increased the stability of the market of TGCs and made the system more efficient (Kitzing et al., 2012).

Other support policies

Other forms of regulatory policies are investment grants, fiscal measures and financing support. Investment grants are a form of financial support provided by either governmental or European institutions to investors in RE projects (Kitzing et al., 2012). They have the form of non-reimbursable payments given during the construction phase of the project. Investments grants aim to assist the construction of the project, thus they do not directly target the amount of RES-E generated. However, in most cases, there are certain conditions for investment grants to be given, e.g. the fulfillment of specific standards of performance or successful integration and connection of the project to the grid.

Financial support comprises of a number of support mechanisms, defined as "financial engineering instruments" (Kitzing et al., 2012). These can be reimbursable investments on equities, grants of venture capital by governmental institutions or debt financing, e.g. in the

form of loans with low interests to RE projects, provided by governmental financial institutions. The most recent such mechanisms include equity guarantees, Mezzanine finance (hybrids of equity/debt), securitization products (CDSs) and loan guarantees provided, amongst others, by the European Investment Bank (EIB). The aim of these mechanisms is to assist the RE projects investors in their efforts to get access to the capital market and obtain adequate finance, thus increasing the possibilities for investment of such projects and providing renewable growth at the lowest cost of support.

3.2.1.2 Voluntary policies

The base of this policy is the willingness of consumers to pay premium rates for renewable energy, e.g. due to concern for Global Warming (Hall et al., 2011). Here, too, there are two main sub-categories: investment focused and generation based policies. From the investment focused policies, the most important are shareholder programs, donation projects and ethical input, while for the generation based, the green electricity tariffs, with and without labeling is the most important policy.

3.2.2 Indirect support policies

Indirect strategies, as is stated by their name, indirectly impact the spreading of renewables (Haal et al., 2011). The most important of these are eco-taxes on electricity produced with non-renewable sources, taxes/permits on CO_2 emissions and removal of subsidies previously given to fossil and nuclear generation. Concerning the promotion of electricity from RES through energy or environmental taxes, either the exemption from taxes can be used or, if there is no exemption for electricity produced from RES, these taxes to be partially or wholly refunded. Both of them will improve the competitiveness of RES in the market and they can also be used not only for old but also for new plants.

The institutional promotion of the development of RES plants like planning of sitting and easy connection to the grid, as well as the operational conditions of feeding the electricity into the system also lie in this category and are of particular importance in the case of intermittent energy production.

3.2.3 Overview of the main support policies for RES in the EU

An overview of the primary and supplementary support mechanisms for RES-E which have been applied in the 27 EU Member States are presented in Table 5, while in Figure 5 the primary support mechanisms of each country are presented. In Table 6 the major RES support policies that are implemented in the EU are presented. Based on these data, the vast majority of the EU Member States use either FiTs or premiums as their primary support mechanism, while six of them apply quota obligations (Klessmann et al., 2011). Although tender mechanisms are used in some of these countries for specific technologies or projects, like biomass in Portugal and France or offshore wind in The Netherlands and in Denmark, none of them uses tender mechanisms as their primary policy anymore. Also, fiscal incentives are used as supplementary support mechanisms in many Member States.

	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE
Feed-in tariff	Х	Х	х	Х	Х	Х		Х	Х		Х	Х	Х	Х
Feed-in					Х		Х	Х	Х					
premium														
Quota		Х												
obligation														
Investment		Х		Х	Х					Х		Х	Х	
grants														
Тах		Х							Х	Х		Х		
exemptions														
Fiscal			Х			Х		Х						
incentives														
Tendering							Х				Х			
schemes														
	IT	LT	LU	LV	MT	NL	PL	ΡΤ	RO	SE	SI	SK	U	K
Feed-in	IТ Х	LT X	LU X	LV X	MT X	NL	PL	PT X	RO	SE	SI X	SK X	U X	K
Feed-in tariff	IT X	LT X	LU X	LV X	MT X	NL	PL	PT X	RO	SE	SI X	SK X	U X	K
Feed-in tariff Feed-in	IT X	LT X	LU X	LV X	MT X	NL X	PL	PT X	RO	SE	SI X X	SK X	U X	K
Feed-in tariff Feed-in premium	IT X	LT X	LU X	LV X	MT X	NL X	PL	PT X	RO	SE	SI X X	SK X	U X	K
Feed-in tariff Feed-in premium Quota	IT X X	LT X	LU X	LV X	MT X	NL X	PL X	PT X	RO	SE	SI X X	SK X	U X X	K
Feed-in tariff Feed-in premium Quota obligation	IT X X	LT X	LU X	LV X	MT X	X	PL X	PT X	RO X	SE	SI X X	SK X	U × ×	
Feed-in tariff Feed-in premium Quota obligation Investment	IT X X	LT X X	LU X X	LV X X	MT X X	NL X	PL X	PT X	RO X	SE X	SI X X	SK X	U X X	K
Feed-in tariff Feed-in premium Quota obligation Investment grants	IT X X	LT X X	LU X X	LV X X	MT X X	X	PL X	PT X	RO X	SE	SI X X	SK X	UI X X	K
Feed-in tariff Feed-in premium Quota obligation Investment grants Tax	IT X X	LT X X	X	LV X X X	MT X X	NL X X	PL X X	PT X	RO X	SE X	SI X X	SK X X	VI X X	
Feed-in tariff Feed-in premium Quota obligation Investment grants Tax exemptions	X X	X	LU X X	LV X X X	MT X X	NL X X	PL X X	PT X	RO	SE X X	SI X X	SK X X	X X X	
Feed-in tariff Feed-in premium Quota obligation Investment grants Tax exemptions Fiscal	X	X	X	LV X X X	X X X	NL X X X	PL X X X	PT X	RO X	SE X X	SI X X	SK X X	X	
Feed-in tariff Feed-in premium Quota obligation Investment grants Tax exemptions Fiscal incentives	IT X X	LT X	X	LV X X X	MT X X	NL X X X	PL X X X	PT X	RO	SE X	SI X X	SK X X	VI X X	
Feed-in tariff Feed-in premium Quota obligation Investment grants Tax exemptions Fiscal incentives Tendering	X	X	X	LV X X X	X X X	NL X X X X X	PL X X X	PT X	RO	SE X X	SI X X	SK X X	X	

 Table 5 Overview of RES-E support mechanisms in the EU-27 (Klessmann et al., 2011).

	Abbreviation	Number of countries apply the scheme		applying
		RES-E	RES-H	RES-T
		electricity	heat/cool	transport
Feed-in tariffs:	FiT	21	-	-
Guaranteed prices				
Feed-in premiums:	FiP	7	3	-
Production premiums				
Tender schemes	TND	5	2	-
Quota obligations,	TGC	6	8	18
Building obligations				
Investment grants	INV	20	25	11
Fiscal measures (tax	TAX	13	12	22
incentives, etc.)				
Financing support (loans, etc.)	FIN	9	4	-

Table 6 Most common support policies implemented in the EU (Kitzing et al., 2012).

An overview of the implementations of RES-E support mechanisms is provided at the Appendix and the basic conclusions are presented here. Firstly, price-control schemes, and especially FITs, dominate among the policy support mechanisms for RE in the EU (Kitzing et al., 2012). Not only are they implemented in most EU countries, but at the same time, they have the highest growth rate. TGCs have stopped being implemented in the EU countries after 2005, despite their initial "boom" in the early '00s, while for the already existing TGCs in the UK and Italy, an addition of FiT policies for small installation sizes has occurred. Moreover, EU countries have begun to apply multiple support policies at the same time, with Denmark being an indicative example by applying six different support policies. Again, however, combinations including FiTs and other major support schemes dominate, and especially combinations of FiTs and Tenders or also TGCs, like in Italy and the UK. The only country that applies only one support scheme (FiT), thus being the exemption, is Ireland.



Figure 5 Main RES-E support instruments in the EU-27 (Klessmann et al., 2011)

3.3 Main support measures for RES-E by solar PV in the EU

So far, the schemes supporting RES-E in the EU have been presented. However, the focus of this Thesis is on the support measures for solar PV. There are two main political purposes of incentive mechanisms for solar PV systems; first, the promotion of PV technologies, despite their cost being significantly higher than the grid parity, thus enabling them to achieve the economies of scale needed in order to achieve grid parity. And second, the promotion of national energy independence, the creation of high-tech jobs and the reduction of CO₂ emissions (Campoccia et al., 2007).

A number of different types of support for PV systems have been used in the EU the last 15 years, e.g. green tags, capital subsidies, FiTs, tax credits, net metering, VAT reductions, etc. Table 7 presents the different support policies each western EU member adopted (with the definition of western Europe being in accordance with UNESCO), while Table 8 presents those of the eastern European countries. The most popular support policies in Europe are the FiT system and the quota system regulation combined with a TGC market (Dusonchet

and Telaretti, 2010a), while other support schemes frequently used as supplementary measures are capital subsidies, green tags, FiTs and net metering. A description of the green tags support mechanism and of capital subsidies are provided at the Appendix.

Country	FiTs	TGCs	Capital subsidies	Tax credit	Net metering
Austria	Х		Х		
Belgium ^a		Х	Х	Х	Xa
Cyprus	Х		Х		
Denmark			Х	Х	Х
Finland ^b					
France	Х			Х	
Germany	Х		Х	Х	Xc
Greece	Х		Х	Х	
Ireland ^d					
Italy	Х		Х	Х	Х
Luxemburg	Х		Х	Х	
Malta			Х	Х	Х
Netherlands	Х			Х	
Portugal	X ^e		Х	Х	X ^f
Spain	Х			Х	
Sweden ^g			Х		
United		Х	Х	Х	
Kingdom					

Table 7 Support policies for PV systems in the western EU (Dusonchet and Telaretti, 2010a).

^aEnergy subsidies for PV plants are implemented separately for the three regions of Belgium (Flanders, Brussels and the Wallonia Region). Net metering is available only in Wallonia, for PV plants below 10 kWp. ^bAt present, no FiT schemes or purchase obligations are available in Finland. ^COnly for PV installations smaller than 30 kWp. ^dA FiTs plan is active, but PV is not included. The use of solar electricity is very low in this country. ^eValid only for PV installations below 3.68 kWp (16A single-phase). ^fValid for PV installations below 5.25 kWp (25A single-phase). ^gA new support mechanism for installation of PV systems in Sweden, in 2009, has been announced by the government (valid for a 3-year period) but it is still not active.

Country	FiTs	TGCs	Capital subsidies	Tax credit	Net metering
Bulgaria	Х	-			
Czech	Х		Х	Х	
Republic					
Estonia	Х		Х	Х	
Hungary	Х		Х		Х
Latvia	Х				
Lithuania			Х		
Poland		Х		Х	
Romania		Х	Х	Х	Х
Slovak	Х		Х	Х	
Republic					
Slovenia	Х		Х		

Table 8 Support policies for PV systems in the eastern EU (Dusonchet and Telaretti, 2010b).

Until 2010, many European countries were developing bright support strategies for PV. Italy and France were emerging as the new markets with high potential, with others, like Greece, Portugal and Belgium following with promising support strategies (Dusonchet and Telaretti, 2010a). If these policies had been kept the same, the share of electricity production from RES would reach 15-18% of total electricity consumption, with the target being 20% (Harmelinka et al., 2006).

Concerning the western EU countries, Italy, Greece and France seemed to have the most profitable support strategies for small and medium-sized PV systems, by having the lowest payback period (lower than 10 years) and the highest internal rate of return and net present value (Dusonchet and Telaretti, 2010a). Cyprus, Germany Belgium and Spain had implemented good support policies for the development of PVs, with their payback period being lower than 16 years. The less successful support policies were those implemented by Luxembourg, Malta, Portugal, Denmark and the UK, where the payback period was around 25 years and the internal rate of return around zero. Even worse were the strategies chosen by Austria and the Netherlands. These differences occur based on the different regulations used in each country. For example, in the cases of the Netherlands, Luxembourg, Finland, Ireland and Sweden, the impact is very limited because the tariff that was used did not cover the expenses of the PV installation. But even in the cases where the tariff was motivating, the effectiveness was still limited, like in the case of Austria, where the cap was too low and the FiTs' values were guaranteed for a too short period or in the case of Greece, where the administrative procedures were too complicated or hindering.

As far as the eastern EU countries are concerned, the FiT support mechanism seemed to be the most profitable, while the TGC support mechanism yielded long payback values and due to the low cost of the electricity bill in these countries, so did the net metering support mechanism (Dusonchet and Telaretti, 2010b). More specifically, the high FiT value used in the Czech Republic, Bulgaria and Slovakia made it the most profitable support scheme, with the Czech Republic yielding the best results among the three. Slovenia, Romania and Latvia, which used support schemes other than FiTs, yielded long payback periods of around 25 years.

Summing up, PV installations increased their competitiveness in production and trade only in the countries where the FiTs were high enough to recover the investment cost in a reasonable time and the cap was realistic. Germany, Spain and Italy were the leading EU countries in the implementation of PV systems at a large scale. At the end of 2012, Germany and Italy had a cumulative installed solar PV capacity of 32 GW and 17 GW, respectively, while during 2008, Spain was the largest solar PV market globally (Brown, 2013). However, due to economic, political and power system concerns, these countries had to adjust, change or even reduce their financial support incentives.

The PV industry has suffered the most from such changes, due to the very quick, strong and unexpected decrease in the price of PV modules, which reached 60% over a period of few years (EREC, 2013). In Germany, the policy officials rapidly reduced the financial incentives for solar PV and set a limit of 52 GW on the solar PV capacity support, after which there will not be any more incentives for new projects (Brown, 2013). This was done in order to

control the increasing overcharging on consumers' electricity bills. In June 2013, the support limits for solar PV were reached in Italy and there were no more FITs available for new projects, while Spain completely suspended FIT incentives for RES-E and implemented retroactive incentive reduction policies, which affected the revenues, the cash flows and the investment returns of the existing projects in operation. The investors and producers were unable to pay back their bank loans, which could lead their projects to bankruptcy, thus further destroying the trust in the RE sector (EREC, 2013).

These retroactive incentive reductions used for controlling the costs occurring from the support to RES-E, despite their fiscal necessity, are likely to affect the future renewable electricity development, as they introduce a policy risk; and this policy risk causes financing costs, and in turn production costs, to rise (Brown, 2013). However, this rise of costs is only artificial, as it origins from the reluctance of investors to invest in the RE sector, because of the risks such an investment has, and the cautiousness of banks to finance such projects, leading to higher interest rates and increased cost of capital (EREC, 2013).

Summing up, a transition is taking place for the EU countries, which move from electricity production-based incentives such as FiTs to market integration incentives, e.g. market premiums, bonus payments for remotely controlled solar projects and flexibility premiums for RE generation, which can reduce the instability of the grid (Brown, 2013). The integration of RES into the power market, together with the decreasing costs of renewable electricity, could yield a more stable, but smaller, competitive market for electricity generation from RES. Together with the retroactive policies mentioned before, this transition could lead to lower renewable capacity additions for some EU countries, but at the same time support the future renewable electricity market growth of the EU, if combined with carbon policies and declining costs of technology for RES (Brown, 2013).

3.4 Summary

Through a series of Directives, the EU has set a very ambitious goal concerning the share of RES in gross final consumption of energy of the EU Member States. However, due to the cost disadvantage of RES compared to fossil fuels, which is caused by the environmental externalities and technological immaturity of RES, a number of support policies needs to be set and undertaken by the Member States. The various policy schemes that have been applied in the EU can be classified in a number of categories, such as direct and indirect promotion strategies, regulatory and voluntary promotion strategies and price or quantity driven and investment or generation focused promotion strategies.

An overview of the primary and supplementary support mechanisms for RES-E which have been applied in the 27 EU Member States shows that price-control schemes, and especially FiTs, dominate among the policy support mechanisms (Kitzing et al., 2012). Not only they are implemented in most EU countries, but at the same time, they have the highest growth rate. TGCs have stopped being implemented in the EU countries after 2005, despite their initial "boom" in the early '00s, while for the already existing TGCs in the UK and Italy, an addition of FiT policies for small installation sizes has occurred. Moreover, EU countries have begun to apply multiple support policies at the same time, with Denmark being an indicative example by applying six different support policies. Again, however, combinations including FiTs and other major support schemes dominate, and especially combinations of FiTs and Tenders or also TGCs, like in Italy and the UK.

More specifically, for the case of solar PV support policies, the most popular support policies in Europe are the FIT system and the quota system regulation combined with a TGC market (Dusonchet and Telaretti, 2010a), while other support schemes frequently used as supplementary measures are capital subsidies, green tags, FiTs and net metering. The reasons of the preference of the EU countries towards the FiT support scheme lie on the fact that FiTs offer greater effectiveness compared to the rest of the support strategies, higher certainty to the investors, flexibility towards different technologies and incentives for technological innovation. However, in the absence of proper design and timely adaptation of the policy, it may result in an over-capacity for a specific technology and lead to increased costs.

Finally, the choice of the support policy is a political subject and it represents the preferences of the government and the citizens towards the promotion of renewable electricity markets. If the focus is on electricity markets and the control of the overall cost of their support, then a quantity-based scheme may be chosen. If, on the other hand, quantitative targets such as increased capacity have been set, then price-based systems seem to be the most appropriate choice. But no matter how effective or efficient a support policy scheme is in theory, its implementation takes place in a unique environment, totally different from the ideal circumstances. As a result, its performance and results will be different than those described in theory.

4. Solar PV technologies

The reasons calling for a support on RES, as well as the policies used across Europe for this support, have already been discussed. It has also been pointed out that the focus of a support policy scheme is to trigger investment in new and sustainable capacity. One way of producing such capacity is through solar PV technologies, which is the focus of this Thesis. However, in order to better understand whether a policy is suitable for the support of a certain technology (in this case for solar PV) or not, information is needed on the technology itself, its applications and, most importantly, its costs. The aim of this chapter is to present this information through an analysis of the methods currently used for energy production using solar PV.

The chapter is divided in two parts. In the first part, an introduction in the field of solar cell technologies is carried out, through the presentation of the solar cell technologies available, the processes they use, their technology status and their performance. The various applications of solar PV are also briefly explored in this part. In the second part of the chapter, a presentation of the current costs and the cost projections of solar PV takes place. The term "grid parity" and its importance as a driver for the widespread adoption of solar PV, as well as the current competitiveness of solar PV systems are briefly discussed. Also, a lifecycle breakdown of a solar PV investment project takes place, in order to specify the various costs of a solar PV system. The chapter closes with a discussion on the levelised cost of electricity (LCOE), as this the most often used "tool" when comparing electricity generation technologies or considering grid parity for emerging technologies, such as solar PV.

4.1 Solar cell technologies

The sun is an abundant, free and non-polluting energy source, with numerous possible applications. The energy potential of the sun can be harnessed naturally, through the photosynthesis of plants or through buildings that are designed so that they maximize room heating/cooling and illumination (Kirkegaard, 2010). However, the potential of the sun can also be harnessed artificially, with two groups of active solar technologies existing: solar thermal technologies can be used for producing heat or electricity through turbines which use steam (concentrated solar power, CSP), while solar PV technologies generate electricity from solar radiation through a semi-conducting material of the solar PV cell absorbing protons from the sunlight. These photons cause electrons to be released and flow through the semi-conducting material, thus generating electricity. The intensity of the light defines how much electrical power is generated by each cell (Tyagi, 2013). Apart from electricity, heat, kinetic and chemical energy can also be produced through the conversion of solar energy.

Despite its high potential, solar energy remains "an energy technology cluster in its infancy, with several different applications, high levels of R&D spending and venture capital (VC) funding, new breakthrough technology applications and continuing high levels of efficiency improvements in existing technologies" (Kirkegaard, 2010). This means that policy support is crucial for the further implementation of solar PV applications.

A number of countries have implemented specific policies and incentives to support the deployment of PV over the last years, causing a rapid increase of the total PV installed capacity, from 1.4 GW in 2000 to around 70 GW at the end of 2011, with 30 GW of this capacity being installed in that year alone (IEA-ETSAP and IRENA, 2013). This increase was accompanied by industrial learning and market competition which led to significant and rapid cost reductions for PV systems. The continuity of such cost reductions is essential for the acceleration of grid-parity of electricity generated by on-grid solar PV systems. Generally, PV power is now fully competitive with the diesel-based power in both on- and off-grid systems, while in countries where high enough solar resources and high electricity tariffs exist, the prices of residential solar PV electricity are already equal to the retail prices of conventional electricity.

Currently, the crystalline silicon (c-Si) and the thin-film (TF) technologies dominate the global PV market (IEA-ETSAP and IRENA, 2013). In the c-Si PV systems, slices of highly pure solargrade silicon, also known as wafers, form cells which are in turn assembled into modules and connected electrically to each other. On the other hand, in the case of the TF technology, thin layers of semi-conducting material are deposited onto low-cost substrates of large size, such as glass, metal or polymer. The c-Si consists the oldest and the currently dominant PV technology, owing around 85% of the PV market share (Tyagi, 2013), as shown in Figure 6.



Figure 6 Market share of solar cell technologies in 2010 (Tyagi, 2013)

The manufacture of solar PV systems generally consists of four phases (IEA-ETSAP and IRENA, 2013):

- 1. <u>Production of the semi-conducting material</u>: 90% of the polysilicon is supplied by companies from China, the US, Japan and Europe.
- 2. <u>Production of the PV cells</u>: this is the phase where sophisticated manufacturing often takes place. The majority of solar cells are produced in Japan, China, Germany and the US.
- 3. <u>Production of the PV modules:</u> this is a labour-intensive process, where encapsulation of the cells and frames with protective materials takes place for increasing the strength of the module. Currently, around 1200 companies worldwide produce solar PV cells and modules.
- 4. <u>Installation of the PV modules</u>: this phase includes the inverter for connecting the PV system to the grid, the power control systems, the devices for energy storage (if any) and the final installation in residential or commercial buildings or in utility-scale plants.

The cost of a PV module is typically in the range of 30-50% of the total cost of the system, while the remaining costs include balancing the system and the installation cost (IEA-ETSAP and IRENA, 2013). In the case of utility-scale PV plants, the cost of PV modules can be as low as 20%, while for residential applications, it can reach 50-60% and in off-grid systems it can reach 70%, including the energy storage (usually batteries) and the back-up power. More details concerning the cost of PV modules are given in subchapter 4.3.

The choice of solar PV technology for installation is often based on a trade-off between investment cost, module efficiency and electricity tariffs. Compared to c-Si-based PV systems, the production of TF PV systems is less energy-intensive and requires significantly less semi-conducting material, characteristics which make them generally cheaper, however, significantly less efficient. In addition, they require substantially more surface area for the same output compared to their c-Si-based equivalents. On the other hand, the module cost of c-Si PV systems has fallen by more than 60% over the last years, with the modules produced in China reaching an average price of 0.75 USD/W in September 2012. As a result, despite their huge growth a few years ago, the market share of TF PV is now decreasing, with the prospects for future growth in its deployment being uncertain and heavily dependent on technology innovation.

By being a variable renewable electricity source, solar PV can be readily integrated into existing grids up to a penetration level of about 20%, depending on the configuration of the existing generation mix and the demand profiles (IEA-ETSAP and IRENA, 2013). Increasing the integration of the highly variable renewable power from PV systems into the electricity grids generally requires rethinking of the grid readiness concerning the connectivity, the demand-side response and/or the energy storage solutions. However, the on-going reduction of financial incentives in many leading markets, combined with the overcapacity of the PV manufacturing industry, suggest that module prices will continue to decline, leading to parity in on- and off-grid PV. It is worth mentioning that since 2001, the global PV market has grown faster than even the most optimistic estimations.

4.1.1 Basic process and technology status

PV solar cells can convert solar energy directly into electricity using the *photovoltaic (PV) effect*. According to this, two different or differently doped semi-conducting materials (e.g. silicon, germanium), which are in close contact with each other, when exposed to sunlight they generate an electrical current (IEA-ETSAP and IRENA, 2013). The sunlight provides the electrons with the energy to move across the junction between the two materials more easily in one direction than in the other, thus giving a negative charge to the one side of the junction with respect to the other side (p-n junction) and generating a voltage and a direct current (DC). The PV cells work with both direct and diffused light and generate electricity even during cloudy days, however with reduced production and conversion efficiency.

PV electricity was discovered in the 19th century; however, the first modern PV cells for electricity generation based on Si semi-conductors were developed only in the 1950s. The large-scale commercialization of PV devices started after 2000, following the financial incentives given in many countries as part of the government policies to mitigate CO₂ emissions and improve their energy security, as PV electricity is environmentally friendly and has literally unlimited potential. Currently, PV power provides only a small percentage of the global electricity supply, but the market is rapidly expanding, driven by financial incentives and rapid cost reductions. Over the past decade, the global cumulative installed PV capacity has grown from 1.4 GW in 2000 to around 70 GW at the end of 2011, as it is shown in Figure 7Figure 7, with 30 GW of them being installed in 2011 alone and annual revenues which are estimated to reach around 93 billion USD. As far as newly installed capacity is concerned, the leading countries in 2011 were Italy with 9.3 GW, Germany with 7.5 GW, China with 2.2 GW, the US with 1.9 GW and Japan with 1.3 GW. In terms of total installed capacity, Europe holds around ¾ of the global total, with the leading countries being Germany, Italy and Spain. Outside Europe, China, the US, Japan, Australia, Canada and India constitute the largest markets. China, Germany, the US and Japan are also the leading producers of PV components and systems.



Figure 7 Global installed PV capacity in MW until 2011 (IEA-ETSAP and IRENA, 2013)

PV power can be used for either grid-connected applications like residential, commercial or utility systems, or off-grid installations. In fact, more than 90% of the installed capacity consists of grid-connected systems. The primary applications consist of systems for residential and commercial buildings, with unit sizes of up to 10 kWp and 100 kWp, respectively, followed by utility systems with sizes greater than 1MWp and off-grid applications, e.g. telecommunication towers, rural supply, consumer goods. In 2013, the share of the residential sector was 60%. Currently, no material availability or industrial constraints exist for the growth of the share of PV power in the global energy mix and the PV industry has quickly increased its production capacity to meet the growing demand. At present, the supply exceeds the demand by a large margin and although more than 1000 companies produce PV products like PV cells, modules and systems worldwide, 90% of polysilicon, which is the basic material, is produced by only a few companies, mostly in the US, Japan, Europe and China.

4.1.2 PV technologies and performance

The basic element of a PV system is the PV solar cell, which converts solar energy into directcurrent (DC) electricity. The PV cells are assembled and electrically interconnected to form PV modules, which in turn are connected to each other in series or/and in parallel in order to increase the voltage and/or the current produced, respectively (IEA-ETSAP and IRENA, 2013). In order the PV modules to be integrated into the grid and used with most electrical appliances, an inverter is required for the conversion of DC into AC. A modular PV system is consisted of the modules together with the balance of system (inverter, racking, power control, cabling and batteries, if any) and its capacity ranges from a few kW to hundreds of MW. The PV systems can be integrated into building-structures (building-adaptive or integrated PV systems, BAPV or BIPV), placed on roofs or ground-based.

A number of PV technologies are commercially available, while more are under development. In the solar PV industry, three generations of technologies exist: 1st, 2nd and 3rd generation PV technologies (Kirkegaard, 2010). The 1st generation technologies refer to wafer-based crystalline silicon (c-Si) technologies. The cells are cut from a silicon ingot, casting or grown ribbon. So far, this generation dominates the market because of its high conversion efficiency, defined as the percentage of sunlight that is converted into electrical energy, as well as its extensive manufacturing base. Monocrystalline PV cells today have an efficiency of 16% to almost 20%, while the cheaper to produce multicrystalline PV cells achieve a slightly lower 14-15%. Crystalline solar PV cells are usually interconnected and encapsulated between a transparent front (typically glass) and insulating back cover material, to form a solar PV module, which is usually mounted in an aluminum frame.

The 2nd generation PV technologies are referred to as thin-film (TF) technologies, as thin layers of PV materials are deposited on low-cost substrates, like glass, stainless steel or plastic (Kirkegaard, 2010). Their advantage is that they are significantly cheaper to produce, as smaller amounts of materials and much thinner layers are used, compared to the monoand poly-crystalline cells, thus lowering the manufacturing cost, but their efficiency levels are still much lower (Tyagi, 2013). The oldest and most prevalent thin film technology is amorphous silicon, with a conversion efficiency of just 6-7%, while hybrid amprphous/microsilicon technologies achieve around 8% (Kirkegaard, 2010). Other thin film technologies use compound semiconductors, such as Germanium (an amorphous silicon thin film), cadmium telluride (CdTe) or copper iridium di-selenide (CIS) and have achieved commercial conversion efficiencies of up to 11-12%. These improvements in thin film efficiencies have led to a very rapid expansion of these segments of solar PV technologies in recent years, with their market share rising from less than 5% in 2004 to over 22% by 2008.

The 3rd generation PV technologies refer to emerging and novel PV technologies, including concentrating PV, organic PV, advanced thin films and other novel concepts, which have not yet been deployed on a large scale (IEA-ETSAP and IRENA, 2013). These are the focus of current R&D efforts which use various organic and nanotechnologies in order to achieve higher efficiencies and/or much lower costs (Kirkegaard, 2010). Figure 8 shows the different steps of the production chain of polysilicon and thin film PVs, while in Figure 9, an overview of the PV technologies of all the PV generations is provided.



Figure 8 Solar PV production chain of polysilicon and thin film (Kirkegaard, 2010)



Figure 9 Overview of PV technologies (Tyagi, 2013)

Individual solar PV modules typically range from 50-300 W in capacity (Kirkegaard, 2010). Multiple solar modules can subsequently be connected and configured to generate the desired power load level. Solar PV systems can therefore range in scale from just a few W in small, separate applications powering streetlights or small consumer electronic equipment, to hundreds of MW in utility-scale solar power plants. In addition to the cell/module, a PV system includes balance of system components, such as the module mounting structure, the wiring and other switchgear and an inverter, which converts the direct current (DC) electricity produced by the semiconducting material to the alternate current (AC) suitable for applications and the electricity grid.

Over the last 20 years, the performance of PV technologies has been improved remarkably in terms of their efficiency, lifetime and energy pay-back time (IEA-ETSAP and IRENA, 2013). Their costs have also reduced significantly and this trend is expected to continue in the future. The main goal of the current research is the increase of the efficiency and the lifetime of the various technologies and the reduction of the investment cost, which in turn will lead to minimum electricity generation costs. Table 9 provides an overview of the current PV technologies and their performance.

As it has already been mentioned, the current commercial technologies include wafer-based crystalline silicon (c-Si) and thin-film (TF) technologies. The c-Si technology can be further categorized into mono-crystalline silicon (mono-c-Si), multi-crystalline silicon (multi-c-Si) and ribbon-sheet grown silicon, while the TF technology currently includes four sub-categories: amorphous silicon (a-Si), amorphous and micromorph silicon multi-junctions (a-Si/ µc-Si), cadmium-telluride (CdTe) and copper-indium-[gallium]-[di]selenide-[di]sulphide (Cl[G]S). It is worth noting that the module efficiencies are lower than the commercial cell efficiencies, which are in turn lower than the best efficiency performance in laboratory conditions. Apart from the current commercial technologies, 3rd generation PV technologies are also present in Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε., which promise to be significantly advanced in terms of both performance and cost. In 2011, c-Si accounted for 89% of the global market and TF technologies accounted for the remaining 11%. Among the TF technologies, the market is shifting towards CdTe and CIGS, while among the emerging technologies, concentrating PV and organic solar cells are entering the market and are expected to gain some percentage points by 2020. The evolution of performance over time for commercial PV modules is presented in Table $10\Sigma\phi\dot{\alpha}\lambda\mu\alpha!$ To $\alpha\rho\chi\epsilon\dot{\alpha}\rho\sigma\dot{\alpha}\lambda\epsilon\nu\sigma\eta\sigma$ the αναφοράς δεν βρέθηκε.. An analysis of the various solar cell technologies is provided in the Appendix.

	Cell efficiency (%)	Module efficiency (%)	Record commercial (and lab) efficiency (%)	Area/kW (m²/kW) ^{a)}	Lifetime (yr)
c-Si					
Mono-c-Si	16-22	13-19	22 (24.7)	7	25 (30)
Multi-c-Si	14-18	11-15	20.3	8	25 (30)
TF					
a-Si		4-8	7.1 (10.4)	15	25
a-Si/µc-Si	7-9		10 (13.2)	12	25
CdTe	1	0-11	11.2 (16.5)	10	25
CI(G)S	7	7-12	12.1 (20.3)	10	25
Org. Dyes		2-4	4 (6-12)	10 (15)	Na
CPV	Na	20-25	>40	na	Na

Table 9 Commercial PV technologies and their performance (IEA-ETSAP and IRENA, 2013).

a) A module efficiency of 10% corresponds to about 100 W/m^2

Table 10 Performance and targets for PV technologies (IEA-ETSAP and IRENA, 2013)

	1980	2007	2010	2015-20	2030+
Module efficiency (%)	< 8	13-18			
Mono-c-Si	20	15 10	13-19	16-23	25-40
Multi-c-Si			11-15	19	21
TF	Na	4-11	4-12	8-16	Na
c-Si material use (g/Wp)			7	3	<3
c-Si wafer thick (mm)			180-200	<100	Na
Lifetime (yr)	Na	20-25	25-30	30-35	35-40
Energy payback (yr)	>10	3	1-2	1-0.5	0.5

4.1.3 Balance of System (BoS)

The balance of the system (BoS) includes components other than the PV modules, such as the DC/AC inverter for converting DC into AC, the power control systems, cabling and racking and energy storage devices, if they exist (IEA-ETSAP and IRENA, 2013). The BoS consists of rather mature technologies and components; however, recently, the cost of BoS has declined, in line with the price of the PV modules in most competitive markets and it

remains to be seen whether this trend can be maintained in the future. Apart from reducing costs, the main targets for the inverter are improved lifetime and reliability and control of the reactive power in the grid-connected systems, which may help grid integration. Inverters are available at capacities ranging from a few kW to 2 MW, for use in large-scale systems. For a single PV system, either one or more inverters can be used, depending on the design requirements.

The BoS can also include electricity storage. In this case, a number of new energy storage devices are being developed, in addition to the lead-acid batteries and the traditional pumped hydro-storage systems (suitable only for large scale applications). These new devices include new battery technologies, electric capacitors, compressed air systems, super-conducting magnets and flywheels. Apart from pumped hydro, none of these technologies is currently mature and cost-effective for large scale commercialization. Cost-effective electricity storage could significantly boost the market penetration of PV power by helping to manage the variability of solar energy. In the case of batteries, current R&D efforts focus primarily on performance, lifetime and cost of electrical batteries, e.g. Ni-MH and Li-ion batteries, but a number of other options are also under consideration. More specifically, NaS batteries could be a competitive long-term, large-scale solution. Off-grid PV systems must also be equipped with back-up power, such as diesel generators, biomass-fired generators and wind power, in order to supply energy when there is no sunlight available.

4.2 Solar PV applications

The large degree of flexibility in the assembly and installation of solar PV applications means that several distinct categories of solar PV power generating applications exist (Kirkegaard, 2010). The standard classification demarcates based on application type and size and distinguishes between four different solar PV categories:

- 1. Consumer products: small applications of less than 10 W. Includes small items such as solar calculators, watches, garden lighting or camping-related equipment.
- 2. Distributed PV, off-grid: applications between 10 W to 100 kW. The modular flexibility of PV makes it ideal for production of electricity close to the point of consumption. Off-grid systems operate as stand-alone systems, without access to the electricity network. They are well suited for power consumers located in remote areas, subject to very high transmission costs, but who in such areas require electricity for essential services like lighting, telecommunication, infrastructure signalling, refrigeration, water pumping or irrigation. Typical off-grid residential PV systems produce around 1 kW and are most widely used in large countries with vast rural hinterlands or in developing countries to provide rural infrastructure.
- 3. Distributed PV, grid-connected: applications between 10 W to 100 kW. As with distributed off-grid PV applications, PV's modular adaptability enables the production of electricity at residential or industrial premises. Grid-connected solar PV applications are located at the power consumer's premises, e.g. rooftop

applications or so-called Building Integrated PV (BIPV), where solar PV panels form an architecturally integrated part of a building or broader built-up environment. Distributed grid-connected PV applications first aim to cover the consumer's own power demand, while feeding any surplus electricity into the local grid. If netmetering standards or a feed-in tariff are in place, this creates an additional benefit for the owner of the PV system. Most residential rooftop PV systems are smaller than 100 kW, but installations on commercial rooftops may be larger and reach several MW.

4. Centralised solar PV power stations: applications from more than 100 kW to multi-100 MW utility scale. Like ordinary power plants, centralised PV power stations produce electricity for distribution to consumers through the regular electricity network. As large ground-located structures, the scale of solar PV plants is limited only by space constraints. While some centralised plants, typically 5-30 MW, can be located near distribution centres, the largest centralised PV plants are usually located in remote areas with high solar irradiation, such as desert-like locations, but often far away from centres of power consumption. This can create significant challenges for grid transmission and balancing that is exacerbated by the fact that solar power is forecastable but variable and only produces electricity during daytime.

The diversity of applications and scales has important implications for the analysis of the solar PV sector. It makes an accurate measurement of installed solar PV power production capacity, as well as the amount of solar power actually produced, very challenging. It is likely that the real total level of solar PV applications is being significantly underestimated and global aggregates and most national-level solar PV capacity and production data must be regarded as merely indicative of the actual situation.

4.3 Current costs and cost projections

Following a 2-year slump, in which oversupply drove down module prices and many manufacturers reported negative gross margins, the solar PV industry began to recover during 2013 (REN21, 2014). 2013 was still a challenging year, particularly in Europe, where shrinking markets left installers, distributors and others struggling to stay afloat. Consolidation continued among manufacturers but, by late in the year, the strongest companies were selling panels above cost. However, the rebound did not apply lower down the manufacturing chain, particularly for silicon makers. Low module prices also continued to challenge many thin film companies and the concentrating solar industries, which have struggled to compete. International trade disputes also continued through 2013.

Module prices stabilised, with c-Si module spot prices increasing by about 5% in 2013, in response to robust demand growth in China, Japan and the US in the second half of the year. At the same time, module production costs continued to fall. Low material costs, particularly for polysilicon, combined with improved manufacturing processes and scale economies have reduced manufacturing costs far faster than targeted by the industry, with top Chinese

producers approaching costs of 0.50 \$/W in 2013. Interest has turned to lowering soft costs to further reduce installed system costs, which have also declined but not as rapidly as module prices, particularly in Japan and the US. Although investment in solar PV in dollar terms was down for the year, actual installed capacity was up significantly, with the difference explained by declining costs of solar PV systems in recent years (Figure 10).



Figure 10 Global solar PV capacity additions and annual investment in the period 2004-2013 (REN21, 2014)

With the market evolving on a monthly basis due to increased competition among suppliers, changing policy incentives in many countries, continuous innovation in materials and technologies, growing economies of scale and dramatic cost reductions, it is a challenge to provide up to date PV prices (IEA-ETSAP and IRENA, 2013). Currently, solar PV power is economically competitive for off-grid applications. However, the recent cost reductions mean that residential and commercial grid-connected systems have started to become economically attractive in the most favourable geographical locations, even with the absence of policy incentives, thus enabling them to become competitive in the near future. The financial incentives offered by many governments for the promotion of PV installations as part of their policy program for combating climate change, especially in the case of the developed countries, have significantly helped the spur of PV deployment and have led to reduced costs through mass production of components and systems. The so-called *grid parity*, referring to "the parity between the *generation cost* for residential and commercial PV systems and the *electricity retail price* for households" (IEA-ETSAP and IRENA, 2013), has been (almost) achieved in the most favourable locations.

Grid-parity consists an important driver for the adoption of PV, by enabling the electricity produced by PV to be delivered at current utility or market rates (Skeikh, 2011). This is the result of the commercial introduction of the 2nd generation TF technologies which compete with the 1st generation silicon-based panels. As a result, the homeowners, who pay an average retail price of about 10 cents/kWh for electricity from the grid, and utility

companies, which have average wholesale power costs of around 5 cents/kWh, will be able to use solar PV power without paying a premium over traditional, fossil-based electricity. By 2030, the retail and wholesale cost of solar PV is expected to be 6 cents/kWh and 5 cents/kWh, respectively (Skeikh, 2011), while already, in 2011, the electricity prices for households in the EU-27 ranged between 83-291 USD/MWh excluding taxes and the average cost of PV electricity for large, ground-mounted systems was ranging from 160 USD/MWh in southern Europe to 270 USD/MWh in northern Europe (IEA-ETSAP and IRENA, 2013).

From the perspective of the utilities, in the absence of incentives, the PV generation cost cannot yet compete to the generation cost of conventional, base-load power technologies and remains an expensive way to generate power, with the exception of certain countries which have excellent solar potential and high fossil fuel prices (IEA-ETSAP and IRENA, 2013). This is because of the relatively high investment cost and the limited capacity factor of PV plants, despite the high industry learning rates and associated cost reductions that solar PV has experienced in the recent past. The overall cost of power generated from a solar PV system over its lifetime (levelised cost) still lingers between 0.15-0.40 \$/kWh, which is two to three times the level of other currently available large-scale grid-connected electricity sources (Kirkegaard, 2010). However, in this simple comparison, the fact that PV systems generally produce during daily peak-demand hours, when the marginal cost of electricity is higher, is not taken into consideration (IEA-ETSAP and IRENA, 2013). Following this trend, the producers of PV systems consider that large-scale utility systems, such as the most competitive PV installations in terms of investment and electricity costs, will lead to reduced levelised cost of electricity (LCOE - "the cost per unit of electricity required to cover all investment and operational costs over the lifetime of the system, without profits (IEA-ETSAP and IRENA, 2013)) of PV systems, by between 90-200 \$/MWh in southern and northern Europe by 2020 and 50-70 \$/MWh in Sun Belt countries. These projections account for the annual solar irradiance variability, e.g. 1.000 kWh/m² in Scandinavia, 1.900 kWh/m² in southern Europe and 2.200 kWh/m² in the Middle East. Residential PV prices are also expected to decline sharply, but they will remain higher than those of large ground-mounted systems. The PV costs have to be compared with the rising costs of gas- and coal-fired power, considering that many countries, the governments still subsidize conventional power and fossil fuels.

The investment cost of PV systems is also rapidly declining, with the price of PV modules being decreased in the past 30 years by between 18-22% with each doubling of the cumulative installed capacity. More recently, prices have dropped even faster, as increased competition and a surplus in the supply have pushed down the PV module prices, while further reductions of 40-60% are feasible by 2020, with the increased efficiency being an important component of this cost reduction.

In the second quarter of 2012, the cost of small PV systems in Germany was just 2.200 USD/kW, while in 2010 the same average cost was 3.800 USD/kW. However, not all PV markets are as competitive as Germany's. There countries in which small-scale systems, e.g. less than 10 kW, may cost twice as much as in Germany. According to forecasts, by 2020, the cost of small-scale rooftop PV systems could decline between 1.750-2400 USD/kW in the

most competitive markets, while for the average cost of large, utility-scale PV projects, this decline could be between 1.300-1.900 USD/kW.

4.3.1 Cost breakdown of PV systems

The typical cost of a c-Si module includes about 45-50% for silicon, 25-30% for cell manufacturing and 20-25% for cell assembling into modules (IEA-ETSAP and IRENA, 2013). The cost breakdown for a commercial PV system includes 50-60% for PV modules (TF and c-Si, respectively), 10% for the inverter, 23-32% for installation of BoS and about 7% for engineering and procurement. In the period 2007-2012, the share of PV modules has declined from about 60-75% to 40-60%, depending on the technology. As a result, the cost for the inverter and BoS declined as well. Markets like Germany have seen these costs decline in line with the module costs, but others have stickier soft-costs, particularly for residential installations, and as a result, BoS costs have not come down as rapidly. In Europe, BoS prices have fallen to 1.300 \$/kWp for residential roof installations, but tend to be lower for ground-based, utility-scale systems.

A more detailed analysis of the cost structures of solar PV applications helps to illustrate the most important cost drivers and suggest where future strategies should focus in order to bring down the overall costs. In Table 11, the cost structure of a typical 5 MW ground-mount field project in Europe is broken down. The initial installation expenses account for about three-quarters of total lifetime costs. Variable costs, such as operation, maintenance, lease and insurance fees only account for around 25% of total costs. Within upfront costs, solar modules and the rest of the system (BoS) roughly account for 40% each. Project permits and development fees, which are highly variable by installation and country, account for the rest. Within variable costs, two-thirds are made up of operation and maintenance costs and the remaining third is evenly split between land lease expenses and insurance fees.

The cost structure varies slightly for other solar PV applications. For example, the composition of the initial capital costs is somewhat different for smaller-scale systems, but the proportion of upfront capital cost to variable costs remains similar. Grid connected rooftop systems require fewer approval fees and a smaller investment in interconnections than field projects do. However, smaller-scale rooftop projects can have higher transaction costs per W, since the sails and due diligence process for multiple rooftop projects is often more expensive. Large-scale greenfield projects, often referred to as utility-scale projects, typically have higher associated environmental permitting and interconnection fees, as well as permitting risks that increase the cost of capital. Simultaneously, economies of scale often allow for lower equipment and installation costs on a per W basis for utility-scale projects. The cost structure for off-grid systems is also different from grid-connected systems, as BoS components play a more important role. They can account for up to 70% of total PV system costs.

A detailed analysis of the various costs of solar PV systems takes place in the Appendix.

Upfront capital costs (in euros)						
			Percentage composition			
	Per watt	Total	BoS (percent)	N. Mod (percent)	Sys (Percent)	Tot (percent)
Inverters	0,21	1.050.000	14	11	6	6
Module mountig structure	0,19	950.000	12	10	6	5
Transformer	0,05	250.000	3	3	2	1
Other electrical devices	0,03	125.000	2	1	1	1
DC cables and string connectors	0,03	125.000	2	1	1	1
AC cables and underground connectors	0,1	500.000	6	5	3	3
Civil work	0,11	550.000	7	6	3	3
Labor cost	0,18	900.000	12	10	6	5
Construction management	0,35	1.750.000	23	19	11	10
Other administrative fees	0,3	1.500.000	19	16	9	8
Total balance of system installation	1,54	7.700.000	100	81	48	43
Project permits	0,35	1.750.000		19	11	10
Total non-module cost	1,89	9.450.000		100	58	53
Solar modules	1,35	6.750.000			42	38
Total system installation cost	3,24	16.200.000			100	90
Assorted development fees	0,35	1.750.000				10
Total system financing price	3,59	17.950.000				100
	Variab	le costs				
	Per watt	Total	BoS	N. Mod	Sys (Percent)	Tot
Solar farm annual O&M costs	0,04	200.000			67	
Annual site lease	0,01	50.000			17	
Annual site insurance	0,01	50.000			17	
Total annual variable costs	0,06	300.000			100	
20 year variable costs		6.000.000				
	Overall life	etime costs				
Total system financing price		17.950.000				75
Total 20 year variable costs		6.000.000				25
Total lifetime cost		23.950.000				100

Table 11 Lifecycle breakdown of a solar PV investment project of 5 MW in Europe(Kirkegaard, 2010).

4.3.2 Current competitiveness of solar power

Although grid parity also depends on several external and regional factors, such as grid electricity prices, fossil fuel prices or the amount of solar radiation, the most important determinant of future competitiveness will be the price of solar electricity itself and thus, the total lifecycle costs of solar PV installations (Kirkegaard, 2010). The total costs over a lifecycle of 20-30 years can be divided into fixed capital costs that occur as a one-off investment at the time of installation and variable costs that occur every year. Taken together and spread over the lifetime of a project, these make up the levelised costs.

Over the past decades, the levelised costs of grid-connected solar electricity dropped from over 2 \$/kWh in the 1970s to 0.15-0.40 \$/kWh in 2008, depending on the application and the geographic conditions. Even under a scenario where carbon pricing would increase the price of fossil fuels, the levelised cost of solar PV energy would still be among the highest of

all currently available energy technologies. Broadly speaking, the price for solar energy would have to further decline by 30-50%, to around 0.10 \$/kWh, in order to reach grid parity and become competitive with other forms of grid-connected energy generation, as shown in Figure 11.



Figure 11 Levelised cost of energy: solar versus other energy sources in 2009 (Kirkegaard, 2010)

4.4 Levelised cost of electricity (LCOE) for solar PV

As it has already been mentioned, the tipping point for solar PV adoption is considered to be when the technology achieves grid parity, given that conventional-powered electricity prices are rising while PV install prices are falling. As has also been mentioned, "grid parity" refers to the lifetime generation cost of the electricity from PV being comparable with the electricity prices for conventional sources on the grid, often graphically given as the industry average for solar PV electricity generation against the average electricity price for a given country. While this is a useful benchmark, its validity depends on the completeness and accuracy of the method used to calculate the lifetime generation cost of solar PV electricity (Branker, 2011). In addition, claims of grid parity at manufacturing cost instead of retail price have contributed to confusion. The economic feasibility of an energy generation project can be evaluated using various metrics, but the levelised cost of electricity (LCOE) generation is most often used when comparing electricity generation technologies or considering grid parity for emerging technologies such as PV.

A clear understanding of the relative cost-effectiveness and feasibility of different energy technologies is paramount in determining energy management policies for any nation. The actual electricity prices depend on the marginal cost of electricity generated by the given power plant and market-based or regulatory measures. Various power plants can compete to supply electricity at different bids, such that the electricity price from suppliers varies depending on the accepted bid and technology. To reduce this volatility, calculations are used by retailers to assume a fixed or tiered system that is predictable for consumers and that accounts for any volatility in the supplied electricity price, upgrades to the grid system and other administrative duties. Thus, the final electricity price paid by consumers will be different from the cost of generation.

In general, estimates for LCOE for solar PV tend to be fairly high compared to alternatives based on common assumptions and it should be noted that these estimates are highly timedependent, as the cost of PV has dropped dramatically in the last years. The main assumptions made in the LCOE calculation are the choice of discount rate, the average system price, the financing method, the average system lifetime and the degradation of energy generation over the lifetime. In the rest of this subchapter, some clarification is provided concerning the assumptions that should actually be made when calculating the LCOE for solar PV.

Discount rate

Firstly, the choice of the discount rate comes with ample uncertainty and this is dealt with using sensitivity analysis (Branker, 2011). The concept of discount rate puts a value on time preference on money, which varies by circumstance, location and the time period considered. Furthermore, some investors vary their discount rate between technologies to reflect their perception of its financial risks. The choice of discount rate can largely affect the energy technologies, which are relatively more competitive. The private sector favors higher discount rates to maximize short-term profit, but these may be too high to capture the benefits of long-term social endeavors undertaken in the public sector, such as infrastructure and energy projects. Governments often estimate a social discount rate for rating public projects that have long-term social benefit. Finally, there is a distinction between real and nominal discount rate, where inflation is included in the nominal rate.

System costs, finances and incentives

Generally, there are 4 categories of solar PV system costs: the "project" costs, which are associated with the actual system, its design and installation, the "administrative" costs, such as insurance and interconnection, the "financing" costs, associated with the financing method and the "public" costs, associated with taxes (Branker, 2011). However, what is not often considered in all power generation technologies are the economic, environmental and health costs of negative externalities. The system price, apart from capacity and manufacturing variability, is highly dependent on the type of the solar PV system and the location and type of the dwelling. For example, in general, a thin-film system is less costly per unit power than a c-Si system. Inverters have variable prices, types and fifes and the type of racking and installation needed depends on the house. Nevertheless, most LCOE studies report an average for solar PV without distinguishing between different technology

types and BoS costs. If averaging needs to be made for simplification, then the assumptions made and how common they are should be reported. In general, the BoS and labour costs represent around 50% of the system cost, but strategies are being developed to halve these compared to best practice. Solar manufacturing prices have been rapidly declining with economies of scale through turn-key manufacturing facilities and industrial symbiosis. Inverter life and warranties are being extended to 10 years and micro-inverters may provide an economical choice for residential systems, which may suffer from partial shading challenges. Finally, installation costs will decrease with technological experience, although not as drastically.

System life for solar PV

The financeable life for a solar PV system is usually considered to be the manufacturer's guarantee period, which is often 20-25 years (Branker, 2011). However, research has shown that the life of solar PV panels is well beyond 25 years even for the older technologies, while the current ones are likely to improve their lifetime further. A 30-year lifetime or more is becoming expected.

In general, the working life of an asset is the life for which it continues to perform its tasks effectively. It is often true that the operation and maintenance (O&M) costs rise with the age of the asset. Since annual capital costs tend to decline and annual O&M costs rise, there is a minimum average cost per year at which point it is considered the economic life of the asset. At the economic life, the asset is then replaced or refurbished, since it becomes more expensive to run the asset thereafter. For solar PV, the O&M costs are due to replacing inverters (usually every 10 years), occasional cleaning and electrical system repairs, which are relative costs that will decrease with time. It should also be noted that the life of many conventional power plants is much longer than rated, since they tend to be refurbished or re-commissioned indefinitely; the same could be true for solar PV plants. Thus, what is considered the economic life of the system depends on the acceptable energy output, which depends on the degradation rate (rate at which there is a reduction in output). Table 12 illustrates the effect of degradation rate and acceptable performance on the lifetime of the system in terms of a percentage of maximum power output (P_{max}).

Degradation rate	Lifetime to 80% P _{max} (years)	Lifetime to 50% P _{max} (years)
0.2%	100	250
0.5%	40	100
0.6%	33	83
0.7%	29	71
0.8%	25	63
1.0%	20	50

Table 12 Effect of degradation rate and performance requirement on system life (Branker,2011)

Finally, the lifetime and reliability of solar PV can be considered for different solar PV technologies. Crystalline silicon wafer based PV modules offer the best in-field data being the technology established on the market for the longest time. For PV technology, it is difficult to define the lifetime, since ordinarily there is no single catastrophic event but more gradual aging and degradation. The end of life of the system has not been reached once the power output still satisfies the user. Gradual degradation occurs due to chemical and material processes associated with weathering, oxidation, corrosion and thermal stresses.

Degradation range and energy output

Determining the energy output of solar PV over its lifetime depends on the assumed degradation rate of the panels (Branker, 2011). Module encapsulation protects against weather factors, moisture and oxidation and can withstand mechanical loads (e.g. wind and hail). PV systems are often financed based on an assumed 0.5-1% per year degradation rate, although 1% per year is used based on warranties. This rate is faster than some historical data given for silicon PV. It has been found for c-Si modules, that faster degradation occurs earlier and then it stabilizes indefinitely. Moreover, more than 70% of 19-23 –year old c-Si modules had an annual degradation rate of 0.75%, still less than the 1% assumed. The failure losses are summarized in Table 13. It should be noted that amorphous silicon (a-Si:H) PVs consist a special case, which suffers from light-induced degradation. In a-Si PV cells, performance degrades rapidly in the first 100 h of exposure to sun illumination until a degraded steady-state is reached. This effect has not been eliminated yet, but a-Si:H PVs are sold with warranties valued at the degraded steady-state value, ignoring the above specified initial performance.

	Average losses (%)	Standard deviation	Reasons
		(%)	
Power loss	17.3	23.5	Combination of losses in V_{oc} , I_{sc} and FF
Loss in V _{oc} (open circuit	10.6	18.5	Loss of substrings in module in 6 series
voltage potential across			modules
terminal)			
Loss in I _{sc} (short circuit	5.8	20	Module aging process (gradual
current – maximum current			degradation of semiconductor
delivered)			properties, cell interconnections,
			encapsulant browning), optical
			properties degradation
Loss in Fill Factor FF (ratio of	9.1	22	Module aging processes (gradual
maximum actual power to			degradation of semiconductor
maximum theoretical power)			properties, cell interconnections,
			encapsulant browning), microscopic
			cracks and degradation of
			interconnections increase resistance

Table 13 Summary of power loss results for 204 modules installed in 1982-1986 with 19-23years (Branker, 2011).

<u>Grid parity</u>

As it has already been mentioned, grid parity is considered a tipping point for the costeffectiveness of solar PV and entails reducing the cost of solar PV electricity to be competitive with conventional grid-supplied electricity. For parity, the total cost to consumers of PV electricity is compared to retail grid electricity prices. Although the LCOE is not the same as retail electrical prices, it is used as a proxy for the total price to be paid by consumers, adding in as many of the realistic costs as possible (Branker, 2011). The LCOE methodology is then used to back calculate what the required system and finance costs need to be to attain grid parity.

4.5 Conclusions

Solar PV technology is growing rapidly in the past decades and can play an important role to meet the high energy demand worldwide. In this chapter, the worldwide status of PV technologies has been presented together with the various costs of these technologies. It can be concluded that specific policies and incentives for supporting the deployment of solar PV over the last years caused a rapid increase in the total PV installed capacity. This increase was accompanied by industrial learning and market competition, which led to significant and rapid cost reductions for PV systems. Currently, the crystalline silicon (c-Si) and the thin-film (TF) technologies dominate the global PV market, with c-Si owing around 85% of the PV market share, from which more than 40% is owned by mono- and polycrystalline PV technologies, with efficiencies of 15-17%. Thin-film polymer based solar cells and 3rd generation solar cells are also in the development stage with improved efficiencies being expected.

The typical cost of a c-Si module includes about 45-50% for silicon, 25-30% for cell manufacturing and 20-25% for cell assembling into modules. The cost breakdown for a commercial PV system includes 50-60% for PV modules (TF and c-Si, respectively), 10% for the inverter, 23-32% for installation of BoS and about 7% for engineering and procurement. Low material costs, particularly for polysilicon, combined with improved manufacturing processes and economies of scale have reduced manufacturing costs of solar PV far faster than targeted by the industry.

Currently, solar PV power is economically competitive for off-grid applications. The financial incentives offered by many governments have significantly helped the spread of PV deployment and have led to reduced costs through mass production of components and systems. As a result, grid parity has been almost achieved in the most favourable, in terms of solar capacity, locations.

5. An adoption model for solar PV under FiT policy

So far, the renewable energy policy instruments for the support of the adoption of RES have been analyzed, with the focus being on FiT schemes. This chapter explores the FiT policy for solar PV adoption in more detail. Using a general economic model, according to *Shum*, it is possible to capture the cost as well as the possible income benefits of adopting solar PV under FiT for smaller PV systems, thus obtaining an equilibrium condition of technology adoption (Shum, 2013). Two sources of economic effects have been modelled: the conventional volume based cost learning curve effects on the PV systems and a negative network externality, associated with the renewable payment that the adopter-to-be is facing. Both the above effects influence the adoption decision.

According to the author, the findings of the model suggest that under the abovementioned effects within a FiT regime, the PV electricity generation would exhibit an abrupt pattern with a rapid and sharp increase. It is also suggested that a critical threshold of adoption or generation exists beyond which sharp increase would take place. Moreover, the author claims that this model seems to be able to quantitatively discern the recent PV electricity pattern in Germany. It is the aim of this Chapter to try and discern the solar PV electricity pattern in the three countries examined in this Thesis, which are Greece, Spain and Germany, using this model and elaborate on the results by comparing them with the findings of *Shum* and with the real life.

5.1 The adoption model

For modelling the solar PV adoption decision, a microeconomic approach is used. According to this approach, the income possibility is considered to be an important factor in the decision condition of the agent to adopt solar PV under the FiT scheme. As a result, it is assumed that the objective of a rational decision maker is to balance the costs and benefits of the adoption. Moreover, the heterogeneity of the adopter population is summarized by a normal distribution f of the income derived from the FiT scheme.

By adopting, the adopter of type θ would receive income θ , but also share the burden of all feed-in tariffs paid to all other adopters in the same grid. So, the adopter of type θ adopted at time *t* earns the tariff and mitigates this *per capita* feed-in tariff cost. Assuming a linear utility function, this means that the following equation is valid:

Equation 1:

$$c_0 \times \left[\int_0^\infty f(t)dt\right]^{-a} = \theta - \lambda \times \left[\int_0^\infty tf(t)dt\right]$$

where:

α: learning elasticity to output volume of the PV system c₀: initial cost of generation equipment λ: strength of network effects $f \sim N(\mu, \sigma^2)$: the feed-in tariff income normal distribution of the adopter population

5.1.1 Model assumptions

The Left Hand Side of Equation 1 (LHS) is the investment cost embodied in the PV equipment cost, which is itself subjected to learning by doing. The conventional formulation of the learning effect is in terms of cost learning over time. The learning effect can also be in terms of the unit cost, which depends on the cumulative volume of production, and this is the formulation used in this model for facilitating working in terms of the size of existing installed base in the electricity network. Minimal production learning spillover from the installation in another network is assumed. By a simplification of the model, the learning elasticity is that of the PV system itself.

The Right Hand Side (RHS) depicts the utility formulation of the agent. The population of agents can be characterized and ranked by θ or the individual willingness to invest. This is assumed to be proportional to their intention to generate PV electricity and hence, is a proxy to the FiT income. The individual agent would adopt when the condition of Equation 1 is gradually satisfied.

The income θ is the net present value (NPV) of the future income stream guaranteed under the FiT scheme. In this model, the interest is on this NPV of FiT, once qualified, to be earned by the individual adopters. However, the aggregate income or payment will be transferred to the energy users in the network, thus consisting the negative term in the utility formulation. The total NPV income paid to all the adopters for their generated electricity will be shared by all the energy users and this is a negative network effect for a non-adopter. It must be emphasized that while λ is interpreted as a network effect above, it is determined by the burden sharing scheme (financing mechanism) inherent in the FiT scheme, e.g. what percentage of the payment needs to be contributed by all the energy users. Different schemes vary in this respect and it is assumed that λ is taking this into account.

Summing up, the Probit equilibrium adoption condition of Equation 1 incorporates the dual sources of non-linear effects at the micro-agent level: supply side learning by doing and demand side network externality. It can be suggested that the waiting agent will see an increasingly declining cost of equipment and an increasing payment to those who have adopted. As a result, the two effects compete against each other in the decision making process.

Because:

$$\int_0^\infty f(\theta)d\theta = 1 - F(\theta)$$

the adoption condition can be simplified into:

Equation 2:

$$\theta = \frac{c_0}{(1-F)^a} + \lambda \times \mu \times \left[1 - L \times \left(\frac{(\theta-\mu)}{\sigma}\right)\right] + \frac{\lambda \times \sigma}{\sqrt{2 \times \pi}} \times e^{-\frac{1}{2} \times \left(\frac{(\theta-\mu)}{\sigma}\right)^2}$$

where:

 α : learning elasticity to output volume of the PV system

c₀: initial cost of generation equipment

λ: strength of network effects

 μ , σ : mean value and standard deviation of the FiT income normal distribution of the adopter population

L: the CDF (Cumulative Density Function) of the abovementioned normal distribution

Equation 2 cannot be solved analytically, as L, the cumulative normal, is not a closed form expression. As a result, in order to graphically display the functional mapping of Equation 2, Excel is used together with different combinations of the parameters summarizing the learning elasticity, network strength, initial cost and the statistical properties (heterogeneity) of the adopting population.

5.1.2 Data used in the model

Equation 2 will be graphically displayed for four cases: the first graph will be for the case examined by *Shum*, while the next three graphs will concern the cases of Greece, Spain and Germany. In order to do this, a number of parameters need to be determined. In this section, the parameters chosen for each case will be presented and their choice will be discussed.

Selection of data

Concerning the values used for the cases of the three countries, the following assumptions were made:

- the examined period starts in 2009, which is the year in which all three countries had implemented a FiT tariff law for some time, and the first results were showing, until 2032, which is an average lifetime of a solar PV system.
- the data available cover the period 2009 2014. Thus, it was also assumed that the legislative framework for solar PV in the three countries will remain as it is today, with no other changes.
- for the calculations, a rooftop system of 3 kW, connected to the grid, was used.
- for the three cases, areas where chosen which have as similar as possible solar irradiance in kWh/day. Table 14 shows the areas chosen, together with the

electricity generated per kW of installed solar PV, as well as the total electricity generated per year in the chosen areas.

- for the cost of the electricity generation equipment, the values used are also shown in Table 14. These values are the average values which occurred after a search online for the cost of this equipment in each of the three countries.
- θ equals the difference between revenue, which is the income from the FiT, and cost, which is the cost of the equipment.
- the revenues were calculated based on the feed-in tariffs used in the chosen countries through the period 2009-2015 and for the period 2015-2032 it is assumed that the policy will remain as it is today. More details on the values of the FiTs and how these have evolved through the years and the different policies are provided in the next chapters.
- the value of μ was calculated as the average of the non-dimensional revenues through the period 2009-2032 and σ as the standard deviation of the same population.
- all the values used in the calculations need to be non-dimensional. In order to make the values non-dimensional, the logic of *Shum* was used, according to which a base is formed when diving the revenue of the first year with 50 and this base is used in order to make all the values non-dimensional.

Country	City	Solar capacity (kWh/day)	Electricity generated (kWh/kW)	Total electricity generated (kWh/year)	Cost (€)	Non- dimensional cost
Greece	Athens	4.30*	1340	4020	16065	363.29
Spain	Saragossa	3.91*	1427	4281	15498	532.38
Germany	Kempten	2.69*	982	2946	10010	686.08

Table 14 Data used in the calculations

* (JRC, last accessed in 19/08/2015)

The various values used in the calculations for the graphical display of Equation 2 are shown in Table 15. For the reproduction of the model case, the values used were those provided by *Shum*.

Table 15 Ideal values used for the parameters of Equation 2

Parameter	Value		
α	0.1		
λ	1.0		
μ	7.044		
σ	16.909		

5.2 Discussion of results

5.2.1 Reproduction of Shum's model

Under the right conditions, as these are defined by *Shum*, the graph of Figure 12 occurs for the difference between the LHS and the RHS of Equation 2. In this graph there is a multiplicity of solutions to Equation 2, which suggests that the system has the ability to exhibit accelerated adoption effects when the time path shifted from one solution (network size) to another in a short duration.



Figure 12 Difference between LHS and RHS of Equation 2, as defined by Shum.

Based on Figure 12, at high values of θ , in this specific case θ >35, the net return is positive and there will be adoption. The reason behind this adoption is that, since the value of θ is high, the negative network externality, that is the higher electricity cost due to the FiT, is still smaller than the difference between θ and c_0 , which are the FiT benefit and the investment cost, respectively. Once θ takes values in the interval between (10, 35), the net benefit becomes negative. In this case, the adoption process is stalled. For values of θ <10, the new technology is fully adopted, as the learning process has led to a point where the investment cost of the technology is not such high to need the support for its adoption.

According to *Shum*, varying the values of the learning rate (λ) and the network strength (α) affects the form of Figure 12. More specifically, an increase of the learning elasticity to higher values, such as α =0.3, would initially spur adoption and generation, however, if combined with strong negative network externality effect, such as λ =1.5, then the adoption process would be "choked", resulting in a minimum interval of stalled adoption. On the other hand, if the learning elasticity is reduced and the network effect becomes moderate,

e.g. α =0.1 and λ =0.5, then the adoption dynamics can sustain a larger interval. Based on these two extreme cases, *Shum* suggests that the installed base, which is driven by cost learning, should be done very fast and an optimal rate might exist for building the installed base under negative network externality. As a result, he suggests that it might be prudent to start with "moderate" learning and "moderate" network effects for sustaining the deployment process in the initial case.

5.2.2 The case of Greece

Using the ideal conditions of Table 15 and the data of Table 14, the graph of Figure 13 occurred when plotting Equation 2 for the case of Greece.



Figure 13 Difference between LHS and RHS of Equation 2 for the case of Greece

If this graph was plotted in the same graph with Figure 12 then it would be noticed that the zero value of the x-axis for the Greek case is in the middle of the ideal case. This can be explained by the choice of the period that was chosen for studying this case. This time period is from 2009 onwards, when the FiT policy for solar PV was adopted in Greece. However, in 2012, a "boom" took place in the Greek solar PV market. Initially, the FiT policy provided very high tariffs for electricity generation by solar PV. In fact, these values were so high that they soon attracted the interest of many investors. However, due to a number of reasons that are discussed in the next Chapter, the situation started getting out of control, with thousands of applications being submitted during the first year of the policy. The government, in its effort to regain control of the situation, dramatically decreased the tariffs offered, thus decreasing the revenues for the investors, while the investment cost of solar PV remained the same. This change in the legislation, together with other factors, ended up in a stall of the adoption of solar PV in the country.

This pattern can also be seen in Figure 12. Initially, the difference between revenues and costs (net benefit) is very high, as the tariffs provided were very high. By lowering the values of the tariffs, this difference began to decrease. For values of θ <42, the net benefit becomes negative, causing a stall in the adoption process. The graph also shows that the network externality (higher electricity cost due to the FiT) is still higher than the net return.

5.2.3 The case of Spain

Using the ideal conditions of Table 15 and the data of Table 14, the graph of Figure 14 occurred when plotting Equation 2 for the case of Spain.



Figure 14 Difference between LHS and RHS of Equation 2 for the case of Spain

As in the case of Greece, a number of legislative changes took place in Spain, varying the values of the tariffs offered for electricity generation using solar PV from their initially very high values to rapidly decreasing them. So, in the case of Spain, also, an initial "boom" was caused by the high FiTs offered, which was followed by a dramatic drop, both in the tariffs and the adoption of the technology. However, in the case of Spain, the government took one step further in order to face the situation, which was getting out of control, again through the high attraction of the policy for investors. This step was the suspension of the FiT policy for solar PV, being uncertain when and whether it will start again.

The pattern shown in figure 14 is very similar to that shown in Figure 13 and it closely follows the sequence of the events that took place in the FiT policy for solar PV in Spain. The difference in this case is that the policy has been suspended, which means that there is no indication of whether a continuation of the policy could eventually lead to the full adoption
of the technology or not, or whether a change could take place that could change the situation.

5.2.4 The case of Germany

Using the ideal conditions of Table 15 and the data of Table 14, the graph of Figure 15 occurred when plotting Equation 2 for the case of Germany.



Figure 15 Difference between LHS and RHS of Equation 2 for the case of Germany

Based on the successful implementation of the FiT policy for the support of solar PV in Germany, a graph similar to that of Figure 12 was expected to occur. Instead, the one of Figure 15 was obtained. In this case, it can be seen that there is a drop in the net benefits of the policy for Germany, too. Although there was indeed a reduction in the FiT values also in Germany, this reduction was not so dramatic that could explain the drop shown in Figure 15. However, this drop can be explained by another factor, which did not exist in the cases of Greece and Spain.

As it has already been mentioned, the network externality is the higher cost of electricity due to the FiT. In the cases of Greece and Spain, part of this extra cost is covered by a RES Fund. In the case of Germany, however, this extra cost is directly passed on the electricity bills of the consumers, thus increasing the cost of electricity and as a result, the network externality. As the values of the tariffs offered are decreasing and the electricity cost is remaining the same, the net benefit is reduced, thus explaining the shape of the graph in Figure 15.

5.3 Conclusions

In this Chapter, an attempt was made to explain the adoption process of solar PV under the FiT support policy, by including both the learning and the network effect. The network effect is inherent in the FiT scheme, as all the energy users have to contribute to the payment for renewable energy generation. As a result, the adopters cause a negative externality to the non-adopters.

This attempt was carried out by using the model described by *Shum*. According to this model, the joint effects of learning by doing and network externality in a FiT income and policy regime can cause negative effects, as it was shown in the examined cases, either due to a rational profit maximization condition (Greece and Spain) or to the interaction between themselves (Germany).

However, as the model used cannot be solved analytically, only a quantitative approach can be taken for evaluating the results. Even so, the model can follow realistically the real cases; however, the ideal case cannot be reached.

6. The case of Greece

So far, the European Renewable Energy Policy has been discussed and the problems that require the attention of the governments of the EU Member States have been identified, thus setting the agenda for the choices that should be made in terms of the energy policy by these countries. Chapter 6 analyzes the deployment of solar PV energy in Greece. The chapter starts by setting the agenda for a policy framework based on the solar capacity and needs of Greece, thus providing the rationale for the objectives set, and also justifying the choices of the specific policy schemes used. This is achieved by providing some general information for solar PV in Greece, shortly presenting the electricity system of the country and by a brief analysis of the electricity tariff deficit of the country. Furthermore, the actions taken by the Greek government towards adopting the EU Directives and reaching the goals set are presented, together with the regulatory framework and the support policies used for the promotion of solar PV energy. Finally, an evaluation of the policy is provided, through a discussion of the results of the support scheme, through an overview of the costs for solar PV in Greece and a description of the Greek solar PV market, as this was formed following the changes in the legislation together with the main legislative issues and investment drawbacks which hinder the further deployment of solar PV in the country.

6.1 Agenda setting for the policy framework of Greece

6.1.1 The solar potential of Greece

The solar potential of Greece is extremely high, making the country ideal for the wide deployment of solar PV applications, particularly because (Pure, 2008):

- It has high solar radiation throughout the year (the highest in Europe), as it can be seen in Figure 16, Figure 17.
- The electricity needs of the islands are not secured and are covered mainly by using diesel, which is highly polluting and has high costs for power production.
- The security of energy supply in the islands and the off-grid areas is not satisfactory.
- They respond to the large seasonal fluctuations of the peak demand of the islands and other tourist areas, especially during summer, due to the significant correlation between seasonal demand and electricity production from PV.



Figure 16 PV solar electricity potential in European countries (Joint Research Center, 2012)

In countries with such a high solar irradiation potential, and based on what has been mentioned so far in this Thesis concerning solar PV support policies, an improved feed-in tariff system could have the greatest and most direct effect on the PV market (Karteris, 2013). With such high average solar irradiation as in Greece (around 30% higher than that of the northern Europe), generous tariffs are not needed for keeping the annual profits at desirable levels. But the success of a FiT system does not always depend only on rational parameters, like generous FiT subsidies, and this was proven in the case of Greece up to 2012. "Monetary and financial terms consist only one, however dominant, aspect of an entrepreneurial environment, while cultural and social influences, even on the public opinion of *how things work*, another" (Karteris, 2013).



Figure 17 Average annual solar energy per unit area (kWh/m²) in Greece for the period 2002-2013 (Greek Solar Energy Network HNSE, 2013)

6.1.2 The Greek electricity system

The Greek electricity system was mainly developed after 1960 with the aim of electrifying the country through the exploitation of the domestic energy sources (Development, 2009). The demand of the grid connected system of the mainland was initially covered by oil units and later, by lignite power stations and hydro-electric plants, while the electricity needs on the islands were covered by autonomous oil plants and wind farms (the latter after 2006), and remained non-interconnected due to the high cost of a possible interconnection. Until 2006, the largest part of the electricity production was a product of lignite combustion, while natural gas was used as a fuel for the first time in 1996. The total power output of the electricity system in 2006 was 13.6 GW, with 36% of which corresponding to lignite power stations, which mainly meet the base load, and therefore, the largest power rate is derived

from them. After the oil crisis, the main priority of the Greek energy policy was the systematic exploitation of the lignite deposits of Northern Greece and Peloponnesus.

In 2006, the net electricity production was 57 TWh, from which 52% was produced by lignite combustion, 14.2% from oil products, 11.5% from hydro and 3% from wind. The net electricity production increased by 76% compared to its 32 TWh value in 1990, with an annual growth rate of 3.5%. A significant increase in the lignite use was noticed during the period 1990-2006, with its electricity production increasing from 23 to 29 TWh, while the introduction of natural gas, which reached a production of 10.1 TWh in 2006, was an important aspect of the electricity production of the country. The rest of the electricity was produced from petroleum products, hydro and wind farms while also, in the last years before 2006, an increased rate of imports was noted. Table 16 presents an analysis of the net electricity generation in 2006.

2009). Total net Interconnected Crete Rhodes Power

Table 16 Analysis of the net electricity generation in Greece (GWh) in 2006 (Development,

Fuel	Total net production	Interconnected system	Crete	Rhodes	Autonomous Power Stations
Wind	1683.4	1199.4	348	24	112
Biomass	65.5	65	0.5	-	-
Hydro	6484	6484	0.2	-	-
Natural gas	10169	10169	-	-	-
Oil	8045	3309	2472	674	1590
Lignite	29165	29165	-	-	-
СНР	983	983	-	-	-
Total	56595	51374.4	2820.7	698	1702

The electricity demand of the country increased rapidly since 1990. The main increase was caused by the residential and tertiary sectors, with the latter being the largest electricity consumer in 2006, with an annual consumption of 17.7 TWh. Moreover, the industrial sector which was the largest electricity consumer in 1990, with 12.1 TWh fell to the third place in 2006, with a consumption of 14.1 TWh, while the household sector in 2006 was greater compared to the industrial, consuming 17.6 TWh and showing an overall increase of 93% compared to its 1990 levels, as shown in Table 17. Figure 18shows the evolution of total installed capacity in Greece.

Sector	1990	1992	1994	1996	1998	2000	2002	2004	2006
Industry	12.1	11.7	11.7	12.1	12.9	13.5	14.1	14	14.1
Commercial	5.6	6.6	7.9	8.8	10.8	12.3	14	15.9	17.7
and public									
buildings									
Households	9.1	10.6	10.9	12.3	12.8	14.2	15.8	16.9	17.6
Agriculture	1.6	1.6	2.1	2.2	2.6	2.9	2.5	2.8	2.7
Transportation	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Total	28.5	30.7	32.7	35.6	39.3	43.2	46.6	49.7	52.4

Table 17 Development of electricity consumption in the period 1990 – 2006 in TWh (Development, 2009).



Figure 18 Evolution of total installed capacity (MW) in Greece (Papanikolaou, 2008)

A special feature of the Greek electricity system is the peak load of the grid system, which occurs in the middle of the day in July. The change of this peak from winter to summer, which occurred for the first time in 1992, was caused by the increased use of air conditions and was related to the increase of the average income of the consumers and the changing climate conditions, especially in urban areas.

The Greek electricity system is divided into the grid of the mainland and the island system of Crete, Rhodes and the autonomous plants of the rest of the Greek islands (Development, 2009). The interconnected system is well developed and has connections with all the neighbor countries, however, the system is not evenly distributed, with 68% of the electricity being generated by the lignite deposits in Northern Greece and 33% of the consumption taking place in the region of Attica. The insular system concerns a large

number of islands, mainly in the Aegean Sea region. It includes autonomous systems which use mainly fuel oil 3500 and diesel fuel. The technologies used are mainly gas turbines, internal combustion engines and steam turbines, as well as combined cycle units. The Greek energy field, as it was formed in 2007 is presented in Figure 19.



Figure 19 The energy field of Greece in 2007 (Oikonomou, 2007)

The annual growth rate of demand in Crete and Rhodes are greater, and the load factor is lower, compared to that of the interconnected system, meaning that these systems have more intense peak problems, mainly due to the booming demand during summer, caused by tourism. As a result, the electricity produced at the islands costs much more compared to that produced in the interconnected system. However, due to the single pricing, this extra cost is not transferred to the local consumers. A brief historical overview of the Greek electricity market is provided in the Appendix. This overview will be helpful in understanding the various actors of the legislative framework for solar PV in Greece.

6.1.3 The electricity tariff deficit of Greece

An *electricity tariff deficit* can be defined as "a shortfall of revenues in the electricity system, which emerges when the tariffs for the regulated components of the retail electricity price are set below the corresponding costs borne by the energy companies" (Johannesson-Linden, 2014). Tariff deficits relate to the regulated components of the electricity price, which concern primarily network costs, such as transmission and distribution, and levies related to subsidies to renewable energy or to public service obligations. The scope of electricity tariff deficits differs widely from one country to another, with some Member States having the deficit on the renewable energy account, when the tariff revenues are not sufficient to cover the costs, e.g. when the aggregated costs for subsidies to renewable energy are rising so fast that the tariffs do not match them. In other countries, tariff deficit may cover public service obligations, the network costs or the "access costs", which include

network costs plus the costs of electricity subsidies to renewables, to capacity payments, to the provision of electricity to remote or isolated areas, etc.

Greece faces a deficit in the special account for renewable energy (RES account). The cumulative tariff debt in the RES account was estimated at 700 million € (0.4% of GDP) in early 2014. Tariff deficits have been recorded since 2011, with the deficit in the RES account reaching 195 million € (0.1% of GDP) in 2011 and 340 million € in 2012. This reflects large investments in renewable generation capacity. The installed solar PV power capacity increased for example from 48 MW in 2009 to 620 MW in 2011 and 2600 MW at the end of 2013. In 2014, PV was expected to cover 7% of electricity demand in Greece.

The expansion of solar power generation was pushed by very generous incentives, in the form of PV tariffs for PV. Such incentives were not promptly adjusted to take into account the decrease in the cost of technologies, thus creating windfall profit opportunities. The ensuing surge of the cost of supporting renewable energy should have been covered through a substantial increase in renewable levies, which was however difficult to implement as users were hit by the economic crisis. This led to an emergence of tariff deficit, and therefore of cumulative debt on the RES special account managed by LAGIE, the market operator, since 2011.

6.1.4 Understanding the policy

The Greek policy is based on the principle that RES are environmentally friendly and a key component of sustainable development, while, at the same time, they contribute to the energy independence of the country and the better spatial utilization of the natural resources of the country (Pure, 2008). As the minimum target, the achievement of the national targets for climate mitigation and RES promotion are set, as determined by the European and international obligations of the country. This national target is a PV penetration of 20.1% by 2010 and 29% by 2020.

Moreover, in order to eliminate the deficit and the debt mentioned above, the authorities allocated several additional sources of revenues to the RES account. In addition to the levy paid by electricity consumers and the revenues from RES production sold in the wholesale market, the revenues of the RES account include a levy from the production electricity from lignite, revenues from the sale of unused CO_2 allowances and a part of the revenues from the television license fee. An additional source, from 2012 to 2014, is a solidarity contribution, with rates between 25% and 30% of the revenues received, paid by producers of electricity from photovoltaic plants, and of 10% paid by the producers from other RES sources. In spite of these revenues, however, the RES account remained financially unsustainable, also because the solidarity contribution would expire in July 2014 and a financial gap estimated at 400 million \notin yearly would have emerged.

In March 2014, following a public consultation, the authorities announced further measures to correct the situation in a structural way and bring the debt in the RES account to zero by the end of 2014, in line with the economic adjustment program. These measures include

retroactive cuts in feed-in tariffs by, on average, 28% for PV plants and 5.4% for wind and hydro projects, a write-down of arrears owed to RES producers by 310 million \in (equivalent to a 28.7% write-down for PV producers and 10% for others) and the introduction of a 200 MW annual cap on new PV installations receiving support. The retroactive cuts were differentiated to take into account the size and the vintage of the investment and thus, the extent of overcompensation and windfall profits, and any state aid received. As a compensation for lower tariffs, the authorities extended the agreements with renewable power producers for seven years. Finally, the energy regulator raised the renewable levy paid by electricity consumers up to 15 \in /MWh, an increase of 4.8 \in /MWh or 47% and with further adjustments of the levy being possible in the future, if needed.

6.2 The legislative framework for PV in Greece

Law 3468/2006 – The first appealing FiT for solar PV

In 1999, with the Law 2773/1999, the Greek government authorized a tax for renewable energy to finance the FiT (Campoccia et al., 2014). The general assessment of the situation in Greece until 2006 was (Thomopoulos, 2006):

- 1. <u>Market development</u>: satisfactory off-grid development but little activities in the on-grid segment.
- 2. <u>Industry development:</u> fair representation relatively to the small national market.
- **3.** <u>Cost reduction:</u> following trends in EU.
- 4. <u>PV acceptance:</u> very high public acceptance.

Until 2006, major legislative weaknesses, such as low tariff and short guaranteed periods, complex and long-lasting licensing procedures and regulatory and technical obstacles regarding the access to the grid, resulted in a discrepancy between objectives set and reality in relation to PV diffusion in Greece (Karteris, 2013). Law 3468/2006 was enacted in 2006 in Greece, providing for the first time after the initial deregulation of the national electricity market (Law 2273/1999) an appealing FiT scheme for PVs. The response of the market was immediate with more than 7.940 applications, with an overall capacity up to 3.7 GWp, for licenses having been submitted in less than 2 years' time, leading unexpectedly during 2008 to the postponement of any further submission of PV applications to the Regulatory Authority of Energy (RAE). The tariff varied from 0.40 to 0.45 €/kWh for PVs installed in the interconnected network and 0.50 to 0.55 €/kWh for PVs installed in the non-interconnected islands. The tariff was guaranteed by signing a contract with the network operator (Transmission System Operator – TSO) for a time period of 10 years and with an extension for another 10 years at a tariff to be determined. A national target until 2010 (590 MWp in mainland plus 200 MWp in non-interconnected islands) was also set, showing the political commitment towards solar energy's development, as part of its overall national target for renewables (RES). According to Law 3468/2006, it was not mandatory to acquire any license to produce electrical energy for a PV plant of less than 150 kWp; an exemption from this obligation was granted instead by RAE. Moreover, no authorization regulations were specified for small-scale building applied PVs (BAPVs). Still, time limits were foreseen for the actions of all authorities, bodies and organizations involved in the bureaucratic procedures. Additionally, by means of a decree, a land-planning map of Greece was established for RES imposing new particular conditions and terms applied for that kind of projects.

Law 3734/2009 – The second FiT Law

In 2009, the second FiT law (Law 3734/2009) was brought forward due to the legal uncertainties associated with the tariff's terms, as well as the frequent discrepancies recorded among authorities until then, because of the total absence of planning and construction regulations for PV systems. Therefore, this law included for the first time specific installation terms for PVs both for land and building applications. Furthermore, for new sale contracts, a semester progressive decrease of tariff by 10% was foreseen, but in the same time, the guaranteed duration of the tariff was extended from 10 to 20 years. Finally, a national development program for BAPVs was initiated, providing investors with a remarkably high tax-free tariff of $0.55 \notin$ /kWh for 25 years (Karteris, 2013) and is annually adjusted for inflation (25% of last year's consumer price index) (Dusonchet and Telarreti, 2010)

Law 3851/2010 - The "boom" in the Greek solar PV market

Until 2010, a large number of applications had already been submitted, which resulted, however, in time-consuming licensing procedures carried out by RAE. At that time, the third FiT law (Law 3851/2010) was enacted, intending basically to facilitate authorization processes and give priority for older PV applications over new ones (Karteris, 2013). Similar priority was also granted to professional farmers, who were allowed to apply for grid connection offers of new PV stations up to 100 kWp, while the residential BAPV systems below 10 kWp gained the ultimate priority of all, thus were served first. Residential systems could be installed in all regions, in contrast to previous regulations which excluded the autonomous island grids, while applications previously excluded, such as facades, louvers, warehouses, carports, etc., were feasible in the residential sector (Winkel, 2011). On the other hand, time limits were imposed on investors for new PV applications, with a penalty clause included if the installation with signed sale contract delayed to become gridconnected (Karteris, 2013). In particular, PV investors were forced to pay a guarantee fee of 150 €/kWp (by giving a letter of credit) plus they should provide a certificate on behalf of a credit bank, where it will be declared that the bank intends to support financially the proposed investment. The FiT level was again amended, but only for non-interconnected network, as shown in Table 18, while PV stations with installed capacity smaller or equal to 1 MWp (Karteris, 2013) as well as rooftop systems of any size (Winkel, 2011) were ruled out from obtaining production license. In those cases, though, environmental license remained prerequisite as long as the PV capacity exceeds 500 kWp. Besides, the construction licensing of PVs became more direct and short-term, with lesser justifications needed. Planning terms about PVs on buildings and fields were also reconsidered, facilitating effectively design and installation works. Moreover, in contrast to the initial land-planning map of Greece, PV stations were allowed in agricultural land of high productivity, if only the land is located out of the boundaries of already enacted land use and development plans on municipal level. Finally, PV systems on historical buildings could be deployed under a special authorization procedure (Winkel, 2011). Solar plants could not enjoy the capital incentives as other RES sources, but were exempted of the payment of the 3% sale tax. The revenues from the sale of energy were also exempted from the income tax. Details about the authorization procedures of PV stations foreseen in 2011 are shown in Table 19.

	Month	Rooftop	Mainland gr	id (€/MWh)	Islands (€/MWh)	
Year		systems	Billion Bi	(6)		c,,
	Capacities	<10 kWp	≤ 100 kWp	>100 kWp	> 100 kWp	≤ 100 kWp
2000	February	550.00	450.00	400.00	450.00	500.00
2009	August	550.00	450.00	400.00	450.00	500.00
2010	February	550.00	450.00	400.00	450.00	500.00
2010	August	550.00	441.05	392.04	441.05	490.00
2011	February	550.00	419.43	372.83	419.43	466.00
2011	August	550.00	394.89	351.01	394.89	438.00
2012	February	522.50	375.54	333.81	375.54	417.00
2012	August	522.50	353.55	314.27	353.55	392.00
2012	February	496.38	336.23	298.87	336.23	373.00
2013	August	496.38	316.55	281.38	316.55	351.00
2017	February	471.56	302.56	268.94	302.56	336.00
2014	August	471.56	293.59	260.97	293.59	326.00
2015	February	447.98	-	-	-	-
2013	August	447.98	-	-	-	-
For every						
year v						
, from		-4.5% per	$1.4 \times SMP_{v-1}$	$1.3 \times SMP_{v-1}$	$1.4 \times SMP_{v-1}$	1.5×SMP _{v-1}
2015		semester				

Table 18 The FiT foreseen for PVs by Law 3851/2010 (Karteris, 2013) (Winkel, 2011),(Dusonchet et al., 2010) (Papamichalopoulos, 2012).

SMP_{v-1}: the average System Marginal Price during the previous year

The national targets for renewable sources until the end of 2020 were restated, in accordance with the directive 2009/28/EC, as follows (Karteris, 2013):

- The contribution of the energy produced from RES to the gross final energy consumption was set by a share of 20% and
- the contribution of the electrical energy produced by RES to the gross electrical energy consumption was planned by a share of at least 40%.

Table 19 Authorization procedures of PV stations according to Law 3851/2010 (Karteris,2013).

Type of PV stations	Procedures/mandatory approvals and licences
BAPV systems	
	i. Grid connection contract with DSO, namely the
Capacity \leq 10 kWp (national	Public Power Corporation (PPC)
development program for BAPVS)	ii. Sale contract with the DSO
	i. Grid connection contract with DSO
$10 \text{ kWp} < \text{Capacity} \leq 100 \text{ kWp}$	ii. Sale contract with the TSO (currently DESMIE S.A.)
	i. Approval of small-scale construction works
100 kWp < Capacity ≤ 1 MWp	ii. Grid connection contract with DSO
	iii. Sale contract with TSO
	i. Production license
	ii. Approval of small-scale construction works
1 MWn - Capacity	iii. Grid connection contract with DSO
I WWP < Capacity	iv. Installation license
	v. Sale contract with DSO
	vi. Operation license
PV parks	
	i. Certificate of exemption from environmental
	licensing
Capacity < 100 kW	ii. Approval of small-scale construction works
Capacity ≤ 100 kW	(simplified process)
	iii. Grid connection contract with DSO
	iv. Sale contract with DSO
	i. Certificate of exemption from environmental
	licensing
$100 \text{ kW} \propto Capacity \leq 500 \text{ kW}$	ii. Approval of small-scale construction works (detailed
	process)
	iii. Grid connection contract with DSO
	iv. Sale contract with DSO
	i. Environmental license
	ii. Approval of small-scale construction works (detailed
500 kWp < Capacity ≤ 1 MWp	process)
	iii. Grid connection contract with DSO
	iv. Sale contract with DSO
	i. Production license
	ii. Environmental license
	iii. Approval of small-scale construction works
Capacity above 1 MWp	iv. Grid connection contract with DSO
	v. Installation license
	vi. Sale contract with DSO
	vii. Operation license

Considering the above targets, the cap of the installed capacity of PVs was readjusted for 2014 and 2020, as shown in Table 20. As it can be noticed, a rather high percentage of up to 34% of installed capacity was granted to farmers, whereas in practice, there was no limitation imposed on residential BAPV applications.

PV plant type	Target	(MWp)
	Until 2014	Until 2020
PV parks belonging to professional farmers	500	750
Other PV parks	1000	1450
Total	1500	2200

 Table 20 National targets for PVs for 2020 according to the Law 3851/2010 (Karteris, 2013).

2012 – Issuing new measures to reduce the deficit of the RES Fund

In August 2012, the Greek Parliament passed new measures to drastically reduce PV funding and to stop new PV system approvals, in order to reduce the deficit of the Renewable Energy Sources Fund, which is used to pay RES producers in Greece (Dusonchet et al., 2015). Accordingly, PV FiTs were slashed by up to 46% and no new applications for producer licenses and connection requests have been accepted. This temporary suspension of the licensing process does not apply for the PV projects that have already been included in the provisions of the Fast Track Law and for roof PV projects of less than 10 kWp that already have a production license or a license for connection (HELAPCO, 2014). This decision affected over 7.5 GWp of PV projects (Keepontrack.eu, 2013). In November 2012, the Greek government decided to impose a levy on the supposedly "guaranteed" gross income of all operating RES projects in Greece. The decision was rushed through the Greek Parliament and hastily approved by a slim parliamentary majority, as a part of a package of fiscal austerity and economic reform measures. It aims at reducing the continuously growing deficit of the Greek electricity market operator by unilaterally cutting the operator's payment obligations to the RES producers for three (2+1) years. The levy ranges from 25% -30% for operating PV systems > 10 kW and 10% for wind farms, small hydro and biomass. In addition, new, lower PV tariffs were announced by the Greek Ministry of Environment, Energy and Climate Change (YPEKA) in May 2013, with a further 40% FiT reduction (Dusonchet et al., 2015). The new FiTs are shown in Table 21. It is worth mentioning that the already connected PVs are not affected by the new, reduced prices, but they continue to be normally paid at the rate indicated at the netting contract that initially been signed. It is also worth noting that, besides the reduction, a change in the process of entering the price between the owner and the supplier of electricity (PPC - Public Power Corporation) was also decided, which will be valid for 25 years. So, the price will be determined based on when the connection is activated and not on the time at which the compensation agreement is signed. For example, if the contract is signed in September 2013 and the connection is activated in March 2014, the price will be fixed at 0.12 €/kWh and not 0.125 €/kWh. This decision is valid from 1st June, 2013 (HELAPCO, 2014).

Year	Residential and commercial rooftop systems (€/MWh)	Mainland gr	id (€/MWh)	Islands (€/MWh)
	≤10 kWp	≤ 100 kWp	>100 kWp	> 100 kWp	≤ 100 kWp
2014	120.00	115.00	90	95	95
For every year v from 2015	-4.35% per semester for the period 2015 – July 2017	1.2×SMP _{v-1}	1.1×SMP _{v-1}	1.1×SMP _{v-1}	1.1×SMP _{v-1}
Power purchase agreement duration	25 years		20 y	rears	

 Table 21
 The new FiT for PVs after May, 2013 (HELAPCO, 2014).

SMP_{v-1}: the average System Marginal Price during the previous year

2013 Current framework – Introduction of retroactive tax and net-metering

As part of new austerity measures approved by the Greek Parliament, in May 2013 a new retroactive tax on revenue generated by RES plants was introduced, according to which, existing PV installations will be required to pay a tax between 25% and 42%, aiming to reduce RES deficit. The tax excludes rooftop PV systems with a capacity lower than 10 kW. These measures threaten the viability of many European companies based in Greece involved in the development, installation and operation of RES projects and drives away investments, wiping out any serious prospects for continued RES growth in a country with significant unexploited renewable energy potential (Keepontrack.eu, 2013).

In August 2013, the Greek Parliament also introduced net-metering to support residentialscale projects, under its new legislation on renewable energy systems (Law 3468/2006 amended by Law 4203/2013). The new legislation includes a provision allowing households and businesses to install PV systems and small wind installations to compensate for their own energy consumption (Dusonchet L. T., Comparative economic analysis of support policies for solar PV in the most representative EU countries., 2015). These installations will be exempt from the suspension of producer licenses and connection requests. However, no payments are granted for any surplus PV energy injected into the grid, after offsetting the energy produced and consumed at the end of each metering period. For these reasons, the Hellenic Association of Photovoltaic Companies (HELAPCO) considered the net-metering legislation "insufficient", since it requires a very long period for the investment to be paid back.

At the end of 2014, the Greek authorities introduced a legislation to facilitate net-metering for solar PV arrays, allowing installations up to 500 kWp (HELAPCO, 2015). The Greek netmetering scheme, decided on December 30th 2014, is applicable to all solar PV systems that aim for self-consumption, thus expands to both rooftop and ground-mounted systems.

The upper-limit for residential net-metering PV installations in Greece's mainland grid is set at 20 kWp. However, in commercial applications, where the required load exceeds 20 kWp, the new scheme allows for net-metering for installations that exceed the 20 kWp limit and reach up to half the power consumption of the consumer. In this case, net-metering systems can reach up to 500 kWp. Moreover, for either governmental or non-governmental not-forprofit organizations, e.g. universities and hospitals, the net-metering law allows for PV installations that cover an organization's electricity needs fully. In this case, too, a netmetering PV installation cannot exceed 500 kWp of capacity. Regarding Greece's autonomous electricity grids, e.g. islands that are not interconnected to Greece's mainland grid, the upper limit for net-metering installations is set at 20 kWp. An exemption to this rule is the island of Crete, where consumers can install systems up to 50 kWp. Energy compensation for net-metering owners will be taking place on an annual base.

The current legal framework for FiT in Greece is Law 3468/2006. According to the legislation, network operators are obliged to pay the PV producer for the electricity exported to the grid (Dusonchet et al., 2015). In addition, they are obliged to connect PV plants to the grid and to carry out the necessary grid development works. FiTs are granted for 20 years and their cost is borne by the electricity users, who pay a special Tax for the Reduction of Greenhouse Gases. The amount of the tax depends on the consumer category and is revised twice a year by the Regulatory Authority for Energy (RAE), according to Law 4001/2011. Small rooftop PV plants are eligible for a special FiT regime if their rated power is lower than 10 kW. If so, FiTs are remunerated for 25 years at higher tariffs than those granted under the standard FiT regime.

Summing up and in order to avoid confusion concerning the feed-in tariffs currently valid in Greece, Table 5 of the Appendix summarizes the most recent recorded tariffs per qualifying category of PV investors.

6.3 First evaluation of the policy

6.3.1 Costs of solar PV in Greece

PV plants in Greece are quite profitable, especially for BIPV systems (IRR=4.59% for the 3 kW and IRR=5.55% for the 20 kW PV plant) (Campoccia A. D., An analysis of feed-in tariffs for solar PV for six representative countries of the European Union., 2014). This is mainly due both to the good degree of FiT remuneration as well as to the high level of equivalent

operating hours, since the energy yearly produced in 2013 was equal to 1435 kWh/kW. *Campoccia et al.* calculated the economic indexes of the Discount Cash Flows (DCF), the Pay-Back Period (PBP), the Net Present Value (NPV) and the Internal Rate of Return (IRR) for different sized PV systems in France, Germany, Greece, Italy, Spain and the UK and the results for Greece are presented in Table 22. More recently, *Dusonchet and Telaretti* in 2015 made the same calculations and the results are presented in Table 23.

Rated power (kW)	Type of plant	Form of support	PBP (years)	IRR (%)	NPV (k€)
3	BIPV	FiT	14	4.59	2.048
20	BIPV	FiT	13	5.55	18.56
500	Ground- mounted	FiT+direct selling	15	3.04	5.626

Table 22 PBP, IRR and NPV for Greece in 2013 (Campoccia, 2014).

Table 23 PBP, IRR and NPV for the Greek case (Dusonchet L. T., 2015).

Rated power (kW)	Type of plant	Form of support	PBP (years)	IRR (%)	NPV (k€)
3	BIPV	Net-metering	15	4.66	1.88
20	BIPV	Net-metering	11	8.22	31.58
100	BIPV	Net-metering	12	6.95	101.73
500	Ground-mounted	FiT	16	3.32	25.34
1000	Ground-mounted	FiT	14	4.4	209.54

From the above Tables it can be noticed that Greece, despite the impressive reduction in the FiT rates in recent months, still has a good remuneration level, especially for BIPV systems(Dusonchet et al., 2015). This is mainly due to the following reasons:

- Greece has very high solar radiation levels;
- the net-metering scheme, recently introduced in Greece, has a high degree of profitability, greater than current FiT values. As further evidence of the latter, Table 24 shows a comparison of economical indexes for a test 3 kW PV system, in case of FiT or net-metering. As is clearly shown, the convenience of the investment is much improved when only net-metering is considered.

Table 24 PBP, IRR and NPV for the 3 kW BIPV systems in Greece (Dusonchet L. T., 2015).

Rated power (kW)	Type of plant	Form of support	PBP (years)	IRR (%)	NPV (k€)
3	BIPV	FiT	> 25	-0.17	-2.77
3	BIPV	Net-metering	15	4.66	1.88

As a consequence of this, *Dusonchet and Telaretti* believe that the PV sector in Greece will continue to grow, mainly due to net-metering, although there might be a slowdown due to the economic crisis that is sweeping the country.

6.3.1.1 Cost of grid integration

As it has already been mentioned, in the middle of the economic crisis, the growth rate of PV in Greece was, until 2012, quite promising, with a keen interest in investments. Greece will potentially have 8 GW of PV by 2020, covering about 18% of its national energy needs (Tsoutsos, 2013). As the peak demand in Greece is determined by the loads of the summer days that coincide with the peak power of PV (Figure 20), the guaranteed power (capacity credit) of PV is high and can displace the power produced by conventional energy sources. In a penetration rate of about 9%, the cost becomes positive, thus creating a positive overall result, however still relatively low compared to other Member States.



Figure 20 Performance levels of PV on a daily peak demand during a year in Greece (Tsoutsos, 2013).

According to Figure 21, the application of demand response for the flattening of the load curve in low PV penetration levels has a negative impact, reducing the contribution of PV. However, the demand response could lead to savings, when the PV penetration is 9% or higher.



Figure 21 Capacity credit and additional production cost of PV in Greece (Tsoutsos, 2013).

Greece is ideal for developing PV systems, compared to other European Countries, since the installation of new PV causes a reduction of the peak load and produces more power in the network, thus causing reductions in the distribution cost of energy. The distribution cost of PV energy in the grid is negative for Greece, forming a good example of the savings that can be achieved through PV systems. This phenomenon is illustrated in Figure 22. In this context, the need for Demand Side Management is reduced, as is necessary for most European countries.



Figure 22 Additional distribution network cost of PV power in €/MWh in Greece (Tsoutsos, 2013).

The total additional delivery cost and the cost of production capacity are negative for penetration of up to 10% and quite low for higher penetration, with respect to the rest of Europe (Figure 23). However, the costs tend to be reduced for higher penetration rates. Due to this uneven distribution of PV in Greece, in some places with a higher number of PV systems, higher network costs may have already been observed.



Figure 23 Additional distribution network and generation cost of PV in €/MWh in Greece (Tsoutsos, 2013).

6.3.2 The PV market in Greece

In 1998, the total installed PV power in Greece was only 634 kW, while in 2007, after the establishment of the Law 3468/2006, it reached 9.2 MW (Pure, 2008). The introduction of the Law 3851/2010 allowed for the submission of new PV applications both in fields and buildings, although that procedure was postponed in 2008 (Karteris, 2013). A noticeable diffusion of PVs was for the first time registered in Greece by means of 143 MWp connected to grid until the June of 2011, namely in six months' time, as shown in Figure 24 24. The main reasons resulting in this boost were associated with the once again approval of new PV applications and the accelerated evaluation of the older ones. The diffusion data referred only to 53 MWp of PVs being in operation until the September of 2009, although at that time the applications exceeded 3.7 GWp. In 2010, the development remained equivalently meager, with only 150 MWp additionally becoming operational.

However, the more recently available data verified why the time-consuming grid-connection procedures stood for the major barrier for PV deployment in Greece since 2006. Apart from the already submitted PV applications of 3.7 GWp until 2008, an enormous amount of applications was also recorded during 2010 and 2011, provided the highly improved new authorization terms of Law 3851/2010, thus creating a serious congestion in their local

services, although it was explicitly foresaw that the admittance of new applications should start a few months after the entrance of the Law into force, with only few exemptions. More specifically, over 30.000 applications for PV stations were submitted in one year's time, as shown in Table 25. Besides, at that time, among the older applications, those before 2008, only 2.8 GWp had been approved by RAE, whereas there were 1.1 GWp remaining unevaluated even until the end of 2010, despite of their granted priority over new PV applications and their exemption from obtaining approval by RAE in advance. As far as farmers were concerned, approximately 6.000 applications of about 100 kWp each were submitted and eventually, the relative 2014s goal was reached before June 2011. Regarding residential BAPVs, 98 MWp of applications were submitted, whilst 28 MWp were already grid-connected in June 2011.



Figure 24 Progress of applications submitted for PV stations after 2008 in terms of cumulative capacities (Karteris, 2013).

PV plant type		Applica	Applications to DSO (PPC)			PV systems in operation		
		Until	Until	Until	Until	Until	Until	
		2009	2010	2011	2009	2010	2011	
				(June)			(June)	
BAPVs < 10 kWp	Sum of	155	2757	1727	0	EQE	2251	
	applications	133	5752	4752	0	505	3331	
PV plants of farmers	Sum of		6107	2006				
(< 100 kWp)	applications		0197	2080				
Other PV plants	Sum of	2220	20420	1/175	502	2041	2652	
	applications	2220	20429	14125	552	2041	3053	
All PV plants	Sum of	2/02	20278	20042	600	2626	7004	
	applications	3433	20270	20945	000	2020	7004	

Table 25 Amount of applications submitted for PV stations or become operational after 2008(Karteris, 2013).

More than 900 MW of PV systems were installed in 2012, 112 MW of which were installed on islands not connected to the mainland grid (Dusonchet et al., 2015). PV installations are mainly concentrated in rooftops, mainly in commercial and industrial segments, with around 10% only for the utility-scale one. Despite the significant increase in 2012, grid operators expect a substantial decline in the second half of 2013, mainly caused by the disincentive measures introduced by the Greek Parliament. As a consequence of the sharp decline of PV FiT, the Greek PV market plummeted from the 801 MW installed in the first quarter of 2013 to only 6 MW per month in August and September.

The size of PV installations ranges from few kWp, mainly in the case of solar systems installed in houses and small companies, to few MWp (Tsilingiridis, 2013). The OEM classifies PV systems in four capacity categories: (a) lower than 20 kWp, (b) 20-150 kWp, (c) 150-2000 kWp and (d) higher than 2000 kWp. The first category (<20 kWp) does not include small installations (<10 kWp) in houses and small companies, which constitute a special category. In June 2012, although the 20-150 kWp category was the largest, covering 38% of the total installed capacity (Figure 25Figure 25), higher categories covered more than 50%, specifically, 33% the 150-2000 kWp and 21% the >2000 kWp category. The evolution of PV installations in the different geographical regions of Greece is presented in Figure 26.



Figure 25 Installed PV capacity per category (HELAPCO, 2015)



Figure 26 Installed capacity (%) per region of Greece in June 2012 (Tsilingiridis, 2013)

Concluding, the fact that the national goals for 2014 in one year's time were already surpassed by six times, raised reasonable doubts about the long-term viability of the Greek market, taking into consideration the existing absorption capacity of the grid, as well as the unaffordable FiT cost for PVs, which is continuously cumulated and it will ultimately be passed on to the consumers (Karteris, 2013). It is telling that, in 2011 the total cost for FiT for PVs ran up approximately to 300 M \in . If one considers the values of the avoided conventional electricity production to be almost 50 M \in , as the system's average marginal production cost was 74.4 \in /MWh, the remaining 250 M \in represent the cost that had to be covered by passing it on the consumers. Even though this high FiT cost can be reduced, if one bears in mind the reduction in investments for power plants to cover peak demands and also the decrease in imports to address the national peak loads, especially during summer, it represents a very significant burden to the consumers.

In Table 26, the annual installed capacity of PVs in Greece is presented for the period 2010 – 2014, while Figure 27 shows the evolution of the Greek PV market for the period 2007-2014. The Greek PV sector has vastly shrunk in 2014, installing only about 17 MWp, where in 2013 the country had installed a record 1.04 GWp of new PV (Karteris, 2013), ranking Greece in the second place internationally, in relation to the contribution in overall energy consumption, and in the fourth place internationally, in relation to the installed PV power per capita, putting Greece for the third consecutive year in the top-10 of the world market in relation to the new annual installed capacity (HELAPCO, 2015). The sharp drop in new installations was mainly the result of a freeze on the receiving and processing of new applications for PV systems from August 2012 until April 2014 (Karteris, 2013). In April 2014, Greece set a new target for PV until 2020, aiming at the installation of 2 more GWp of PV until the end of the decade.

	Year	Grid- connected	Autonomous	Total
2010	Annual installed capacity	150.3	0.1	150.4
	Total installed capacity	198.5	6.9	205.4
2011	Annual installed capacity	425.8	0.1	425.9
	Total installed capacity	624.3	7.0	631.3
2012	Annual installed capacity		912.0	
	Total installed capacity		1536.3	
2013	Annual installed capacity		1042.5	
	Total installed capacity		2578.8	
2014	Annual installed capacity		16.95	
	Total installed capacity		2595.75	

Table 26 Annual installed capacity of PVs (MWp) in Greece for the period 2010 – 2014 (HELAPCO, 2015).



Figure 27 The evolution of the Greek PV market for the period 2007-2014 (HELAPCO, 2015)

6.3.3 Licensing issues and investment drawbacks

In the period 2006-2009, the development of PV systems was the center of domestic and foreign investors (Kaliviotis, 2009). The reason was the generous financial incentives provided by the Laws 3468/2006 and 3469/2009 and the Law for Development 3299/2004, which provided a 40% subsidy for PV projects. This, in combination with the excellent solar potential of the country, caused everyone to believe that the PV sector in Greece would

have a rapid and impressive growth. However, this did not happen in practice. The reason was, and still is, the tortuous and lengthy bureaucratic licensing procedures that prevent the rapid and healthy development of the market. More specifically, the following barriers can be distinguished:

- Meaningless involvement of many governmental bodies.
- Lengthy permitting procedures, without the existence of any rules or deadlines.
- Failure of the involved licensing authorities to comply with the Law.
- Changes of the Law during the licensing process, ultimately penalizing the investors who respected the initial settings.
- Meaningless procedures for licensing, e.g. requirement of environmental permits for PV systems on commercial rooftops, whose capacity is higher than 20 kWp.
- Unclear to unreasonable regulations related to land use, e.g. forbidding PV installations in the high productivity land, demand for buildable land, etc.
- Lack of flexibility for small systems, e.g. not allowing small household systems at the off-grid islands.

To further analyze the above facts, the assessment of the Greek FiT system, since its initial introduction in 2006, should involve all the historical amendments made, ensuring safe conclusions firstly about the system's overall effectiveness with respect both to its general impact on the PV market and to the degree it contributes to PV promotion into the national supply electricity mix, and secondly, about its ability to preserve a healthy and progressive market (Karteris, 2013).

<u>Law 3468/2006</u>

Initially, the first law (Law 3468/2006) did not specify the interval within which the tariff would remain fixed, but noted that the basic tariffs can be unexpectedly modified by means of a Ministerial decree taking into consideration the international evolution of PV technology costs and the support level considered to be adequate, under oncoming circumstances. This was rather extraordinary, because tariff options are generally adjusted on an annual basis in the most successful FiT systems, mainly in accordance with market predictions for the following years. Additionally, the guaranteed period for fixed tariff of only up to 10 years, whereas an extension for the sale contract for another 10 years would be carried out at a rate to be determined, as well as questionable terms associated with the obligations on behalf of the TSO and DSO (PPC), the access to the grid, discouraged investors from getting interested in PVs, at least in the early beginnings of FiT scheme's implementation. Nevertheless, the Development Law's subsidies of up to 40% of required capital compensated to an extent for these drawbacks and attracted many investors, though, in some occasions, without serious financial capabilities. This led, as mentioned above, to thousands of PV applications submitted to RAE for license approval. However, the low ability of the majority of applicants to support realistically a PV investment, led to the recorded postponement of the submitting procedures on behalf of RAE in 2008. Additional risks for the investors were also implied on the grounds that in Law 3468/2006 there were no technical and legal specified conditions related to the priority over conventional resources considering the grid connection. Moreover, a two years' absence of land-planning map of Greece for RES caused, also, tremendous discrepancies among local public authorities, regarding the land-using siting suitability for PV stations, although some of them were already applied for license approval in RAE. Similar issues were occurred due to lack of construction regulations for PVs, at least for 3 years. Eventually, PV stations' licensing became a complex task when it came to the construction permits or to the approval of environmental conditions. For instance, a larger-scale PV plant of more than 150 kWp required the permissions from 32 public-sector entities on a central, regional, prefectural and local level. Thus, a licensing procedure could exceed in practice 24 months, whereas in theory, and according to the legislation's time limits, the procedures should be conducted prior to 9 months. Law 3468/2006 was criticized for its complexity considering building systems. PV investors, even if they were private owners, were fiscally considered as enterprises, and had therefore to submit periodically value added tax declarations, whilst the revenues from solar electricity were taxed as a regular income, meaning in the order of 25-40%. This led practically to zero residential systems' installations until 2010. Overall, within Law 3468/2006, only 1% of the initial PV applications was put in operation, a 60% was licensed by RAE in due time, whereas the remaining 39% was not examined at all.

<u>Law 3734/2009</u>

The second FiT law (Law 3734/2009) aimed at confronting all above barriers, by improving FiT terms, such as the guaranteed period and its adaptation on the future PV costs as well as the recorded annual diffusion of PVs in the electricity supply mix. In that sense, for example, the tariff's abatement for new PV investors was verified in a degree as long as the PV costs were reduced steadily since 2006, owing to the rapidly international growing capacity of making silicon crystals. Grid parity was already achieved for some specific applications in some countries. The rate at which PV system prices will decrease depends on the installed PV capacity. In 2010, the cost for large PV systems was approximately at 2.75 €/Wp, whereas in 2015 it is predicted to drop under 2 €/Wp. Following this trend, by 2030 prices could drop to between 0.7 to 0.93 €/Wp. By 2050, the price could be even as low as 0.56 €/Wp. As a positive measure of Law 3734/2009 was also considered the guarantee extension of the sale contracts from 10 to 20 years, which eliminated all reasonable doubts emerged until then for TSO's obligations. The 18 months' time limit for completing PV installation was also a drastic, positive step towards the acceleration of PV diffusion. Significant results were also witnessed with the enactment of BAPVs' diffusion program that set off a large market which, so far, was in meager progress. Besides, the clarification of the construction and siting regulations for both PV parks and BAPVs facilitated the bureaucratic processes. However, given that a large fraction of submitted PV applications had already been located in areas such as high-productivity agricultural lands, as long as the land-use siting regulations for RES had not been set on time, hundreds of investments could not be approved for their environmental conditions or obtain a construction permit. Ultimately, Law 334/2009 did not permit transactions of production licenses or approvals prior to the grid-connection of a PV station. This term aimed at mitigating this tendency caused by the unexpectedly long-term assessments of PV applications of behalf of RAE and other component authorities since 2006. This led also to the deterioration of hundreds business plans of PV investors, who, eventually, lost their interest in this kind of investment. In particular, the trading of licenses was one of the most determinant factors of the weak development of PV market until then.

Nevertheless, 2009 was one of the first years of an actually recorded diffusion of PVs, on the one hand due to the efficient definition of construction and siting regulations and on the other hand, due to the predicted decrease in tariff, which forced the investors to accelerate the completion of their PV projects.

<u>Law 3851/2010</u>

As mentioned above, during the summer of 2010, the last FiT law, Law 3851/2010 was enacted, since the large amount of uncompleted and unauthorized PV applications brought the national PV market on the verge of its breakdown. This particular law simplified the administrative procedures for all kinds of PV systems. Equivalently, it foresaw PV systems' locating in agricultural lands of high-productivity, thus unblocking PV applications which were under environmental impact evaluation for a long time. Additionally, it favoured easier installations on fields and buildings and considered as eligible installations PVs placed on smaller fields or on all available surfaces of buildings' envelope, as far as BAPVs are concerned. The market of BAPVs had already taken off in 2009, but the prospects after 2010 were definitely improved by this law, as long as the special development program was established both for interconnected system and non-interconnected islands, as well as for buildings of the public sector. Besides, for BAPVs with capacities less than 100 kWp, no construction permits or approvals of small-scale construction works were even required. Still, in the case of non-interconnected islands, the PPC did not proceed immediately with PV applications' evaluation, attributing this unjustified decision to the theoretically saturated grids of the islands. Consequently, until 2012, this respective diffusion of BAPV systems in these regions remained meager, despite the great interest demonstrated by potential investors. Overall, the Law 3851/2010 seemed to be a realistic opportunity, but only under absolutely administrative aspects, for the Greek PV market to rebirth and progressively expand against the discouraging entrepreneurial conditions emerged in an era of general recession of the Greek economy. The most supportive market strategic measures concerned the strict time limits imposed on competent authorities, and mostly on DSO, which were expected to have a drastic effect on the bureaucratic processes. The penalty clauses included in grid-connection contracts would mostly ensure that only fiscally capable PV investors would enter the PV market.

Other drawbacks

Still, the bottom line is that the serious issue related to the thousands of PV applications submitted since 2006 seemed to remain unsolved for once again, despite the implementation of the Law 3851/2010. The enormous aggregate of 20.000 unevaluated PV applications interfered with the regulated timeframes set upon the DSO's local authorities. It should be remarked, though, that approximately 2.000 MWp and extra 500 MWp of PVs were granted with grid-connection offer and with sale contracts, respectively in six months' time during 2011. Considering the 8.000 remaining applications that had already acquired share within the supply electricity market by means of sale contracts but kept uncompleted due to lack of funding liquidity, the Greek market faced for once again its breakdown during 2011. Especially, as far as older applications were concerned, although last FiT law provided them with priority within grid-connection procedures, it also clarified that a production

license or a grid-connection contract cannot ensure that PV investors will be able to sign sale contract with the TSO, a fact that eventually created further investment risks. In other words, the sale contract was the key for PV investors to acquire an actual share within the supply electricity market.

Regarding the new PV applications, the administrative obstacles referred to their vast amount, which could not be elaborated by the inadequate qualified DSO's personnel. Besides, the unknown potential capacity of the existing grid, especially in agricultural regions, expanded the lack of transparent procedures followed by some DSO precincts, thus contributing to greater extend to the recorded delays. Within that context, for certain regions, DSO declared saturated grids without any technical justification, as the law dictates. Time limits were not followed, while there was no available information provided to potential investors about the sum of the submitted applications per region or the sections of the network with low capacity potential.

In addition to that poor administrative and entrepreneurial environment, banks during 2011 reduced their offers for beneficial loans to PV investors, thus the investment capital in most occasions became unaffordable. An unexpected increase in black market transactions of production licenses was witnessed since 2010, despite the last FiT administrative improvements. Another issue of great significance was associated with the rather low ceiling determined for PVs both for 2014 and 2020, which did not reflect the anticipated potential of the market that was eventually verified by the tremendous amount of the new PV applications. In addition to the potential capacity of old PV applications that reached 3.7 GWp in 2008, there were more than 4.5 GWp of PVs submitted for evaluation after the enactment of the last FiT law, thus both targets for 2014 and 2020 were surpassed in short time in early 2011. Eventually, the applicants of nearly 6 GWp of PVs, both old and new PV applications, became undoubtful for signing sale contracts and obtaining share in the electricity mix. Still, these investors had spent a remarkable amount of money, not for reinvestments in other beneficial business ventures, but for the conduction of the engineering studies, the application deposits and penalty clauses and other management expenses requires for PVs. On the other hand, taking into account the shares provided to farmers and the rest of the investors, the law led also to serious discriminations emerging among the investors, since it did not comply with the rules of a free electricity supply market.

Overall, the less ambitious goals set for PVs for 2020 undeniably put directly in jeopardy the viability of the growing Greek PV industry. The supporters of this decision foresaw an unreasonable increase in the solar generation costs compared to the other RES and especially wind energy. There were intensive internal public concerns about the unaffordable FiT cost, which will be passed on to consumers and especially, in case all purposed PV projects become operational, although there is a prevailing rational belief across the EU that the use of financial incentives will progressively be abandoned, as competitiveness will be succeeded before 2020, taking into consideration the ongoing reduction of PV costs and the increase in conventional electricity prices. Especially in the case of Greece, with high solar radiation, the FiT cost restriction will probably take place

earlier than in northern countries, thus the social expenses will be eventually cut down before 2020.

6.4 Conclusions

The potential of the Greek PV market has undoubtedly great development prospects and the initial FiT scheme implemented in 2006 enhanced the expectations, with thousands of interested investors submitting applications for PV plants. Before 2010 and despite the generous FiT scheme of Greece, the PV market of the country was constrained by a series of heavy administrative procedures causing the main weaknesses of the Greek FiT law to result from issues concerning the initial attractiveness of the law to investors and its effectiveness in developing a healthy and prosperous PV market. In 2010, a significant improvement occurred for the first time in the Greek PV market, with around 150 MW being installed and connected to the grid, while until June 2011 the registered installations exceeded 145 MW and the predictions were foreseeing an extra 300 MW of PVs becoming operational until 2012.

This was the time when the necessary supportive measures were introduced and ensured the viability of such investments. As a proof of the attractiveness of the FiTs can be presented the fact that despite the administrative and bureaucratic barriers, already in early 2012 projections showed that it was possible to reach the goal set for PVs' propagation in 2014. Despite the impressive reduction in FiT rates in recent months, Greece still has a good remuneration level, especially for BIPV systems, mainly due to high solar irradiation level of the country. Also, the net metering scheme recently introduced to the country has a high degree of profitability, better than the current FiT values.

7. The case of Spain

This chapter analyzes the deployment of solar PV in Spain, following the same structure as Chapter 6. The only difference is that in the case of Spain, no information was available concerning the cost of solar PV in the country.

7.1 Agenda setting for the policy framework of Spain

7.1.1 The solar potential of Spain

Solar energy is expected to play a key role in the future energy scene and Spain, with a total solar irradiation on a horizontal plane estimated at between 1.48 kW/m²·day and 3.56 kW/m²·day (Dincer, 2011) will most likely become one of the leading countries in terms of its implementation, expertise and development of new technologies. Support for renewable energy technologies in Spain dates back to as early as 1980, with the passage of the Law for Energy Conservation (Brown, 2013). Since then, Spain has implemented a variety of policies that encourage renewable electricity generation through grid access, specified tariffs for renewable electricity and market premium options for certain renewable power generators.

7.1.2 The Spanish electricity system

The electricity system in Spain has two key characteristics that are crucial to understanding how the solar PV sector and support policies developed (del Rio P. a.-A., 2014).

Spain is virtually an energy island, with limited interconnection or trading with neighboring countries (about 3% of electricity demand was imported in 2011) (del Rio P. a.-A., 2014). As a result, virtually all domestic electricity production has to be consumed within Spain, given that electricity cannot be stored. This fact, along with poor long-term planning, has resulted in the Spanish electricity system having significant excess electricity generation capacity. In 2009, installed capacity was around 93.000 MW, taking into account all technologies, while maximum peak demand was only around 44.000 MW.

In Spain, the data indicate the peak demand conditions are driven both by air-conditioning loads for heating in winter and cooling in summer (Figure $28\Sigma\phi\dot{\alpha}\lambda\mu\alpha!$ To $\alpha\rho\chi\epsilon$ io $\pi\rhoo\dot{\epsilon}\lambda\epsilon\nu\sigma\eta\varsigma$ $\tau\eta\varsigma$ $\alpha\nu\alpha\phi\rho\rho\dot{\alpha}\varsigma$ $\delta\epsilon\nu$ $\beta\rho\dot{\epsilon}\theta\eta\kappa\epsilon$.) (Pudjianto, 2013). While peak demand in summer coincides with PV output, the contribution of PV for peak demand in winter is modest. This limits the capacity credit of PV, as shown in Figure 29. An analysis carried out by *Pudjianto et al.* suggests that the additional capacity cost due to PV in Spain is within 12.5-13 ξ /MWh.



Figure 28 The level of PV output at daily peak demand across one year period in Spain (Pudjianto, 2013)



Figure 29 The capacity credit and additional generating capacity cost of PV in Spain (Pudjianto, 2013)

An overview is provided in the Appendix of the relationship between photovoltaic power generation and the Spanish market.

7.1.3 The electricity tariff deficit of Spain

Tariffs and market premiums paid for renewable electricity are defined in Royal Decrees. Electric utility companies, by law, pay the tariff and premium rates for qualified renewable electric power (Brown, 2013). Further, the method by which the utility companies are then compensated to make up the difference between the tariffs/premiums paid to special regime generators and the revenue received from the sale of renewable electricity in the wholesale market is somewhat complicated and requires a brief discussion about the broader electric power market in Spain. Regulation of the Spanish electric power system has undergone a number of changes since 1997. One aspect of the power system that continues to gradually change is the rates enduse consumers pay for electricity. Prior to the electricity market liberalization efforts, consumer electricity rates were set and regulated by the federal government, in an effort to control electricity prices as a measure to protect consumers, despite the fact that expenditure on electricity by Spanish households represents a small share of total household expenditures (del Rio P. a.-A., 2014). Figure 30 shows the proportional change in average electricity tariffs between 1996 and 2011 at nominal and real prices, while in Figure 31 are shown the annual electricity tariff deficits for the period 2000-2012. Prices in 2011 had risen to around 150% of their nominal value in 1996. But, in real terms, taking into account inflation as measured by the Consumer Price Index (CPI), they have remained essentially unchanged since 1996. During this period, they have usually been lower than their 1996 levels. At their lowest, in 2005, they were just under 70% of their real 1996 value. However, average real tariffs have increased in the years 2007-2011. This means that, unlike many other countries, FiTs for solar PV and other RETs have not led to price increases for rate payers. Instead, they have fed into a massive "tariff deficit", along with the cost of subsidizing conventionally generated electricity. So, these rates typically did not cover the total cost of electricity services (Brown, 2013). As a result of selling electric power at a loss, Spanish utility companies have been accumulating a tariff deficit. Renewable generation has also contributed to the tariff deficit, since qualified projects receive above-market tariffs and market premiums for electricity from renewable energy sources.



Figure 30 Evolution of the electricity retail price in Spain in the period 1996-2011 (del Rio P. a.-A., 2014)



Figure 31 Annual electricity tariff deficits in the period 2000-2012 (Brown, 2013)

However, unlike many other countries, FiTs for solar PV and other renewable energy technologies have not led to price increases for ratepayers. Instead, they have fed into a massive "tariff deficit", along with the cost of subsidizing conventionally generated electricity. By the end of 2012, after increasing over the last several years, the accumulated tariff deficit was estimated to be 35 billion € (Brown, 2013), equating to around 3% of Spanish GDP (del Rio P. a.-A., 2014). Given that Spain's public debt in 2012 was equal to 85.3% of GDP, this is not an insignificant contribution to the country's broaden debt burden.

While some steps have been taken to adjust electricity rates to better reflect the all-in cost of electricity (i.e., generation, transmission and distribution), many consumers continue to pay rates that are less than all-in electricity costs (Brown, 2013). In 2014, the deficit had gradually been securitized and placed in international financial markets, first directly by utilities and, from 2010, by a specific entity managed by the Government (del Rio P. a.-A., 2014). The full cost of subsidizing electricity has therefore still not been felt by the Spanish economy and has been shifted onto future consumers.

7.1.4 Understanding the policy

From the 1990s, the Spanish government's rationale for supporting renewable energy sources for electricity (RES-E) and solar PV in particular, was related to environmental protection, industrial policy and employment creation (del Rio P. a.-A., 2014). It was also part of an effort to help diversify Spain's energy mix and reduce dependence on fossil-fuel imports. In addition, supporting the deployment of RES-E was intended to help Spain comply with commitments to renewable energy and greenhouse gas reduction targets contained in international regulations, including the Kyoto protocol, the Renewable Electricity Directive (Directive 77/2001/EC) and the Renewable Energy Directive (Directive 28/2009/EC).

Spanish policy-makers chose to use FiTs as the main policy mechanism to support RES-E development. The Spanish government chose to use FiTs based on the fact that alternative policies in the mid-1990s were considered to be performing ineffectively, such as the bidding scheme in the United Kingdom, whereas FiTs were performing effectively in Germany and elsewhere. Political economy reasons played a role as well. Social and political opposition to a FiT was regarded as unlikely by the government, given the environmental and employment benefits associated with RES-E deployment. It was thought that electricity consumers paying for the policy would be unlikely to complain, as the expected costs of the policy would not be high, at least in the short term, due to a low level of RES-E penetration and would be paid by a large number of captive electricity consumers. Policy-makers also regarded FiT as less administratively burdensome than other support mechanisms and more likely to achieve energy and industrial policy goals. FiTs also had the support of RES-E generators and investors, who lobbied for the adoption of such a system.

7.2 The legislative framework for PV in Spain

Spain's renewable energy policies were geared towards helping to achieve the EU target of 12% of gross energy consumption coming from RES by 2010 (del Rio P. a.-A., 2014). Spain's FiT policy began with the Electricity Sector Law, introduced in 1997 (Law 54/1997). This set up the Special Scheme or Regime (Régimen Especial) to provide RES-E and co-generation with special treatment compared to conventional electricity generation and large hydro, a preferential price for electricity fed into the grid by RES-E plants. In the interim years, subsequent policies provided differentiated tariffs based on system sizes and solar PV developers were able to choose between fixed FiT adjusted manually and a fixed premium on top of the electricity market price. The deployment levels of solar PV were stable but low and remuneration levels were revised annually. Since 1998, under Royal Decree 2818/1998, solar PV has been promoted in Spain mainly with a FiT, adjusted in 2004 and 2007 (del Rio, 2012). The FiT of 1998 did not have a significant effect on RES-E deployment, mostly due to the relatively low support levels and the uncertainty for investors related to the annual updating of support. Moreover, despite the fact that net-metering was apparently encouraged, with an attractive FiT for installations less than 5 kW being established, specific administrative rules to promote were never set up.

Royal Decree 436/2004 – The first amendment

In 2004, the first amendment was made with Royal Decree 436/2004 (del Rio P. a.-A., 2014). This support system was based on the possibility of the producer to choose whether to sell the produced electricity with a fixed tariff, expressed as a percentage of the reference average tariff (RAT) or whether to sell it in the free market, taking favor of the sales price (Solangi K. I., 2011). FiTs were supplied for an undefined number of years, with a reduction after 25 years. This system also introduced a target of 150 MW of solar PV (del Rio P. a.-A., 2014). Once the target was reached, support levels would be revised. This change came in response to criticism from RES-E generators who argued that annually revised support levels were not transparent and increased the risk for investors, causing a higher risk premium to

be charged by lending institutions. To improve stability, support levels were set as a percentage of the electricity price, or the "Average electricity Tariff" (AET), and revised every four years rather than annually. Overall, the new regulation led to a more favorable treatment of solar PV technologies, both large- and small-scale. However, it failed to introduce best-practice FiT design elements, such as degressive FiT rate, laying the foundation for the future solar PV boom. The FiTs for electricity generated from PV systems in Spain, according to the Royal Decree 436/2004, are shown in Table 27.

Table 27 FiTs for electricity generated from PV systems in Spain according to the RoyalDecree 436/2004 (Solangi K. I., 2011)

PV systems					
Kind of installation	FiT (€/kWh)				
Rated power ≤ 100 kWp – first 25 years	575% of RAT				
Rated power > 100 kWp – first 25 years	460% of RAT				
Rated power ≤ 100 kWp – following years	300% of RAT				
Rated power over 100 kWp – following years	240% of RAT				

Royal Decree 661/2007 - The "boom" in the Spanish solar PV market

After a year of negotiations, Royal Decree 661/2007 entered into force in June 2007 and had a significant impact on Spain's solar PV sector. Since solar deployment was relatively behind the targets of the Renewable Energy Plan 2005-2010, with 400 MW being the target for 2010, the aim of the new Royal Decree was to accelerate solar deployment in order to comply with the targets (del Rio, 2012). Moreover, the new RD de-linked the FiT rate from the AET because the AET had increased significantly between 2005 and 2006 by 4.5%, and the overall costs of RES-E support had therefore also increased, forcing the government to consider system reform (del Rio P. a.-A., 2014). Solar PV installations were from this point no longer allowed to choose to receive a FIT "premium" and were obliged to instead accept a fixed rate. The tariff level for solar PV did not change, with the notable exception of the category from 100 kW to 10 MW, whose remuneration increased by 82%, in order to foster greater investment in larger facilities. Other main features of RD 661/2007 and significant changes with respect to the previous regulation were:

- The revision of FiT rates was scheduled for once every four years, starting in 2010 or once a given capacity target had been reached (371 MW for PV generation). Once 85% of the target had been installed, any additional capacity for a period of 12 months thereafter would be remunerated at the wholesale electricity price, meaning that the FiT regime would come to an end. This transition period was designed to allow for the negotiation and enactment of a new FiT regime.
- Mandatory guarantees were established to prevent speculation, at the request of the solar PV association. PV plants had to deposit guarantees of 500 €/kW with relevant authorities (roof-mounted installations were excluded) on applying for grid access and 20 €/kW for other RES-E technologies.

- 3. **RES-E would receive priority access to the electricity grid and renewable plants of a capacity greater than 10 MW had to be connected to a generation control center.** Furthermore, technologies with intermittent electrical output (wind and solar PV)n would not receive capacity guarantee payments. The level of energy provided by wind and solar PV was restricted to no more than 5% above anticipated energy output, with generators allowed to correct output predictions one hour before the opening of the market.
- 4. The Renewable Energy Plan for 2011-2020 was developed further, taking into account the revision of support levels scheduled in 2010, signaling to investors that support would continue after 2010.
- 5. A cap-and-floor price system, for installations participating in the market. If the market price plus the premium were above the cap, then, RES-E generators would only receive the cap level. If they were below the floor, they would receive the floor price.

The key branches of the government involved policy development were:

- The Ministry of Industry
- The IDAE (*Instituto para la Diversificación y Ahorro de Energía*/ Institute for the Diversification and Energy Saving)
- The CNE (Comisión Nacional de la Energía/ National Energy Comission)

The central government, through the Ministry of Industry, decided on both the general goals and the design elements of the RES-E promotion policy. The IDAE is a branch of the Ministry of Industry, specifically devoted to diffusion and educative actions, technical assessment and financing of innovative projects. The CNE is the regulatory body of the energy sector, in charge of liquid fuels, gas and electricity, including generation, transport and distribution.

Communication channels between the Ministry of Industry and solar PV investors and generators on technical issues were ad hoc and not systematically organized, although general meetings were held between the relevant sectors connected to the PV sector and the Ministry. There was no framework in which information could have been shared and issues negotiated in the development of Spain's solar PV policy. It was also reported that, in some instances, the government relied on external consultants to contact the PV sector to obtain information. Consultants would then elaborate recommendations based on stakeholder feedback. In the case of RD 661/2007, it was also reported that IDAE was responsible for contacting existing solar PV installations to obtain data on the economic conditions for solar PV farms at the end of 2006 (around 100 MW) in order to set FiT rates.

Communication between the government and other stakeholders was generally limited. Information was shared with the broader public via posts on the Ministry's and IDEA's official websites. The CNE undertook some public consultation procedures, but the participation of civil society was seen to be quite indirect in this context. From these, it is suggested that robust measures were not put in place to ensure that data on technology costs was independently assessed. Instead, this was provided by equipment manufacturers and solar PV generators, often communicating directly with government agencies, resulting
in the risk that those being regulated could take advantage of the regulators, due to the problem of asymmetric information availability.

Spain's solar PV boom began in 2007, after Royal Decree 661/2007 was implemented. Solar PV deployment levels had been trailing the official targets set out in Spain's Renewable Energy Plan (2005-2010). Royal Decree 661/2007 was intended to accelerate solar PV deployment rates in order to comply with those targets. Figure 32 shows the evolution of annual solar PV capacity installations from 1999 to 2012: modest amounts of installation per year, until 2007 and 2008, when the installations rose 5-fold and 26-fold in comparison with 2006. The following year, annual installed capacity dropped dramatically, first to zero and then back to relatively modest levels up until 2012. From April 2007 to August 2008, the installation rate was astonishingly fast. Nearly 500 MW of capacity were installed each month between June and September 2008 (Figure 32).



^{*} Monthly Average Compound Growth Rate

** Monthly Average New Capacity

Figure 32 The impact of the boom and the cost-containment measures on the monthly additional PV capacity (del Rio P. a.-A., 2014)

The exponential growth in solar PV deployment caused a corresponding growth in the costs of the FiT. Table 28 shows the evolution of these costs from 2004 to 2011. It also shows solar PV electricity generation as a share of total electricity generation across these same years. As Table 28 illustrates, solar PV provided a relatively small share of all RES-E, while representing a substantial portion of all RES-E subsidies. Since 2008, the tariffs received by the solar PV sector have accounted for close to 50% of all support provided to RES-E, despite its low contribution of total electricity generation. Following the boom, total subsidies paid to PV generators skyrocketed from 194 million \in in 2007 to 990 million \in in 2008 and 2.6 billion \in in 2009.

Year	Total tariffs paid	Average	% PV tariffs with	% MWh PV into	%MWh PV into the
	to the PV	tariff cost of	respect to all	the renewable*	global generation
	generation (€)	MWh PV (€)	renewable* tariffs	generation mix	mix
2004	6.146	341,44	0,93%	0,08%	0,01%
2005	13.995	341,34	1,75%	0,15%	0,01%
2006	39.887	372,78	3,53%	0,35%	0,04%
2007	194.162	392,25	13,44%	1,36%	0,16%
2008	990.830	388,71	40,88%	6,09%	0,96%
2009	2.634.236	424,60	55,90%	11,72%	2,45%
2010	2.653.720	414,25	49,66%	10,65%	2,46%
2011	2.402.986	390,22	47,79%	10,46%	2,41% (2,91%) ²
2012	2.567.302	392,31	47,28%	11,98%	2,58% (2,89%) ²

Table 28 Evolution of PV tariffs and generation (del Rio P. a.-A., 2014).

⁺ January to mid-December 2012

² % eligible and non-eligible MWh PV

Royal Decree 1578/2008 – A new regulation

It was September 28, 2008 by the time that the new regulation, RD 1578/2008, entered into force. This new regulatory framework implied changes in two main lines; on one hand, there is a reduction of the FiTs' value of the order of 30%, with better values for PV installations in roofs and facades (Solangi K. I., 2011). On the other hand, and in order to control the impact of the FiTs in the national economic situation, a quota of 500 MW in 2009 and similarly for the next three years had been established. This implied a strong reduction in the Spanish market, compared to the extraordinary increase of 2008. Tariffs and caps were adjusted quarterly, according to the demand in previous quarters, as explained in Table 29. Additional support applied to PV systems was tax incentives. Law 35/2006 established a tax rebate of 6% in 2008, 4% in 2009 and 2% in 2010 from the annual benefits of the PV system. The annual digression rate was capped at 10% and the annual caps were adjusted in reverse proportion to digression. Moreover, although the transition period was only one year, it was too long given the modular, easy-to-install nature of solar PV technology (del Rio P. a.-A., 2014). Installation time during the boom in 2007 and 2008 could take between six and twelve months. Solar PV capacity at the end of 2007 had been only 544 MW, but had reached 3116 MW by the time the new Royal Decree was introduced. The increase in the level of installed capacity represented an enormous rush of application during the transition year between subsidy regimes.

 Table 29 Adjustment of tariffs and caps according to the demand in previous quarter (Solangi K. I., 2011)

Percentage of the CAP referred to the previous quarter CAP	Adjustment		
> 75%	Rates increase by a maximum of 2.5% and		
≥ 75%	the cap is increased by the same amount		
< 50%	Rates increase by a maximum of 2.5% and		
<u> </u>	the cap is decreased by the same amount		
50-75%	Incentive levels and caps remain the same		

Controlling the growth in solar PV capacity and setting cost-containment mechanisms were priorities for the government, once the scale of the solar PV boom became evident. This led to the introduction of several new regulations, which partially amended either RD 661/2007 regulating PV plants installed before September 2008 or RD 1578/2008 regulating plants installed after September 2008. The main measures introduced by the government included:

- Classifying PV installations into new categories with different tariff levels.
- Introducing capacity quotas on the amount of installed capacity which could be introduced during a quarterly period.
- A subsequent reduction in tariff levels.
- Setting a maximum period the subsidy was available instead of it being open-ended, retroactively for existing solar PV plants.
- Implementing a cap on the number of operating hours facilities could deliver electricity, retroactively for existing solar PV plants.
- Introducing tighter legislation on repowering solar PV systems.
- Imposing a moratorium on new projects.
- Special electricity tax and change to system for updating tariffs.
- A campaign against developers defrauding the subsidy scheme.

RD 1578/2008 reclassified PV installations into a range of categories:

- Type I, consisting of solar PV mounted on roofs and facades, with subtypes based on their size, including
 - Subtype I.1 (< 20 kW)
 - Subtype I.2 (> 20 kW but less than 2 MW)
- Type II, consisting of ground-mounted and other solar PV technologies.

For the first projects under the new system, the regulated tariffs were 0.34 \notin /kWh for subtype I.1 installations and 0.32 \notin /kWh for subtype I.2 and type II installations.

As part of RD 1578/2008, a "cupo" or capacity quota system for each type and subtype of PV system was adopted. This set out a maximum amount of new solar PV capacity that would be allowed to register for subsidy support in each quarter of the year. It led to creation of a registry for the pre-allocation of support, in which all solar PV installations were to be registered in sequential order up to the capacity quota. The definitive list of solar PV plants

which were authorized in the first call as part of the capacity quota was published in February 2009. In total, 392 projects were registered with 664 being refused registration because the target (*cupo*) had been exceeded. Another 543 projects were not admitted due to incomplete or incorrect applications. The second and the third calls linked to the capacity quota were published, respectively, in April and September 2009.

Figure 33 shows the evolution of registered capacity by plant type for 2009 and 2010, once RD 1578/2008 was introduced. The number of rooftop installations was below the target until the end of 2009 and the beginning of 2010. Roof-mounted installations had four calls a year of 66.75 MW each. In contrast, ground-mounted installed capacity was clearly above the allocated target, even though the quota of 33.25 MW per call was temporarily increased by 25 MW per call in 2009.





Capacity under the quota was allocated to developers on a first-come first-served basis. It was also linked to the FiT rate in the following manner:

- 1. If less than 75% of the quota was met, then the pre-established FiT level was maintained for the next call.
- 2. If more than 75% of the quota was met, then the FiT level was reduced according to a proportion set out in a predetermined formula. With installed capacity equal to 100% of the quota or less, the FiT would be reduced by 2.6%.

Assuming that the quota was met in every quarter of the year, this means that the tariff would diminish at an inter-annual rate of 10%. The system also linked the capacity allocating for calls in the following year to tariff changes. Capacity targets for the second and following years would increase if the tariff was reduced or decrease if the tariff was increased. In this way, capacity installations determined tariff changes, which in turn went on to determine quarterly capacity quotas.

As expected, new capacity additions after the passing of RD 1578/2008 stagnated (del Rio P. M.-A., Support for solar PV deployment in Spain: Some policy lessons, 2012). Although 502 MW were accepted, only 155 MW were actually installed in 2009. Moreover, the delay in the publication of the first call for the first quarter of 2009 literally paralyzed the Spanish market for several months (October 2008 – March 2009). In addition, lack of experience with the administrative procedures in the new FiT may have discouraged new capacity additions. Finally, the economic crisis and the difficult access to credit also played a role. Indeed, the Association of the Solar Industry (ASIF) argues that this later factor has been the main barrier to solar PV deployment in the short and medium terms. Another problem was the huge number of PV projects still in progress when the regulation changed: in 2009, applications for ground installations were high above annual targets (4400 MW vs. 500 MW). It should be noted here that, in contrary to the indicative targets (caps) in the German system, the Spanish cap is a quota, i.e. a mandatory cap that cannot be exceeded, since capacity exceeding the cap is not eligible for the FiT. In 2009, the target for building (roof) installations was not covered, due to the inexperience in installing them and administrative hurdles. In 2010, the target was finally met for building installations.

The Spanish regulatory framework for solar PV, including RD 1578/2008, has only encompassed commercial installations, all sizes comprised. In 2006, 21% of new capacity installed in that year (32 MW) was from installations below 5 kW. In 2007, this share went down to 6.5% (45 MW) and in 2008 it was even lower (1.7%, 58 MW). Compared to Germany, the share of small installations is much lower. In Spain, only 5% of the installations are small roof-top plants below 20 kW, but practically, all of them commercial. In Germany, the newly installed power of plants below 30 kW in 2009 was approximately 40% of the total. A survey for administrative barriers for solar PV deployment in several EU countries shows that in Spain, these hurdles for the residential sector, i.e. small installations of 3 kW, are significantly higher compared to other countries. Indeed, on the one hand, administrative procedures have been lengthy than adequate and the pre-registration, a very long and bureaucratic process on which the eligibility of every PV project depends on, has had an important impact on the PV deployment. On the other hand, specific measures for promoting net-metering have not been implemented in Spain. The project procedure has almost been identical for the residential, commercial rooftop and ground-mounted systems.

The tariffs of RD 1578/2008 were also subsequently reduced by another Royal Decree in 2010 (del Rio P. a.-A., 2014). A correction factor of 0.95, 0.75 and 0.55 was applied to type I.1 (small roof systems), type I.2 (large roof systems) and type II (ground-mounted systems) installations, respectively. Reduced levels of support entered into force in the second quarter of 2011. In combination with the tariff reductions triggered by the new quota system, this meant that by the second quarter of 2011 tariffs had been reduced to 0.2888 €/kWh for type I.1 plants, 0.2037 €/kWh for type I.2 and 0.1346 €/kWh for type II systems. As a result, over a three-year period, from the end of 2008 to the end of 2011, tariffs were reduced by 19%, 39% and 61% for type I.1, I.2 and II installations, respectively. Table 30 shows the evolution of solar PV FiT from 1998 until 2011.

The first Royal Decree introduced to control subsidy costs, RD 1578/2008, reduced the duration of support for new solar PV plants. Previously, plants had been offered subsidy

payments across their entire operating lifetime. Under the new rules, newly installed plants would only receive support for 25 years.

	Types of PV facilities									
Royal Decree	Year	Quarter/s	≤5 kW	> 5 kW	≤ 100 kW	> 100 kW to ≤ 10 MW	> 10 to 50 MW	Roof ≤ 20 kW	Roof≥20 kW ro 2 MW	Ground ≤ 10 MW
	1998	IV	39,6	216						
	1999	I-IV	39,6	216						
	2000	I-IV	39,6	216						
	2001	I-IV	39,6	216						
2818/1008	2002	I-IV	39,6	216						
2010/1990	2003	I-IV	39,6	216						
	2004	l I	39,6	216	41,4414	21,6216	21,6216			
	2004	II-IV			41,4414	21,6216	21,6216			
	2005	I-IV			42,1498	21,9912	21,9912			
	2006	I-IV			44,0381	22,9764	22,9764			
136/2001	2007	I			44,0381	22,9764	22,9764			
430/2004		II-IV			44,0381	41,75	22,9764			
661/2007	2008	1-11			44,0381	41,75	22,9764			
001/2007		111			44,0381	41,75	22,9764	34	32	32
		IV						34	32	32
		I						34	32	32
	2009	II						34	32	30,72
	2005							34	32	29,91
1578/2008		IV						34	32	29,09
		I						34	31,17	28,1
	2010	II						33,47	30,31	27,32
	2010	111						33,06	29,52	26,55
		IV						32,2	28,68	25,86
		1						31,35	27,89	25,17
1565/2010	2011	П						28,88	20,37	13,46
1303/2010	2011	- 111						28,1271	19,8353	13,0324
		IV						27,3817	19,317	12,497

Table 30 Evolution of solar PV FiT in €cents/kWh (del Rio P. a.-A., 2014).

Royal Decree 1565/2010 – Retroactive changes

The next Royal Decree, RD 1565/2010, was introduced at a time when the tariff deficit had increased substantially and the government had decided to take drastic measures to reduce it. The aim was to reduce electricity system costs by 4.6 billion € in three years, half of which would come from cutting solar PV subsidies. One of its measures for achieving this was to extend the 25-year cap such that it applied to all solar PV plants developed under RD 661/2007. Beyond this period, plants would still be able to sell their electricity to the grid, but at wholesale prices.

This was considered a retroactive change by the solar PV sector, as RD 661/2007 had originally promised plants payments across their operating lifetime. The government's rationale was that support should no longer be provided once plants had been fully paid-off.

Royal Decree Law 14/2010 – More cost-cutting measures

In its subsequent Royal Decree Law, RDL 14/2010, it later increased the duration of support to 28 years, to compensate solar PV plant operators for other restrictions that had been introduced on the number of operating hours that plants would be eligible for FiT payments.

RDL 14/2010's other key cost-cutting measure was to implement a cap on operating hours for most existing solar PV plants, those installed under RD 1578/2008 and RD 661/2007. Any electricity generated within the cap would be remunerated at the relevant FiT rate, whereas electricity generated outside of the cap could only be sold at the pool electricity price. Operating hours for plants installed under RD 1578/2008 were capped until 2013 and differentiated according to the solar radiation zone where the plant was located. A greater number of hours were allocated to solar PV plants located in places with better solar resources, such as zones IV and V, as illustrated in Figure 34. The number of running hours also differed according to the type of tracking mechanism used by the plant, e.g. fixed, single-axis or dual-axis tracking. Table 31 shows the running hours allocated to solar PV plants based on their location and tracking mechanisms.



Figure 34 Solar radiation zones (del Rio P. a.-A., 2014)

Table 31 Equivalent hours for plants subject to RD 1578/2008 (del Rio P. a.-A., 2014).

Type of	Equivalent annual hours eligible for FiTs						
installation	Zone I	Zone II	Zone III	Zone IV	Zone V		
Fixed	1.232	1.362	1.492	1.632	1.753		
1-axis tracking	1.602	1.770	1.940	2.122	2.279		
2-axis tracking	1.664	1.838	2.015	2.204	2.367		

The cap on operating hours for plants installed under RD 661/2007 was not differentiated according to their location within solar radiation zones. This cap was more restrictive because the operating hours that were granted were lower than those provided to the plants installed under RD 1578/2008, with the exception of RD 1578/2008 plants operating in zone I (Table 32).

Type of installation	Equivalent annual hours eligible for FiTs
Fixed	1.250
1-axis tracked	1.644
2-axis tracked	1.707

Table 32 Equivalent hours for plants subject to RD 661/2007 (del Rio P. a.-A., 2014).

Both these caps, for PV installed under RD 1578/2008 and RD 661/2007, were retroactive changes, with restrictions in this respect being contained in either of the original decrees setting out the conditions under which PV systems would receive support.

RD 1565/2010 also addressed repowering. It stipulated that all repowering had to involve the use of new equipment and that repowered solar PV plants would receive the current tariff. This would prevent developers from repowering systems with outdated modules or from building "new" plants with modules that had previously been installed elsewhere.

Royal Decree 1003/2010 – Facing fraud issues

From late 2008 until late 2011, Spanish newspapers and other media published articles citing allegations of fraud relating to solar PV support policies (del Rio P. a.-A., 2014). It was alleged that administrative procedures authorizing support for solar PV systems had been bypassed, with some solar PV plants falsifying the dates they had begun feeding electricity into the grid, in order to qualify for higher subsidies under RD 661/2007. The CNE launched an inspection campaign in late 2008 with the goal of ensuring all PV installations benefiting from the RD 661/2007 scheme had actually been feeding energy into the grid prior to 28th September 2008.

The government started to enact a new Royal Decree, RD 1003/2010, issued in August 2010, to verify that the authorization procedures for suspect plants had been correct. The RD offered an amnesty for plants in breach of procedures if they would "voluntarily" resign from the RD 661/2007 subsidy framework and switch to support measures provided by RD 1578/2008. However, this was a failure as practically no plant operators chose to accept the amnesty. However, solar PV associations estimated that the capacity considered to be "irregular" was about 600 MW.

In 2011, the CNE provisionally suspended FiTs to some plants which were considered to be in contravention to the provisions of RD 1003/2010. However, by late 2011 only 89 MW of solar PV plants were considered to be operating under irregular administrative conditions.

In addition to registration fraud, there have also been rumors since the boom, of a secondary market for the purchase of the solar PV installation rights. To prevent this

practice, the RD 661/2007 established that promoters had to provide a mandatory guarantee of $500 \notin kW$. This encouraged genuine developers who had to commit financial resources to the project and discourage speculators for securing a project permit which they could quickly sell for a profit.

Royal Decree Law 1/2012 - More efforts to reduce the tariff deficit

The need to cut the tariff deficit led to the introduction of RDL 1/2012 on January 27, 2012. This Royal Decree Law effectively differed for an indefinite period the registration of preallocation applicants for new projects and abolished all types of RES-E preferential tariffs and premiums for new projects. It also declared that calls for new solar PV installations for 2012 were suspended.

Two other main regulatory changes were made to the treatment of RES-E. First, a special tax on all sources of electricity generation, including solar PV plants, was approved on December 2012. Second, a new criterion the tariffs would be annually updated was approved in 2013 by Royal Decree Law 2/2013. Instead of using the Consumer Price Index (CPI), it declared that the core inflation rate, the CPI minus the prices of food and energy products, would be used to set tariffs. This change was designed to lead to a freeze of FiT levels in 2013 and the likely reduction of those FiT levels for later years in real terms. Finally, in July 2013, the government approved Royal Decree RDL 9/2013, which indicates that investment returns for renewable projects will be set at around 7.5% (Brown, 2013). For some projects, this return level is much lower than the returns on which finance and investment decisions were based.

Royal Legislative Decree 1/2012 – Suspension of solar PV support policies

PV support policies in Spain were suspended by the Royal Legislative Decree 1/2012 and no other support scheme is active at this time (Campoccia A. D., An analysis of feed-in tariffs for solar PV in six representative countries of the European Union, 2014). At present, the Spanish Government is working on a partial net-metering support scheme for PV systems below 100 kW, where the compensation of electricity flows will be calculated on a yearly basis.

7.3 First evaluation of the policy

7.3.1 The PV market in Spain

The general introduction of solar PV in Spain started in 2008, when 2708 MW were installed, with an increase of 500% compared to the value for 2007 (Romero, 2012). In the period 2007-2013, the installed capacity of PV in Spain increased more than 35 times, from 155 MW in 2006 to 5.2 GW by the end of 2012, steamed by generous incentives (Pudjianto, 2013). Amidst financial crisis and changes in FiT, the rate of new PV installations has slowed down. Spain, also, suffers lack of interconnection with Europe, which limits the ability of the Spanish system to integrate larger amount of new PV in their electricity system. With the

capacity until 2013, PV supplied slightly more than 2% of the Spanish electricity consumption. This capacity needs to be doubled by 2020, if the NREAP target of 8.4 GW is going to be met, or more than tripled for the EPIA projection of 18 GW to be realized.

The constantly decreasing costs of photovoltaic panels, which reflect daily effects in the economies of scale and improvements in the technological learning curves, have added to their financial appeal, to diversification in the activities of many companies and to normative changes to push this technology into levels that were hard to imagine only a few years ago (Romero, 2012). In Figure 35, the increase in installed capacity and the number of installations of PV energy are shown. While there was considerable growth in 2008, the trend has stagnated as a result of regulatory changes and difficulty in financing the projects.



Figure 35 Total installed capacity and total number of installations of PV energy (Romero, 2012)

The Spanish photovoltaic sector includes companies that exploit all the chain value of this industry, from manufacturing of cells to promotion of farms, inside and outside the borders of the country. Their strength gives an idea that several companies dedicated exclusively to this activity have entered the stock market. Figure 36 shows the PV cells production in Spain for the period 2009-2012, and Figure 37 Figure 37 the modules production for the period 2008-2011.



Figure 36 PV cells production in Spain for the period 2009-2012 (Dolera, 2012)

MW



Figure 37 Solar PV modules production in Spain for the period 2008-2011 (Dolera, 2012)

The future of the PV sector in Spain is bleak due to the absence of financial support for new installations and the legal uncertainty created by the FiT reforms in 2010 (del Rio P. a.-A.,

2014). The frequent, often retroactive, changes in regulations have reduced the attractiveness of further investments in the sector. Existing generators are also wondering whether further reductions in their remuneration may occur. However, two areas of the sector could be economically sustainable going forward:

- 1. Large solar PV plants, financed by revenues obtained through selling electricity on the wholesale market, can be profitable even in the absence of FiTs, given the lower costs that result from economies of scale.
- 2. When sources of distributed generation, such as solar PV panels at the building level, are used to generate electricity for local consumption and also used to sell electricity back to the grid. There was a first draft of a Royal Decree to regulate on-site generation in Spain, made public in November 2011. However, a second one, probably definitive, was issued in July 2013 and the proposed regulation does not create the best economic conditions for deployment of PV demand-side generation.

7.8 Legislative issues and investment drawbacks

7.8.1 Factors that led to the "boom"

The dominant factors behind Spain's solar PV boom are well-known: FiT rates were too high, technology costs were decreasing and FiT rates were not changed to account for these changing costs. The tariffs were designed to provide developers with an internal rate of return (IRR) for their projects of between 5% and 9%. The government had set this rate allowing for a "reasonable" profitability level of 7%. Actual IRRs for projects in the best locations were, however, between 10% and 15%.

A range of factors helped create the dynamic that caused the crisis in Spain. All of them in some way relate to either profitability, as the gap between FiT rates and the cost of developing a solar PV installation, the speed at which investments could take place or the extent to which costs and investments were anticipated and tracked. These factors include policy, technology, finance and administration.

In terms of policy, the tariff rates that were set "too high" is the most commonly cited factor used to explain the boom. In fact, for small installations (less than 100 kW) and large installations (over 10 MW), tariff levels had not been increased significantly between 2004 and 2007 and had last been revised only slightly upwards in 2006. For two categories of solar PV applications, then, tariff levels had been in place for two years and the level of remuneration for developers had not previously proved to be excessive. The only exception, as illustrated in Figure 38, was the FiT rate for installations between the capacity ranges of > 100 kW and \leq 10 MW, which was almost doubled in RD 661/2007.



Figure 38 Tariff rates for solar PV in €cents/kWh in the period 1998-2011 (del Rio P. a.-A., 2014)

The change to high tariffs for this middle category of installation was important, but what was crucial was the fact that investors could take advantage of the rates, realizing that they could make more money by aggregating small-sized plants close together rather than building one large plant. This kind of plant arrangement was allowed by law. Many such *huertos solares* or "solar orchards" were set up in order to take advantage of the highest FiT rate and benefit from the economies of scale that could be achieved by aggregating smaller systems. In essence, this meant that large-scale systems were able to receive the level of FiT intended for smaller and costlier systems. It also meant that the financial rewards of the FiT would be much larger than intended, resulting in a boom of investment.

But this was not the only reason why some systems were too generously compensated. Across the FiT system, inflexible tariffs that did not respond to changing costs were a major cause of the problem: while rates had rarely changed since 2004, many other aspects of the costs of solar PV project development had gone down. This failure to recognize that profitability is a dynamic between prices and costs and that profitability can be highly volatile in the very short-term, rendered tariffs over-generous where they had previously been sufficient.

Two other aspects of government policy played roles in helping to drive the boom. First, some provisions enabled amendments to existing installations that essentially increased generating capacity. For example, clauses surrounding the "repowering" of sights allowed existing PV plants to install more efficient equipment in order to fall under RD 661/2007's more favorable regulations. The only condition was to maintain their nominal capacity, but because new modules were more efficient, electrical output increased, as did the amount of subsidies received per unit of capacity. In other cases, capacity upgrades took place informally. The legal capacity of a solar PV park was defined as the capacity of its inverter. Therefore, a common practice was to upgrade the capacity of the modules, meaning the

sum of their peak capacities, by 15% to 20% above the inverter nameplate capacity. This led to an increased amount of electricity being fed to the grid.

Second was the effect of the anticipated policy change to less favorable conditions and simply slow policy change. RD 661/2007 set out that if 85% of the solar PV capacity (371 MW) had been reached, then a new Royal Decree with lower FiT levels would need to be approved within one year. This quota was already achieved by June 2007 and a draft of the new Royal Decree was made public in September 2007, including a substantial reduction in support levels compared to the existing regime. Solar PV developers had expected levels to be lower but, due to the size of the decrease, there was a rush in the spring and summer of 2008 to submit proposals in order to qualify for the existing FiT scheme.

From the aspect of technology, along with a general ongoing trend of falling manufacturing costs, there were also increases in efficiency of solar PV panels that effectively increased the production of electricity for a given nominal capacity. In addition, arrays with 1- or 2-axis tracking systems were increasingly used. Both efficiency factors led to a 33% increase in electricity production and consequently increased revenues for developers, thus leading to a higher burden on the government.

A number of factors decreased the cost of finance, increasing the profitability of solar PV projects. Access to credit was relatively easy and low interest rates facilitated the financing of projects for smaller investors. Spain had taken advantage of joining the Euro currency zone and reduced interest rates in 2006. Spanish banks had a large credit capacity due to large deposits and loans from foreign banks, mostly from EU countries, and were financing up to 100% of investments through project finance arrangements. Such schemes were common for projects financed by small investors whose own financial resources were insufficient to finance the upfront capital costs required for solar PV. In addition, the US dollar weakened against the Euro from 2006 to 2008. From June 2007 to August 2008 the average exchange rate was 1.47 US\$/ \in . The stronger euro versus the dollar encouraged imports of solar PV cells and modules since imports were paid in dollars and were effectively becoming cheaper. In 2008, solar PV imports totaled 5185.5 million ϵ , with 55% being imported from China, while exports only amounted to 250 million ϵ . Imports from China represented around 1700 MW, which is around 60% of total installed capacity.

Finally, the housing market, which had been growing rapidly, began to show signs of stagnating in 2007, causing a flight of capital to more profitable investments. Solar PV investments became an appealing financial product because of high internal rates of return coupled with very small risks. Investors from the Spanish housing market were, of course, not the only actors engaged in Spain's solar PV market. A large range of international investors, from small investors to large pension and investment funds, were also operating. The influx of investing from Spanish housing did, however, serve to affect the total volume of investment on the market.

Administrative factors also played a role. Some regional and local governments responsible for the granting of different administrative permits reduced their administrative requirements to speed up deployment, although there were no specific deadlines for issuing permits. The eagerness to grant planning permits was in recognition of the local socioeconomic benefits of solar PV deployment, namely economic activity and jobs, especially in rural areas.

Poor communication between Spain's Autonomous Communities and the central government led to delays in identifying the number of projects applying for the FiT scheme. Although there was a central registry for PV installations eligible for the special FiT regime, most solar PV plants were registered at regional registries, meaning that while authorization for new solar PV plants was provided at the regional level, the subsidy is paid for by all electricity consumers in Spain on a pro rata base. Autonomous Communities were required to pass this information to the central government. The system of reporting between the regional governments and central administration was, however, considered to be antiquated by several experts. In some cases, there was a delay of several weeks between the regional offices passing registration information on to central government. Up until about 2008, it seemed that central government did not have an understanding of the overall number of solar PV projects that were going to be deployed under the FiT scheme. A slow response to this situation may also have been linked to the general election in March 2008, which temporarily paralyzed the central administration. Better coordination between Autonomous Communities and the central government would have improved the monitoring of the monthly registration rates for installed capacity and helped the government react more quickly.

7.8.2 Other legislative issues and investment drawbacks

The combination of quantity and price (support level) controls may be appropriate for expensive technologies with large potential for technical improvements and cost reductions such as solar PV, whose deployment may boom unexpectedly (del Rio and artigues, 2012). Cost-containment mechanisms would then mitigate the problem that a deployment boom leads to an excessive increase in consumer costs. Several cost-containment mechanisms exist, e.g. capacity caps, revisions, flexible degression, caps on total costs, limits on the amount of generation which is eligible for the FiT, and so on. All have their pros and their cons, however. Some of them have been implemented in Spain, limiting the amount of generation eligible for the FiT for existing solar PV plants been the most recent, under RDL 14/2010. However, putting a cap on generation discourages the efficient functioning of existing plants (i.e., MWh of generation/ MW of capacity) and, to some extent, the manufacturing of more efficient technologies by equipment procedures.

Moreover, flexible degression is a particularly attractive cost-containment mechanism, with traditional or "fixed" degression being introduced for the first time in the German EEG in 2000 and refers to previously set percentage reductions over time in support levels (tariffs) for new plants. However, an important disadvantage of this sophisticated form of degression is the uncertainty for investors willing to invest in the future which it introduces, because they do not know precisely what their revenue flows will be. Indeed, the level of support that will be in force in the future changes very often, because it depends on the quarterly evolution of capacity and to worsen things, the amount of new capacity to be added has

been set at very low levels. On the contrary, the German scheme balances the advantages and disadvantages of traditional and flexible degression. It is more responsive to the evolution of the costs of the technology than fixed degression, but it provides more certainty than flexible degression on the revenues investors can expect to receive in the future. In short, while the FiT in Germany is mostly a price-based instrument, the Spanish scheme is a hybrid quantity-based and price-based system.

Retroactive regulation changes should be understood as adjustments which negatively affect revenue certainty of operating plants. Of course, there is no such a case if changes in support levels only affect new installations. Once a generator locks into a given rate, the policy should not be backwardly and arbitrarily readjusted to amend the economic conditions. Both terms refer to a regulatory change modifying the established tariff scheme, which implies a new estimation of the revenues previously gained, probably reducing them, and urging the return of surpluses. In this case there is no doubt: this modification is not acceptable because it is retroactive. However, there is another situation: rates are changed but only with forward effects and provided that the profitability of the investment (internal rate of return) remains unchanged. This kind of regulatory amendment has been accepted by the Spanish Constitutional Tribunal as well as the Supreme Court. They have stated that the principle of juridical security cannot be an obstacle to "regulatory innovation", a point of view shared by the regulator (CNE, Comisión Nacional de la Energía). Put in other words, changes affecting operating plants are admitted but cannot be economically arbitrary, although this later concept is inevitably ambiguous. From a policy perspective, these legal modifications mean that the benefits in terms of lower support costs in the short term can be more than offset by the negative effects on investor confidence and security in the short and medium terms. For example, the changes introduced by RD 1565/2010 and RDL 14/2010 will result in savings of 607 million € in the 2011-2013 timeframe, a very small fraction of the total costs of solar PV. In contrast, investors' confidence will be seriously undermined.

One of the reasons of the Spanish boom was the 85% thresh- old for the PV target which, once reached, would lead to a new royal decree more than one year after. Investors rushed to have their installations approved before September 2008 in order to receive the support level of RD 661/2007 because the new FIT was expected to be lower. Other factors facilitated this rush, including the techno-economic features of solar PV (which can be modular and installed very easily and fast), easy access to credit and the investors' pressure on administrative bodies to streamline the granting of the administrative permits. As a result, the market was overheated. Although it is very difficult to avoid occasional overheating of the market, to establish a long transition period is a very bad regulation design. It was not the threshold by itself but the lack of an accurate plan for the transition period, that is, the extra-time running from the existing regulation (RD 661/2007) to the new one (RD 1578/2008), what was the Achilles'' Heel of the Spanish regulation. This prompted the aforementioned enormous increase in capacity and a huge rise in total policy costs.

Repowering refers to existing PV modules being replaced by new, more efficient ones, increasing the installed power (kWp), without elevating the nominal power of the plant (which is defined by the transformer at the feed-in point). Repowering brings certain

advantages compared to green-field projects: new places are not occupied (circumventing the problem of competition for land) and older plants are upgraded and substituted by new ones with better technologies. It is arguable whether or not repowering should be publicly supported. But if it is so decided, then the Spanish case illustrates how this should not be done. Currently, a solar PV module replacing an existing one would receive the same amount of support as the one being replaced, i.e., the higher support level provided by the previous RD 661/2007. But new modules have better production efficiencies than existing ones. According to CNE, the average number of annual hours per installation have increased from 1272 in 2000, to 1547 in 2006 and 1752 in 2010 (whereas the number of hours used to calculate the support under RD 661/2007 were barely 1378), both as a result of technological changes and a greater number of high-quality radiation hours than expected, making it very profitable for operators to re-power their plants.

Targets in general (whether indicative or binding) provide visions/signals for investors and are instrumental in guiding industry toward making appropriate capital allocation decisions. The adoption of binding targets depends on government priorities: cost-containment or effectiveness in deployment. While Spain has adopted binding targets, worried about the costs of support, Germany has indicative targets, i.e., the targets can be exceeded. Binding targets provide cost-control but also limit market growth and reduce investment stability for market parties.

Finally, in addition to lengthy administrative procedures, the most important impact for the market is the pre-registration, a very long and bureaucratic process. Several alternatives exist to deal with administrative barriers, including simplifying procedures for small systems below 10 kW (even exempting them from getting permits) and establishing a one-stop-shop for all permitting procedures.

7.9 Conclusions

In Spain, a constant level of support provided via the FiT was the status quo before the boom, ignoring the experience and cost curves known to be occurring for modular solar PV technologies. The transition periods between revisions of Spain's FiTs were too long and disregarded the modularity and ease of installation of PV technologies. After the boom in Spain, the government attempted to control growth in capacity through a flexible degression rate, coupled with a small capacity cap and other cost-containment measures, such as non-scheduled FiT reductions and non-eligible generation hours for FiTs. It was, however, arguably too late, given that the ultimate step was to cancel the whole RES policy.

Currently, the legal framework for RES support in Spain is the Royal Decree 661/2007. In 2008, the Royal Decree 1578/2008 was published, setting new regulations for PV systems commissioned after September 29th 2008, introducing a strong reduction for PV FiTs. The support mechanism for PV systems in Spain is based on the possibility for the producer to choose whether to sell the electricity produced under a FiT mechanism or whether to sell it

in the free market, taking advantage of a premium above the market price. FiTs are supplied for an undefined number of years with a reduction after 25 years.

8. The case of Germany

This chapter analyzes the deployment of solar PV in Germany, following the same structure as the previous two case studies on Greece and Spain. The only difference with the previous case studies is that no mentioning is taking place concerning the electricity tariff deficit of Germany, as it does not exist.

8.1 Agenda setting for the policy framework of Germany

8.1.1 The solar potential of Germany

Despite its worse solar conditions, with 900 peak sun hours annually, compared to Spain and Greece (Table 33), the powerful German industry has achieved not only a spectacular development of solar technologies, but also an outstanding deployment all over the country. However, the contribution of solar energy sources in terms of share is still minor nowadays at 1.9% (Fernandez, 2013).

Table 33 Yearly solar radiation in the northern, central and southern areas of Germany,Greece and Spain (Campoccia and Telarreti, 2014).

	Germany	Greece	Spain			
Yearly solar radiation (kWh/m ² per year)						
North	889	1384	1018			
Center	911	1435	1387			
South	1015	1663	1449			
Variation of the solar radiation with respect to the central area of the country						
North	-2%	-4%	-27%			
South	11%	16%	4%			

8.1.2 The German electricity system

Electricity surcharges have emerged as a political issue ahead of September 2013 national elections (Brown, European Union Wind and Solar Electricity Policies: Overview and Considerations, 2013). Germany's approach to pay for renewable electricity incentives is to spread the costs over a large electricity consumer base. Therefore, Germany does not use federal tax revenues to fund the EEG. In practice, the EEG financial mechanics, known as the Equalization Scheme, includes several nuances and complexities. Generally, however, grid system operators pay feed-in tariffs to renewable power projects and the above-market

costs of the FiT incentives are passed along to certain domestic retail electricity consumers through an EEG surcharge that is added to customer electricity bills.

The EEG surcharge applied to some consumer (residential, commercial and industrial) electricity bills has increased since 2000 and annual increases have emerged as an important public policy issue. Figure 39 illustrates the cost components of residential electricity prices in Germany from 2000 to 2011. For reference, the 2013 EEG surcharge was set at approximately 5.3 €cent/kWh, an estimated 47% increase over 2012.



Some more information on the German electricity market are provided in the Appendix.

Figure 39 Cost components of German residential electricity prices (nominal euros) (Brown, 2013)

8.1.3 Understanding the policy

In the 20th century, Germany was one of the few large industrial states without oil resources and no large oil corporation of its own (Jacobsson, 2006). Partly for this reason, it came to rely with particular intensity on domestic coal, and later on nuclear energy. This was reinforced by the energy crises of the 1970s, where such a choice was imposed in a rather authoritarian fashion by Chancellor Helmut Schmidt and was continued by his successor Helmut Kohl after 1982. But then, this choice led to intense controversies and the rise of a strong anti-nuclear movement in the 1970s, a strong environmental movement in the 1980s and the first big Green party in Europe. Early on, RES caught public attention as an alternative to the nuclear path towards a plutonium economy. Under pressure from a movement in favor of renewables, the above governments, with some reluctance, also supported the development of RES, though not for domestic use at first. However, to be successful, the diffusion of RES must be defensible also on economic grounds, forming a need for support. Moreover, Germany's binding EU 2020 renewable energy target requires that 18% of total energy be provided by renewable sources by 2020 (Brown, European Union Wind and Solar Electricity Policies: Overview and Considerations, 2013). As required by the EU Directive, Germany has published a National Renewable Energy Action Plan (NREAP), which outlines the country's plan to achieve the renewable energy target. Germany's NREAP, published in June 2010, indicates that Germany plans to generate 38.6% of electricity from renewable energy sources by 2020. Since then, Germany developed its Energy Concept, which aims to have 35% of electricity sourced from renewables by 2020, rising to 80% by 2050. This portion of the Energy Concept was included in Germany's 2012 renewable electricity policy amendments.

Finally, the government of the Federal Republic of Germany had decided to reduce CO_2 emissions into the atmosphere by 25% by the end of 2005, as compared to the level of 1990 (Jacobsson, 2006).

8.2 The legislative framework for PV in Germany

Erneuerbare-Energien-Gesetz (2000) – The first FiT system in Germany

Germany has had a FiT system since 2000, when the Erneuerbare-Energien-Gesetz (EEG) was first introduced (del Rio P. M.-A., A cautionary tale: Spain's solar PV investment bubble, 2014). Although a number of amendments were made to the EEG up to and including 2008, its basic structure in this period remained relatively stable from 2003: a tariff rate paid for by increased consumer bills, with tariffs differentiated by technology size and by application (façade, ground-mounted, etc). Since its inception, the EEG also contained a design feature known as "digression", whereby tariff rates were set to be reduced by a pre-determined amount every year. A digression rate of 5% was established for solar PV in 2003 and raised to 6.5% for ground-mounted plants in 2008.

Introducing the "corridor system" (2009)

Following rapid increases in solar PV deployment in 2008, the first major modification was made to the EEG in 2009: the introduction of a "corridor" system. The corridor system was designed as an attempt to respond to the rapid decreases in solar PV prices (del Rio P. M.-A., A cautionary tale: Spain's solar PV investment bubble, 2014), allowing the FiT level to decline according to the market evolution (Dusonchet L. T., Comparative economic analysis of support policies for solar PV in the most representative EU countries , 2015). This has been achieved by splitting the FiT rate into two components: a base rate, equal to 1% and a flexible rate, dependent on the total capacity of newly installed PV systems registered in the month. The flexible digression rate is modified every quarter, considering the total amount of newly installed PV capacity in the past 12 months. This means that the larger the amount of capacity installed, the greater the digression rate would be (del Rio P. M.-A., A cautionary tale: Spain's solar PV investment bubble, 2014). The range of the corridor and the associated change in the digression rate were set by a political decision, based on expectations about the PV experience-cost curve and a forecast impact of solar PV subsidy policies on electricity

bills. The corridor was established to allow a range of tariff reductions between 5.5% and 7.5%.

However, the price of PV modules fell by around 40% in 2009 alone and the projected additional capacity of 1500 MW was easily exceeded. As a result, some non-scheduled adjustments, in other words, ad hoc and larger changes to digression rates were introduced. The digression rate can both increase and decrease the overall digression, depending on the gap between the newly installed PV capacity and a selected yearly margin, ranging between 2500 and 3500 MW, as shown in Table 34.

Amount of deviation (MW)	
	Exceeding the target
≤ 1000	1.4% (0.4%)
>1000	1.8% (0.8%)
≥ 2000	2.2% (1.2%)
≥ 3000	2.5% (1.5%)
≥ 4000	2.8% (1.8%)
	Below the target
≤ 500	0.75%
≤ 1000	0.5%
≤ 1500	0%
≥ 1500	0% and the FiT is increased by 1.5%

 Table 34 Total (flexible) digression rate of FiTs in Germany (Dusonchet and Telarreti, 2015).

Furthermore, the digression rate was adapted to the market growth (Solangi K. I., 2011). If the growth of the PV market (new installations) in a year is higher or lower than the defined growth corridor, the digression rate will be increased or decreased by 1% for the next year. For 2009, the corridor was set between 1000 and 1500 MW, as shown in Table 35. The rates were guaranteed for an operating period of 20 years. For small systems <30 kW installed in 2009, the producers have the possibility to auto-consume the electricity they produce. In this case, they receive a premium FiT of 0.2501 €/kWh for 2009, instead of 0.4301 €/kWh, for the self-consumed PV electricity. In one includes the savings on electricity delivery costs, which are approximately 0.22 €/kWh, this way of operating the PV system may become attractive, as every kW of PV power is worth 0.47 €/kWh.

Table 35 Upper and lower limits of the growth corridor of the PV market in Germany, from2009 to 2011 (Solangi K. I., 2011).

Growth corridor	Degression	2009	2010	2011
Upper limit in MWp	Above: +1%	1500	1700	1900
Lower limit in MWp	Below: -1%	1000	1100	1200

In July 2010, the digression rate was immediately increased to 13% for building-mounted systems and from 8% to 12% for freestanding installations (del Rio P. M.-A., A cautionary tale: Spain's solar PV investment bubble, 2014). In October 2010, an additional 3% was added to all systems' digression rates. This interim revision included a 1% additional increase to the 2011 rate for each GW installed in excess of the 3.5 GW baseline in 2010. In July 2011, another revision took place, according to which, for each GW over 3.5 GW to be installed in 2011, 3% would be added to the digression rate for the second half of the year. In other words, the interim revision accelerated the digression rate up to a maximum value of 15%.

Erneuerbare-Energien-Gesetz 2012 – Replacing the FiT with a market premium system

On June 30, 2011 the German Parliament adopted EEG 2012, which came into force on January 1, 2012. The feed-in tariff was replaced with market premium system, where RES-E generators sell their electricity directly into the wholesale market and, in addition to the pool market price, they will receive a premium. This premium is equal to the difference between the FiT available at any given month, which is decreasing over time according to a given corridor, and a reference price, calculated on a monthly basis, which has two components. The first one is the average of the spot market prices for the previous month. The second one, called the "management premium", is a proxy for the additional cost that RES-E generators incur for accessing the pool, including the stock exchange admission and the trading connection fees. The amount of the "management premium" for solar PV generation was set at 0.012 €cents/kWh in 2012 and to decline thereafter.

The preferential prices in 2012 declined by 24% due to the huge capacity installed in 2011. However, since the authorities wanted to maintain the target corridor at between 2500 and 3500 MW, the EEG 2012 was amended again in the middle of 2012. It was then decided that solar PV remuneration rates would be adjusted on a monthly basis. Furthermore, monthly digression would be adjusted every three months, according to the capacity installed during the previous 12-month period, with the switch from the old to the new corridor system lasting until August 2013. However, monthly FiT digressions can be difficult for project developers to navigate, since development times for large projects can take months or longer to develop (Brown, European Union Wind and Solar Electricity Policies: Overview and Considerations, 2013). The 2012 amendment also introduced a 52 GW threshold for PV capacity in order to be eligible for support under the EEG (del Rio P. M.-A., A cautionary tale: Spain's solar PV investment bubble, 2014). It is expected that, if the target corridor holds, this capacity would be achieved between 2019 and 2022.

In Germany, a PV owner can compensate for the energy produced by the PV system through a self-consumption scheme, thus reducing the electricity bill (Dusonchet L. T., Comparative economic analysis of support policies for solar PV in the most representative EU countries, 2015). The excess of PV energy injected into the gird is remunerated through a FiT system. Until 2012, German authorities incentivized self-consumption by assigning a premium above the retail electricity price. The premium was granted only for a percentage of autoconsumption higher than 30%. With the declining cost of PV technology, the bonus was removed. In the same way, a cap for FiT was established at 90% for PV installations between 10 kW and 1 MW, in order to force self-consumption. The remaining 10%, if injected into the grid, is remunerated at a lower market price. This market integration model was put into force in January 2014 and applies only to installations erected after 31 March 2012.

The current legal framework for RES support in Germany is the Act of Granting Priority to Renewable Energy Source (EEG) (Campoccia A. D., An analysis of feed-in tariffs for solar PV in six representative countries of the European Union, 2014). This document establishes the FiT mechanism in the country, with a contract duration time of 20 years, plus the year in which the installation was put into operation, and a constant remuneration for the energy produced. PV installations with rated power up to 10 MW can benefit from FiT (PV plants higher than 10 MW were incentivized before September 2012) (Dusonchet L. T., Comparative economic analysis of support policies for solar PV in the most representative EU countries , 2015). In order to be eligible for support, PV plants up to 10 MW must satisfy the following conditions:

- PV systems with rated power over 100 kW must be equipped with devices that allow the grid operator to reduce, at any time, the power injected into the grid.
- PV systems with rated power up to 30 kW must either meet the above-mentioned requirement or limit the power injected to the grid to 70% of the rated power.
- Ground-mounted systems must be built within the territorial application of a local development plant.

The FiT values are differentiated depending on the capacity of the PV system and the type of installation (building-mounted installations, such as roofs, facades or noise barriers and ground-mounted plants) (Campoccia et al., 2014). Table 36 presents the FiT values for PV systems in Germany valid in April 2013. The above mentioned building-mounted systems have higher FiT values, while lower FiT rates are established for ground-mounted systems. As an alternative to receiving the FiT, PV producers can choose whether to sell electricity to a third party by a supply agreement or sell it directly at the stock market. In the latter case, the PV owner may claim a market premium from the local Utility, updated each month.

	FiT (€/kWh)	
Rated power (kW)	Installed in, at or on building or noise protection wall	Freestanding facility
< 10	0.1592	0.1102
10.01 - 40	0.1510	0.1102
40.01 - 1000	0.1347	0.1102
1000.01 - 10000	0.1102	0.1102

Table 36 FiTs for electricity generated from PV systems in Germany, in April 2013(Campoccia et al., 2014).

Recent changes

The 1st of May 2013, the German government introduced a support mechanism for promoting the growth of storage systems, with the purpose of increasing self-consumption. Indeed, storage units can be used in conjunction with RES for small/medium scale public

facilities, thereby reducing the impact of renewable technologies on the electricity network. Custom devices can be adopted to ensure a proper interconnection and a reliable control system, according to the national technical specifications. The success of the incentive program is still being evaluated.

The latest change was announced in November 2013 by the German Federal Network Agency, with a reduction of 2.2% in the monthly PV FiT (Dusonchet and Telarreti, 2015). For November 2013, PV installations over 1 MW will receive 0.0974 \notin /kWh, with systems under 10 kW receiving 0.1407 \notin /kWh, as shown in Table 37. A legal cap of 52 GW in 2020 is established for the German FiT mechanism. When the cap is reached, FiTs are removed on the first day of the next month.

Table 37 FiTs for electricity generated from PV systems in Germany, November 2013(Dusonchet and Telarreti, 2015).

	FiT (€/kWh)	
Rated power (kW)	Installed in, at or on building or noise protection wall	Freestanding facility
< 10	0.1407	0.0974
10.01 - 40	0.1335	0.0974
40.01 - 1000	0.1191	0.0974
1000.01 - 10000	0.0974	0.0974

As it has already been mentioned, in Germany, instead of receiving a FiT, the energy produced by a PV system can be sold directly in the electricity market through a "market premium". The producer can go back and forth to the FiT system or the market premium at their own convenience. The market premium is determined each month and its value is calculated taking into account:

- the difference between the FiT rate and the average stock market price;
- a so-called management premium, calculated on top of the market premium, which covers the cost of variations in actual grid exports compared to the forecast, and stock market participation.

Like the FiT, the market premium is subject to digression, as specified in the EEG. The management premium is also reduced every year.

Additional supports are long-term and low-interest loans, with an effective interest rate of 1% per year and a fixed interest period of 5 or 10 years (Campoccia A. D., An analysis of feed-in tariffs for solar PV in six representative countries of the European Union, 2014). In addition, facilitated connection procedures and priority connection to the grid are available for all RES plants. However, with FiT rates constantly changing, obtaining project finance for some new projects may be difficult due to the complexities of accurately estimating project revenue, cash flow and profitability (Brown, European Union Wind and Solar Electricity Policies: Overview and Considerations, 2013). The abovementioned changes to Germany's incentive structure are contributing to expectations that annual solar PV installations in 2013

and beyond may drop to approximately 2500 MW, less than half of the more than 7000 MW installed in 2012.

8.3 First evaluation of the policy

8.3.1 Costs of PV in Germany

According to an analysis carried out by *Solangi et al.* in 2007, grid-connected PV systems are still not economically feasible in Germany (Solangi K. I., 2011). But they would make profit if systems with longer lifetime of up to 40 years were available. Even the calculations carried out considering FiT schemes showed that PV systems with shorter system lifetime, e.g. 25 years, are not economically feasible. The breakeven analysis showed that the systems would have been at breakeven as of today, if the module price was as low as $0.72 \notin$ /Wp or the base year electricity price was as high as $0.29 \notin$ /kWh. In 2007, the module price was around 1.52 \notin /Wp and the base year wholesale electricity price around $0.13 \notin$ /kWh. It has been calculated that the learning investment for PV systems between year 2009 and breakeven year 2021 will be around 29.4 billion \notin . This loss will be covered by the installations after this year and a win point is expected to occur in 2032-2033.

In Germany, where BIPV systems are remunerated through a combination of FiT and selfconsumption, the investment in a rooftop PV system is more profitable than that in a ground-mounted PV system, due to the high cost of the retail electricity (campoccia et al., 2014). Obviously, the presence of capital subsidies often granted in Germany could reverse the situation, especially for large-sized PV systems. It is useful to point out that the gap between the economic indexes for the 20 kW and the 100 kW PV systems is essentially due to the difference between the assumed electricity prices, household for the 20 kW and industry for the 100 kW PV system. *Campoccia et al.* calculated the economic indexes of the Discount Cash Flows (DCF), the Pay-Back Period (PBP), the Net Present Value (NPV) and the Internal Rate of Return (IRR) for different sized PV systems in France, Germany, Greece, Italy, Spain and the UK and the results for Germany are presented in Table 38. More recently, *Dusonchet and Telaretti* in 2015 made the same calculations and the results are presented in Table 39.

Rated power (kW)	Type of plant	Form of support	PBP (years)	IRR (%)	NPV (k€)
3	BIPV	FiT + self-	17	3.83	1.092
5	Birv	consumption			
20	RID\/	FiT + self-	12	60	27 800
20	DIFV	consumption	15	0.5	27.055
500	Ground-	FiT + direct celling	>25	- 2 72	- 5/15 2/12
500	mounted	FIT + unect seming	~25	- 3.72	- 545.545

Table 38 PBP, IRR and NPV for the German case (Campoccia et al., 2014)

Rated power (kW)	Type of plant	Form of support	PBP (years)	IRR (%)	NPV (k€)
3	BID\/	FiT + self-	15	1 83	2 18
5	DII V	consumption	15	4.05	2.10
20	BIPV	FiT + self-	10	9.1	37.40
20		consumption			
100	BIPV	FiT + self-	19	2 27	- 17 0/
100	Dir V	consumption	15	2.27	17.04
500	Ground-	FIT	> 25	- 2 96	- 116 85
500	mounted	111	~ 25	2.50	+10.0J
1000	Ground-	FIT	> 25	- 7 7	- 693 97
	mounted		- 25	2.2	- 093.97

Table 39 PBP, IRR and NPV for the German case (Dusonchet, 2015).

From the above Tables it can be noticed that in Germany, medium and low-sided PV systems are quite profitable, especially thanks to self-consumption (Dusonchet et al., 2015). For a better comparison, Table 8 shows the IRR and the NPV for the 3 kW PV system if only FiT is considered or if FiT and self-consumption are both allowed. As is clearly shown in Table 8, the convenience of the investment is much less when only FiTs are considered. On the other hand, IRR in *Dusonchet et al.* continue being negative for ground-mounted PV plants, for which self-consumption is not eligible, as in *Campoccia et al.*, with a PBP slightly longer than 25 years. Obviously, the presence of capital subsidies, often granted in Germany, could reverse the situation, especially for large-sized PV systems. It is useful to point out that the gap between the economic indexes for the 20 kW and the 100 kW systems is essentially due to the difference between assumed electricity prices (household for the 20 kW and industry for the 100 kW PV system).

8.3.2 The solar PV market in Germany

The story of the solar PV industry in Germany has been one of a spectacular rise, followed by a crash in parts of the sector, within just one decade (Lutkenhorst, 2014). From negligible capacity and production levels in 2000, with a newly installed physical capacity of 45 MWp and solar PV power generation of 64 million kWh, and initially modest growth rates, the industry recorded two-digit and at times even three-digit growth rates between 2004 and 2010, when installed capacity growth started to stagnate and reached a plateau of approximately 7500 MWp annually, which, up to 2012, made Germany the largest solar PV producer in the world. Within the broader EU context, Germany currently accounts for about half of the entire solar PV capacity and exhibits a PV per capita ratio of 400, measured in terms of Wp per inhabitant; this is four times higher than Spain and three times higher than the EU average. Over time, the average size of installed PV solar systems has increased significantly. Back in 2000, more than 60% of PV systems installed were operating at a

capacity below 10 kWp and only slightly more than 10% at more than 100 kWp. A decade later, the situation had reversed: only 10% of systems installed in 2011 were below 10 kWp, yet more than 50% above 100 kWp.

Germany is Europe's strongest PV market, with more than 35700 MWp of cumulated installations in 2013, as shown in Figure 40 (Germany Trade and Invest, 2014). This is equivalent to more than a quarter of the world's PV installations, making Germany home to every fourth solar module in operation worldwide. Capacity of 3300 MWp was installed in 2013 alone, as shown in Figure 41. Total electricity consumption share of almost 5% (30 billion kWh) was produced with more than 1.4 million PV systems in 2013. PV energy has recorded the highest growth rates among all renewables in recent years, making it the third largest renewable electricity source after wind and bioenergy.



Figure 40 Globally installed PV capacity at the end of 2013 in MWp (Germany Trade and Invest, 2014)



Figure 41 New PV installations in Europe in 2013 in MWp (Germany Trade and Invest, 2014)

The German federal government has made a commitment to a total FiT-supported installation level of 52 GWp. This volume is expected to be reached within the next three years. The estimated PV share of total electricity consumption is expected to reach 10% by this time (Germany Trade and Invest , 2014), while with an estimated share of about 14% of total electricity production in 2007, Germany had already significantly exceeded its minimum target of 12.5% set for 2010 (Dincer, The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy, 2011).

In 2008, more than a third of the global cumulative PV power installed was located in Germany (Dincer, 2011). However, although the absolute market figures kept growing in Germany, the market share of the country in Europe was shrinking through that year, as markets like Spain and Italy finally followed the successful German path. Germany has a diverse mix of PV applications. In 2008, 40% of the German PV systems were installed on residential homes (1-10 kW), 50% on commercial rooftop systems (10-1000 kW) and 10% of the PV systems were installed as very large ground-mounted systems. Also, out of all solar PV systems installed in Germany, about 99% are connected to the grid and only 1% is off-grid (Solangi K. I., 2011).

So, feed-in tariff incentives are generally credited with the rapid deployment of renewable electricity generation in Germany, especially the deployment of solar PV systems (brown, 2013). At the end of 2012, more than 32000 MW of solar capacity had been installed. Total installed solar PV capacity was larger than any other country in the world, as of the end of 2012. As discussed above, financial incentives for solar electricity have evolved over time and each policy change affected the economics and market demand for solar power generation. Figure 42 shows annual wind and solar PV capacity in Germany since 1991 and illustrates how changes and modifications to renewable electricity policies impacted solar PV deployment.



Figure 42 Annual wind and solar capacity additions in Germany (Brown, 2013)

Solar PV did not experience market penetration until the 2000 EEG was enacted, which created technology-specific FiTs based on electricity production costs. As FiTs for solar PV were adjusted over time in order to encourage deployment, the solar equipment market became very competitive and solar equipment prices began to rapidly decline in the late 2000's. The combination of these factors resulted in attractive economic returns for German solar PV projects. Annual installations quickly rose to 7000 MW per year by 2011. Since this level of capacity additions was twice the targeted amount and costs associated with FiT incentives were rising rapidly, the German government has since made several modifications to solar PV incentives, in order to control and manage future installation rates.

Moreover, Germany is Europe's leading manufacturer of PV modules and components (Germany Trade and Invest, 2014). Hi-tech PV technologies such as wafer-based, thin-film and organic PV, as well as new, innovative inverter and energy storage technologies are developed, produced and made commercially available in Germany. Leading global PV

players, innovative small- and medium-sized enterprises (SMEs), renowned research institutes and equipment and material suppliers help for the most innovative and holistic PV and PV battery industry clusters in the world. Germany is home to more than 40 manufacturers of silicon, wafers, cells and modules. As well as this, there are more than 100 PV material and equipment suppliers, over 100 balance-of-system (BOS) component manufacturers and more than 70 PV research institutes as well as thousands of project development, system integration and installation companies.

The level of renewable electricity deployment in Germany has also had an effect on the grid system operators (Brown, European Union Wind and Solar Electricity Policies: Overview and Considerations, 2013). While the system operators are able to recover costs associated with FiT incentives, they also must manage the integration and economics of variable sources of renewable power. For example, large amounts of solar power generation can reduce the value of electric power during peak demand/price periods. As a result, they support that conventional power generation assets (coal, nuclear, and natural gas) might not be able to generate enough revenue needed to pay for capital, operating, maintenance, and finance costs of certain power plants. While this may result in the retirement of less efficient fossil energy plants, it may also result in the electricity market not providing enough economic incentive to justify building and operating flexible power generation units that are likely needed to complement variable renewable electricity output. This is a critical issue that Germany is grappling with and it is one of the primary reasons why incentives are shifting from production-based to integration-based.

On the other hand, people in Germany see this energy transition as a worthwhile experiment in the global effort to address climate change and accept that this will come at a high cost (Ebinger, 2014). German consumers have been largely comfortable with this experimentation and have been willing to pay for a learning curve to support their convictions about climate change and renewables. Households, farmers and other small enterprises comprise the majority of the owners of renewable energy in Germany. The EEG has remained in place even as costs have risen and successive governments across the political spectrum have continued to support the policy framework.

Grid parity was achieved in Germany in 2011, with levelised cost of electricity (LCOE) of newly install systems below retail electricity prices for private households (Germany Trade and Invest, 2014). Direct consumption of self-generated PV electricity is becoming increasingly attractive, for commercial and industrial customers alike. As the gap between PV LCOE and retail electricity prices widens, a number of new technologies are taking momentum and with them, a variety of new business models are becoming visible. In this innovative market, companies have the opportunity to test, define and introduce new technical standards for this next-level PV world market. This will not only guarantee Germany's leading role in times of grid parity markets, but also consolidate its attractiveness for new business and investment opportunities, including energy storage systems, energy management, demand side management, as well as smart grid and smart home technologies, and broaden partnership opportunities with system integrators, project developers, utilities and R&D institutes.

It is widely recognized that the German solar boom was largely caused by the investment stability and strong incentives provided by the EEG, essentially through guaranteed, generous FiTs combined with priority grid connection for supplied electricity (Lutkenhorst, 2014). This was coupled with unexpectedly strong price decreases for PV systems: between 2006 and 2012, prices fell by roughly two thirds, from 5100 to 1750 €/kWp. In 2012 alone, solar module prices tumbled by 45%. The 2012 profile of the sector is summarized in Table 40.

New capacity installed	7.600 MWp
Share of world total	31%
Total cumulative capacity	32.400 MWp
Share of world total	47%
Power generated	28.060 GWh
Total cumulative number of installed PV systems	1.280.000
Share of gross electricity generation	4.7%
Share of gross electricity generation from renewables	20%
Number of PV companies (including installers and	
suppliers)	5.000
Thereof: Number of companies producing cells, modules	200
and components	
Export share of production	60%
Investment	€11.2 billion
Employment	87.800

Table 40 Key indicators of the PV solar industry in Germany in 2012 (Lutkenhorst, 2014)

However, the rapid rise of the German solar PV industry under favorable market conditions has created a highly diversified sector with significant industrial capabilities and capacities in practically all segments of the value chain, as presented in Table 41, although it is not exhaustive and does not fully reflect some very recent cases of company bankruptcies and there are also minor inconsistencies in the classification, as some vertically integrated companies are active in several value chain segments. In general, the German solar PV industry is facing tough conditions with fierce competition from low-cost Asian (mainly Chinese) suppliers. Market turbulence has increased and already a large number of companies, among them Q-Cells, once the global leader in solar cell production, Solon, Solar Millennium, Solar, Solarhybrid and Odersun, have gone bankrupt. At the same time, several industrial players with core expertise outside the solar industry are abandoning their solar PV operations: in March 2013, Bosch announced the discontinuation of its PV ingot, wafer and cell production and the sale of all its solar business units; Siemens is closing down its solar division after having entered the solar business only in 2009 with great expectations and WürthSolar, after a thorough evaluation, completely exited from its solar PV production in May 2013. Of course, this cannot be blamed on the FiT policy, however, it is an important aspect that should been taken into consideration in this discussion.

 Table 41 Solar PV industry value chain: Number of leading business and R&D players in

 Germany in 2013 (Lutkenhorst, 2014)

PV manufacturers	46	
(silicon, wafer, cells modules)		
PV module materials	61	
(glass, frames, junction boxes, etc.)	01	
PV system components (inverters, cables, connectors)	53	
PV equipment suppliers (silicon equipment, thermal equipment, wet		
chemistry, coating, stringers, thin film, automation, laser processing,	94	
etc.)		
PV mounting and tracking systems	63	
Sub-total: Business players	317	
Specialized R&D institutions	73	
Total value chain	390	

In 2012 alone, 19 German companies in the solar PV sector left the market, either due to genuine insolvency, strategic decisions or takeover by competitors. Specifically, this included two companies in wafer production, three cell manufacturers and one module manufacturer, six producers of silicon thin film, five producers of CIS modules and two companies producing inverters. Only a few companies, such as Wacker Chemie AG, Joint Solar Silicon, PV Crystallox, the latter in serious economic turmoil, are engaged in the capital-intensive upstream production and processing of silicon. Wacker AG is the dominant player and has in recent years expanded its production capacity significantly.

Most German companies are active in solar cell production, a market segment that has in recent years come under intense pressure from imported cells, above all from Chinese companies entering the high-volume German market. Competition is fierce, profit margins have become exceedingly low and a mature technology leaves only limited space for quality as a selling proposition. Furthermore, in this segment there are no distinct advantages of proximity to end users.

A number of companies, such as Bosch Solar Energy, Schott Solar, Conergy, Solar World and Sovello, are/were fully vertically integrated across the manufacture of wafers, cells and modules. In principle, this allows both for internal cross-subsidization of different lines of production and for a positioning as a supplier of system solutions with a high advisory and service content. However, survival has become difficult in this market segment as well. Sovello is being closed down, Solar World is heavily in debt and faces an uncertain future and Schott Solar, with glass manufacturing as a core business, is withdrawing from crystalline silicon manufacturing while staying in the thin film business. As recently as July 2013, Conergy had to file for bankruptcy and was looking for new investors. With regard to solar PV equipment manufacturers, such as cell coating, module stringers or automation, many companies originate from, and still serve, other industrial sectors, such as automotive or medical and are applying their core expertise now also to solar PV production.

Finally, there is increasing potential for German firms in the field of installation systems and services. This is an area with significant customer proximity advantages. However, with module prices coming down fast, the relative share of installation costs is bound to rise and will be subject to intense price reduction pressure in the future.

8.4 Legislative issues and investment drawbacks

The German PV market has undergone a dynamic development in the last years and will establish itself as a key pillar of the German energy supply (German Solar Industry Association, 2011). At the end of 2009, the cumulative installed PV capacity in Germany was 9.8 GW; at the end of 2010, it was approximately 17 GW. In its National Action Plan for Renewable Energy Sources of August 2010, the Federal Government states that the level of installed PV capacity will reach approximately 52 GW by 2020. This means that photovoltaics will cover 10% of the annual gross electricity demand by 2020, while the German industry has established an expansion of between 52 and 70 GW of PV capacity as an ideal target corridor in terms of economics and energy economics.

The legal-administrative hurdles for the project development and installation of PV systems in Germany and the complexity of the planning processes are still relatively low in comparison with other European countries. This particularly applies to rooftop PV systems, the realisation of which does not, in the majority of cases, require an application for administrative permission. For ground-mounted PV systems, the processes have proven to be more difficult and wearisome. This chapter demonstrates the difficulties that exist at Federal level and how these can be overcome. Additional difficulties in connection with the planning and approval of PV systems arise due to state, regional and local regulations.

To begin with, the Forum Grid Technology/Grid Operation (FNN) is responsible for the definition of technical standards for grid safety as well as the connection and operation of energy-generating installations within the Association of Electrical, Electronic and Information Technologies (Verband der Elektrotechnik, Elektronik und Informationstechnik, VDE). For historical reasons, it is above all the grid operators who have joined forces in the FNN, whilst the renewable energy industry (RES industry) is, on the other hand, underrepresented. In addition, the cooperation between the FNN and the RES associations is insufficient. Due to the legal uncertainties and the FNN's controversial way of working, the value of the FNN-standards as recognized rules of technology is in part disputed and/or criticized by planners, installers and operators.

Moreover, the immediate connection of a PV system to the power grid is not always guaranteed to an adequate extent in day-to-day practice and this can cause a decisive delay in the realization of PV installations. Due to the unclear definition of the allocation of the grid connection point in the EEG, grid operators also try to off-load in part inappropriate fees to the operators of PV systems. In order to unify the grid connection process and to make it more transparent, it is therefore urgently necessary to define in the EEG a legal entitlement of the system operators to a connection study, resulting in the awarding of a grid connection

point. The individual steps that are implemented in the context of an orderly connection study must be defined and anchored in the EEG. It must also be regulated by law that the system operator should receive all the information that is necessary for the allocation of the grid connection point and to be able to verify the financial consequences of this allocation. Furthermore, the EEG must contain a list of the minimum information that must be supplied within the framework of the entitlement to information. The introduction of a statutory deadline for the realization of the connection study within six weeks of the filling of an application is also an urgent requirement. The deadline for the disclosure of the grid data should, in its turn, be halved, from eight to four weeks. In order to make the connection study more uniform and transparent, the possibility of raising fees for the implementation of the connection study should be regulated by the EEG. The amount of the fees should be regulated by the Federal Network Agency (Bundesnetzagentur).

The systematic adjustment of the distribution networks to the increasing share of renewable energy in the generation of power is unsatisfactory. In the future, this may lead to considerable problems, with regard to the integration of renewable energy into the grid and already today represents, in part, an obstacle to the further expansion of photovoltaics. In order that the necessary adjustment of the distribution networks should indeed take place, it is a matter of some urgency that the Federal Network Agency should assess the costs that can be expected for the expansion of the grids in the future in order to achieve transparency, pertaining to the necessary investments and their reallocation. Furthermore, grid operators should develop regional grid concepts that take the expansion scenarios for renewable energy sources into account.

The mid to long range costs of grid modification that come about through the growing share of RES in the energy mix must be systematically recognized by the Federal Network Agency within the framework of defining the upper limits on prices and revenues. It is also necessary that the concept of the economical reasonableness of the expansion of the grid should be clarified in the EEG as quickly as possible. To this end, a catalogue of criteria should be introduced in the Act, which the grid operators are required to take into account when assessing economic reasonableness.

Furthermore, in the EEG, the definition of the open fields eligible for EEG remuneration for PV systems is, in part, unclear. It is therefore not always easy to judge whether the prerequisites for remuneration are fulfilled, which creates uncertainty among investors. There is also the problem that there are some areas of land which do qualify for remuneration, but upon which is not possible to erect ground-mounted PV systems for practical or building regulation reasons, even though they are actually intended for that purpose in the EEG. This makes an unambiguous definition of the areas eligible for remuneration in paragraph 32 of EEG, necessary in order to create clarity and legal certainty for project developers. For those cases which cannot be definitively settled legally, criteria must be created in the EEG on the basis of which the eligibility of the land for remuneration can be proven to the grid operator. The building regulations must also be adapted in such a way, that those areas that are eligible for EEG remuneration can indeed have ground-mounted PV systems built upon them.

Moreover, as there is no legal definition of exactly when the prerequisites for the technical operational readiness of a PV system are given, it is unclear from a legal point of view, when the technical operational readiness of an installation has been effected and when its commissioning has taken place. The time of commission is of the greatest significance for the operators of the systems, because it determines the amount of the feed-in remuneration under the EEG. In order to remove all doubt concerning this point, it should be clarified as soon as possible when the commissioning of a PV system has taken place.

Also, many municipalities refuse to allow the settlement of ground-mounted PV systems with, in part, the argument that the situation regarding the trade tax revenue is unclear and they do not have any economic advantages from granting a permit. The "location municipalities", upon whose land a ground-mounted PV system is to be built, do not, as a rule, have any legal entitlement to a share of the trade tax. These are rather dependent upon the good-will of the "residence municipalities", where the project development company is located, to arrive at voluntary agreements pertaining to a splitting of the tax benefits. In order to increase the municipalities' support for the settlement of RES projects on their land, the allocation criterion that was introduced for wind energy in the annual tax law of 2009 must be extended to include all RES. In this way, 70% of the trade tax would be received by the location municipality and 30% by the residence municipality, which would considerably increase the acceptance of ground-mounted PV systems among the municipalities.

The erection of PV rooftop systems in residential areas is not unproblematic, as in such areas, if the installations are used commercially, a license or exemption is required from the responsible building authority. Most of the time, however, no such authorization or exemption is applied for, so that PV systems violate the prescriptions of the Building Code. Furthermore, it is not clearly defined which PV systems must be registered as a trade. Numerous PV systems are not registered as a trade, even though registration would have been necessary. PV systems not registered as a trade and not in possession of a license or an exemption from building authorities thus violate, in part, both the trade law and the Building Code. In order to guarantee legal certainty for PV installations, there must be a legally binding definition as to when PV systems have to be registered as a trade.

Taking a step further, digression creates planning uncertainty (Fulton, 2012). The time required to complete PV projects in Germany has decreased markedly as the markets have grown and the supply chain has become more efficient. Residential systems, for example, can take around 6 weeks to complete, but there have been reports of systems that have been fully installed and interconnected in as little as 8-10 days. As a result, the monthly digression schedule may not create as much uncertainty for project developers in Germany as in other countries, where development timelines are significantly longer. The fact that the digression level stays the same for three months can also give developers a degree of transparency. Nevertheless, the fact that the digression rate changes every three months will decrease TLC for developers that operate with longer planning horizons, such as those building larger projects or those attempting to develop a pipeline of projects over multiple years.
Also, the 90% limit creates an incentive for generators to consume their output onsite. The amount of generation that can be consumed, however, and the rate at which the generation will be credited are uncertain. First, the amount of onsite load may not be sufficient to absorb the output from the PV system and/or may not be well-matched to PV production. Buildings that shut down on weekends, for example, may not be able to consume weekend PV output. Similarly, buildings without tenants may not be able to offset onsite load. Second, onsite consumption is credited at the retail electricity rate. This rate can change, however, with changes in electricity prices, changes in taxes or surcharges and changes in the host site's rate class. A related consideration is that the "off-taker" for onsite consumption of PV electricity is the host site, which is likely less creditworthy than a long-term off-take agreement from a utility under the FiT. Finally, onsite consumption generates savings for the system host, but not revenue from power sales. Investors must be comfortable that the end user can and will use the savings from the PV system to pay back the investments over the long-term, since a bank cannot take over the operation of a PV system and get revenue from it should the system owner go bankrupt. These factors contribute to a reduction in TLC compared to being able to sell 100% of PV generation under the FiT and may make projects more difficult to finance.

Finally, the 52 GW threshold reduces longevity and transparency. The 52 GW threshold introduces a limitation of policy longevity and also decreases transparency in the mid-term, since it is not clear when the threshold will be reached, e.g. 2014/15 versus 2020/21. More importantly, it is also not clear what policy options may or may not be on the table once the threshold is crossed.

8.7 Conclusions

The German FiT scheme has been characterized by a long contract period (20 years), guaranteed grid priority, technology-specific tariffs on a degressive scale coupled with a direct selling option (market premium) and recently, provisions for tariff evolution in response to deployment trends (the "flexible ceiling"). These design elements have created a stable investment environment and hence a strong readiness of capital markets to finance renewable energy projects at relatively low interest rates. Furthermore, the technology specificity—with differing FiT subsidy bands for each source of renewable energy—has had the advantage of encouraging the early deployment and upscaling of a wide spectrum of technologies. On the downside, it has not allowed for a focus on the most cost-efficient decarbonization technologies. A premium was thus placed deliberately on creating a broad foundation for various renewable energy technologies to develop and become commercially viable. However, this premium seems to have led to a bubble in the German solar PV manufacturing industry. Obviously, the critical challenge is to identify a sufficiently high incentive (subsidy) level for investments to be triggered without creating excessively high rents in terms of windfall profits. This presupposes correct assumptions about future technological learning curves and price trends as a basis for making well-informed decisions about an optimal tariff degression scale. The assumptions in the case of solar PV did not correspond with the considerable cost reductions of PV installations since 2009.

9. Comparative analysis of the case studies

In Chapters 6,7 and 8 the support policy instruments and the surrounding regulatory environment for the promotion of PV energy in Greece, Spain and Germany, respectively, have been presented. The aim of this Chapter is, building on the information provided so far, to evaluate the performance of the FiT scheme.

Concerning the evaluation criteria, they cannot be treated in a uniform way, as they may vary depending on the applied instrument, the country under examination or the technology. The main difficulty is the fact that common criteria such as effectiveness and efficiency cannot be defined on a single manner and they often have multi-layer descriptions. Based on the available literature in the field of RES support schemes two main characteristics are distinguished: first, the viewpoint of the evaluation determines in a large degree the choice of the criteria; and secondly, the nature of the criteria can either be qualitative or quantitative, with the goal to provide a credible and trustworthy assessment. The most widely applied criteria, according to the literature, are effectiveness, cost-effectiveness, dynamic efficiency and certainty. These are the criteria that will be used for the performance evaluation of the policy in the three countries chosen.

9.1 Performance evaluation of the policy

9.1.1 Effectiveness

The most commonly used criterion for the evaluation of a policy scheme in the literature is effectiveness. Effectiveness is described as the extent to which a policy instrument contributes on achieving the targets or objectives set (Van Dijk, 2003) or as the actual increase in the amount of RE generated (Mitchell, 2011) or the additional capacity of RES within a specified period (Verbruggen A. &., 2012). However, these definitions cannot be used in the case of a cross-national comparison, due to differences in the goals of each country, the decomposition of them on a local level and among separate RET. Taking these factors into account, a different definition can be provided as the RES-E production in a period as the result of the support scheme related to the available potential up to a specified year in the future (Held, 2006). This is the definition that will be used for describing the effectiveness of the policy in Greece, Spain and Germany for the period 2007-2012, as in 2012 the solar PV support policy was suspended in Spain.

<u>Greece</u>

Figure 43 illustrates the effectiveness of the FiT policy for solar PV in Greece, while Table 42 shows the data used for the calculations. The data concerning the annual RES-E production are those already presented in Chapter 6 concerning the solar PV market in Greece.

Year	Annual RES-E production (MWp)	Annual RES-E production (MWh)	Annual RES-E production (TWh)	Annual available potential (kWh)	Annual available potential (TWh)	Effectiveness
2007	2	3613,5	0,0036135	1,97936E+14	197935,5	1,82559E-06
2008	12	21681	0,021681	1,97936E+14	197935,5	1,09536E-05
2009	47	84917,25	0,08491725	1,97936E+14	197935,5	4,29015E-05
2010	199	359543,25	0,35954325	1,97936E+14	197935,5	0,000181647
2011	624	1127412	1,127412	1,97936E+14	197935,5	0,000569586
2012	1536	2775168	2,775168	1,97936E+14	197935,5	0,001402057

 Table 42 Data used in the calculation of the effectiveness of the FiT policy in Greece.



Figure 43 Effectiveness of FiT policy for solar PV support in Greece (own elaboration)

Two periods can be distinguished in Figure 43; one before and one after 2010. In the first period, before 2010, the calculated effectiveness is quite low. This is mainly due to the fact that the first FiT law (Law 3486/2006) provided very appealing tariffs, thus causing an immediate response of the market with more than 7.940 applications and resulting in a postponement of any further submission of applications to the Regulatory Authority of Energy. All this delay in the licensing procedures caused a very slow increase in the effectiveness of the policy.

In the second period, after 2010, Law 3851/2010 was enacted with the facilitation of the authorization procedures and the provision of priority for older applications over new ones being its main goals. Priority was also granted to professional farmers, who were allowed to apply for grid connection offers of new PV stations of up to 100 kWp, while the residential BAPV systems below 10 kWp gained the ultimate priority. Moreover, residential systems

could be installed in all regions, unlike in previous regulations according to which the autonomous island grids were excluded. Finally, the construction of licensing became more direct and short-term, with lesser justifications needed and the planning terms for PV on buildings and fields were also reconsidered, facilitating effective design and installation works. The result of these changes was a sharp increase in the effectiveness of the policy.

In the years after 2012, which are not shown in Figure 43, the effectiveness of the policy kept increasing, however with a slower rate. Summing up, it can be concluded that the FiT policy implemented in Greece can be characterised as successful, as the installed capacity of solar PV in the country kept increasing under the implemented policy, despite the reduced tariffs provided by the government. Of course, part of this increase is also due to the high solar potential of the country; however this does not make the policy less successful. Finally, the effectiveness of the policy could have been even higher if the licensing procedures were less complex and time-consuming, thus allowing the solar PV capacity to be installed in shorter periods of time.

<u>Spain</u>

Figure 44 illustrates the effectiveness of the FiT policy for solar PV in Greece, while Table 43 shows the data used for the calculations. The data concerning the annual RES-E production are those already presented in Chapter 7 concerning the solar PV market in Spain.

Year	Annual RES-E production (MWp)	Annual RES-E production (MWh)	Annual RES-E production (TWh)	Annual available potential (kWh)	Annual available potential (TWh)	Effectiveness
2007	693	1239431	1,2394305	6,5003E+14	650030,1733	0,000190673
2008	3354	5998629	5,998629	6,5003E+14	650030,1733	0,000922823
2009	3438	6148863	6,148863	6,5003E+14	650030,1733	0,000945935
2010	3915	7001978	7,0019775	6,5003E+14	650030,1733	0,001077177
2011	4260	7619010	7,61901	6,5003E+14	650030,1733	0,001172101
2012	5221	9337759	9,3377585	6,5003E+14	650030,1733	0,001436512

Table 43 Data used in the calculation of the effectiveness of the FiT policy in Spain



Figure 44 Effectiveness of FiT policy for solar PV support in Spain (own elaboration)

In the case of Spain, three periods can be distinguished in the evolution of the effectiveness of the FiT support policy for solar PV implemented in the country. Before 2007 and the enforcement of Royal Decree 661/2007 the amount of installations per year was very modest. Already in 2007, right after the Royal Decree 661/2007 was enacted, the installations increased by 5 times and until 2008 by 26 times compared to the levels of 2006 (not shown in the graph), showing an astonishing increase of the effectiveness of the policy. The second period is that between 2008 and 2009, which is shown almost as a plateau in figure 44. During this period, the annual installed capacity dropped dramatically to zero. The third period is that between 2009 and 2012, during which the installed capacity returned to relatively modest levels until 2012, when the policy was suspended by the Royal Decree 1/2012.

Summing up, the FiT policy for the support of solar PV in Spain can be characterised as successful when using the criterion of effectiveness. Despite the plateau shown in Figure 44 during the period 2008-2009, for the rest of the period the effectiveness of the policy is increasing and especially in the first period, this increase is remarkable. Of course it can be argued that the increase in the effectiveness of the policy is a result of the increased installed capacity of solar PV while the potential remains the same, thus causing a higher value of effectiveness. However, the values occurring cannot be justified solely by this argument. Moreover, the policy could have yield better effectiveness if the compensation was not such generous for certain solar PV systems, thus enabling the investors to take advantage of the high rates and make profit by aggregating small-sized plants close together rather than building one large plant.

<u>Germany</u>

Figure 45 illustrates the effectiveness of the FiT policy for solar PV in Greece, while Table 44Table 43 shows the data used for the calculations. The data concerning the annual RES-E

production are those already presented in Chapter 8 concerning the solar PV market in Germany.

Year	Annual RES-E production (MW)	Annual RES-E production (MWh)	Annual RES-E production (TWh)	Annual available potential (kWh)	Annual available potential (TWh)	Effectiveness
2007	4200	5365500	5,3655	4,58843E+14	458843,0146	0,001169354
2008	6200	7920500	7,9205	4,58843E+14	458843,0146	0,00172619
2009	10700	13669250	13,66925	4,58843E+14	458843,0146	0,002979069
2010	17700	22611750	22,61175	4,58843E+14	458843,0146	0,004927993
2011	25200	32193000	32,193	4,58843E+14	458843,0146	0,007016125
2012	32800	41902000	41,902	4,58843E+14	458843,0146	0,009132099

Table 44 Data used ir	the calculation	of the effectiveness	of the FiT	policy	in Spain
			0	p = = j	



Figure 45 Effectiveness of FiT policy for solar PV support in Spain (own elaboration)

With almost the same legislative framework since the initial implementation of the FiT policy for solar PV, Germany seems to have the smoother evolution of effectiveness of the three countries studied over the examined period. A modest increase of effectiveness was the result of the initial form of the Erneuerbare-Energien-Gesetz and was followed by a rapid increase in solar deployment after 2008 and the introduction of the "corridor system". Furthermore, the use of the degression rate enabled the continuous growth of the installed solar PV capacity in the country, avoiding the formation of extreme cases, unlike the cases of Greece and Spain. The success of the FiT policy is further supported by the fact that by the end of 2012, more than 32 GW of solar PV capacity had been installed in the country.

Summing up, the FiT support policy for solar PV in Germany can be described as the most successful FiT policy not only among the cases studied in this Thesis but also in general. No formation of extremes or plateaus, but a steady increase of the installed capacity led to a

steady rate of increase of the effectiveness of the policy, made Germany Europe's strongest PV market.

9.2.2 Efficiency

Efficiency can be broadly defined as the ratio of output to input. In the case of RES, it can be defined as the ratio of the renewable energy targets achieved over the economic sources spent (Mitchell, 2011). In the majority of existing evaluations, the efficiency of the various support instruments is examined based on the cost-effectiveness or static efficiency of the instruments. However, apart from its static part, efficiency also has a dynamic part, which adds a time dimension to the criterion of efficiency by including the extent to which technology development and innovation are triggered by the instrument.

Static efficiency

In order to examine the static efficiency of the FiT policy, it will be expressed in terms of how tuned the support level was with the evolution of the technology costs. As a result, the FiT level will be compared to the solar PV generation cost. Next, the criterion of static efficiency will be applied to the three countries.

<u>Greece</u>

Based on the literature and the information provided in Chapter 6, it can be concluded that in the case of Greece, the support level did not follow the downward trend of investment costs for solar PV systems. This might have been translated into generous returns for the investors; however, the cost burdened on the consumers through the electricity bill was significantly higher. Despite the reductions in the investment costs taking place through the years, the tariffs remained almost unchanged and hardly reduced from their 2006 levels. It was not until 2010 and Law 3851/2010 that for the first time, degression tariffs were incorporated in the support scheme and a response to the reduced installation costs took place. Although the FiT policy of Greece has been proved successful in terms of effectiveness, this success could have taken place under a lower social cost, if the FiT values were constantly tuned to incorporate possible reductions of the investment costs.

<u>Spain</u>

According to the literature and the information provided in Chapter 7, it can be concluded that in the case of Spain, just like in the case of Greece, the support level did not follow the downward trend of investment costs for solar PV systems. Despite the many changes that took place concerning the regulatory framework for solar PV support through FiT, none of the Royal Decrees applied included a realistic degression option for reducing the support in line with the changing costs of the solar PV projects. As a result, the FiT policy of Spain in terms of static efficiency cannot be described as successful as that in terms of effectiveness, as the inclusion of constant tuning of the FiT values in the policy, in order to incorporate possible reductions in the investment costs might have prevented the uncontrollable

increase of the FiT cost for the government and thus, the suspension of the FiT policy as a whole.

<u>Germany</u>

As it has already been mentioned in Chapter 8, since its inception, the EEG contained a design feature known as "degression", according to which the tariff rates were set to be reduced by a pre-determined amount every year. Moreover, in order to adjust to the decreased prices of PV modules, which fell by around 40% in 2009 alone and continued falling in the following years, some non-scheduled adjustments were introduced concerning ad hoc changes to the degression rates. Furthermore, in the middle of 2012 it was decided that the monthly degression rates would be adjusted every three months. Based on the above, it can be concluded that as in the case of the effectiveness criterion, in terms of static efficiency also, the FiT support policy for solar PV in Germany can be described as successful, with no further comments on this.

Dynamic efficiency

Dynamic efficiency is evaluated in terms of how successful the support instrument has been in stimulating technological progress and cost reductions for the examined technology.

Technological progress

Greece

The effective promotion of solar PV energy in Greece resulted in an increased diffusion of the technology over the years and had a significant influence on the PV industry of the country. Since 2006, the Greek PV industry has been steadily developed, with a number of companies specialized in the field of solar PV systems, including the areas from research up to modules and frame building being active in the country (HELAPCO, 2015). In 2010, 51 MW of solar PV modules were produced in Greece, 32 MW of which were utilised in domestic installations, corresponding to 29% of the added capacity of that year, while the rest 19 MW were exported to several European countries. In 2011, 68 MW of solar PV modules were produced, with 10 MW of them being exported, due to the high demand in the domestic market.

Another industry, however not directly related to but still an important part of a solar PV system, which was influenced by the rapid deployment of solar PV in the country was that of aluminium and steel. This was due to the fact that aluminium and steel structures expanded their activities in the field of the construction of PV mounting systems, both fixed and movable.

<u>Spain</u>

The Spanish photovoltaic sector, as has already been discussed in Chapter 7, includes companies that exploit all the chain value of the industry, from manufacturing cells to promotion of farms, inside and outside the borders of the country. Their strength can be

supported by the fact that several companies which are dedicated exclusively to this activity have entered the stock market.

<u>Germany</u>

The story of the solar PV industry in Germany has been one of a spectacular rise, followed by a crash in parts of the sector, within just one decade (Lutkenhorst, 2014). From negligible capacity and production levels in 2000, with a newly installed physical capacity of 45 MWp and solar PV power generation of 64 million kWh, and initially modest growth rates, the industry recorded two-digit and at times even three-digit growth rates between 2004 and 2010, when installed capacity growth started to stagnate and reached a plateau of approximately 7500 MWp annually, which, up to 2012, made Germany the largest solar PV producer in the world. Within the broader EU context, Germany currently accounts for about half of the entire solar PV capacity and exhibits a PV per capita ratio of 400, measured in terms of Wp per inhabitant; this is four times higher than Spain and three times higher than the EU average. Over time, the average size of installed PV solar systems has increased significantly. Back in 2000, more than 60% of PV systems installed were operating at a capacity below 10 kWp and only slightly more than 10% at more than 100 kWp. A decade later, the situation had reversed: only 10% of systems installed in 2011 were below 10 kWp, yet more than 50% above 100 kWp.

Moreover, Germany is Europe's leading manufacturer of PV modules and components (Germany Trade and Invest, 2014). Hi-tech PV technologies such as wafer-based, thin-film and organic PV, as well as new, innovative inverter and energy storage technologies are developed, produced and made commercially available in Germany. Leading global PV players, innovative small- and medium-sized enterprises (SMEs), renowned research institutes and equipment and material suppliers help for the most innovative and holistic PV and PV battery industry clusters in the world. Germany is home to more than 40 manufacturers of silicon, wafers, cells and modules. As well as this, there are more than 100 PV material and equipment suppliers, over 100 balance-of-system (BOS) component manufacturers and more than 70 PV research institutes as well as thousands of project development, system integration and installation companies.

However, the rapid rise of the German solar PV industry under favorable market conditions has created a highly diversified sector with significant industrial capabilities and capacities in practically all segments of the value chain, although it is not exhaustive and does not fully reflect some very recent cases of company bankruptcies and there are also minor inconsistencies in the classification, as some vertically integrated companies are active in several value chain segments. In general, the German solar PV industry is facing tough conditions with fierce competition from low-cost Asian (mainly Chinese) suppliers. Market turbulence has increased and already a large number of companies, among them Q-Cells, once the global leader in solar cell production, Solon, Solar Millennium, Solar, Solarhybrid and Odersun, have gone bankrupt. At the same time, several industrial players with core expertise outside the solar industry are abandoning their solar PV operations: in March 2013, Bosch announced the discontinuation of its PV ingot, wafer and cell production and

the sale of all its solar business units; Siemens is closing down its solar division after having entered the solar business only in 2009 with great expectations and WürthSolar, after a thorough evaluation, completely exited from its solar PV production in May 2013. Of course, this cannot be blamed on the FiT policy, however, it is an important aspect that should been taken into consideration in this discussion.

Cost reductions

Technological development and mass production of PV solar cells have resulted into a significant decrease of prices over the last 20 years. More specifically, PV modules in Europe have experienced a 20% learning factor, leading to an average price of $1.2 \notin W$ in 2011, which is almost 70% lower than the average price a decade earlier (EPIA, 2011).

As it has already been mentioned in Chapter 4, the module price reflects 45-60% of the total system price, thus being most significant part of the total investment cost. As a result, a decrease on the module prices is followed by a decrease in the total investment cost of the whole PV project. The evolution of the prices of solar PV systems in Europe indicates a decline of the investment costs over the period 2000-2010.

<u>Greece</u>

The trends in the investment cost per PV installed capacity in Greece are similar to those noted in the rest of Europe; however the decline rates might be different due to certain characteristics of the country. From an initial value of 5500 €/installed kW in 2006, costs for solar PV in Greece were reduced by almost 50% in 2011, falling in 2600 €/installed kW and they continued to decline until 2013, when the price corresponded to only 20% of the initial cost (HELAPCO, 2015).

However, the extent to which the abovementioned reductions in the investment cost of solar PV are a result of the high effectiveness of the Greek FiT system is not clear, as additional factors may be involved.

<u>Spain</u>

As in the case of Greece, the trends in the investment cost per PV installed capacity in Spain are similar to those noted in the rest of Europe and a little lower, as the country consists one of the leading manufacturers of the field. However, in this case too, the extent to which the reductions in the investment cost of solar PV are a result of the high effectiveness of the FiT system of the country is not clear, as additional factors may be involved.

<u>Germany</u>

In the case of Germany as well, a similar pattern as in the previous two cases is followed. However, in the case of Germany, the premium that was placed in order to create a broad foundation for RET for them to develop and become commercially viable seems to have led the German solar PV manufacturing industry into a bubble, as solar PV equipment produced in China has conquered a big part of the European market, thus forcing the investment cost per PV installed capacity to be further reduced in order to be able to compete. As a result, the reduction in the investment cost of solar PV is not directly a result of the effectiveness of the FiT system of the country.

To conclude, examining the dynamic efficiency of a support instrument using empirical data is not an easy task, as it involves a certain degree of risk to unambiguously ascribe any technological progress and cost reductions on a national level to a support scheme, as it might be, at a certain extent, the result of technological spillover effects of other countries (Del Río, 2007). The Greek support scheme proved to be quite effective in fostering technological development. The increased diffusion of PV energy enabled Greek companies to establish in the sector and obtain a dynamic presence in both national and international level. Moreover, an 80% reduction in the total investment cost was achieved in the period 2006 – 2013. A similar pattern was followed by the Spanish and German support schemes, with the difference that the Spanish and German companies of the sector not only have a dynamic presence, but they are actually two of the strongest players in the solar PV equipment manufacture. However, it is not clear to which extent this is caused by the FiT scheme adopted by these countries or by their extended industry.

9.2.3 Certainty for the investors

A major factor for the success of a support instrument is the certainty that it provides to investors and producers (Van Dijk, 2003). Mitigating the risks for investors makes investments more attractive, thus leading to increased number of projects. As a result, it can be argued that certainty encourages the deployment of RES and increases the efficiency of the support instruments, thus reducing deployment costs. Two sources of uncertainty exist: market risks, where the fluctuation of the support level is the major concern and political risks, which are related to the financial support that may or may not be provided.

Market risks

Greece

Initially, the first law (Law 3468/2006) did not specify the interval within which the tariff would remain fixed, but noted that the basic tariffs can be unexpectedly modified by means of a Ministerial decree taking into consideration the international evolution of PV technology costs and the support level considered to be adequate, under oncoming circumstances. This was rather extraordinary, because tariff options are generally adjusted on an annual basis in the most successful FiT systems, mainly in accordance with market predictions for the following years. Additionally, the guaranteed period for fixed tariff of only up to 10 years, whereas an extension for the sale contract for another 10 years would be carried out at a rate to be determined, as well as questionable terms associated with the obligations on behalf of the TSO and DSO (PPC), the access to the grid, discouraged investors from getting interested in PVs, at least in the early beginnings of FiT scheme's implementation. Nevertheless, the Development Law's subsidies of up to 40% of required capital compensated to an extent for these drawbacks and attracted many investors, though, in some occasions, without serious financial capabilities. This led, as mentioned above, to

thousands of PV applications submitted to RAE for license approval. However, the low ability of the majority of applicants to support realistically a PV investment, led to the recorded postponement of the submitting procedures on behalf of RAE in 2008. Additional risks for the investors were also implied on the grounds that in Law 3468/2006 there were no technical and legal specified conditions related to the priority over conventional resources considering the grid connection. Moreover, a two years' absence of land-planning map of Greece for RES caused, also, tremendous discrepancies among local public authorities, regarding the land-using siting suitability for PV stations, although some of them were already applied for license approval in RAE.

Similar issues occurred due to the lack of construction regulations for PVs, at least for 3 years. Eventually, PV stations' licensing became a complex task when it came to the construction permits or to the approval of environmental conditions. For instance, a larger-scale PV plant of more than 150 kWp required the permissions from 32 public-sector entities on a central, regional, prefectural and local level. Thus, a licensing procedure could exceed in practice 24 months, whereas in theory, and according to the legislation's time limits, the procedures should be conducted prior to 9 months. Law 3468/2006 was criticized for its complexity considering building systems. PV investors, even if they were private owners, were fiscally considered as enterprises, and had therefore to submit periodically value added tax declarations, whilst the revenues from solar electricity were taxed as a regular income, meaning in the order of 25-40%. This led practically to zero residential systems' installations until 2010.Overall, within Law 3468/2006, only 1% of the initial PV applications was put in operation, a 60% was licensed by RAE in due time, whereas the remaining 39% was not examined at all.

The second FiT law (Law 3734/2009) aimed at confronting all above barriers, by improving FiT terms, such as the guaranteed period and its adaptation on the future PV costs as well as the recorded annual diffusion of PVs in the electricity supply mix. In that sense, for example, the tariff's abatement for new PV investors was verified in a degree as long as the PV costs were reduced steadily since 2006, owing to the rapidly international growing capacity of making silicon crystals. Ultimately, Law 334/2009 did not permit transactions of production licenses or approvals prior to the grid-connection of a PV station. This term aimed at mitigating this tendency caused by the unexpectedly long-term assessments of PV applications of behalf of RAE and other component authorities since 2006. This led also to the deterioration of hundreds business plans of PV investors, who, eventually, lost their interest in this kind of investment. In particular, the trading of licenses was one of the most determinant factors of the weak development of PV market until then. Nevertheless, 2009 was one of the first years of an actually recorded diffusion of PVs, on the one hand due to the efficient definition of construction and siting regulations and on the other hand, due to the predicted decrease in tariff, which forced the investors to accelerate the completion of their PV projects.

<u>Spain</u>

In 2007 and 2008, Spain experienced an unprecedented boom in the deployment of solar PV modules, due in large part to a generous FiT (del Rio P. a.-A., 2014). This was followed by a

spectacular bust, as the government stepped in to reduce the unsustainable costs of the FiT. Eventually, policy changes that were considered retroactive were made, angering investors and becoming the focus of much analysis and criticism among the international policy community. The principle objective of the FiT was to increase the deployment of solar PV. In the short term, this was indeed achieved. But failing to control costs ultimately damaged the future prospects of ratepayer-funded solar PV deployment in Spain and damaged the country's small domestic industry.

<u>Germany</u>

In the EEG, the definition of the open fields eligible for EEG remuneration for PV systems is, in part, unclear (German Solar Industry Association, 2011). It is therefore not always easy to judge whether the prerequisites for remuneration are fulfilled, which creates uncertainty among investors. There is also the problem that there are some areas of land which do qualify for remuneration, but upon which is not possible to erect ground-mounted PV systems for practical or building regulation reasons, even though they are actually intended for that purpose in the EEG. This makes an unambiguous definition of the areas eligible for remuneration in paragraph 32 of EEG, necessary in order to create clarity and legal certainty for project developers.

Taking a step further, digression creates planning uncertainty (Fulton, 2012). The time required to complete PV projects in Germany has decreased markedly as the markets have grown and the supply chain has become more efficient. Residential systems, for example, can take around 6 weeks to complete, but there have been reports of systems that have been fully installed and interconnected in as little as 8-10 days. As a result, the monthly digression schedule may not create as much uncertainty for project developers in Germany as in other countries, where development timelines are significantly longer. The fact that the digression level stays the same for three months can also give developers a degree of transparency. Nevertheless, the fact that the digression rate changes every three months will decrease TLC for developers that operate with longer planning horizons, such as those building larger projects or those attempting to develop a pipeline of projects over multiple years.

Also, the 90% limit creates an incentive for generators to consume their output onsite. The amount of generation that can be consumed, however, and the rate at which the generation will be credited are uncertain. First, the amount of onsite load may not be sufficient to absorb the output from the PV system and/or may not be well-matched to PV production. Buildings that shut down on weekends, for example, may not be able to consume weekend PV output. Similarly, buildings without tenants may not be able to offset onsite load. Second, onsite consumption is credited at the retail electricity rate. This rate can change, however, with changes in electricity prices, changes in taxes or surcharges and changes in the host site's rate class. A related consideration is that the "off-taker" for onsite consumption of PV electricity is the host site, which is likely less creditworthy than a long-term off-take agreement from a utility under the FiT. Finally, onsite consumption generates savings for the system host, but not revenue from power sales. Investors must be comfortable that the end user can and will use the savings from the PV system to pay back the investments over the

long-term, since a bank cannot take over the operation of a PV system and get revenue from it should the system owner go bankrupt. These factors contribute to a reduction in TLC compared to being able to sell 100% of PV generation under the FiT and may make projects more difficult to finance.

Finally, the 52 GW threshold reduces longevity and transparency. The 52 GW threshold introduces a limitation of policy longevity and also decreases transparency in the mid-term, since it is not clear when the threshold will be reached, e.g. 2014/15 versus 2020/21. More importantly, it is also not clear what policy options may or may not be on the table once the threshold is crossed.

Political risks

<u>Greece</u>

The commitment that the Greek government has shown on the promotion of RES has been a positive aspect, in terms of political certainty. Since 2006, the support of PV energy has been a major priority in order to meet the obligations of the country for RES deployment, with the most characteristic example being the establishment of a deployment scheme only for solar PV energy in 2007. Furthermore, the low complexity of the system and the long duration of the support period offer a long-term stability. More specifically, according to Law 2773/1999 and Law 3468/2006, the guaranteed purchase period was set on 10 years, with the unilateral right for the producer to renew the agreement for another 10 years. With Law 3478/2009, the contract period was extended to 20 years, which is valid until today. Nevertheless, since the right existed to renew the contract after 10 years, the investor was offered a long-term security.

However, a factor that increased the political risks of the system was the large number of revisions since 2010. Despite the fact that a constant period for revision of the FiT prices is necessary in order to integrate the development of new capacity and technology costs in the tariffs, this happened only under Law 3851/2010. The revisions and degression that followed were not neither scheduled nor anticipated by the producers, thus creating an unstable market and high uncertainty regarding the support level.

<u>Spain</u>

The final outcome of the Spanish FiT policy was a lose-lose situation for almost all stakeholders. The electricity system was burdened with costly solar generation for years to come. The policy changes had implications for the ongoing viability of the industry, with solar PV developers feeling betrayed by the government's retroactive tariff changes. Numerous companies involved in solar PV manufacture either had to close or merge, and employment in this sector fell from a high of 41.700 reported jobs to fewer than 10.000 in 2012. Indeed, the repeated changes and amendments had wider implications for renewable energy as a whole, damaging investor confidence in the reliability of Spanish policy frameworks. And the performance of regulators and policy-makers was heavily criticized by industry associations, solar PV investors and environmental NGOs.

<u>Germany</u>

The importance for the degression rate of FiT in Germany has already been discussed and its importance for providing certainty for the investors has been emphasized. Another, equally important, characteristic of the degression rate system of Germany is that the degression rate is adapted to the market growth. If the growth of the PV market in a year is higher or lower than the defined growth corridor, the degression rate will be increased or decreased respectively by 1% for the next year and these rates are guaranteed for a period of 20 years. The result is the creation of certainty for the investors regarding the support level, since this is scheduled and guaranteed in advance and will not change.

Summing up, the Greek support scheme for solar PV can be described by a high degree of market and political certainty. The FiT system combined with a supplementary support scheme through investment subsidies has created a prosperous environment for investments. However, the latest revisions of the FiT values have induced a level of uncertainty which can be characterized as spontaneous reactions of the government in its efforts to face and resolve the complicated problem of the solar PV market of the country. Moreover, it can be concluded that the main source of uncertainty in the PV market results from the absence of legislation for a long term planning and the complex administrative procedures and not from the support scheme itself.

In the case of Spain, the situation is completely different. The Spanish support scheme for solar PV can be described by anything but a high degree of market and political certainty. The continuous reductions in the FiT levels, the retroactive changes and finally, the suspension of the FiT policy have destroyed the trust of the investors, causing a very high level of uncertainty in the PV market.

Finally, Germany, having probably the most complete and integrated FiT system in Europe, has managed through the design of the FiT scheme and the crucial changes when needed, however always scheduled, to establish a very high level of certainty for the investors. This certainty is further encouraged by the long-term energy planning of the country.

9.3 Conclusions

Based on the analysis of this Chapter, it can be concluded that the Greek solar PV support scheme was designed in order to attract investments and stimulate installed capacity, since the solar PV capacity in 2006 was negligible; in both of these aspects, successful results have been delivered. However, despite its effectiveness, the scheme was accompanied by a number of distortions caused in the PV market, mainly caused by the poor design of the policy and the shortcomings or late interventions on the broader regulatory framework.

Concerning the Spanish support scheme, this was designed mainly for diversifying the energy mix of the country and reduce the dependence of the country on fossil fuels. Although initially the policy was characterized by an impressing level of success, soon the

costs of the policy started getting out of control due to the poor design of the policy and the continuous changes and interventions on the regulatory framework. Inability of the government to regain control of the situation caused the suspension of the solar PV policy in the country, thus damaging investor confidence in the reliability of Spanish policy frameworks.

Finally, the case of Germany is the case of a country which managed to successfully implement a FiT policy for the support of solar PV. The careful and detailed design of the policy combined with minimum changes in the framework led to increased certainty for the investors, thus helping the rapid and successful deployment of the solar PV sector in the country.

What can be concluded from this analysis is that choosing the appropriate support scheme is not by itself enough and has to be accompanied by careful design steps and an appropriate implementation environment which will enable the support scheme to provide maximum results.

10. Conclusions – Recommendations

In Chapthers 6 to 9, the support policy schemes for solar PV in Greece, Spain and Germany have been presented and analyzed. It is the aim of this Chapter to present the conclusions of this Thesis and also make recommendations for future research with respect to this Thesis.

10.1 Conclusions

The conclusions are presented in a way that follows the structure of the Thesis, meaning that they are presented by answering the research sub-questions, which ultimately leads to answering the main research question.

What is the rationale for RES support policies?

A series of environmental and socio-economic benefits result from the use of RES, thus contributing to the formation of a sustainable energy sector. Lower emissions compared to fossil fuels, limited environmental damage and diversification and security of energy supply are only some of these benefits. Among the abovementioned environmental and socio-economic benefits, there are some certain characteristics which make RES a perfect fit into the scopes of the European energy policy and more specifically, to securing the energy supply and the establishment of competitive energy costs and prices, once the security in supply is achieved.

However, in their effort to enter the domestic electricity markets, renewable energies are facing two obstacles: firstly, due to their immaturity, it is very difficult for RETs to enter the market and directly compete with the mature fossil fuel technologies. Secondly, electricity wholesale prices do not take into account the cost of the pollution cost caused by the use of fossil fuels. As a result, they are not representative of the real cost of electricity production, thus eliminating the environmental benefits occurring from the use of RES instead of fossil fuels. These two obstacles, the stimulation of technological change and the environmental externalities, consist the two main rationales for supporting RES through public intervention.

This support, in the case of RES-E, includes financial or other forms of help which beneficiaries which meet certain criteria can receive for providing renewable power (Verbruggen, 2012). Support is provided to installed or actually available production capacity (kW) or generated electricity (kWh) and both can be qualified by RE source, technology, ownership or any other feature that can be measured and meet the terms of support. The costs of the support can be charged either to the public budget, with the risk of the latter running dry due to its dependence on political fortune, or to end-users of electricity through electricity suppliers, network companies or electricity generators.

Which are the different supporting measures for electricity production by solar PV systems in Europe?

Through a series of Directives, the EU has set a very ambitious goal concerning the share of RES in gross final consumption of energy of the EU Member States. However, due to the cost disadvantage of RES compared to fossil fuels, which is caused by the environmental externalities and technological immaturity of RES, a number of support policies needs to be set and undertaken by the Member States. The various policy schemes that have been applied in the EU can be classified in a number of categories, such as direct and indirect promotion strategies, regulatory and voluntary promotion strategies and price or quantity driven and investment or generation focused promotion strategies.

An overview of the primary and supplementary support mechanisms for RES-E which have been applied in the 27 EU Member States shows that price-control schemes, and especially FiTs, dominate among the policy support mechanisms (Kitzing et al., 2012). Not only they are implemented in most EU countries, but at the same time, they have the highest growth rate. TGCs have stopped being implemented in the EU countries after 2005, despite their initial "boom" in the early '00s, while for the already existing TGCs in the UK and Italy, an addition of FiT policies for small installation sizes has occurred. Moreover, EU countries have begun to apply multiple support policies at the same time, with Denmark being an indicative example by applying six different support policies. Again, however, combinations including FiTs and other major support schemes dominate, and especially combinations of FiTs and Tenders or also TGCs, like in Italy and the UK.

More specifically, for the case of solar PV support policies, the most popular support policies in Europe are the FIT system and the quota system regulation combined with a TGC market (Dusonchet and Telaretti, 2010a), while other support schemes frequently used as supplementary measures are capital subsidies, green tags, FiTs and net metering. The reasons of the preference of the EU countries towards the FiT support scheme lie on the fact that FiTs offer greater effectiveness compared to the rest of the support strategies, higher certainty to the investors, flexibility towards different technologies and incentives for technological innovation. However, in the absence of proper design and timely adaptation of the policy, it may result in an over-capacity for a specific technology and lead to increased costs.

Which are the solar PV technologies currently used and which are their costs and efficiencies?

Solar PV technology is growing rapidly in the past decades and can play an important role to meet the high energy demand worldwide. In this chapter, the worldwide status of PV technologies has been presented together with the various costs of these technologies. It can be concluded that specific policies and incentives for supporting the deployment of solar PV over the last years caused a rapid increase in the total PV installed capacity. This increase was accompanied by industrial learning and market competition, which led to significant and rapid cost reductions for PV systems. Currently, the crystalline silicon (c-Si) and the thin-film (TF) technologies dominate the global PV market, with c-Si owing around 85% of the PV market share, from which more than 40% is owned by mono- and polycrystalline PV technologies, with efficiencies of 15-17%. Thin-film polymer based solar cells and 3rd

generation solar cells are also in the development stage with improved efficiencies being expected.

The typical cost of a c-Si module includes about 45-50% for silicon, 25-30% for cell manufacturing and 20-25% for cell assembling into modules. The cost breakdown for a commercial PV system includes 50-60% for PV modules (TF and c-Si, respectively), 10% for the inverter, 23-32% for installation of BoS and about 7% for engineering and procurement. Low material costs, particularly for polysilicon, combined with improved manufacturing processes and economies of scale have reduced manufacturing costs of solar PV far faster than targeted by the industry.

Currently, solar PV power is economically competitive for off-grid applications. The financial incentives offered by many governments have significantly helped the spread of PV deployment and have led to reduced costs through mass production of components and systems. As a result, grid parity has been almost achieved in the most favourable, in terms of solar capacity, locations.

Is there a pattern between the adoption of a solar PV FiT support policy and the learning effects of the technology?

Using a general economic model, according to *Shum*, it is possible to capture the cost as well as the possible income benefits of adopting solar PV under FiT for smaller PV systems, thus obtaining an equilibrium condition of technology adoption. Two sources of economic effects have been modeled: the conventional volume based cost learning curve effects on the PV systems and a negative network externality, associated with the renewable payment that the adopter-to-be is facing. Both the above effects influence the adoption decision.

According to the author, the findings of the model suggest that under the abovementioned effects within a FiT regime, the PV electricity generation would exhibit an abrupt pattern with a rapid and sharp increase. It is also suggested that a critical threshold of adoption or generation exists beyond which sharp increase would take place. In an effort to discern the solar PV electricity pattern in the three countries examined in this Thesis, which are Greece, Spain and Germany, using this model it was quantitatively proven that the abovementioned pattern does exist.

Regarding the issues raised from the answers of sub-questions 1 to 4, what lessons can be learned from the experiences of promoting energy production by solar PV systems in the following countries: Germany, Spain and Greece?

A number of lessons can be learned from the experiences of the three countries of promoting energy production by solar PV. The most important of them are summarized below.

The Greek solar PV support scheme was designed in order to attract investments and stimulate installed capacity, since the solar PV capacity in 2006 was negligible; in both of these aspects, successful results have been delivered. However, despite its effectiveness, the scheme was accompanied by a number of distortions caused in the PV market, mainly

caused by the poor design of the policy and the shortcomings or late interventions on the broader regulatory framework.

Concerning the Spanish support scheme, this was designed mainly for diversifying the energy mix of the country and reduce the dependence of the country on fossil fuels. Although initially the policy was characterized by an impressing level of success, soon the costs of the policy started getting out of control due to the poor design of the policy and the continuous changes and interventions on the regulatory framework. Inability of the government to regain control of the situation caused the suspension of the solar PV policy in the country, thus damaging investor confidence in the reliability of Spanish policy frameworks.

Finally, the case of Germany is the case of a country which managed to successfully implement a FiT policy for the support of solar PV. The careful and detailed design of the policy combined with minimum changes in the framework led to increased certainty for the investors, thus helping the rapid and successful deployment of the solar PV sector in the country.

The most important lesson that can be learned from this analysis is that choosing the appropriate support scheme is not by itself enough and has to be accompanied by careful design steps and an appropriate implementation environment which will enable the support scheme to provide maximum results.

All the above form the base ground for answering the main research question:

"Which lessons for policy design and implementation can be learned from experiences with FiT policies in Germany, Greece and Spain in order to improve the promotion of solar PV systems without causing undue burdens on their citizens and public finance?"

The most important lesson that can be learned from the three countries studied is that careful design of the FiT policy will optimize the performance of the policy in terms of promoting a certain technology, in this case solar PV, without imposing undue burdens on the citizens or the public finance.

In the case of Greece, the design of the policy was not optimal. The FiT values were not following the reductions in the investment costs, and continuous changes in the regulatory framework were taking place unexpectedly, thus increasing the social cost of the policy and causing burdens on the finance of the citizens. Moreover, despite the significant increase in the solar PV installed capacity that took place after the establishment of Law 3851/2010, the complex and time-consuming licensing system of the country caused a halt in this increase. Furthermore, the lack of certain criteria for acquiring a license for solar PV energy production under the FiT policy worsened the situation, as an even higher number of applications were submitted to RAE. A characteristic example of the situation is the 8000 applications in 2011, which although had already acquired share within the electricity market by means of sale contracts, they were kept uncompleted due to lack of funding liquidity of the applicants, causing the Greek market to face its breakdown.

Non-optimal design of the FiT policy, however, can also cause burdens on the public finance. In August 2012, the Greek Parliament had to pass new measures in order to drastically reduce PV funding and stop new PV system approvals, in order to reduce the deficit of the RES Fund, which was used to pay the RES producers. Accordingly, PV FiTs were cut by up to 46% and no applications for producer licenses and connection requests were accepted for a period of time. Such solutions not only hindered the deployment of solar PV in the country, but also caused burdens on the public finance; burdens which were in turned passed on the citizens' finance.

In the case of Spain, the situation was even worse. Problematic design of the policy led to a series of regulatory changes, due to the high FiT rates despite the decrease of the technology costs, which in turn led to an uncontrollable increase in the tariff deficit and thus, the public finance of the country. In order to face this problem, the government decided to take drastic measures for reducing the tariff deficit, using, among other, retroactive changes, such as stopping to provide support after the full pay-off of solar PV plants, although RD 661/207 had originally promised plants payments across their operating lifetime. Other regulatory changes were also made, such as the imposition of a special tax on all sources of electricity generation, including solar PV plants and the use of the core inflation rate instead of the CPI would be used to set the tariffs. Finally, in July 2013, the government approved RDL 9/2013, according to which the investment returns for renewable projects would be set at around 7.5%, a return level much lower than the returns on which finance and investment decisions of a number of projects were based. Undue burdens were accumulating on both the citizens and the public finance, ultimately causing the suspension of PV support policies in Spain by Royal Legislative Decree 1/2012 and no other support scheme is active at this time. So, in the case of Spain, the problematic design of the policy, together with some other factors that have already been analyzed in Chapter 7, not only failed to sustainably promote the deployment of solar PV, but also led to the suspension of the policy, as the burdens caused by it were impossible to handle.

So far, the lessons learned concerning what should not be done when designing and implementing a FiT policy for the support of solar PV in order to avoid causing burdens on the public and citizens' finance have been described. However, Germany consists a bright example in the design and implementation of such a policy, thus providing lessons on how this policy should be. Minimum changes in the regulatory framework combined with a degression rate system from the first years of the implementation of the policy are the main reasons of this success. The FiT values closely followed the reductions in the investment costs of solar PV systems, causing the social cost of the policy to be minimal. Moreover, in Germany, a PV owner can compensate for the energy produced by the PV system through a self-consumption scheme, thus reducing the electricity bill. The public finance has also been benefited by the policy, as solar PV deployment has been wide despite the low solar potential of the country. This, in turn, led to enhanced energy production.

10.2 Recommendations for future research

It is inevitable during a research some topics to be treated adequately, while others will be examined at a smaller degree or not at all. This results from the fact that research is exposed to a number of limitations. Therefore, after the end of this Thesis, interesting topics that have either been rejected at the beginning of the research may reveal or topics that occurred during the progress of the Thesis are presented, which can be the basis for future research.

- This Thesis examined the performance of one policy instrument (FiT) for one renewable technology in the context of three countries with bad, mediocre and good results of the policy. However, the performance of different policies applied in these countries could be examined or the performance of the policy in more than one countries, but with similar effectiveness of the policy. In this way, the specific needs of the countries could be pointed out, concerning a support policy for solar PV, or the different reasons that caused the policy to be successful in two different countries.
- As pointed out in Chapter 1, this Thesis takes the viewpoint of the government (public policy makers), who shape the policy framework and set the targets for renewable development. However, deployment of renewables is unlikely to be realized without the participation of individual investors and firms making investors to be considered a key factor of this transition. To that end, the examination of their perspective upon a support policy would generate fruitful results about its effectiveness, enabling possible corrections that will be transformed to investments and subsequently new capacity.
- A more quantitative approach could be used for the analysis, where, among other things, the LCOE for solar PV, the evolution of the investment costs and the IRR could be calculated for the chosen countries.
- The last years, decentralized systems using PV rooftop installations, building integrated systems, small clusters of wind turbines or off-grid biogas generation seem to be the trend. These systems introduce a new term, "prosumers", who are considered to be producers consuming part of their RES-E production themselves, while selling the surplus to the grid. Moreover, new support schemes have been developed for these markets (e.g. net metering). Therefore it would be challenging to examine the performance of these instruments to promote such markets. Another aspect related to the aforementioned topic is the design of market organization and operation of these decentralized markets.

11. Reflection

During the development of this Thesis, a number of structural choices have been made on how to proceed with the research. As a result, after completing the Thesis, it is important to examine the reflection on the research boundaries and the selected methods and the approaches, thus gaining a view on the effect they would have on the results obtained.

11.1 Reflection on research boundaries

11.1.1 Public owner

As it has already been pointed out in Chapter 1, the choice of the problem owner that has been made determined on a large degree the way that renewable policy is treated. This research takes the point of view of the government (public policy makers) who shapes the policy framework and sets the targets for renewable development. However, the support policy evaluation could also have been conducted from the developer's viewpoint. This would suggest the selection of criteria that would have given insights in investor's preferences, which consist a major market actor on the RES development, thus contributing to policy making and setting policy priorities. Therefore, despite the fact that a collaborative approach was aimed on the selection of the evaluation criteria by including the criterion of certainty, the policy evaluation from the investors' point of view could be the base of a future research.

11.1.2 Technology examined

The chosen technology was solar PV, mainly triggered by the intriguing current situation where countries with high solar irradiation failed to successfully implement a FiT policy for supporting the deployment of the technology, such as Spain, while a country with a not so high solar potential managed to design and implement probably the most successful FiT policy (Germany). Choosing another technology would have taken as prerequisite the existence of available data. The consideration of another technology might have altered the analysis of the results, especially when having in mind that solar PV energy faced a remarkable development while other technologies are not widespread yet. However, this would have led to a complete picture about the performance of FiT enhancing the contribution of this Thesis on the debate on the support instruments. Moreover, if such an approach was selected, the formulation of policy recommendations would have been more concrete, since the support scheme, most of the times, is applied for the whole range of RES.

11.2 Methods – Approaches

11.2.1 Evaluation of renewable energy markets

Considering the evaluation of the renewable energy markets of the chosen countries, certain evaluation criteria have been used. However, others factors, such as the regulatory and administrative environment, grid related issues or financial crises could also be treated as a supplementary tool which will enhance the better understanding of the situation and provide a more thorough analysis. Moreover, an analysis could have been made regarding the interactions between the major actors involved.

11.2.2 Evaluation criteria

In Chapter 9 it has been argued that the viewpoint of the evaluation determines in a large degree the choice of the evaluation criteria. From the viewpoint of the government (public policy makers), the adaptation of the effectiveness and efficiency criteria is justified; however, aiming to obtain a more collaborative approach, the criterion of certainty was also chosen. The existing literature offers a variety of policy indicators which can be adopted or not, based on the goals of the research. The above description indicated that, if a different approach has been chosen, other criteria such as conformity, equity (fair cost allocation), social acceptability and impacts could have added on the chosen one.

Moreover, the assessment could also take place in terms of evaluating the costs and the benefits of the scheme (cost-benefit analysis). In this approach, the total support costs for promoting PV energy would be compared with the environmental benefits (total avoided external costs) obtained. While this approach would have produced more concrete and quantitative results, it involves a high degree of uncertainty and that was the reason for not selecting it. Defining the costs of a support instrument is a challenging procedure since, not only direct payment to RES producers, but also indirect costs usually exist. The same challenges occur when considering the benefits of RES deployment, as no broadly accepted approach exist for calculating the externalities of the conventional power generation methods.

11.3 Reflection on the results

The interaction with the existing literature in the field of renewable energy policy for the development of the research had an influence on the author. It is her belief that FiT can be very effective on promoting the RES transition, not because they are superior or outmatch other schemes on a theoretical base (i.e. under ideal circumstances they are expected to produce the same results) but due to their ability to adjust better in real life situation and the existence of design features that enables them to perform close to their optimum.

Nevertheless, this is a personal opinion and should not be correlated with the research results. It is upon the reader to decide if it did affected or not the objectivity and reliability of the outcome.

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Appendix

1. RES-E policy types applied in Europe

The following implementations exist currently in the EU (Kitzing et al., 2012):

- **1.** Fixed feed-in tariff: One tariff is specified for each technology group and the only way this price to change is through changes in the regulation. Examples: Germany, Portugal, Lithuania.
- 2. Time-dependent feed-in tariff: Two or three different tariffs (day/night, peak/offpeak) are pre-determined for each technology group and can be changed only through changes in the regulation. Examples: Hungary, Spain (hydro and biomass).
- **3.** Indexed feed-in tariff: The tariffs are based on certain market indicators, such as the exchange rate to euro or the price of natural gas, thus, their exact value is not known at the time of the investment. Example: Latvia.
- **4.** Adjusting feed-in tariff: The tariffs are not fixed at the time of installations, thus changes in regulation can affect them. Examples: Bulgaria, Czech Republic.
- 5. Target-price feed-in tariff: The tariff is guaranteed as a target-price and paid in the form of an adjusting add-on to the market price, leading to a topped-up or reduced to the guaranteed price. These prices can be predetermined from the regulation for specific technology groups or be subject to project-specific agreements. Examples: Germany and Denmark.
- 6. Contracts for difference (CfD): These are target-price feed-in tariffs which are based on negotiated prices. Example (in progress): UK.
- **7.** Fixed feed-in premium: A premium that is predetermined by the regulation for each technology group which meets certain standards and can only change through regulation changes. Example: Denmark, Estonia, Slovenia, Spain.
- **8.** Adjusting feed-in premium: Just like with adjusting FITs, the premium is not strictly fixed, thus changes in the regulation can affect it. Example: Czech Republic.
- 9. Tenders for fixed feed-in tariffs: Example: France.
- **10. Tenders for target-price FITs:** Example: Denmark.
- **11. Quota obligations with TGCs:** Examples: Sweden, Belgium, Poland, UK, Italy, Romania).
- **12. Investment Grants:** The grants range from 5% to more than 70% of the total investment cost. Examples: Most EU countries.
- **13.** Income tax reliefs: Examples: Belgium, UK, the Netherlands.
- **14. Electricity tax reliefs:** In this case, electricity generators are subject to electricity taxes. Examples: Poland and Latvia.
- **15. Reduced value added tax:** This tax can be applied on sales of qualified technologies. Examples: France and Portugal.
- **16. Net metering for own consumption:** RES-E production for self-consumption can benefit from tax reliefs. Example: Denmark (small house installations).

2. Green tags and capital subsidies

<u>Green tags</u>

"Green tags (GTs) are the property rights to the environmental benefits from generating electric energy from RES. They can be sold and traded and their owners can legally demonstrate to have purchased renewable energy" (Campoccia et al., 2009). For every 50 MWh of electricity produced by RES, one GT is credited to the producer. These GTs are given a unique identification number by a certifying agency, in order to prevent double-counting. After the energy is certified it enters the electrical grid, and the corresponding GTs are sold in the open market.

The main advantages of GTs are, firstly, the reduced generation cost of RES that occurs, which benefits the competition among the producers and secondly, its attraction to new market actors, especially under the obligation of producing a certain quota of energy from RES. The main disadvantage of GTs is their fluctuating prices, which are a function of various parameters, e.g. the location of the facility or the type of power generated, and cause strong uncertainty among the producers. Based on this, only a few number of EU countries use GTs for promoting electrical energy production from RES.

Capital subsidies

Capital subsidies are the most common support mechanism for small PV systems. Part of the PV system's installation cost is refunded by the national government to the owner of the PV system (Campoccia et al., 2007). The capital subsidies are paid out as a function of the installed nameplate PV power produced by the system and are independent of the actual energy yield over time. In this case, the financial burden falls entirely upon the tax payer.

3. Solar PV technologies

3.1 Wafer-based Crystalline Silicon Technologies

The manufacturing process of c-Si modules consists of the following steps (IEA-ETSAP and IRENA, 2013):

- 1. Purification of metallurgical silicon to solar grade poly-silicon
- 2. Melting of poly-silicon to form ingots and slicing of these ingots into wafers. If a wire saw is used for slicing the wafer, up to 40% silicon wastage can be produced. This can be reduced if a laser cutter and ribbon/sheet-grown c-Si will be used instead.
- 3. Wafer transformation into cells, with typical dimensions 15×15 cm and 3 4,5 W output. This transformation is achieved through the creation of p-n junctions and the addition of metal-silver contacts and back-coating (metallization).

4. Assembly, connection and encapsulation of the cell into modules with protective materials, like transparent glass and/or thin polymers, and frames to increase the strength of the module.

In the case of the forms of single-crystal (sc-Si), block crystals (multi-crystalline silicon, mc-Si) and ribbon-sheet grown c-Si, they all use silicon. However, unlike sc-Si cells which have high efficiency, mc-Si cells have lower efficiency, due to their random atomic structure which affects the flow of electrons, and also, they are less expensive compared to sc-Si cells.

GaAs solar cells are another type of solar cells under this category. Instead of silicon, they use GaAs, which is a compound semiconductor formed by gallium (Ga) and arsenic (As) (Tyagi, 2013). Compared to the silicon based solar cells, GaAs cells have higher efficiency and are less thick. Their band gap energy is 1.43 eV and their efficiency can be increased through alloying with specific materials, such as Al, In, P and Sb, resulting in the formation of multijunction devices and increased band gap values. They are normally used in concentrator PV modules and for space applications, due to their high heat resistance. Finally, GaAs solar cells are lighter than mono- and poly-crystalline silicon, however, the materials and the manufacturing process can be expensive.

A standard c-Si module typically consists of 60-72 cells, has a nominal power of 120 - 300 Wp and its surface ranges from 1,4 - 1,7 m², with a maximum of 2,5 m² (IEA-ETSAP and IRENA, 2013). Currently, factory production capacities equal 500 – 1.000 MWp per year, in order to achieve economies of scale and to reduce the manufacturing costs. Special processes for high-efficiency commercial cells include buried contacts by laser-cut grooves, back contacts which currently achieve the highest commercial efficiency of 22%, the Pluto process for improving the absorption of sunlight, with *Suntech* reaching absorption of 19% of sunlight, and HIT for forming a hetero-junction with an intrinsic thin layer, which consists of a sc-Si wafer placed between ultra-thin a-Si layers in order to improve the efficiency, with *Sanyo Electrics* reaching an efficiency of 19,8% for such a system. The maximum efficiency that has been achieved for simple c-Si cells equals 24,7% and belongs to *SunPower*. Higher efficiencies have also been achieved, by using other materials and multi-junction cells, by *Sharp*, which reached 35,8% without concentration and by *Boeing Spectrolab*, which reached 41,6% using 364× concentration.

The main manufacturing challenge for c-Si cells is the improvement of their efficiency and the reduction of their costs through learning-by-doing and reduced use of materials. A 30% reduction has already been achieved in the amount of silicon used in their manufacturing process since 2006, reaching just 5 - 10 g/Wp today by using thinner wafers, process automation and waste recycling. The main aim is reaching a level of 3 g/Wp or less between 2030 and 2050. Concerning the thickness of the wafers, it is around 180-200 µm for typical wafers. To further reduce the costs and enhance the performance, the interconnection and the assembly of the cells are continuously improved by using glass, polymer and aluminium structures and techniques like metallization, back contacts and encapsulation. The reduction or substitution of the high-cost materials which are used in the manufacturing process, like silver which is used in an amount equal to 80-90 mg/Wp, is also a key objective.

Concerning their efficiency, the maximum theoretical efficiency for c-Si is currently estimated to be around 29%. Record cell efficiencies have also been obtained by using expensive laboratory processes, like clean rooms and vacuum technologies, but only a few commercial cells have efficiencies higher than 20%. The current commercial sc-Si module efficiencies, which are lower than those of the equivalent cells, range from 13-19%, and they could reach 23% and up to 25% in 2020 and in the longer term, respectively. However, the majority of commercial modules are based on multi-crystalline silicon and low-cost manufacturing, e.g. screen-printing, thus offering efficiencies of 12-15% and up to 17% in the best cases, with prospects of reaching the goal of 21% in the long term.

3.2 Thin-film technologies

The base of the TF technology is the deposition of a thin (μ m) layer of active materials on large-area (m²-sized or long foils) substrates of materials such as steel, glass or plastic (IEA-ETSAP and IRENA, 2013). TF technologies use small amounts of active materials and can be manufactured at a lower full cost compared to c-Si. Despite their lower efficiency, they have short energy pay-back times (less than a year in southern Europe), good stability and their lifetime is comparable to that of c-Si modules. Plastic TF are usually frameless and flexible and can easily adapt to different surfaces. The capacity of standard TF modules is 60-120 Wp and their size ranges from 0,6-1 m² for CIGS and CdTe and from 1,4-5,7 m² for silicon-based TF (IEA-ETSAP and IRENA, 2013), while their thickness is in the range of 35-260 nm (Tyagi, 2013). Compared to c-Si modules, the efficiency of TF modules is significantly lower (4-12%) but so does their operational experience (IEA-ETSAP and IRENA, 2013). The typical manufacturing process for a typical TF consists of the following steps:

- 1. Coating of the substrate with a transparent conducting layer (TCO).
- 2. Deposition of the active layer using various techniques, e.g. chemical/physical vapour deposition.
- 3. Back-side metallization (contacts) using laser scribing or traditional screen printing.
- 4. Encapsulation in glass-polymer casing.

Roll-to-roll (R2R) techniques are often used with flexible substrates to reduce production time and cost.

The research efforts focus on materials with higher absorption and efficiency, thin polymer substrates, high-stability TCO, deposition techniques like plasma-enhanced chemical vapour deposition (PECVD), hetero-structures, electrical inter-connection, low-cost manufacturing (e.g. R2R coating, sputtering, cheap and durable packaging), quality control and aging tests. The typical manufacturing plant-scale increased from less than 50 MW to hundreds of MW per year in a few years, however, the TF manufacturing industry is undergoing significant changes and the future is quite uncertain, due to the share of TF in the market being challenged by the current low costs of c-Si modules. Four types of commercial TF modules and their efficiencies are presented in Table 45.

	2010	2015-2020	2030+
a-Si			
Max. efficiency (%)	9.5-10	15	Na
Commercial	4-8	10-11	13
efficiency (%)			
a-Si/µc-Si			
Max. efficiency (%)	12-13	15-17	Na
Commercial	7-11	12-13	15
efficiency (%)			
Cd-Te			
Max. efficiency (%)	16.5	Na	Na
Commercial	10-11	14	15
efficiency (%)			
CI(G)S			
Max. efficiency (%)	20	Na	Na
Commercial	7-12	15	18
efficiency (%)			

 Table 45 Performance and targets of TF technologies (IEA-ETSAP and IRENA, 2013).

Key R&D targets: Optimise CVD and plasma deposition process; new roll-to-roll processes; low-cost packaging; new materials (i.e. µc-SiGe, SiC, nano-diamond, cheaper TCO and substrates); replace/recycle scarce materials; better understanding of the physics of advanced concepts (e.g. multi-junctions, doping, quantum dots, up/down converters, photonic crystals).

Amorphous silicon (a-Si) films

Amorphous silicon (a-Si) typically consist of 1 μ m-thick amorphous silicon, which has good light absorption (40 times higher, compared to mono-crystalline silicon, (Tyagi, 2013)) but low electron flow, deposited on very large substrates (5-6 m²) (IEA-ETSAP and IRENA, 2013). The manufacturing costs are low, but so does and the efficiency (4-8%), with the higher laboratory efficiencies reaching 9,5-10%. Among the TF technologies, a-Si is probably the most challenged by the current low cost c-Si and its future is rather uncertain, since some producers have already retired part of the manufacturing capacity.

Multi-junction silicon (α-Si/μ-Si) films

Multi-junction silicon thin films offer higher efficiency compared to their a-Si equivalents. Here, the basic material is combined with other active layers, like micro-crystalline silicon (μ c-Si) and silicon-germanium (μ c-SiGe), to form a-Si/ μ c-Si tandem cells, micro-morph and hybrid cells (even triple junction cells) that absorb light in a wider range of frequencies. An a-Si film with an additional 3 μ m layer of μ c-Si absorbs more light in red and near infra-red spectrum and may reach an efficiency of up to 10%. The best laboratory efficiencies currently are in the range of 12-13% for a-Si/ μ c-Si tandem cells and triple-junction SiGe cells, while the commercial module efficiencies are between 6,5-9%, although prototype modules of multi-junctions have demonstrated efficiencies of up to 11%. As shown in Table 3, short-term targets include the achievement of 15% cell efficiency (17% by 2020) and of 12% module efficiency. Further material options are investigated through research, such as sc-Si (hetero-junctions, HIT), SiC, nanocrystalline-diamond, layers with quantum dots and

spectrum converters, improved TCO and substrates and alternative, low-cost deposition techniques, e.g. without using plasma.

Cadmium-telluride (CdTe) films

Cadmium-telluride films are chemically stable and offer relatively high module efficiencies of up to 11%. They can be easily manufactured at low costs through a variety of deposition techniques, while their efficiency depends significantly on the deposition temperatures, the growth techniques and the substrate material. The highest efficiencies (of up to 16,5%) have been obtained through high temperature (600 °C) deposition on alkali-free glass. The theoretical efficiency limit is around 25%, with the approaches to increase the efficiency including inter-mixing of elements, hetero-junctions, activation/annealing treatments and improved electrical back contacts. In the most efficient CdTe films, the substrate faces the sun. In such a configuration, the TCO properties are crucial for the efficiency of the module. Thinner CdTe layers are also important for the minimisation of the tellurium use, given that its long-term availability may be a concern.

Copper-Indium-[Gallium]-[di]Selenide-[di]Sulphide film (CI[G]S)

CI[G]S films have the highest efficiency among TF technologies, reaching 20,1% lab efficiency, 13-14% for prototype modules and 7-12% for commercial modules, however, the manufacturing process is most complex and costly than any other TF technology. Replacing indium with a lower-cost material or reducing its use could help the cost reduction, as indium is also used in liquid crystal displays), while cost-reduction and module efficiencies of up to 15% can be achieved using better basic processes, such as interface and grain boundary chemistry and thin-film growth on substrates, novel materials, like new chalcopirytes and wide band-gap materials for tandem cells, material band-gap engineering, e.g. spectrum conversion and quantum effects, non-vacuum deposition techniques, electrodeposition, nano-particle printing and low-cost substrates and packaging.

3.3 Emerging and novel PV technologies

A number of emerging and novel PV technologies have the potential for higher efficiency and lower costs, compared to c-Si and thin films and are currently in the research phase. Such technologies include concentrating PV (CPV), organic solar cells, advanced inorganic thin films, thermo-photovoltaics (TPV) and novel concepts which target at either tailoring the active layer for better matching to the solar spectrum or modifying the solar spectrum to improve the capture of energy (IEA-ETSAP and IRENA, 2013). Typical efficiencies and R&D targets are shown in Table 46. Some of these technologies are beginning to emerge in the market for niche applications, while the feasibility of other options depends on breakthroughs in material science, nano-technology, plastic electronics and photonics. Table 46 Performance and targets for emerging PV technologies (IEA-ETSAP and IRENA,2013).

	2010	2015-2020	2030-			
	CPV					
Efficiency (lab), %	20-25 (40)	36 (45)	> 45			
Major R&D areas and targets	lifetime; optic	al efficiency (85%),	sun-tracking,			
	high c	oncentration, up-sc	aling;			
Inorganic TF (sp	heral cells, poly-o	cSi cells)				
Efficiency (lab), %	(10.5)	12-14 (15)	16-18			
Major R&D areas and targets	deposition, int	deposition, interconnection, ultra-thin films; up-				
	scaling, light tailoring					
Organic cells (OPV, DSSC)						
Efficiency (lab), %	4 (6-12)	10 (15)	Na			
Major R&D areas and targets	lifetime (>15 years, industrial up-scaling					
Nove	l active layers					
Efficiency (lab), %	na	(>25)	40			
Major R&D areas and targets	materials, depo	materials, deposition techniques, understanding				
	quantum effects, upscaling from lab production					
Up/down converters						
Module efficiency, %	+10% over reference material					
Major R&D areas and targets	nano-materials, physical stability, upscaling					

Concentrating photovoltaics (CPV)

CPV is the most mature emerging technology. In CPV systems, optical sun-tracking concentrators, e.g. lens, focus the *direct* sunlight on highly efficient solar cells. This high efficiency reduces the need for costly active materials and helps offsetting to some extend the additional cost of the concentration system. The CPV technology is currently moving from pilot and demonstration plants to commercial applications, but further R&D is needed, particularly for cost reduction. A variety of options for cell materials and concentrators, with concentration factors ranging from 2-100 and even up to 1.000 suns, is being tested.

Generally, c-Si modules with efficiencies of 25-25% are used with low-medium sunlight concentration, while III-V semi-conductors and multi-junction solar cells are used for high concentrations (more than 250), such as triple junction GaInP/GaInAs/Ge obtained from metal-organic CVD. These high quality cells can reach lab efficiencies above 40%, and even higher when adding further junctions. The efforts of CPV research focus on low-cost, multi-junction cells with efficiency of around 35% and even high-cost, ultra efficient cells. The concentration systems include lenses, reflection and refraction systems. High concentration factors require high accuracy in optical and sun-tracking systems (0,1 degree) and heat dissipation. Unlike other PV technologies, CPV uses only the direct sunlight component and will make the most sense in Sun Belt regions.
Organic solar cells

Organic solar cells are based on active, organic layers that are also suitable for liquid processing. The technology is based on using very low cost materials and manufacturing processes with low energy input and easy up-scaling (IEA-ETSAP and IRENA, 2013). It might be feasible to achieve costs lower than 0,5 USD/Wp. Other advantages include its mechanical flexibility and its disposability (Tyagi, 2013), however, major challenges relate to the low efficiency and stability over time (IEA-ETSAP and IRENA, 2013). The organic cells include hybrid dye-sensitised solar cells (DSSC), which retain inorganic elements and fully organic cells (OPV). In 2009, the production of DSSC was equal to 30 MW, while in 2012 it was estimated to be in the order of a few hundred MW, with the lab efficiency being in the range of 8-12%, while for commercial applications was around 4%. On the other hand, in 2009, the OPV production summed to 5 MW, with the cell efficiencies being 6% for very small areas and less than 4% for larger areas. Both technologies use R2R techniques and standard printing to reduce manufacturing costs to 0,6-0,7 USD/W, which means they cannot compete with c-Si yet. In order to confirm their feasibility, a lab efficiency of 15% by 2015 and a lifetime of 15 years are required to be achieved. This involves a thorough understanding of the basic physics and synergies with both organic LED and organic electronics. OPV cells are currently used in niche applications and their competitiveness has yet to be proven. In Figure 46, the cross-section of an OPV cell is shown.



Figure 46 Organic solar cell (Tyagi, 2013)

Hybrid solar cells

A hybrid solar cell is the result of combining crystalline with non-crystalline silicon (Tyagi, 2013). *Sanyo*, one of the biggest solar cell manufacturers in Japan, has developed a hybrid solar cell, called HIT, with an efficiency of 21%. The basis of this solar cell is an n-type CZ silicon wafer which functions as a light absorber.

Hot carrier solar cells

Hot carrier (HC) is a challenging method, due to its need for selective energy contacts for converting light into electrical energy without heat production (Tyagi, 2013). The efficiency of HC solar cells can reach 66%, which is triple the efficiency of the existing silicon solar cells. However, due to lack of suitable materials for decreasing the cooling rates of the carriers, these cells have not been commercialized and remain in the experimental stage.

Advanced inorganic thin films

Advanced inorganic thin films include evolutionary TF concepts, such as the spheral CIS approach, e.g. glass beads covered by a thin multi-crystalline layer with a special interconnection between spheral cells, and the multi-crystalline silicon thin films obtained from the high temperature (more than 600 °C) deposition process, which promises lab efficiencies of up to 15%, with 10,5% having already been achieved by *CSG Solar*) (IEA-ETSAP and IRENA, 2013).

Other novel PV concepts

Other novel PV concepts are in a very early stage and their technical feasibility has yet to be proved. In order to provide high efficiency solar cells that either match the solar spectrum using novel and tailored active materials or modify it, in order to increase the energy absorption of the current active materials, they rely on nanotechnology and quantum effects (IEA-ETSAP and IRENA, 2013). In the first case, quantum effects and nano-materials enable a more favourable trade-off between the current and voltage output of the solar cell. R7D efforts target cell efficiencies above 25% by 2015 and to characterise nano-materials and cells with a theoretical efficiency limit of 60%. The second case relies on up/down converters to tailor the solar radiation and maximise the energy capture in existing solar cells. Photon absorption and re-emission may shift the wavelength of the sunlight and thus, increase the energy capture, e.g. plasmatic excitation. The goal is an increase of 10% in the efficiency of existing c-Si cells and TF, however, the full understanding of these processes will take some years.

4. Cost analysis of PV systems

Cost of PV modules

For modules, the learning curve and associated cost improvements are likely to be even more pronounced in the years to come (Kirkegaard, 2010). All types of solar development will benefit from increasing silicon conversion efficiency (measured in g/W) and from yield improvements due to the implementation of automation procedures in Asian production facilities. In 2009, module prices were already falling significantly faster than in previous years, to around 2 \$/W. The goal is to bring the average module cost to around 1 \$/W through a combination of cheaper input materials, technological innovation, economies of scale and more cost-efficient manufacturing. Analysts broadly agree that the single, most important driver of future cost improvements will be the falling price of polysilicon, the input material that currently accounts for more than 50% of total module costs. There has long been a pricing oligopoly and supply bottlenecks in the silicon market, which is now eroding due to new entrants and increasing competition. The fast-growing demand from solar cell producers pushed the spot price for silicon, which was originally mostly used by the semiconductor industry, up to 400 \$/kg in 2008. In 2009, spot prices fell to around 60-80 \$/kg and most analysts expect them to further drop to about 40-50 \$/kg, due to new

capacity, coupled with near-term slackened demand in the semiconductor space. Technological innovation in the form of thinner wafers, increased conversion efficiency or technological breakthroughs in thin film technology will also drive down the costs per installed W.

At a more fundamental level, the price of solar electricity will continue to decrease as the industry transitions from a small-scale market, where the support mechanisms at the system level are feed-in tariffs or other incentive programs, to competing directly on price with fossil-fuel electricity generation. Hereby, it will achieve mass production scale and the cost-plus margin driven model seen in most mature manufacturing industries. This transition needs to occur for solar electricity to reach higher levels of cost efficiency and be competitive on an unsubsidized basis.

More specifically, due to significant overcapacity, the current prices for wafer-based c-SI modules fell to around 800 \$/kW in September 2012 (IEA-ETSAP and IRENA, 2013). In addition to the overcapacity, the reduced use of silicon, the higher efficiencies (5-7% cost reduction per 1% increase in efficiency) and the industrial learning, which was driven by the deployment policies led to a 60% price decline in just two years.

The prices of thin films might be slightly lower compared to those of the c-Si, however, the projected TF growth in the market share has not yet been materialised in the highly competitive market, due to the lower cost structures compared to c-Si. In the long term, the differences between TF and c-Si technologies are expected to converge, however, the future of TF in uncertain under the current climate and will highly depend on technology innovation.

CdTe modules with efficiencies of 11% can compete economically with the cheapest c-Si modules, having a cost of 2 \$/Wp (Tyagi, 2013), and are expected to increase efficiency by up to 15%, while cost reductions should keep them competitive with c-Si modules (IEA-ETSAP and IRENA, 2013). Important steps towards this target include a full understanding of CdTe's basic properties and the use of lower temperature deposition processes. A better understanding of the basic physics can also reduce the cost of CI(G)S modules, by the introduction of novel materials, concepts and manufacturing, such as new chalcopirytes, polymers, metal substrates, quantum effects, spectrum conversion, electro-deposition and nano-particle printing.

Figure 47 shows the cost reduction of PV panels in the period 1995-2020. It can be seen that the PV price dropped dramatically since 1995, reaching 3 \$/W in 2012, while in 2020, this price is predicted to reach 1 \$/W for TF technology and 2 \$/W for c-Si technologies. In Figure 48, the efficiency of PV technologies and their manufacturing cost per Watt and their market share are shown. TF solar cells have lower cost compared to silicon, but they still lack in efficiency while organic cells and 3rd generation technologies are still in the research phase. Polymer solar cells have been a very good competitor compared to c-Si cells, in terms of both their lower production cost and their faster production rate.



Figure 47 PV panel cost in the period 1995-2020 (Tyagi, 2013)



Figure 48 Commercial PV efficiency versus cost per Watt (Tyagi, 2013)

Finally, in Table 47, the current costs of PV system installations globally are shown. It should be noted that the average installation cost for residential systems in lower in Germany and Japan compared to the US.

Solar PV technology	Installed cost (\$/Wp)	Project scale
Crystalline (Europe)	5.00	Utility
Crystalline (China)	4.42	Utility
Crystalline (Japan)	5.02	Utility
Thin-film CdS/CdTe	4.28	Utility
Thin-film a-Si/μ-Si	3.52	Utility
Crystalline and thin-film (USA)	7.50	Capacity weighted average (2009)
Crystalline and thin-film (Germany)	7.70	Residential (2 – 5 kW) (2009)
Crystalline and thin-film (Japan)	4.70	Residential (2 – 5 kW) (2009)
Crystalline and thin-film (USA)	5.90	Residential (2 – 5 kW) (2009)
Crystalline and thin-film (CA, USA)	7.30	Residential \leq (2 – 5 kW) (2009)
Crystalline and thin-film (CA,USA)	6.10	> 100 kW (2010)

Table 47 Summary of current costs of PV installations (Tyagi, 2013)

Cost of non-module equipment

The target for achieving grid parity of solar power is to reduce total non-module costs (in 2010, 1.75-2 \$/installed W) to 1 \$ per installed W (Kirkegaard, 2010). Table 48 maps out a scenario for BoS components and module costs up to 2015. Many experts expect that the industry will succeed in further reducing the costs for BoS components such as inverters and mounting structures. In such a scenario, BoS cost was expected to fall by another 30% in the period 2010-2015. Major drivers of further cost improvements will be global competition, cheaper manufacturing, technological improvements and greater economies of scale. One area with large BoS cost reduction potential is the further standardisation of mounting and installation techniques. Large-scale installations, in particular, will also benefit from improvements in inverter technology, as fewer inverters are required in large projects, effectively lowering the inverter cost per W. Additionally, inverters are becoming more efficient at converting electricity from DC to AC and this efficiency will also bring down solar costs per kWh in the future. Both large- and small-scale installations may benefit from the effective implementation of micro-inverters, which could greatly simplify the installation process and create AC solar panels (instead of the current DC panel, which must then be fed into a central inverter). In addition, cost savings might be possible through lowering the currently high administrative expenses and project approval fees.

	2009	2010	2011	2012	2013	2014	2015
Silicon price per kg	70.00	60.00	50.00	50.00	50.00	50.00	50.00
Silicon grams per watt	6.80	6.50	6.10	5.80	5.50	5.00	4.00
Silicon cost per watt	0.48	0.39	0.31	0.29	0.28	0.25	0.20
Ingot (multi) processing cost	0.12	0.11	0.10	0.09	0.09	0.08	0.08
Wafer processing cost	0.33	0.30	0.28	0.26	0.24	0.22	0.22
Cell processing cost	0.20	0.18	0.17	0.16	0.14	0.13	0.13
Module processing cost	0.40	0.37	0.34	0.31	0.29	0.26	0.26
Module cost	1.53	1.35	1.20	1.11	1.03	0.94	0.89
Module margin	15%	15%	15%	15%	15%	15%	15%
BoS components							
Inverter cost per W	0.30	0.28	0.25	0.23	0.21	0.20	0.20
Mounting structure	0.35	0.32	0.30	0.27	0.25	0.23	0.23
Junction box	0.08	0.07	0.07	0.06	0.06	0.05	0.05
Monitoring system	0.04	0.04	0.03	0.03	0.03	0.03	0.03
Cables and other	0.36	0.33	0.30	0.28	0.26	0.24	0.24
materials							
Labor and construction	0.35	0.34	0.34	0.33	0.32	0.32	0.32
Other BoS costs	0.22	0.20	0.19	0.17	0.16	0.14	0.14
BoS cost	1.70	1.59	1.48	1.38	1.29	1.21	1.21
BoS/installation margin	15%	15%	15%	15%	15%	15%	15%
BoS price	2.00	1.86	1.74	1.62	1.52	1.42	1.42
System cost	3.23	2.94	2.67	2.49	2.32	2.15	2.10
System price	3.80	3.46	3.15	2.93	2.73	2.53	2.47

Notes: BoS is German field installation. Inverter and mounting structure account for 25% each of BoS costs, labor 20% (Europe and US), cables 15%, other costs 11%.

5. A brief historical overview of the Greek electricity market

The Greek electricity market has undergone several major changes in the last decade (Tsalemis, 2012). The first attempt to liberalize the market was with Law 2773/1999, which separated the competitive part of the market (electricity production and supply) from the monopoly part (transmission and distribution). Furthermore, RAE was created and HTSO SA was appointed as responsible for the management and development of the electricity transmission system and the functioning of the variations market. The system operator (DSO) continued to be the PPC.

During this first period of liberalization of the Greek electricity market, in order a supplier to be able to operate and deliver energy to an eligible consumer had to own generating capacity installed in Greece or another EU country. Therefore, only generators could be suppliers. At the same time, the organized wholesale market was designed as a discrepancies market, since the bulk of electricity trading was expected to be directly between the production capacity installed and the supplier who possessed it. Soon, it was found that the banking system was unwilling to finance new investments in power plants, since, during the examination of the loan application, the producer had no proven electricity sale contracts because no eligible customer was prepared to sign a contract for the energy he would absorb 3-5 years later.

In 2003, the first change in the market structure was made, with Law 3175/2003, which was effectively implemented in 2006. A mandatory wholesale market (mandatory pool) was created, where all producers were obliged to sell the produced electricity and from which all suppliers were obliged to absorb electrical energy and sell it to the eligible customers. At the same time, a supplier was no longer obliged to hold productive forces, but instead to ensure long-term availability of electricity from the producers through availability of capacity. The result of this development was the creation of four natural gas power plants with a total capacity of 1700 MW, with the total power produced by independent producers reaching approximately 2600 MW, together with a CHP natural gas unit and a peak natural gas unit of 150 MW. At the same time, several alternative power suppliers formed.

In 2008, the third major change took place in the electricity market, regarding the introduction of the Mechanism of Variable Cost of Production. The reason for introducing this mechanism was the fact that the new natural gas units were built as base units (a gas turbine and a steam turbine on a common axis and sometimes with the same transformer) and as a result, they could not reduce their power during the low load hours of the night due to the high technical minimum. So, in order to enable these units to work during night at least on the technical minimum, it was set that they will be paid at least their variable cost of production plus 5% initially, and plus 10% after 2010. This 10% remuneration practically covers part of their fixed operating costs. Moreover, since the bilateral capacity Availability Contracts between producers and suppliers were never actually implemented, the TSO was obliged to buy the available power from the producers and sell it to the suppliers on a regulated price of $35.000 \notin$ per available MW per year and after 2010 on a regulated price of $45.000 \notin$ per available MW per year.

In 2011, a new significant change took place. In addition to the market of the next day and the discrepancies market, the purchase of ancillary services (primary and back-up) market was also created, which is cleared simultaneously with the market of the next day (originally, the ancillary services were regulated and provided only by specific units with adjustable charge).

Finally, in early 2012, the last change took place with the creation of ITSO SA as a subsidiary of PPC SA and resulted from the merger of HTSO and the General Transmission Division of PPC SA, with the parallel transfer of the transmission assets at this subsidiary. ITSO SA is responsible for the management and development of the electricity transmission system. LAGIE SA was also created through secession from the HTSO, which is responsible for the operation of the market. Recently, DADIE SA was also created which is a 100% subsidiary of PPC SA and was a result of the secession of General Distribution Directorate from PPC SA. DADIE is responsible for the management and development of the electricity distribution system and owns the fixed distribution.

6. Current tariffs per qualifying category of PV investors in Greece

Table 49 Current tariffs per qualifying category of PV investors (HELAPCO, last accessed May2015).

Investment class	Trial operation/ connection activation	FiT (€/kWh)
Professional farmers	Until 30/6/2013	Retain the old tariff in force when the association agreement was signed, e.g. 0.395 €/kWh. A special levy of 30% on turnover is imposed on this.
	From 1/7/2013 until 31/1/2014	0.120 €/kWh for the interconnected system or 0.100 €/kWh for non- interconnected islands.
Other investors of solar PV parks, which are not connected to new HV/MV substation	Until 31/5/2013	Projects ≤ 100 kWp 0.225 €/kWh if the 18-month contract has not expired or 0.215 €/kWh if the 18- month contract has expired Projects > 100 kWp 0.180 €/kWh if the 18-month contract has not expired or 0.172 €/kWh if the 18- month contract has expired
	From 1/6/2013 until 30/6/2013	Projects ≤ 100 kWp 0.225 €/kWh if the 18-month contract has not expired or 0.120 €/kWh if the 18- month contract has expired for the interconnected system or 0.100 €/kWh if the 18-month contract has expired for the non- interconnected islands Projects > 100 kWp 0.180 €/kWh if the 18-month contract has not expired or 0.095 €/kWh if the 18- month contract has expired

	From/7/2013 until	Projects ≤ 100 kWp			
	31/1/2014	0.120 €/kWh for the			
		interconnected system or			
		0.100 €/kWh for the non-			
		interconnected islands			
		Projects > 100 kWp			
		0.095 €/kWh			
Investors of solar PV parks,	Until 12/11/2013	Retain the old FiT in force			
which are connected to new		when the association			
HV/MV substation		agreement was signed (from			
		0.172 €/kWh to 0.392			
		€/kWh). A special levy of			
		34% to 42% of turnover is			
		imposed, based on the time			
		of the signing of the contract			
		and whether the connection			
		is put in trial operation or			
		activated before or after the			
		1 st of July, respectively.			
		Projects with tariffs of 0.172			
		€/kWh and 0.180 €/kWh are			
		not subject to levy.			
	From 13/11/2013 until	0.095 €/kWh			
	31/1/2014				
Househo	old and commercial systems of <	< 10 kWp			
Sign of netting agreement	FiT (€/kWh)				
Until 31/5/2013	0.23875 €/kWh This tariff remains locked if the activation of the connection takes place within 6 months of the signing the netting contract. If the 6 months are exceeded, the tariff is reduced				
	to that in effect at the time of the connection.				
From 1/6/2013 until	0.125 €/kWh				
31/1/2014					

7. Photovoltaic power generation and the Spanish market

In most countries, the competition in the electricity market is heavy (Maassen, 2011). While power generation companies face competition in the merit order system of electricity markets, which makes the efficiency and technical specifications of each power plant extremely important, all electricity producers face the same physical constraints of the independently managed and regulated network, and the fact that their product is completely homogenous. However, in Spain only six distribution companies of electricity serve 95% of all consumers through the Tarifa de Último Recurso16 (TUR, tariff of last resort) in a highly underdeveloped, supposedly competitive market, in which some twenty more distribution companies try to find a way around the fact that the tariff of last resort does not even cover the cost of Spain's electric power supply.

Spain's installed generation capacity in 2009, which is the last year for which data from the Spanish grid operator (Red Eléctrica de España) are available, amounted to 93,729 MW. Spain is generating more electricity than it requires in order to cover its load. The Spanish power grid is interconnected to France, Portugal, Morocco, and Andorra, however, interconnection is not an important factor in order to analyze developments within the Spanish electricity market.

Electric power in Spain is generated using different fuel types. The demand in the years from 2005 through 2009 was covered using a changing mix of various sources. Certain trends exist:

- The contribution of combined cycle plants trends upwards.
- The contribution of nuclear plants remains rather stable.
- Coal-fired plants have greatly reduced in importance.
- The share of renewable sources (hydro, wind, others) has increased steadily, while a small growth in the percentage of renewables from 2007 to 2008 is caused by poor hydro power generation during that year.
- The share of others which include photovoltaic plants has seen a pronounced increase from 2007 to 2008, and again from 2008 to 2009.
- System usage has declined along with the modernization of the infrastructure.
- Spain has been a net exporter of electricity in all of the past five years.

The overall demand for electricity in Spain has steadily expanded, then slowed its growth in the year 2008, and finally dropped sharply in 2009 because of the economic crisis (Figure 49). Despite the reduced demand and in the absence of major supply shocks, both household and industry prices rose particularly from 2008 to 2009.





It can also be noticed that household electricity prices in Spain had remained pronouncedly below household electricity prices in the European Union until the year 2009 as observed inFigure 50. This development can be explained by several factors:

- The shift from coal-fired plants to combined-cycle plants increases energy efficiency and reduces CO2 emissions, but combined-cycle plants are more costly in operation.
- The price increases also coincide with the accelerated expansion of electricity generation from renewable sources, particularly wind and photovoltaic energy, which are also more expensive power generation technologies relative to fossil fuel generation technologies.



• It should also be mentioned that the Spanish electricity market has been running a deficit in recent years, indicating that electricity was and still is underpriced.

Figure 50 Household and industry electricity prices for the period 2005-2009 in Spain (Maassen, 2011)

8. The German electricity market

The current electricity market in Germany has essentially proved to be successful in the first phase of the *Energiewende* (Federal Ministry of Economic Affairs and Energy, 2014). During this period, the share of renewable energy in electricity production has risen to around 25%. In 2011, eight nuclear power plants with a total output capacity of around 8 GW were closed down permanently. The market has proven to be remarkably adaptable. For example, due to the pricing signals received, operators of conventional power plants have adapted operation to the increasingly volatile residual load to an extent that was not considered technically possible just a few years ago. At the same time, innovative demand side management solutions have been trialed.

Germany will phase out nuclear energy by 2022. As a result of the nuclear phase-out, a further 12 GW of generation capacity will be retired. The strong expansion and penetration of renewables will continue as part of the corridor for expansion defined in the Renewable Energy Sources Act. Wind energy and photovoltaic installations will play a central role in this development. Wind and sun are the sources of energy with the greatest potential and the lowest costs. However, they are intermittent sources in that electricity production depends on the weather. This can fluctuate greatly depending on the season or time of day.

There is a decreasing need for base-load and mid-merit power plants. The expansion of renewable energy is changing requirements with regard to the thermal power plant fleet. The overall need for fossil-fired power stations and for base load and mid-merit power plants in particular, is decreasing while the demand for flexible peak load technologies and demand side management is rising.

The German electricity market is increasingly flexible in its response to intermittent electricity production with renewables; larger consumers are becoming more and more active in the electricity market if this allows them to increase their profitability (demand side management). Germany is transitioning from a power system in which controllable power stations follow electricity demand to an efficient power system overall flexible producers, flexible consumers and storage systems respond increasingly to the intermittent supply of wind and solar power. This transition will take place over the coming years.