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The Portuguese Photovoltaic Innovation System

Lessons for economies of high application potential and emerging industries in photovoltaic technologies

Master of Science Thesis in Industrial Ecology

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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2010

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Cover:
Off-grid PV installation on a remote lighthouse.
Picture: Ulrich Wilhelm Paetzold

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The Portuguese Photovoltaic Innovation System
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Abstract

On a global scale, the fossil fuel based energy supply sector produces the largest share of anthropogenic greenhouse gas emissions. Therefore, an indispensable action, to encounter the threads of a climate change, is the structural change of the energy supply system. Photovoltaic technologies are one very promising renewable energy technology. To overcome institutional barriers and increase the development of this technology the blocking and inducement mechanisms of the diffusion of PV technologies are researched.

Within the last two decades the photovoltaic technology has been researched and developed leading to continuous cost reduction and performance improvement (IEA 2009 b). If the PV technology will continue its worldwide expansion numerous new national PV technology clusters are expected to appear. In the near future especially late developed national PV markets with favourable geographical conditions for PV technologies will show a high development potential. In this regard, this work investigates Portugal as an exemplary case. It is further assessed whether general key lessons can be derived for other economies of high application potential and emerging industries in photovoltaic technologies.

This work was conducted as a master thesis at Chalmers University of Technology. The data collection was conducted partly during an internship with Schott Solar AG in Barcelona and several visits to Portugal. The Technology Innovation System framework was used to analyse the functionality of the Portuguese PV innovation system.

The analysis indicated, fife blocking and four inducement mechanism which delay and obstruct or induce and accelerate the development of the Portuguese innovation system, respectively. Surprisingly some mechanisms have been found to accelerate and delay the development at the same time. In a second step, key lessons for economies of high application potential and emerging industries in photovoltaic technologies are derived from the analysis of the Portuguese PV innovation system.

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A very special thank is addressed to Ducan Kushnir for his excellent support during the entire course of this work. Despite all spatial distances he was always available for the discussions of results and their interpretation. His expertise and experience in the field of innovation system analysis led to many new perspectives and deeper insights into my observations. With good ideas, constructive criticism and a lot of motivation he helped me through the frustrating moments of this work.

Part of the study and collection of raw data was conducted during an internship with Schott Solar in Barcelona. Without the help of Daniel Etschmann and his personal guidance this study would not have been possible. His contacts and introduction into the Iberian photovoltaic market are highly acknowledged.

Finally, I would like to thank all the people that kindly agreed to share their knowledge, impressions and visions with me on the Portuguese PV innovation system.

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List of Abbreviations

ADI	agência de inovação (engl.: Innovation Agency)
ADENE	agência para a energia (engl.: Energy Agency)
AFTEM	associação pelo formação tecnológica engenharia mecânica e materiais em portugal
APESF	associação portuguesa de empresas de solar fotovoltaico (engl.: Portuguese association of companies from the PV sector)
APISOLAR	associação portuguesa de indústria solar (engl.: Portuguese association of the solar industry)
APREN	associação portuguese de energies renováveis (engl.: Portuguese association of renewable energies)
CENFIM	centro de formação profissional da indústria metalúrgica e metalomecânica
DGGE	direcção geral de energia e geologia
EPIA	european photovoltaic industry association
EDP	energias de portugal
FiT	feed in tariff
GDP	gross domestic product
GHG	green house gas
IEA	International energy agency
IPP	Independent power producer framework
IS	innovation system
PV	Photovoltaic
QREN	quadro de referência estratégico nacional (engl.: national reference framework)
SPES	sociedade portuguesa de energia solar (engl.: Portuguese society of solar energy)
TIS	technology innovation system
MAET	ministério das actividades económicas e do trabalho
MEAOT	ministério da economia e do ambiete d do ordenamento do território
MEI	ministério da economia e da de inovação (engl. ministry of economy and innovation)

1. Introduction

Within the last decades a human induced increase of the concentration of greenhouse gases in the atmosphere has been identified as the cause of an emerging climate change (IPCC 2007). The dimension and impact of this climate change is still subject of ongoing research. However, despite all discussions, any change in the complex climate system implies tremendous risks for the anthroposphere and hence for mankind. One of the most important greenhouse gases is carbon dioxide. Its concentration in the atmosphere has increased from 280 ppm in pre-industrial times to 383 ppm in the year 2007 (Quéré et al. 2008). According to the Fourth Assessment Report of the IPCC from 2007, the fossil fuel based energy supply sector produces the largest share of anthropogenic greenhouse gas emissions. Therefore, an indispensable action to stabilize the concentration of greenhouse gases in the atmosphere is the structural change of the energy supply system. Fossil fuel based power plants need to be replaced by renewable sources of electrical energy. Due to the virtually inexhaustible energy reservoir of the sun and large flow available on earth, photovoltaic technologies are a very promising renewable energy technology.

Within the last two decades, photovoltaic technology has been researched and developed under continuous cost reduction and performance improvement (IEA 2009 b). Numerous experts expect that, within the next five years, in several southern European countries the costs for electricity generated from PV installations will equal the costs for electricity generated from conventional energies (EPIA 2010). If the PV technology will continue its worldwide expansion numerous new national PV technology clusters will appear (Jäger-Waldau 2009). Currently, the leading national PV markets are not geographically located within the most favourable regions for PV generation. Therefore, in the near future especially, late developed national PV markets with favourable geographical conditions will show a high development potential. In this regard, the Portugal is an illustrative example.

Portugal is one of the European nations with the highest level of solar energy irradiation (see Section 2.1). This geographical condition provides a high potential for the PV technology. However, currently the leading national PV innovation systems are located in Germany, Japan, China and USA (IEA 2009 a). Despite the high potential, today, Portugal is only an economy with emerging production of PV technology. In terms of cumulative PV module production, Portugal's development of the PV technology is late. In 2009 the German PV module production exceeded more than 30 times the Portuguese module and thin-film solar cell production (IEA 2009). In other words, the development of Portugal's PV cluster is more than 6 years behind the leading nations like Germany. This is a severe problem as the production of PV technology currently enters the economics of scales. Low production costs might only be achieved at high quantities.

In order to generate conceptual understanding of the development and diffusion of the photovoltaic technology in this work, the *technological innovation system* (TIS) analysis is applied to the Portuguese PV innovation system. The TIS method identifies institutions (e.g. regulations and networks) and actors (e.g. governmental agencies, companies and research units) related to the photovoltaic technology. In a second step the TIS analyzes their interconnections. Especially, the on-going processes which influence the development and diffusion of the photovoltaic technology inside an innovation system are investigated. The subsequent analysis of the functional dynamics aims to disclose inducement and blocking mechanisms of the overall photovoltaic innovation system (Bergek et al. 2008). Within several previous studies the technological innovation system approach has been successfully applied to study the development and diffusion of the photovoltaic technology (e.g. Jacobsson et al. 2004b, Crassard and Rode 2007, Porsö 2008, Jesle and Johanson 2008). The TIS approach was applied to different aspects of the PV technology such as building integrated PV technology (Crassard and Rode 2007) as well as different national PV innovation systems (Porsö 2008, Jesle and Johanson 2008).

Therefore, in this contribution the development of the Portuguese PV innovation system is studied. Blocking and inducing mechanisms which obviate and induce the development of the Portuguese PV TIS are searched. In a subsequent step, the findings on the Portuguese innovation system are analysed in order to identify lessons which can be transferred to other high-potential national PV innovation systems of current small market size and late development. In short the research objective of this work can be divided in two parts:

1. *Evaluate the performance of the Portuguese PV innovation system by applying the TIS framework.*
2. *Investigate whether the analysis of the Portuguese PV innovation system offers lessons to other economies of high application potential and emerging industries in photovoltaic technologies.*

1.1 Outline

This introductory chapter is followed by a short chapter which provides essential background information on the photovoltaic power generation, geographical and economical aspects of Portugal. The third chapter provides a brief introduction into the theoretical framework of this contribution. Important aspects and literature on technical innovation system approach are reviewed. The fourth chapter describes the methodology of the investigations performed in this work. The fourth chapter reviews the Portuguese PV innovation within the technical innovation system framework. The key functions are described and their functionality is evaluated. Finally, the outcomes are presented in the sixth chapter. The work closes with a chapter containing a discussion of what conclusions can be drawn.

1.2 Background

This subsection provides some general background information for the study. In the first part, a brief introduction into the PV power generation and general aspects related to PV economics are given. The second part reviews briefly the geographical and economical conditions of Portugal related to PV technology and the energy sector in general.

Figure 1-1: On-grid PV installation with tracking system in Venda do Pinheiro (Portugal)

1.2.1 Principles of Photovoltaic Technology and Photovoltaic Economics

A photovoltaic (PV) process is defined as the direct energy conversion of the energy of irradiated light into electrical energy (i.e. an electrical current) without surpassing the detour of thermal energy. The fundamental physical process of photovoltaic energy conversion consists of two steps. First, the energy of photons (in other word light rays) is absorbed by creating energy rich electrons within an absorber material. Second, the energy rich electrons are dislocated from the positive charged background of the absorber layer. The attraction between the positive charged background of the absorber and the negative charged electrons drives an electrical current (Würfel 2009).

Solar cells, or in other words PV systems, apply the photovoltaic process to generate electrical power from irradiated solar light. On one side the solar cells can be differentiated by the applied absorber semiconductor-material. In 2008, more than 85 % of the produced solar cells were based on crystalline silicon. (Jäger-Waldau 2009). The core element of this technology is mono- or polycrystalline silicon wafers, which are manufactured similar to those for numerous other applications in the silicon semiconductor industries. Several wafers are connected and encapsulated in a solar cell module. The latter step is commonly described as the module assembly (see Figure 1-4). Of continuously increasing relevance are thin-film solar cells. In order to produce such solar cells, a thin film of the solar cell absorber semiconductor is deposited directly on a large area cheap substrate material. An additional encapsulation material finishes the solar module. Different types of thin-film semiconductors are currently used for the absorber layer. The most relevant ones are amorphous and microcrystalline silicon (a-Si and µc-Si), cadmium telluride (CdTe) and copper-indium selenide (CIS) (Jäger-Waldau 2009). Depending on the absorber material the energy conversion efficiency of state of the art solar modules varies between 6% and 20%. Solar cells of lower energy conversion efficiency need to compensate this disadvantage by much lower production costs (Jäger-Waldau 2009). Highest energy conversion efficiencies of solar modules for the electrical power sector are obtained today by crystalline solar modules which are in turn more expensive in production.

Figure 1-2: Off-grid PV installation on a remote lighthouse in Souzon (Belle Îlhe en Mer - France)

A number of solar modules are connected in a PV installation. Aside of the solar modules other electrical and mechanical components, called balance of system (BOS), components are needed. Depending on the installation and type of solar module their fraction of the overall costs varies between 20% and 70% (IEA 2009). The most expensive BOS components are tracking systems and inverters (see figure 2-1). In order to induce the generated electricity into the public grid an inverter is needed to transform the DC voltage of a solar module into the AC voltage of the public grid. In addition, these inverters meter the amount of electrical energy sold to a public grid. Tracking systems follow the inclination angle of the solar irradiation and provide a better yield per installed module area. However, as tracking systems are costly, they are only applied in regions of high direct and low diffuse solar irradiation. The part of direct solar radiation on the total solar radiation increases the closer the installations is too the equator (i.e. tracking systems are much more favourable in south Europe than in north Europe).

Figure 1-3: Building integrated PV installations at INETI (Lisbon - Portugal).

Solar cells and PV installations are also differentiated by their way of deployment. Those systems connected to the public electricity grid are called grid-connected or on grid installations. In contrast off-grid or stand alone PV installations operate autonomously. Especially, where no public grid is available or connections are very expensive off-grid PV installations are used (e.g. see Figure 1-2). Building integrated photovoltaic (BIPV) installations are another type of field of application for solar modules (see Figure 1-3).

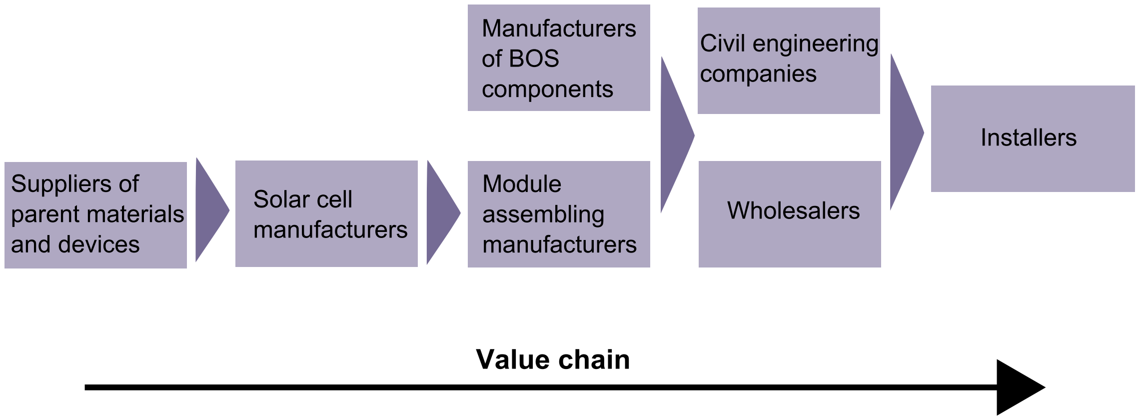


Figure 1-4: Categories of companies involved in the value chain of a PV installation

There are numerous categories of companies and actors involved along the value chain in the manufacturing and installation of a PV system (see Figure 1-4):

- Suppliers of parent materials and devices: Depending on the applied absorber material different raw materials need to be supplied. In case of crystalline solar cells the raw material consists of silicon mono or multi-crystals. These crystals (or ingots) are later on sawed in silicon wafers, the parent product of crystalline solar cells. The thin-film absorber layers are evaporated, deposited or sputtered on the cheap substrate. Depending on the process and material reactive gases, pure materials and chemicals need to be supplied.
- Manufacturers: The manufacturer produces the core technology, the solar cell or PV device, of a solar module. In case of thin-film solar cells, the manufacturer conducts the deposition. In case of crystalline solar cells, the manufacturer processes the wafers.

  Aside from solar modules, manufacturers also produce all BOS components like inverters and tracking systems.
- Module manufacturers: The solar cells produced by the manufacturers are encapsulated and combined by module assembling manufacturers in order to protected the device against environmental and operate at highest energy conversion efficiency possible. In case thin-film silicon solar cells the manufacturer is identical to the module assembling manufacturer. In case of crystalline solar cells manufacturer of solar cells and module assembling manufacturers are often separate companies.
- Wholesalers: The solar cells and BOS components are distributed by specialized wholesalers. Especially within the market of small installations wholesalers provide the connection between manufacturers and installers.
- Civil engineering companies: This group includes architects and civil engineers which design and promote buildings and large PV power sites.
- Installers: The final mounting of the solar cells and BOS components as well as the connection to the conventional grid is conducted by installer. Furthermore, the installers conduct the maintenance.

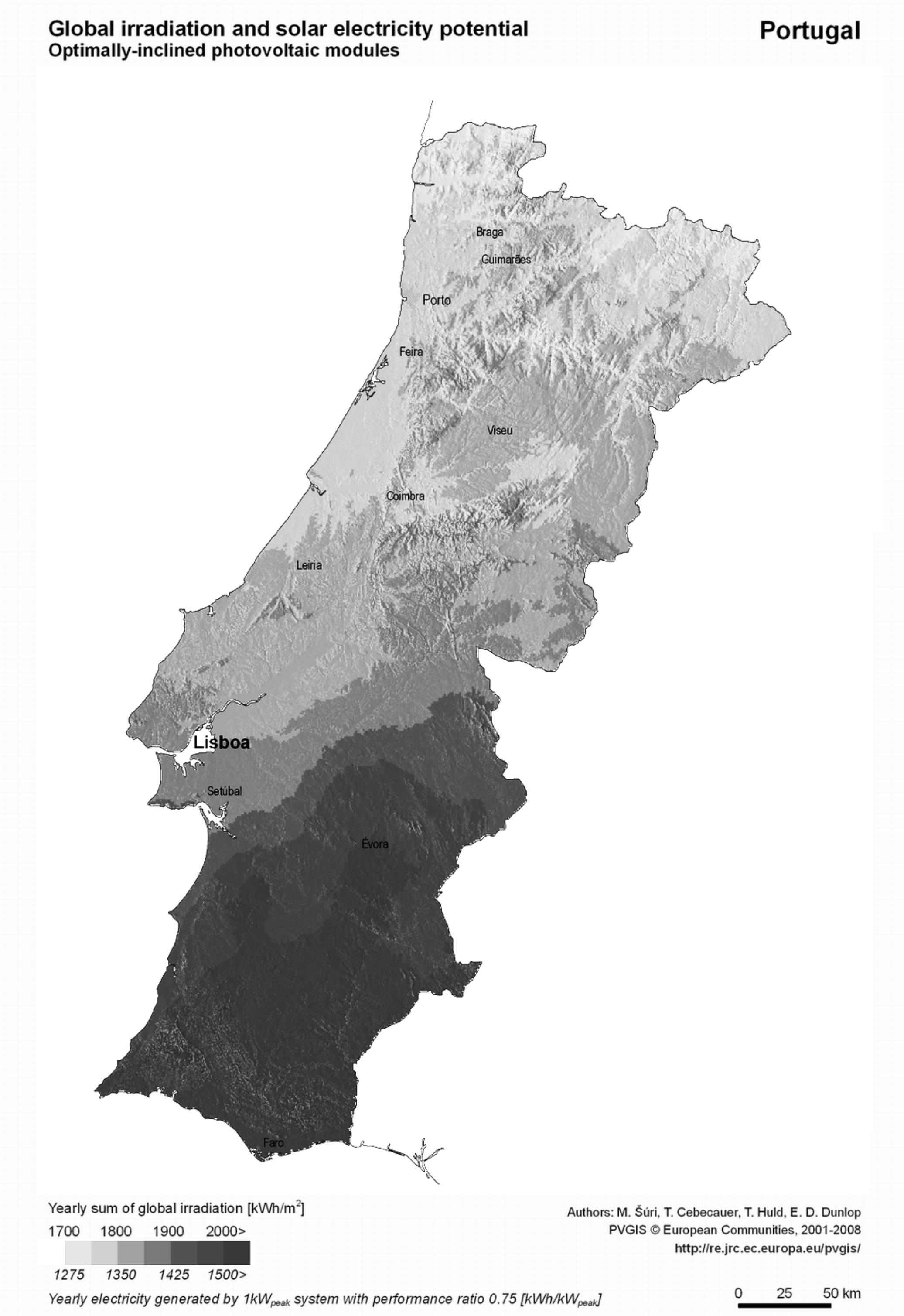


Figure 1-5: Portugal: Geographical PV potential under optimum angle. (Šúri et al. 2007)

1.2.2 Geographical and Economical Potential of Solar Energy in Portugal

Portugal is one of the European countries with the highest levels of solar energy irradiation per area. In particular, the south of Portugal (i.e. the Alentejo region) enjoys excellent geographical conditions for PV installations (see Figure 1-5). Per installed kWp, up to 1600 kWh can be generated per year in the Alentjo region (regarding optimally inclined solar modules and a system performance ratio of 75%). For comparison, the maximum yield in Germany varies between 850 kWh and 1000 kWh per installed kWp and year. These perfect geographical conditions make Portugal a high-potential market for PV installations.

The Portuguese energy supply is based on high primary energy imports. On one side Portugal lacks on own sources of natural gas and oil. On the other side, Portugal processes much of the primary energy and exports it afterwards in tradable goods. According to a study from the Direção Geral de Energia e Geologia (DGGE 2008), the energy import value corresponded to 10.25 Billion Euros in 2008. This corresponds to 6.5% of the Portuguese GDP. The most important imported energy goods were oil (77,1%), natural gas (12,2%) and electricity (6,2%). The high dependency of Portugal on energy imports is recognized as a threat for the Portuguese economy. In order to decrease the dependencies, natural gas as an energy source was introduced in the Portuguese energy system during the 90's. Also, the Portuguese government supports the development of renewable energy sources. Besides solar energy, wind and hydro energy have a high potential and development prospects in Portugal. Over the last few years, the amount of electricity produced from renewable energy sources continuously exceeded 30%. The largest contributions are due to hydro energy, which shows strong annual up and downturns depending on the annual irrigation. The amount of electricity generated from wind power plants has shown the largest increase over the same period (see figure 2-6).

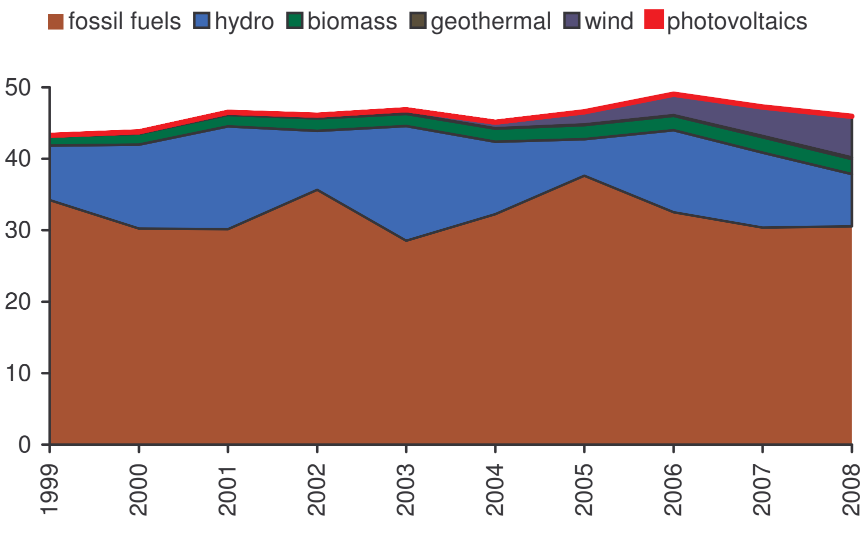


Figure 1-6: Electricity Production in Portugal from 1999 to 2008 (DGGE 2008)

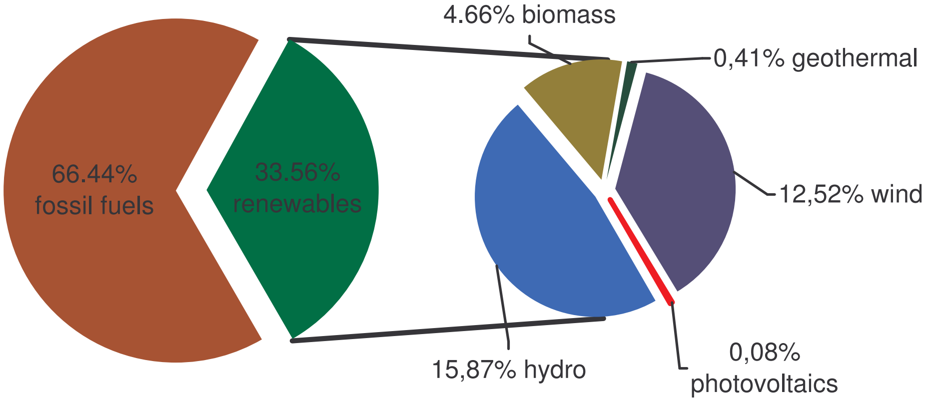


Figure 1-7: Energy sources for electricity production in Portugal in 2008 (DGGE 2008)

2. Theoretical Framework and Scope of the Study

This chapter briefly reviews the concept of "functional dynamics of technological innovation systems" which is deployed in this study. The chapter heavily draws on the work "Analyzing the functional dynamics of technological innovation systems: A framework of analysis" by Bergek et al. 2008. Embedded in the theoretical review this chapter delimitates the scope of the study and explains the applied methodology of the study.

2.1 Technological Innovation Systems

Technological innovation systems (TIS) are a subset of the general innovation system (IS) concept, which generally applies a system approach to viewing the process of creating innovations. The innovation system analysis is rather cross disciplinary and tries to include all elements such as actors, institutions and society structures which influence the creation of innovation (Hekkert et al 2004). According to Carlson et al. (2002) an innovation system consists of components, relationships and attributes which generate, diffuse and utilize a technology. Thus in innovation system analysis, interactions and collective functionalities of many actors are highlighted. The system itself is conceived as an important factor in large scale technical changes.

There are three main types of innovation system approach, the national innovation system approach, the network innovation system approach and the technological innovation system approach (Carlson et al. 2002, Jacobson and Johnson 2000). The first and second approach emphasizes geographical boundaries and subjacent networks of innovation systems, respectively. The technical innovation system approach delimitates a system in first place by a product or technology. In second order additional geographical and sectorial boundaries can be defined (Jacobson and Johnson 2000). According to a frequently cited definition, a technological innovation system is a:

> "*…network of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks.*" (Carlson et al 1991)

In this study, the technological innovation system (TIS) approach will be used. The studied innovation system will be delimitated in first place by the photovoltaic technology. However, a national perspective will be launched as this contribution investigates exclusively the photovoltaic technology in Portugal (see Section 2.2).

The structural level of technical innovation systems consists of three components according to Jacobson and Bergek (2004) as well as Bergek et al. (2008). However, it is important to bear in mind that the technological innovation system approach often looks at emerging technologies. Thus, both the existence and non-existence of structural components, such as institutions can be of great interest (Bergek et al. 2008):

- The **actors** within a technological system are all kind of entities related to the investigated technology. In explicit, important actors are companies, public bodies, interest groups, research institutes, associations, universities, clients and users. Companies along the whole value chain are included, raw material suppliers, manufacturers, companies which supply services, wholesalers and craftspeople. Public bodies include regional, national and supranational entities (e.g. European Union)

- The **networks**, within a technological innovation system are channels to transfer and interchange knowledge, products, viewpoints, interests, goals and goods between the actors in the technological innovation system. Networks can be, both, formal and informal (Bergek et al. 2008). Networks provide a certain dynamic to a technological innovation system and can help to identify problems, develop technological solutions and spread knowledge (Jacobsson and Johnson, 2000).
- The **institutions** which belong to a technological innovation system are culture, laws and regulation which influence the development of the technology system under study (Bergek et al. 2008). They provide the framework for the development of the TIS and influence often the direction that the investigated technological innovation system takes.

2.2 Scope of the Study

Regarding the delimitation of the investigated innovation system, in this work the technology system approach was used (see Section 2.1). Thus, the system was delimited by products, services and applications related to photovoltaic (PV) technology. Photovoltaic technology was defined as a technology which converts irradiated solar energy directly into an electrical current (i.e. electrical energy) without the detour of thermal energy. The later case describes the solar thermal technology which is a different technology. Within photovoltaic technology, the analysis focuses on those PV technologies which are relevant for the electrical energy sector. In explicit, photovoltaic sensor applications and photovoltaic power supply solutions for small electronic items (e.g. calculators) were excluded.

Geographically, the Portuguese PV innovation system was delimited by a national perspective on Portugal. Thus, products, services, knowledge and applications related to the photovoltaic technology which are produced, generated or traded within the national borders of Portugal were considered for the analysis. The applied national perspective on the Portuguese innovation system does not exclude interaction with other national innovation systems. The status of other national innovation systems and their interaction were considered as external factors which by definition can not be steered or influenced within the Portuguese PV innovation system.

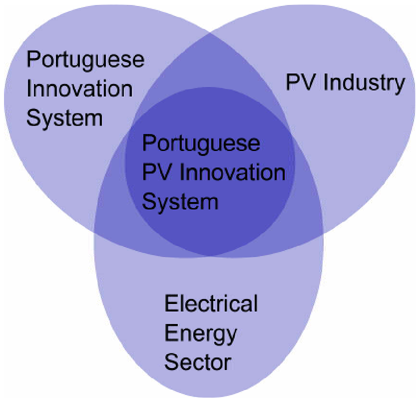


Figure 2-1: Delimitation of the Portuguese PV innovation system

Figure 2-1 illustrates the above mentioned context in which the Portuguese photovoltaic innovation system is situated. The following definition is derived:

The Portuguese photovoltaic innovation system consists of Portuguese actors, institutions and networks which employ and diffuse services, products, knowledge, technology and innovations regarding the development, production and installation of PV technology in Portugal for the electrical energy sector.

2.3 Functional Level Analysis of Innovation Systems

In order to identify the performance of a technological innovation system, an analysis framework needs to be specified. In this study, a functional-level analysis is applied which aims at identifying the strengths and weaknesses of the system, i.e. inducement and blocking mechanisms (Bergek et al. 2008). Instead of solely looking at structural components, the functional level analysis evaluates a set of key functions which are created and influenced by the elements of the innovation system described in Section 2.2. The functions selected are key processes which drive the dynamics of the TIS (Bergek et al. 2008). Weaknesses and strengths of these functions are related to the performance as well as to the blocking and inducement mechanisms of the innovation system. Furthermore, the functions provide a framework for the analysis. The seven functions defined by Bergek et al. (2008) are used:

Functional Analysis

Function 1: Knowledge development and diffusion

Function 2: Influence on the direction of search

Function 3: Entrepreneutrial experimentation

Function 4: Market formation

Function 5: Mobilization of resources

Function 6: Legitimation

Function 7: Development of positive externalities

Figure 2-2: Functional level analysis of innovation systems

Function 1- Knowledge Development and Diffusion: This function describes the knowledge base and the potential of the technical innovation system under study to generate and diffuse knowledge. This study distinguishes between a scientific knowledge, a technological knowledge, production related knowledge, market related knowledge as well as application and design specific knowledge. The scientific or academic knowledge base is created in R&D units and highly research oriented companies. The technological knowledge is associated to knowledge needed to produce state of the art high-tech products in the considered innovation system. The design and application specific knowledge describes the knowledge base needed to properly install and monitor the considered technology. Quantitative measures can be the number and value of patents, research projects, research industry collaborations, publishes articles, number of emerging innovative companies.

Function 2- Influence on the direction of search: Knowledge development, financial investments or the design of products may be influenced by factors such as financial incentives, beliefs in the growth potential, laws and regulations, market pressures and political acceptance. For example the governmental vision on a specific technology might highly influence the future prospects or even result in financial incentives. The laws and regulations provide a framework in which new companies act and guide the direction of search within a whole innovation system.

Function 3 – Entrepreneurial experimentation: A major challenge of a new innovation system is to reduce the uncertainties which hinder new entrants to enter the market and incorporate their knowledge, innovation and resources into the innovation system. This function evaluates the degree of experimentation, both, by new entrants and established actors within an innovation system. It is important to bear in mind, that entrepreneurial experimentation is important in various levels of the value chain of the product.

Function 4 – Market formation: This function evaluates the creation and development of one or several markets and market segments associated to the investigated technology. The relevance of markets can be characterized according to the extent of development and size. Commonly, markets are divided into a formative phase consisting of nursing markets, a bridging or taking-of phase and mature markets. In addition this function relates to how the demand for the technology under study is articulated and what are the drivers of the market development or blocking.

Function 5 - Mobilization of resource: The mobilization of resources is major challenge for an emerging innovation system. In many cases an emerging innovation system needs to activate new sources for rare goods and resources or competes with other innovation systems for financial or human resources.

Function 6 – Legitimation: This function evaluates the extent of acceptance and legitimation of the technology by relevant stakeholders. In addition the function reviews how well institutions and the technology are aligned. Furthermore, factors which induce and reduce legitimation are searched.

Function 7 – Development of positive externalities: A strong innovation system generally generates positive externalities such as free utilities available to the whole innovation system. Examples of positive externalities are pooled labour markets, networks, political impact or specialized suppliers. The absence or existence itself of positive externalities can decrease the legitimacy and functionality of an investigated innovation system.

2.4 Methodology

This study uses the functional level analysis of a technical innovation system to identify the inducement and blocking mechanisms of the Portuguese PV innovation system. From the Portuguese reference case, lessons are drawn for other economies of high application potential and emerging industries in photovoltaic technologies.

The analysis follows the suggested steps by Bergek et al. (2008). In Figure 2-2 the major steps are illustrated. Continuous cross checking of results and conclusions was indispensable. Having identified the research question and delimitated the innovation system under study, the structural components of the Portuguese PV innovation systems were mapped first. Second, the functional patterns were described. Third, the functionality of the innovation system was determined by applying the system goals of the Portuguese government as a measure. Investigating the strength and weaknesses, the blocking and inducement mechanisms were identified. Finally, lessons for other for other economies of high application potential and emerging industries in photovoltaic technologies were drawn.

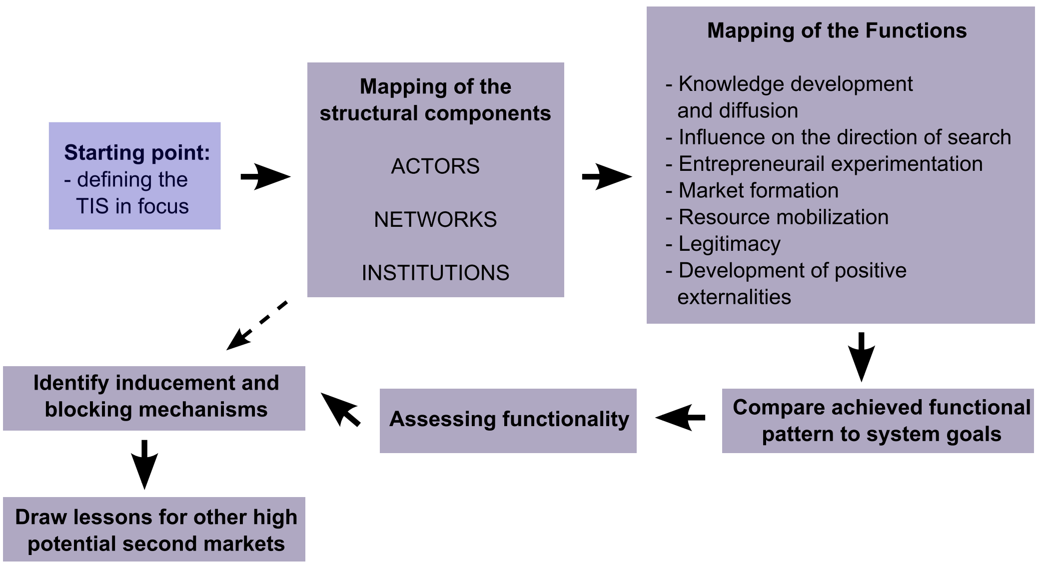


Figure 2-3: Scheme of analysis (modified and adapted from Bergek et al. 2008).

In order to provide a basis to measure the functionality of the Portuguese PV innovation system, two system goals were drawn from the vision of the Portuguese government. In Section 3.2.1 these goals are explained in detail. Both goals describe very general expectations of policy makers on a PV innovation system within economies of high application potential and emerging industries in photovoltaic technologies. For these economies, economic benefits from the national PV innovation system are desirable and cost efficient PV installations are feasible. Thus, in other economies of high application potential and emerging industries in photovoltaic technologies, these goals are also likely of highest importance. Consequently, the applied analysis of the Portuguese PV TIS is expected to generate lessons for other economies of high application potential and emerging industries in photovoltaic technologies.

This study started in April 2009. During and internship with Schott Solar AG in Barcelona, the author collected, in compliance and agreement with the supervisors and Schott's authorisation, general economic data on the Portuguese PV innovation system. A preliminary study based on literature helped to identify the structural components of the Portuguese PV innovation system. Important sources were PV magazines such as Photon, PV internet platforms such as the solarserver (www.solarserver.de) and membership lists of PV industry associations such as EPIA and APISOLAR. A visit to the fair Genera 2009 in Madrid, the largest Iberian construction fair, completed the search for structural components of the Portuguese PV innovation system. In a second phase, first contacts made at Genera 2009 were followed up in phone and e-mail interviews. Of particular importance in this phase were recommendations to identify additional actors. The so called "snowballing effect", where interviews with one actor lead to new contacts, was used to get in contact with as many actors and group of actors as possible.

In a second phase about 20 detailed face to face interviews were conducted with a selected set of important and representative actors of the Portuguese PV innovation system (see Appendix B). Many of those interviews were conducted during the fairs TECNOFIL and TECTONIKA in Lisbon (Portugal). In addition a workshop on solar energy in Portugal at the innovation brokerage event "4 journadas da inovação" was attended. All these events were excellent opportunities to meet as many actors as possible in a short time. Additionally, these events provided the opportunity to meet additional actors. Numerous short interviews at the fairs TECNOFIL and TECTONICA in Lisbon were conducted.

By the end of the data collection period in August 2009, the interviewees were frequently referring to each other. Thus, it can be concluded that the collected insights and view points on the development of the Portuguese innovation system is somewhat complete.

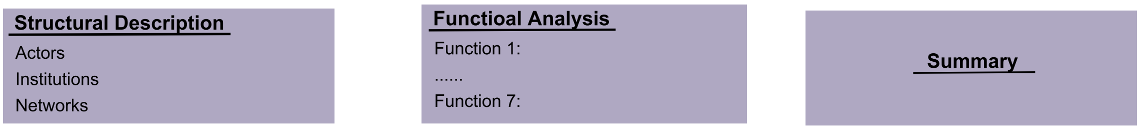
A set of open-ended questions was used in interviews to obtain as much information as possible from the interviewee and to invite the interviewee to freely share his or her viewpoints. Although, the questionnaire was continuously improvement similar questions were addressed to all interviewees in order to check the reliability of the answers. In general notes were taken during the interview and later merged within less than a day into an interview transcript. The viewpoints presented within this study are taken from these interview transcripts. Only such viewpoints were presented and included which were supported by a number of interviews. Within the study, however, only the most striking statements are explicitly cited.

Having finalized the data collection phase in the beginning of August 2009, the data from literature and interviews was gathered and organized. First, a timeline of important events was created. Second the structural components were summarized and the results were mapped onto the functional pattern. Afterwards, an analysis according to Bergek et al. (2008) was conducted.

Despite the efforts to improve the quality of the data collection, this study carries uncertainties. Due to the limited timeframe for the data collection not all actors were interviewed in detail. Also, the interviews focused on the Portuguese actors in the Portuguese innovation system only a very limited number of international actors which might intend to move into the Portuguese market were interviewed. Also some groups of actors are underrepresented, in particular politicians and investment funds. Their viewpoints were obtained in indirect information channels such as literature and interviews with other actors.

3. Analysis of the Portuguese PV Innovation System

This chapter contains the analysis of the Portuguese PV innovation system. It is divided into three sections. Firstly, the Structural description of the Portuguese innovation system is given. Second, the functional patterns of the innovation system are assessed. The chapter closes with a summary of the strength and weaknesses of the functional pattern of the Portuguese PV innovation system.



3.1 Structural Description of the Portuguese PV Innovation System

In this section, the structural components of the Portuguese PV innovation system within the system boundaries are described. Applying the snowball principle, within numerous interviews and assessing the member lists of Portuguese PV industry associations, an overview of relevant actors, institutions and networks was achieved. Some structural components which are mentioned in Section 2.1 have not been located and identified within this work. In particular, informal networks and cultural aspects have been excluded from the institutions of the Portuguese PV innovation system. The identified and missed subgroups and characteristics of actors, institutions and networks are described in the following paragraphs.

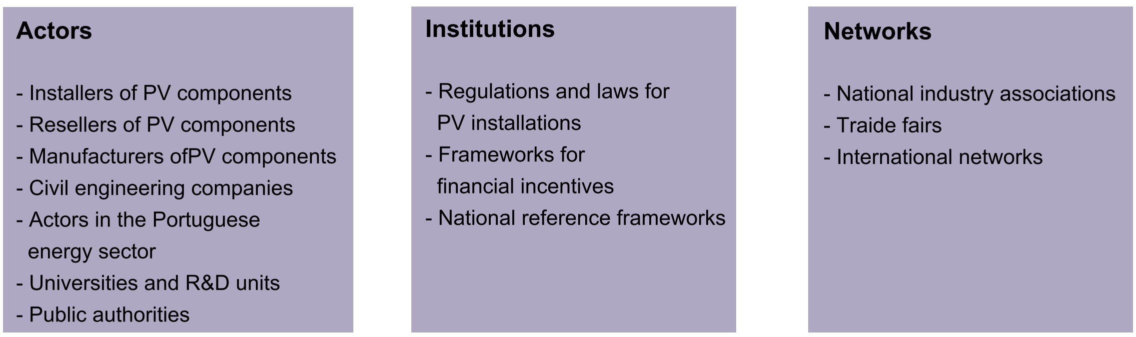


Figure 3-1: Identified segments of structural components of the Portuguese PV innovation system.

Actors:

Installers:

Since 2008, the number of installers of PV components increased strongly within Portugal. A new legislation favoured distributed small size PV installations, creating new business opportunities for new installers distributed throughout the country (Joyce 2009, Freitas 2009, Arnedo 2009). Many of the installers of PV components in Portugal were formerly active in the climatisation or roofing sector (APISOLAR 2009). Currently, more than 350 installers from all parts of the country provide their services to the PV sector (CERTIEL 2009 a).

Wholesalers:

The distinction between installers and wholesaler is not always perfectly clear, as many large installers also resell equipment and work with subcontracted companies which do the pure installation service. Within this study, three major groups have been identified from the companies which distribute PV modules and equipment in Portugal. The first group consists of Portuguese wholesalers with former experience in the climatisation sector (e.g. Resul, FFSolar, BrightSolar, WS Solar). Often these companies have additional installer competence (e.g. BrightSolar, WS Solar, FFSolar). The second group consists of large wholesalers which join international contacts directly to the manufacturer but also face international competition (e.g. Donauer, Schüco, Assunim). The last group consists of large Portuguese corporation which use their strong selling network within Portugal (e.g. Martifer, EFACEC). Similar to the installers, the number of wholesalers in Portugal increased significantly since 2008 (Joyce 2009, Freitas 2009).

Manufacturers:

The company Lobo Group is the only Portuguese manufacturer of solar cell modules with a long term experience (started in 1994). Since 2006 a hand full other companies started the manufacture solar modules in Portugal (Martifer, Solarplus, DST, Earthlife - Goosun, Moura assembling plant). According to the information provided by the manufacturers themselves, at the end of 2009 a national power production capacity of 120 MWp was reached. Aside from Solarplus, a manufacturer of thin-film silicon solar cells, all manufacturers exclusively assemble crystalline solar cells to modules. There are no relevant Portuguese producers of inverters and electrical solar cell equipment. Two innovative companies manufacturer complementary products and a new photovoltaic concept. WS Solar commercialised a low concentration and tracking systems and Magpower commercialised concentrating PV with Fresnel optics.

Civil engineering and project companies:

Various companies in Portugal develop and engineer large photovoltaic power sites in the MW range (e.g. Netplan, Caventum, EFACEC, Genereg). All of them have former experiences in developing wind power plants.

Important actors in the Portuguese energy and electricity sector

Twenty years ago the energy sector in Portugal was completely controlled by the government. During the energy market liberalization in the 90's the company Electricidade de Portugal, S.A. (EDP) became the dominating Portuguese company in the electrical energy sector of Portugal. Since the takeover of Horizon Wind Energy, a wind power producer based in Texas, in 2007 the EDP group is the second largest generator of electricity from wind power world (Bugge 2008, EDP 2008). Another important company is the Rede Eléctrica Nacional (REN) which is owned by 30% by EDP and 20% by the Portuguese Government. The REN was founded in 1994 to break the EDP monopoly and the connection between the electricity grid ownership and electricity production. One important task of the REN is to provide a connection for the producers of electricity (also PV installation and PV sites).

Universities and research activities

Numerous R&D units in Portugal research in the field of PV at national research institutes and at universities (see Table 3-1). The fundamental research addresses mostly the field of thin-film silicon solar cells, crystalline silicon ribbon solar cells and organic solar cells.

Applied research is mainly performed in national research institutes as the *Laboratório Nacional de Energia e Geologia* (LNEG formerly INETI), the Centre for Innovation, Technology and Politics Research (IN+) and Instituto de Engenharia de Sistemas e Computadores (INESC).

Public authorities:

There are a number of public authorities interacting with Portuguese PV innovation system via control and legislations. The Ministerio da Economia e da Inovação (MEI) is the Portuguese ministry responsible for implementing the EU energy objectives and the electrical energy sector in Portugal in general. The Portuguese national department Direcção Geral de Energia e Geologia (DGGE) carries out the conception and promotion of the allocation process of the licences for grid-connected PV installations in Portugal which profit financial incentives such as a fixed Feed in Tariff (FiT).

Institutions

Concerning regulations and laws the most important ones are the subsidy frameworks. Today, effectively two subsidy frameworks are operational. The Independent Power Producer (IPP) framework was joined in 2001 and supports mostly large PV power sites (MAEOT 2001 and MEAT 2005). The microgeneration framework started in 2008 and is exclusively directed towards small installation of installed power capacity smaller than 3.68 kWp (MEI 2007 a). The corresponding module area size corresponds roughly to half of a roof of a single family house. Both subsidy frameworks work with a fixed FiT which is paid over a fixed time.

Another field of important governmental institution are agencies, funds and national reference frameworks which provide incentives for the technological development of the Portuguese PV innovation system. The most important ones are the *Quadro de Referência Estratégico Nacional* (QREN), the *Agência de Inovação* Portugal (ADI) as well as various European funds.

Cultural aspects have been excluded from the analysis as the author of this work was not able to obtain a sufficient and reliable database in this field.

Networks

Within Portugal, three associations explicitly promote the Portuguese PV innovation system. The Sociedade Portuguesa de Energia Solar (SPES) is the oldest association founded in 1980. It is a society of public interest open mainly for individuals (Mendes 2004). The Associação Portuguesa de Indústria Solar (APISOLAR) founded in 1998 is an industry association of the solar energy sector. The industry association Associação Portuguesa de Empresas de Solar Fotovoltaico (APESF) was founded in 2008 and is directed exclusively toward the PV technology. In addition Portuguese associations from the energy sector (Agência para a Energia - ADENE) in general or the renewable energy sector (Associação Portuguese de Energies Renováveis - APREN) exist .

The above mentioned Portuguese associations and formal networks are well connected to superior international and European associations such as the European Photovoltaic Industry Association (EPIA) or the International Energy Agency (IEA).

In addition innovation and trade fairs in Portugal like the fairs TECTONIKA and TEKNOFIL provide a basis for network within the Portuguese PV innovation system.

In this group informal networks have not been assessed as a sufficient database for a detailed analysis was missing when the study was conducted.

3.2 Functional Analysis of the Portuguese PV Innovation System

Having described the structural components of the Portuguese PV innovation system in the former section, in this section the functional pattern of the innovation system are described and assessed. Firstly, the system goals of the functions of the Portuguese PV innovation system are defined in order to provide a basis to measure the functionality. Second the functions are described. The strength and weaknesses of every function is evaluated according to the system goals in the following section and summarized within the functions' strengths and weaknesses.

Functional Analysis

Function 1: Knowledge development and diffusion
Function 2: Influence on the direction of search
Function 3: Entrepreneutrial experimentation
Function 4: Market formation
Function 5: Mobilization of resources
Function 6: Legitimation
Function 7: Development of positive externalities

Figure 3-2: Functional level analysis of innovation systems

3.2.1 Definition of System Goals for the Functionality

Most of the literature applies either industry lifecycle models or system comparisons to measure the performance of innovations systems. Both ways of assessment have been employed successfully in the past to analyse national PV innovation systems which have developed technologically early in comparison to competing national innovation systems (Jacobson et al. 2004b, Jelse and Johnson 2008, Crassad and Rode 2007). In this work, general system goals are applied to provide a basis to measure the functionality of the Portuguese PV innovation system. *The system goals are derived from the vision of the Portuguese government on the national PV innovation system.*

The vision of the Portuguese government regarding the photovoltaic innovation system is embedded in the general vision of the future energy sector. As for all economies, the energy sector is of strategic importance for Portugal. Regarding renewable energies, the ministry of economy and innovation identifies them as "… a way to reduce the overall energy costs, as a way to protect the environment in the face of climate change or as a way to further modernise the technology used by economic agents and businesses" (MEI 2007 b and MEI 2007 c). First objectives for the renewable energy sector in Portugal were defined in the resolution of the council of ministries number 154/2001, which created the E4 program (PCM 2001). Within a next resolution number 63/2003 in 2003 the Portuguese government has constituted guidelines expressing the vision of the renewable energy sector by the National Energy Strategy. The security of supply, a sustainable development and the promotion of national competitiveness were defined as three strategic vectors of the national energy policy (PCM 2003). The fundamentals of these policy guidelines continued in the current strategy which is constituted in the resolution 169/2005 in October 2005 (PCM 2005). In short the objectives are summarized are:

- To provide a secure and independent supply of energy from a diversified portfolio of primary sources and energy services
- To promote energy efficiency and the use of renewable energy sources in order to decrease the emission of green house gases
- To liberalize the energy market in order to stimulate high competitiveness and efficiency within the energy business and services
- To support a sustainable growth of the Portuguese economy and to strengthen Portuguese companies

From this overall strategy, the key expectations of the Portuguese government concerning the Portuguese PV innovation system can be derived. The Portuguese PV innovation system should create energy independence, economic benefits and decrease GHG emissions. In general, these requirements can be met with a robust Portuguese photovoltaic innovation system which generates competitive and low emission electricity from PV as well as comprehensive economic benefits. Currently, however, Portugal is a 2nd market in PV technology. Only within the last three years has the market started evolve and gain international relevance (IEA 2009). Stronger and more experienced national PV innovation systems exist in connected markets like Spain and Germany. These PV innovation systems provide highly competitive products and services for the Portuguese PV sector. Their dominance is a threat to keeping the desired economic benefits in Portugal. High benefits for Portugal can only be obtained if a large part of the value chain and services are provided by Portuguese companies and Portuguese employees.

Therefore, in order to generate a competitive PV innovation system in Portugal which generates sustainable growth, the functions of the Portuguese PV innovation system need to be oriented toward enforcing the innovation system to generate long-term prospects (i.e. goods and services of future competitiveness). Consequently, the first system goal to be applied on the functional patterns is the extent to which the system creates economic prospects and competitive goods, regarding strongly connected and competing markets. The second, rather intuitive, system goal to be applied on the functional patterns is the extent to which the system can generate electricity production capacity based on PV in Portugal.

System goals:

1. Potential of the system to generate long term economical prospects for the Portuguese innovation system and competitive goods, regarding strong connected and competing markets?

2. Potential of the function to support the installation of electricity production capacity based on PV in Portugal.

In first place, the above defined system goals provide a basis for the assessment of the functionality of the Portuguese PV innovation system. In addition, they suit well to a more general perspective on economies of high application potential and emerging industries in photovoltaic technologies. Both defined goals describe very general expectations of policy makers on a PV innovation system.

The above described goals are rather general and the use of detailed indicators bears the risk of losing complexity and completeness in the analysis. Therefore, instead of ranking each function with grades of several indicators, the system goals are applied more qualitatively.

3.2.2 Knowledge Development and Diffusion

This section is intended to review and assess the national knowledge base and knowledge generation in Portugal related to the PV technologies as well as the PV market itself. Depending on the product, service or good, a specific actor in the innovation system has to provide, demand or generate different kinds of knowledge. In this section, the type of knowledge is differentiated by scientific, technological, design and application specific, production and market knowledge. Each section finishes with a paragraph on the strength and weaknesses of the mapped function. This way, impacts on the functionality according to the above described goals is determined.

Scientific knowledge:

Scientific knowledge about currently available and future PV technologies is generated and gathered in universities, national research institutes and highly research oriented companies. Due to their open character as public entities universities and research institutes are of particular importance in the Portuguese innovation system for the communication and exchange of scientific knowledge. In addition, these institutions educate skilled labour for the PV sector.

In Table 3-1 numerous R&D units of Portuguese universities and institutions which research in the field of PV technologies, PV systems and PV electricity system integration are shown. Most of the technological research addresses the field of thin-film solar cells, organic solar cells and crystalline silicon ribbon solar cells. These technologies have currently very small market shares but have a promising potential for future solar cell products. This indicates that Portuguese universities obtain an advanced knowledge base regarding the scientific knowledge. Contributions of the associated scientific R&D units at international expert conferences and articles in scientific papers indicate a high level of quality in research and interaction with international academic partners (e.g. LAFS 2009 or INETI 2009).

The field of PV systems and electricity system integration is often researched in the broader framework of renewable energy system integration or power system network analysis. Several R&D units in Portugal cover this research topic (see Tabel 3-1).

R&D Unit	**Topic**	**Institute / University**
Technology of Chemistry Industries Department	- Organic solar cells	LNEG (former INETI)
Renewable Energy Department	- Crystalline silicon solar cells - Organic solar cells - Power system network analysis	LNEG (former INETI)
Laboratory of Photovoltaic Applications Semiconductors; Condensed Matter Physics	- Crystalline silicon ribbon solar cells	University of Lisboa
Group of Complexity and Electric Proprieties; Centre of Physics	- Thin-film silicon solar cells	University of Minho
Group of Functional Coatings Centre of Physics	- Thin-film silicon solar cells - Organic solar cells	University of Minho
Centre of Excellence in Microelectronics Optoelectronics and Processes Centre for Materials' Research	- Thin-film solar cells	New University of Lisboa
Faculty of engineering	- Organic solar cells	University of Porto
Group of Molecular Chemistry Centro for Structural Chemistry Instituto Superior Técnico	- Organic solar cells	Technical University of Lisboa (UTL)
Physics Department; Instituto Superior Técnico	- Thin-film silicon solar cells	UTL
Centre of Semiconductor Physics, Optoelectronics and Disordered Systems Department of Ceramics and Glass Engineering	- Thin-film silicon solar cells - Organic solar cells - nanotechnologies for PV	University of Aveiro
Group for Research and Applications on Microelectronics, Optoelectronics and Sensors	- Thin-film silicon solar cells	Institute of Engineering of Lisboa (ISEL), Lisboa Polytechnic Institute (IPL)
Instituto Superior Técnico Instituto Superior de Economia e Gestão	- PV power system integration	UTL
Faculty of Economy Faculty of Sciences and Technology	- PV power system integration	University of Coimbra
Faculty of Sciences	- PV power system integration	University of Lisboa
Power system unit	- Power system network analysis - Smart electricity networks	INESC Porto
MIT Portugal	- PV power system integration - Smart energy networks	University of Coimbra, University of Lisboa, UTL

Table 3-1: Fundamental research activities in Portugal

One particular outstanding institution which underlines the advanced reasearch knowledge in the research field of sustainable development is the *MIT Portugal.* This instutitution started in 2009 and constitutes a research colaboration between a number of faculties from different universities in Portugal and the MIT in the USA. Within the *Sustainable Energy Systems* program, fields of interest are energy planning including economics and smart energy networks (MITPortugal 2009).

Technological knowledge:

Scientific knowledge on its own does not necessarily improve products and services. Networks and cooperation between economic entities and universities as well as national research institutes are needed in order to transfer the scientific knowledge into technological knowledge about advanced PV technologies. An indicator for the extent of transformation of scientific knowledge into technological knowledge are R&D projects which resulted in commercial projects. Within the last years the companies WSEnergia, MagPower and Solarplus reported to have successfully industrialized commercial products developed within R&D projects.

WSEnergia developed and patented a low concentration tracking system which doubles the annual energy yield of commercial PV modules. The projects advanced when Lobo Group, a Portuguese manufacturer of crystalline silicon solar modules, warranted the performance of it's modules in the low concentrating tracking system of WSEnergia (Sorasio 2009, Reis et al. 2009). Within the QREN framework, this collaboration is supported by the government.

Solarplus, developed building integrated PV modules based on amorphous silicon (Joyce 2009, Dolores 2006). In cooperation with Portuguese universities, fields of application of nanotechnology in thin-film silicon solar cells was investigated. These two collaborations between universities and companies were financially supported by the government via the *Agência de Inovação*, a national agency which organizes the funding of innovative projects of the Portuguese industry.

The company MagPower developed and industrialised Concentrated Photovoltaic (CPV) systems. These devices concentrate the irradiated solar energy onto a III-V triple junction photovoltaic cells. At the fair TECNOFIL 2009 in Lisbon detailed expansion plans for industrial production were presented (Silva 2009).

Another outstanding academic-industry partnership was established in 2009 to develop thin-film PV solar cells fully integrated in ceramic tiles (IEA 2009, Fortunato 2009). The project, called solar tiles, is founded under the Portuguese National Strategic Reference Framework. The associated partners are from ceramic industry, universities and research institutes and system integrators. A combined fundamental research project on crystalline silicon ribbon was started by BP Solar and LAFS (Laboratório de Aplicações Fotovoltaicas e Semicondutores) in 2006 and resulted in patents and scientific publications (LAFS 2009).

Within the field system integration different universities generate concepts for the electrical energy system integration from renewable energy sources into the conventional grid (see Table 3-1). This research was in first place strongly enforced by the large wind power installations in Portugal (Lopes 2009). A demand for smart solutions to enable the conventional grid to take up more electricity from renewable energies was created. For example EDP, the former state owned energy supply company in Portugal, started collaborations with universities like the INESC in Portugal to investigate *smart grids* and renewable energy system integration. (INESC 2008).

Overall, despite the above mentioned cases, only a limited number of new high-tech businesses started in the field of PV technology over the study period. Little of the promising scientific knowledge base was used to create new products, services and economic actors in the Portuguese PV innovation system.

Production knowledge:

Regarding existing and market relevant technologies, the production knowledge base for solar cells and modules of most manufacturing companies is imported or developed in tight cooperation with more experienced companies from other countries. So far, no companies which produce wafers, silicon raw material or production and processing machinery for the solar cell are located in Portugal. Therefore, even of those solar cells currently produced in Portugal, much of the economical value is generated outside of Portugal. Within the largest market segment, crystalline silicon solar cells, Portuguese companies are exclusively active in the PV module assembling. Current PV module assembly manufacturers with production sites in Portugal are Martifer, OpenRenewables (Lobo Group), Goosun, Mouro Solar plant and DSTSolar. Most of them bought fully developed module assembly lines from strategic partners outside of Portugal (Joyce 2009, Martifer 2009, Hirshmann 2006). Only a small part of the production knowledge was afterwards developed in house. The only exception is OpenRenewables (Lobo Group). This company has long-term experience in the module assembling. Since 1994 the Lobo Group manufactures PV modules, mostly for the export in other European countries (OpenRenewables 2009). At these times no standardized processes and module assembly lines were available. Own processes and knowledge were developed in the Lobo Group. A high level of production and technological knowledge was created (Joyce 2009).

Solarplus, the only manufacturer of thin-film silicon solar cells and modules in Portugal also bought the machinery for their production lines from a strategic partner is the USA (Joyce 2009). However, the knowledge base of amorphous silicon solar cell and module production was developed in house. In particular the in house development of BIPV modules requires an advanced production knowledge base (Dolores 2006, IEA 2008).

Despite the relative large amount of universities which research in the field of promising future PV technologies, no research at national research institute or university is directed explicitly towards to the production and manufacturing of solar cells and modules.

The production knowledge for new and innovative products commonly has to be developed by the companies themselves. No standardized production concepts and machinery is available. WS Solar and MagPower developed their own new and innovative products as well as the needed production knowledge base.

Design and application specific knowledge:

In order to properly fulfil the designated function in the Portuguese PV innovation system, the actors need to exchange design and application-specific knowledge. For example, the manufacturers of a solar cell module need to somehow pass the application specific knowledge of their product to the installer. Otherwise the installation is likely of low quality and will in return harm both the installer's and manufacturer's reputation. On the other hand, the manufacturer benefits highly from the installer's feedback on the performance, perception and difficulties of his products.

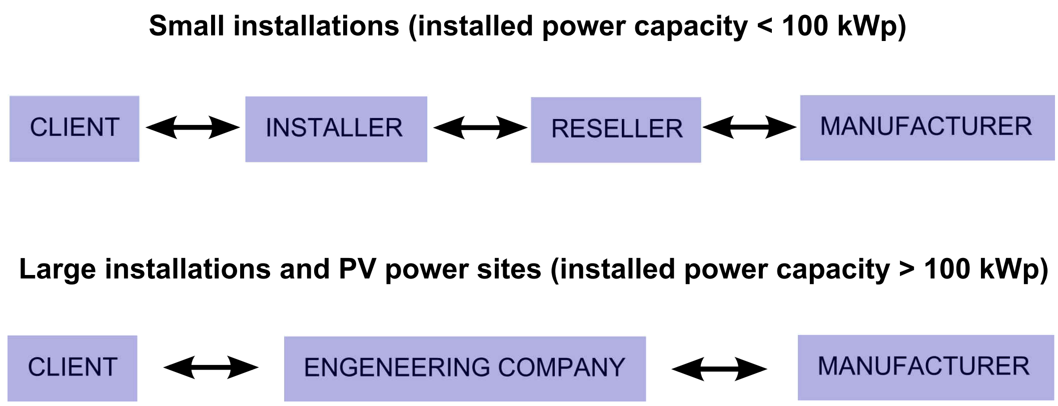


Figure 3-3: Flow of design and application specific knowledge

Throughout this study in various interviews (see Appendix A) a framework for the exchange of design and application specific knowledge was observed which is shown in Figure 3-3. For small installations, which can be roughly determined by their size of installed power capacity below 100 kWp, an information chain of four chain links exists (client, installer wholesaler and manufacturer). The information flows, both, from the left side to the right side and from the right side to the left side. The installer is in contact with the final client and receives the client's demand but also suggests the products and solutions. Subsequently, the installer discusses the case with the wholesaler who is in contact with the manufacturer. In Portugal installers of PV systems have often former experiences in the climatisation or roofing sector (Certiel 2009 a). Due to the recent increase of PV installations within the last two years (2007 and 2008) they started to acknowledge the PV market as a valuable business opportunity. The resulting large number of new inexperienced installers and the lower educational background of installers (e.g. in comparison to installers in Germany) created a high demand for design and application specific knowledge in the last years. Especially, the demand for courses and vocal trainings which pass design and application specific knowledge to the installers is very high (Arnedo 2009, Herbers 2009). New courses and teachings programs are currently developed at national research institutes and public entities like national research institutes (e.g. LNEG and LAFS) or vocational training institutes (e.g. CENFIM and AFTEM) (Joyce 2009). In addition, the wholesalers often provide technical support to the installers (e.g. a technical hotline or workshops organized together with manufacturers) (Arnedo 2009, Herbers 2009). Some of the few Portuguese installers with long term experience have developed an additional distributing competence. These companies use their long term experience and knowledge which new installers in the field are often lacking.

The wholesalers obtain application specific knowledge from the manufacturers of the corresponding product and pilot projects (e.g. for BIPV – INETI building) which are widely promoted. Both, Portuguese and foreign, wholesalers do business in the Portuguese PV market. No specific technical application specific knowledge was reported for the Portuguese market. However, the wholesalers adapt their product portfolio and PV system sizes to the favoured installation sizes within the Portuguese FiT. Due to the relative small market size most of the manufacturers of solar modules and PV systems focus so far on other larger markets.

For large installations and PV power sites of installed power capacity above 100 kWp, the plant owner or monitoring entity is in contact with a civil engineering company which conducts the project and discusses the specifications with the manufacturers (see Figure 5-1). As these businesses are of large financial volume international companies compete directly with Portuguese companies. For very large projects in the past only very few Portuguese companies had the essential financial and technical experience to promote such projects. For example the Moura power plant, the largest PV power plant in 2002, was promoted by the Spanish company ACCIONA although Portuguese companies were clearly favoured. At that time no Portuguese civil engineering company had the financial resources and technical experience to promote the project (MEI 2007c, Hirshman 2006). However, within the recent years, also Portuguese companies promoted successfully large PV power sites (e.g. EFACEC; Martifer, Cavalum)

Market knowledge:

As electricity generated form PV systems is currently still much more expensive than electricity generated from conventional sources, the PV market strongly relies on the governmental support. The knowledge about the legislation framework and the procedures for the allocation of licenses is available to the public. The DGGE, a national department responsible for the conception, promotion and evaluation of policies related to PV, monthly informs in the internet about the status of the allocated licenses as well as electrical energy produced by PV in Portugal (DGGE 2009 a, DGGE 2009 b, Certiel 2009 b).

Additional and informal information about the market are in general discussed from person to person at fairs or within assemblies of the three associations (APISOLAR; ASPEF, SPES). No institutional platform or business supplier for market related knowledge has been found during this study.

Strengths and weaknesses of the function *knowledge development and diffusion*

In order to generate economical benefits for Portugal from well functioning TIS, a large number of innovative products manufactured in Portugal are essential. A high transfer rate of scientific knowledge to industrialized products as well as correlated production knowledge is desired. Regarding the assessed quality of research and number of R&D universities, scientific knowledge on future PV technologies is generated in Portugal. Several Portuguese R&D Units were reported to research in the field of promising PV technologies. However, a comparably small number of R&D projects resulted in commercial products. Thus, the connection between industry and research at universities and national research institutes is poor and economic benefits for Portugal low. Additionally, minor support from the academic side regarding the production knowledge for PV technologies was observed. Most of the production knowledge in the manufacturing companies is imported from outside of Portugal.

In order to increase the installation of power capacity based PV technology, a high level of application-specific knowledge of an increasing number of installers and civil engineering companies needs to be ensured. An increase in the number of courses and vocal trainings for installers is needed. Furthermore, for small markets the exchange of application specific and market knowledge via person to person might be sufficient. With increasing size of a sector institutional platforms need to be provided.

The industry and research collaborations in the field of energy system integration are essential for the integration of a large amount of electricity generated from PV electricity in the grid.

3.2.3 Influence on the Direction of Search

The transformation of a national energy system and the associated business sector is a far-reaching alteration affecting economic, social and ecological aspects of Portugal. As currently electricity generated from installed PV power capacity remains expensive, governmental incentives and guidance is of particular importance for the future evolution of the Portuguese PV innovation system (IEA PVPS 2009 b). Therefore, in this section the provided incentives and guidance of search in the Portuguese PV innovation system is reviewed.

Goals and Expectations of the Portuguese Government and the European Union:

No separate strategy or vision for the prospects for PV technology exists currently in the European Union. However, regarding renewable energies, the EU has been working towards a renewable energy supply equivalent to 12% of the total EU's energy consumption by 2010 since 1997. This target was derived from the signed commitment within the Kyoto protocol on the climate change adopted on 11 December 1997 in Kyoto (EU 2007). In 2007 European leaders reached agreement on new targets. By 2020, 20% of Europe's total energy consumption requirements shall be supplied from renewable energy sources (European Parliament 2007). The targets were included in the first common energy policy for Europe which was approved at a meeting of the European Council on 8th March 2007 (IEA 2008). One major objective of this common energy policy is to transform the European Union into a low carbon economy. In addition, the European energy policy aims to improve the competition of energy markets, security of supply and employment prospects. Regarding explicit targets, it was decided to cut at least 20% of GHG emissions from primary energy sources by 2020 and 50% in carbon emissions from primary energy sources by 2050 (the 1990 levels serve as a reference). This leads in turn to challenging goals for energy consumption and renewable energy sources (Commission of the EU communities (2007) :

- Increasing the energy efficiency - achieving a 40% higher efficiency by 2050;

- Diffuse the renewable energy to more than 33% of total primary energy by 2050 (near-term objective 20% by the year 2010)

In general, favourable circumstances for renewable energies are created by the energy policy of the European Union. However, depending on the country different actions are taken and different renewable energy sources are favoured in order to achieve the common energy policy targets. Only within the EU Strategic Energy Technology Plan (SET PLAN) the PV technology is explicitly mentioned. In this technology plan large scale demonstration PV sites are supported (IEA 2008).

As a member of the European Union, Portugal has adapted the European energy policy as described above and defined similar objectives for the national energy policy (MEI 2007 b). In order to meet the requirements of the Kyoto protocol and in compliance with the European efforts to reduce the GHG emissions, specific national targets were defined. In 2001, within the E4 Program (Energy Efficiency and Endogenous Energies), Portugal set the targets to increase the electricity produced from renewable energy sources to 39% of the annual gross electricity production by 2010. This ambitious target was even increased in 2003 to 45 % within the Cabinet Resolution 63/2003 (IEA PVPS 2008). The development of a strong renewable energy sector is seen as a challenge as well as an option to create "… many opportunities: more investigation and technological development, more innovative investment and more jobs" (MEI 2007 b). In terms of PV as one prominent renewable energy technology, the Portuguese government defined a target of 150 MWp installed power capacity by the year 2010. This is a fairly low amount in comparison to the target of other renewable energy sources (e.g. wind 5300 MWp installed by 2010). Due to high costs the Portuguese government does not expect that the photovoltaic technology will have an important share in the next decades. "However, as costs decrease deployment may gain a greater dimension" (MEI 2007 d).

Expectations of the Portuguese economy associated with the photovoltaic innovation system

Due to the wide range of business sectors, expectations regarding the PV growth potential and economical interests a broad variety of visions of the photovoltaic innovation system exists within the Portuguese economy. However, many of those companies that provide technical services or produce industrial goods related to PV are parts of the associations SPES, APISOLAR and APESF. Though these associations have a different focus all of the associations promote the photovoltaic technology and a sustainable growth of the related economic cluster in Portugal (SPES 2005, Herbers 2009, Freitas 2009).

Regarding the expectations of the Portuguese economy for the PV TIS, a large uncertainty was reported in the short term (Arnedo 2009, Freitas 2009). Despite the strong increase of market size in the last two years and the decreasing costs for PV technology, no new short- or mid-term targets have been announced from the Portuguese government side, yet. However, the current targets apply only until the end of 2010.

Surprisingly, the financial crisis and collapse of the 2nd largest PV market in Spain in 2008/2009 has little impact on the Portuguese PV market and the actor's expectations (see Section 4.3.5). This can be mostly attributed to the prices decline for PV modules which dropped within less than 1 year partly more than 30 % (Hug 2009). This decrease compensates the difficulties on the financial market. Also the size of connected markets in other countries is in general expected to increase strongly in the next year (IEA PVPS 2009 a).

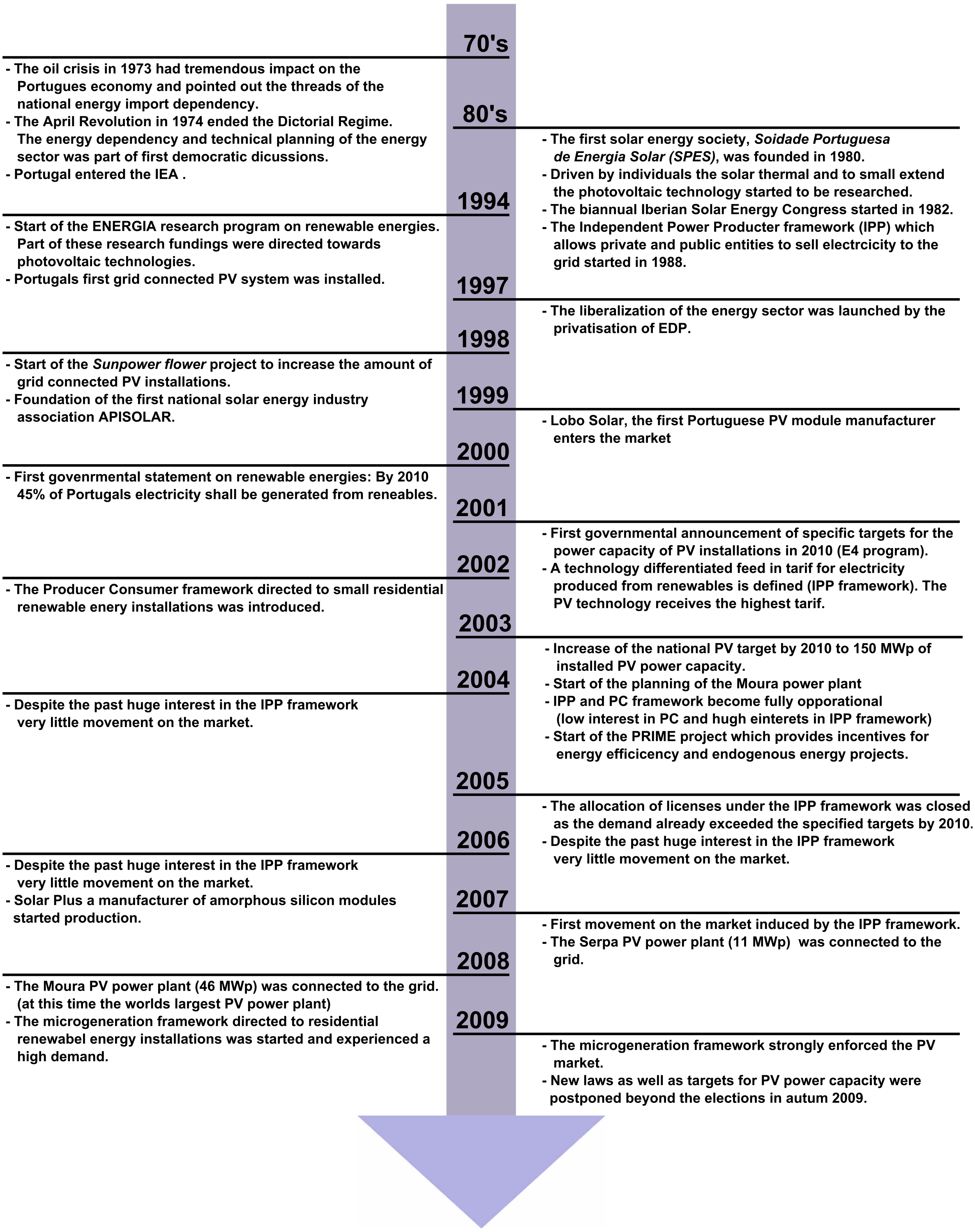


Figure 3-4: Timeline of the Portuguese PV innovation system.

Regulations and policy framework applicable to PV:

Currently, two subsidy frameworks which support electricity generated from PV power capacity are effectively operational in Portugal. On the one hand, the Independent Power Producer (IPP) Framework is mainly directed towards large PV installations. On the other hand, the microgeneration framework exclusively supports small PV installations (< 3.68 kWp). In addition the Producer Consumer (PC) exists; however, it is not considered at all to be financially attractive and was virtually never employed. Both subsidy frameworks apply a fixed FiT which is paid over a guaranteed time of operation.

IPP Framework:

The IPP framework institutionalised the concrete goals specified in the E4 Program of the Portuguese government in 2001 (IEA 2008). The initial Cap of 50 MWp installed capacity of PV by 2010 was increased in 2003 to 150MWp. Since the beginning of allocation process for licenses, which was managed by the DGGE (Directorate General for Geology and Energy), the demand for licenses was high (Rodrigues 2006). In particular in 2004 when all legal conditions of the IPP framework and the allocation procedure became transparent to the actors in the market, the interest in licenses increased tremendously. From 2002 to 2004, about 128 MWp PV were licensed (DGGE 2009 a). Therefore in April 2005, the DGGE closed the allocation procedure for PV installations within the IPP framework. The amount of received requests exceeded the national target of installed power capacity by 2010 by a wide margin (IEA PVPS 2008). Until 2010 no new licenses have been allocated within the IPP framework. However, the realization of several PV installations and solar power plants licensed under the IPP framework took until 2010. Only a very small quantity of licensed power capacity was attributed afterwards to NGOs.

The fixed FiT of the IPP for installations connected since 2005 is guaranteed for either the first 15 years of operation or the first 21 GWh/MWp induced into the grid (MEAOT 2001). Before the last modification of the IPP framework in 2005, the FiT was guaranteed for the lifetime of the plant (MEAT 2005). In general the FiT was considered to be highly attractive (Herbers 2009, Joyce 2009). Once the license was allocated the owner had more than 3 years to accomplish the installation.

Within the IPP framework 85,3% of all installed PV power capacity which was intended to be built until 2010 (governmental objective of 150 MWp) was licensed. Out of the 128 MWp licensed PV power capacity, 120MWp were allocated to large photovoltaic power plants (> 1MWp) (DGGE 2009 a). It was part of the governmental strategy to build large reference projects. The first large photovoltaic power plant in Portugal was connected in January 2007 to the grid. The so called "Hercules" Serpa solar power plant has a power capacity of 11MWp, representing almost 9 % of the capacity licensed under the IPP framework. In the year of its connection to the grid, the cumulative installed PV power capacity connected to the grid increased from 3.42 MWp to 17.87 MWp. This is a more than 5 fold increase of the cumulative installed PV power capacity. Though the "Hercules" Serpa solar power plant was initially promoted by a Portuguese IPP, it was financed and initially owned by GE Electrical financing. The technology was imported from Powerlight Cooperation (USA). Apparently, most of the benefit stayed in foreign countries with little added value for the Portuguese economy (Rodrigues 2006).

An even larger photovoltaic power station was connected to the grid in December 2008. At the time of it´s completion, the Amareleja photovoltaic power station (or Moura power plant) was the world's largest PV power site (Hirshman, IEA 2008, Alves 2008). Currently, it is the third largest photovoltaic power station in the world. It covers an area of 250 hectares. The installed power capacity is 46,4 MWp, enough for around 30,000 Portuguese private homes. The initial owner of the licenses was the Municipality Moura which promoted the project in the initial phase. The municipality negotiated with interested companies also other economical values than exclusively financial interests. After some iteration and negotiations with various potential partners the Spanish energy company Acciona Energia joined the Moura Municipality as a financially capable and technically experienced partner in order to promote the project. The tracking system was provided by a company associated to Acciona. The PV panels were provided by the Chinese PV module manufacturer Yingli. As part of this contract also a PV module assembly facility (invest 7.7 M€) was build aside of the PV power plant by Acciona. Other economic values generated for the Municipality were a 3M € Social fund contributed by Acciona Energia, the construction of a laboratory for renewable energies and the support for research and development (Alves 2008, IEA 2009). However, regarding the total financial volume of the project (invest of 261 M€) and the nationality of the companies gaining experience with this reference project, the additional economic values for the local municipality and Portugal are less significant.

Producer consumer framework

In 2002 the Producer Consumer framework was introduced in the context of demand side policies aiming at small residential installations (< 150kWp) (Rodrigues 2006). It includes a FiT which is differentiated between the technologies. PV gained explicit attention. In all cases within this framework 50 % of the generated energy have to be self consumed. As furthermore the FiT of 0,25 EUR/kWh is much lower and the time for a guaranteed FiT is shorter in comparison to he FiT of the IPP framework this framework was not at all considered to be financially attractive. Virtually no installations were realized under this framework (DGGE 2009 a).

Microgeneration framework

In 2007 the government started to develop an additional subsidy framework for small electric power producers from renewable energy sources, the so called microgeneration framework (Mei 2007). The framework is operational since March 2008 and after some initial problems with the web-based allocation procedure, it has started to stimulate the Portuguese PV market (IEA 2009). The electricity in this framework is sold 100% to the grid.

The maximum interconnection power by installation under this framework is limited to 3.68 kWp. In case of PV crystalline modules this corresponds approximately to the area of half of a roof of a single family house. All installations need to be registered and require a license from the DGGE. The web based registration process is intended to be open once per month (Certiel 2009 b). However irregularities in the allocation phases have been observed frequently in the first year (DGGE 2009 b). After the payment of the registration fee of 250 €, the installation of the system and a final inspection, the owner obtains the permit to connect the system to the grid and start operation. The installations need to be finalized 3-4 months after the payment of the registration fee.

PV receives the maximum tariff of all renewable energy sources. The calculation of the tariff however is somewhat difficult. The initial tariff was 0,65 €/kWh. This tariff decreases with every 10MW installed power. Due to the size of the installations and the highest tariff, PV installations accounted for more than 95% of all grid-connected systems under the microgeneration framework in the first year.

As 128 MWp of the targeted 150 MWp installed PV capacity until 2010 were already allocated within the IPP framework, only a small amount of 22MWp until 2010 was for the microgeneration framework. The annual cap was initially set to 10MW (April 2008 to April 2009). It increases by 20% every year. The fairly high tariff is guaranteed for 5 years and afterward decreases stepwise to the level of the base tariff (MEI 2007).

In contrast to the IPP framework, the microgeneration framework active since March 2008 supports exclusively small installations (< 3.68 kWp). This subsidy framework is has a yearly cap which sums up to 22 MWp and 36.4 MWp of installed power capacity at the end of 2009 and 2010, respectively.

After initial problems with the allocation procedure, the microgeneration framework highly reinforces the market for small size installations (Herbers 2009). Within the first year, the maximum cap of 10 MWp was fully exploited. Especially within the group of wholesalers and installers, the microgeneration framework seems to cause substantial and sustainable growth (Arnedo 2009, Freitas 2009, Joyce 2009). Industry associations like APISOLAR reported an enormous enhanced interested of these actors for the PV sector. The number of members in the association increased tremendously since the microgeneration framework is operational (APISOLAR 2009, Certiel 2009 a).

Strengths and weaknesses of the function *influence on the direction of search*:

Today, electricity generated from installed PV power capacity remains expansive in comparison to conventional sources for electricity generation. Thus, governmental incentives are needed to create an economically favourable situation for the growth of a Portuguese PV TIS. Such incentives have direct implications on the direction of search of search. The current European und Portuguese strategies and objectives regarding energy policies are very supportive for renewable energy sources in Portugal. Both on the European and national level, politicians perceive renewable energies as an option to decrease the energy import dependency and decrease the GHG emission. In general, the Portuguese PV innovation system profits from this political strategy. However, in Portugal other renewable energy sources, namely wind, are favoured. As both wind and PV enjoy excellent conditions in Portugal and wind is currently a cheaper renewable energy source, the PV technology receives less incentives and attention. This way a competing renewable energy source is a threat to the PV innovation system development in Portugal, affecting both, the economic development of the sector and the total amount of installed power capacity in Portugal.

On the policy side, Portugal established three frameworks in the past. At first the IPP framework was introduced. The initial non-transparency of the policy delayed the interest in the subsidy framework. Once the actors on the market perceived the functionality of this subsidy framework, it was highly demanded. The high FiT and a too long timeframe for the completion of the licensed installation caused a contradictory situation. Although all licenses were allocated at the end of 2004, it was not before 2007 that a considerable quantity of installed MWp was connected to the grid. Due to the end of the allocation process in 2005, no new licenses and contracts were accessible in the market until 2008. This is a threat for new innovative and growing actors in the Portuguese PV TIS. The necessary dynamics for an emerging market which is supposed to generate economical prospects for Portugal are blocked.

A second weakness of the IPP is its focus on large scale PV power sites. An illustrative example in this regard is the "Hercules" Serpa power plant. Few economic benefits are generated by large PV power sites which are often promoted, financed and built with foreign expertise and companies. In the case of the Moura power plant, some economical benefits, like the PV assembly facility were explicitly negotiated. This is surely a favourable situation in comparison to the Serpa power plant which was almost 100% realized by foreign countries. However, in comparison to the microgeneration framework, little momentum was provided by the Moura power plant to the Portuguese PV TIS. The microgeneration framework enforced the Portuguese innovation system by involving numerous actors into the TIS. Especially on the installer and wholesaler level, many new entrants have been observed. The large projects provided considerable external attention. The direct economic benefit for the Portuguese TIS however was fairly low.

3.2.4 Promoting Entrepreneurial Experimentation

For the emerging PV innovation system in Portugal, entrepreneurial experiments are essential. Such experiments imply a probing of new technologies, applications and services in various levels of the value chain of PV modules (Bergek et al. 2008). In this section, the entrepreneurial experimentation of new entrants on different market levels were investigated mostly by interviews (see Appendix A).

Installers:
The market size of photovoltaic system increased within the years 2007 and 2008. Especially within the microgeneration framework a large number of small size PV installations were build from April 2008 on. In the first year of the microgeneration scheme more than 3000 installations were licensed and connected to the grid (Certiel 2009 b). Subsequently the PV market gained an increasing attention from installers. Many of these new entrants were formerly active in the climatisation and roofing sector (Certiel 2009 a, APISOLAR 2009). These new entrants in general have a lack of application and technological knowledge.

Wholesalers:

In the past, this segment was mainly dominated by companies with a long term experience in the renewable energy sector in Portugal (e.g. FFSolar, BrightSolar, Donauer). Within the last years companies from the engineering sectors with strong reselling network in Portugal entered the market (e.g. Resul, Martifer). While the installers are mostly from Portugal, many of the wholesalers are from other European countries with branch offices in Portugal.

Civil engineering companies:

The large PV power sites (> 1MW) licensed under the IPP framework were mostly developed by specialized civil engineering companies with project expertise. Usually these companies have former experience in the engineering of larger wind farms (e.g. Genereg, Cavalum, Netplan, Ampersolar, ACCIONA – Spanish). So far no emerge of new entrants exclusively specialized on PV technologies has been observed.

Manufacturing companies:

Of particular interest of the Portuguese government are manufacturers of products associated with the PV TIS. It was mentioned in several interviews that within face to face negotiations that manufacturers who build up new plants in Portugal and create jobs, receive additional incentives and might be favoured in the licensing process (Joyce 2009, Herbers 2009). An illustrative example is the Moura power plant. The license to connect 46 MWp to the conventional grid with the favoured FiT was associated with the commitment to build and maintain a module assembly factory that created more that 100 new jobs.

Until 2007 only a single module assembling manufacturer, Lobo Group, was active in Portugal. Within the last few years, about one new manufacturers per year appeared in the Portuguese PV innovation system. Today there is one thin-film silicon solar cell manufacturer and 5 assembling factories for crystalline modules. There are no relevant Portuguese producers of inverters and electrical solar cell equipment. Two innovative companies manufacturer complementary products and a new photovoltaic concept. WS Solar commercialised a low concentration and tracking systems and Magpower commercialised concentrating PV with Fresnel optics.

Different funds are accessible for new entrants (e.g. European Union (different funds), ADI (*Agência de Inovação* - Portugal), QREN (*Quadro de Referência Estratégico Nacional*), Prime (MEI)). However, despite the financial support, new innovative companies like WS Solar mentioned the lack of institutional support in the initial phase of creating a business (Sorasio 2009).

Strengths and weaknesses of the function *entrepreneurial experimentation*

The number of new entrants differs strongly on the market level. The financial incentives induced a favourable market situation for installers and wholesalers. Especially, within the microgeneration framework small size installations were realized. This business segment is very regional and therefore dominated by actors located in Portugal. Their participation in associations as well as their contribution in the public discussions enforces the political and public legitimacy of the Portuguese PV TIS.

On the manufacturer level, a lack of variety exists. Despite one manufacturer of thin-film silicon solar cells all manufacturers assemble crystalline solar modules. Most of the manufacturers bough the equipment and their production lines as well as the high-tech supply product, silicon wafers, outside of Portugal.

3.2.5 Market Formation

Past market development:

In Table 3-2 and Figure 3-5 the past market development of the Portuguese PV innovation system is illustrated in terms of installed power capacity. The market formation of the Portuguese PV innovation system is reviewed in the following section with respect to these figures.

Year	Off-grid (MWp)	On-Grid (MWp)	Total annually installed power capacity (MWp)	Cumulative installed power capacity (MWp)
Up to 1995	0,30	0,01		0,34
1996	0,09	0	0,09	0,42
1997	0,10	0,01	0,11	0,53
1998	0,10	0,02	0,12	0,65
1999	0,10	0,18	0,28	0,93 or 0,84 *contradictory statistics
2000	0,22	0,08	0,3	1,14
2001	0,13	0,05	0,18	1,25
2002	0,29	0,07	0,36	1,67
2003	0,40	0,01	0,41	2,07
2004	0,55	0,08	0,63	2,70
2005	0,22	0,07	0,29	2,99
2006	0,20	0,23	0,43	3,42
2007	0,20	14,25	14,45	17,87
2008	0,20	49,98	50,08	67,95

Table 3-2: Installed PV power capacity in Portugal Sources: IEA PVPS 2002, IEA PVPS 2009.

Nursing market:

Describing the market development and market formation of the PV sector in Portugal it is important to bear in mind, that up to today the electricity generated with PV installations is comparably expensive. Only for a small number of stand-alone off-grid systems electricity generated by PV installations is economically attractive. Such systems created the first so called "nursing market" for PV installations in Portugal. Until 2007 the PV market development in Portugal was done mostly with stand-alone off-grid PV installations (see Table 3-2). The late development of the grid connected market is however less probable due to the importance of off-grid solutions in Portugal, than the very late market development of grid-connected PV installations and political support.

First experiences with grid connected PV installations were gathered in the Sunflower Project from 1998 to 2002 (Rodrigues 2005, IEA PVPS 2002). Within this project about 250 kWp of power capacity was installed on top of Petrol stations of BP in Portugal and connected to the grid. This quantity represents almost 100% of the grid-connected PV installations until 2003. The importance of this project for the Portuguese market is highlighted in the market data of the year 1999, when the installed power within the "Sunflower Project" overtook the installed power of all stand-alone PV applications.

In 2001, the Portuguese Government launched the "Energy Efficiency and Endogenous Energies Program" (short: the E4 Program), which provided commitment and strategic targets for the PV market. These targets were concretised later that year in the decree-law 339-C/2001. A favourable and technology-differentiated feed-in tariff for grid connected electricity production from renewable energy sources was introduced within the so called independent Power Producer (IPP) framework. Favourable fixed feed in tariffs (FiT) above the actual price paid for conventional energy were guaranteed (MEAOT 2001). Although, the FiT and the period of validity of the FiT was altered frequently in the following years, the high tariff always underlined the intention of the government to enforce strongly the grid-connected PV market in Portugal (MEAOT 2001, MEAT 2005). The initial goal in 2001 of 50MWp installed PV capacity (by 2010) was increased in 2003 to 150MWp (by 2010). The institutionalisation of the market was also manifested in the creation of a national technical committee on PV systems to monitor the European standards (CTE 85).

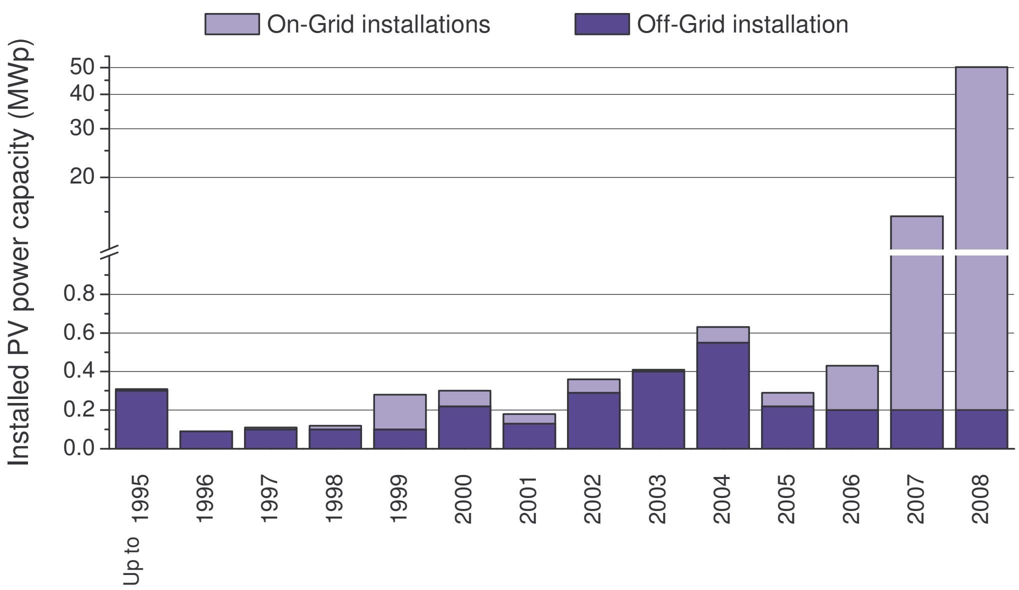


Figure 3-5: Installed PV power capacity in Portugal

Although specific goals were defined in 2001 by the politicians and a favourable FiT was introduced, the PV market in Portugal showed no considerable movement during the years 2002 to 2006. While the market of off-grid installations saturated, the market of grid-connected PV installations showed no enforcement. This is even more surprising, as the demand for licenses under the IPP framework was tremendous (Joyce 2009). Already in the first month of the allocation process under the IPP framework (January 2002), licenses with an accumulated capacity close to the overall objective at that time of 50 MWp (by 2010) were allocated. The rumours about the future increase of the overall objective to 150 MWp (realized in April 2003) kept the demand for licenses high (Rodrigues 2009). Until the end of 2004 128MWp of licenses were allocated. Due to a strong request for licenses that would by far exceed the limit of 150MWp, the DGGE, responsible for the allocation process, had to freeze the licensing process at the beginning of 2005 (DGGE 2009 a). Aside from a small quantity of exceptions this status remains until today for the IPP framework.

Bridging market (from 2007 on):

The launching of the PV market in Portugal from 2007 on can be accounted to financial incentives of two subsidy frameworks, the IPP framework and the microgeneration framework. From 2007 these policy frameworks stimulated the market and helped to enforce the Portuguese PV TIS.

Only in 2007 did the annual installed power capacity of grid-connected installations exceed the annual power capacity of stand-alone off-grid installations. This is remarkably late, considering that already in 2002 licenses with an overall capacity of around 50 MWp of PV installations were allocated. The reason for this is likely correlated to the fact that the majority of the licenses allocated were obtained from the market segment of large photovoltaic power plants (more than 120 MWp out of 128MWp under the IPP framework (DGGE 2009)). These very large installations require a long time of development and planning, leading to a late realization. An illustrative example is the Moura power plant in the Alentjo region. The corresponding licenses of accumulated 46,4 MWp were the first one's allocated in January 2002. They present about 31% of the governmental objective for 2010 (150 MWp). Being fully operational at the end of 2008 the Moura power plant became the world's largest photovoltaic power plant. Another example is the 11 MW photovoltaic power plant in Serpa which was fully grid-connected in 2007.

These two power plants were mainly responsible for the large increase of annually installed grid-connected power in 2007 and 2008, respectively. However, despite the impressive number of installed capacity, most of the noble technology expertise necessary for installing these photovoltaic power plants was originated outside Portugal (see Section 4.3.2). The knowledge created within the Portuguese innovation system is limited to mounting and civil engineering of large installations.

Although small installations could benefit from a higher FiT within the IPP framework, promoters of such systems were not prepared and familiar with the licensing processes (Herbers 2009). Eventually most of the licenses were directed toward the market segments of large installations and photovoltaic power plants. The Producer Consumer (PC) framework created in 2002, initially intended to support the market segment of small residential installations proved to be not attractive at all, due to a lower tariff in comparison to the IPP framework and a mandatory 50% self usage of the generated electricity.

In 2007 the government started to develop a second FiT based subsidy framework directed towards small electric power producer from renewable energy sources. The so called microgeneration framework requires a 100% grid-connected power production. In case of PV as the technology for electricity generation, the installation of 2m² of solar heating is mandatory. In addition licensed capacities need to pass the final inspection within 3-4 months. Due to the small scale of the power generation diff actors on the market estimate that over 95% of the licensed installations are PV based (MEI 2007).

Since April 2008 the microgeneration framework is operational and after some initial problems with the web-based allocation procedure and a lack of transparency in the published statistics, it starts to stimulate the small installations segment of the Portuguese PV market. From April 2008 to April 2009, licensed installations with an accumulated capacity of around 10 MWp registered for the final inspection (Certiel 2009 b). This quantity represents the maximum installed capacity according to the corresponding decree-law 363/2 11 2007. Due to the high FiT, this subsidy framework will very likely create a substantial and sustainable market in the midterm future.

Market segments:

Due to the dependence on financial incentives, the size and segments of the Photovoltaic market are determined primarily by the subsidy schemes and segments therein. In Portugal the microgeneration scheme created a particular market for small grid-connected systems. These PV installations typically cover an area that corresponds to half of a family house roof. The market of other grid-connected photovoltaic installations can be divided in large installations, which are typically installations on large industrial roof, and photovoltaic power plants (or PV power sites) in the MWp range. The market segment of BIPV (Building Integrated Photovoltaic) plays no significant role so far in Portugal. Aside from grid connected installations also off-grid systems create a market segment. Overall in this study the following Portuguese PV market segments have been identified:

- small installations < 5kWp (including microgeneration regime: < 3.68 kWp)
- large installations > 5kWp
- photovoltaic power plants > 1 MWp
- Off-grid (non grid-connected systems)
- BIPV (Building Integrated Photovoltaic)

Strengths and weaknesses of the function *market formation*:

Stand alone PV systems and the "Sunflower project" provided the nursing market for PV technology in Portugal until 2002. A lack of political support limited in this phase the growth of the PV TIS. From 2002 a legal framework (IPP) to support and subsidise the PV innovation system in Portugal was initiated. In general a very positive perception of the IPP framework was observed on the market side, resulting in a very large demand for licenses. However, due to non-transparency of the legal framework and missing enforcement to promptly realize the allocated MWp capacity, the effects of the IPP framework on the market were postponed. From 2002 to 2007 no substantial development of the real market was obtained. This lead to the late development of the Portuguese PV innovation system in comparison with that of other national innovation systems (Jacobson and Bergek 2004, Jelse and Johnson 2008).

From 2007 the market evolved into a bridging market. The amount of annually grid-connected PV installations increased strongly. However, most of the power capacity connected to the grid in 2007 and 2009 originated form large PV power plants which were planed and realized mostly by foreign companies. The economic benefits for the Portuguese PV innovation system were limited. In contrast the microgeneration scheme which exclusively supports small PV installations stimulated significantly the Portuguese PV innovation system directly from April 2008 on.

3.2.6 Mobilization of Resources

These results presented in this section were gathered from various interviews (see Appendix A).

Mobilization of human resources

So far no ominous lack of human resources was mentioned by various actors (manufacturers, installers and wholesalers). However, a continuous demand for skilled labour force in all market segments was reported.

The Portuguese universities have a good international reputation and generate enough skilled labour force for R&D and technology driven market segments. New Master-programs and PhD-Programs with an emphasis on renewable energies were created at different universities in the past years, reflecting the increasing relevance of this sector (see Table 3-1). On the installer side, an increasing demand for training courses for installers has been reported within the last years. Specialized courses for these actors have been organized (e.g. at INETI & FCUL or CENIMAT).

Mobilization of financial resources

Due to the guaranteed FiT for a long time of operation and the long technical guarantees provided for photovoltaic modules (typically 20-25 years) as well as technical equipment such as inverters (typical 10 years) and trackers (typical 5- 15 years), the overall risk of an investment for a PV installation is fairly well assessable. In addition past experiences with the PV technology in other innovation systems (e.g. in Germany since the early 90's) provides a necessary confidence in the technology. Consequently, the financing of PV installations is less problematic if licenses are at hand. In this case low loan rates are usually offered by financing institutes for PV installations. For the increasing market segment microgeneration, some banks included standardized products in their portfolio (e.g. Banco Espirito Santo). Furthermore, wholesalers and installers partly offer support regarding financial investment when promoting a small size installation with the owner (Herbers 2009, Arnedo 2009).

For new, innovative companies, several funds are available. There are a number of funds available under the administration of the European Union and the ADI (*Agência de Inovação* - Portugal). According to S.G., the manager of WSSolar, a young innovative company, it is more difficult to obtain structural than financial support (Sorasio 2009). In addition various programs under the QREN framework (directed by the MEI) provide financial incentives to develop new technologies inside companies. The DEMTEC Program is oriented towards demonstration projects, the SIPIE Program helps in general with the development of an industry sector and the SIME-IDT is intended to enforce industrial research and implementation of innovations.

Complementary assets:

As the Portuguese PV innovation system is a 2nd market much of the technology development was done earlier outside Portugal. This also applies to the typical complimentary assets as complimentary services and products related to the PV technology. Due an intensive connection within Europe to other strong PV innovation system (e.g. Germany) international networks as the PV power systems programme of the International Energy Association (IEA) and the European Photovoltaic Industry Association (EPIA) is also accessible for Portuguese actors. Within Portugal three associations currently explicitly promote the Portuguese PV innovation system (SPES, APISOLAR and APESF)

Strengths and weaknesses of the function *resource mobilization*:

The mobilization of financial and human resources in the Portuguese PV innovation system is progressive as long as financial incentives (microgeneration scheme and IPP framework) generate sufficient confidence. In this case both, financial institutes and employees are willing to turn towards the PV innovation system in Portugal.

3.2.7 Legitimisation

It is difficult to discuss the legitimation of the PV innovation system in Portugal in general. Therefore, this section differentiates the legitimation of the Portuguese PV innovation system regarding the perspective of various actors in the innovation system, the public perspective and some general aspects.

Public legitimisation of the PV technology

Within several interviews performed within this study, actors of the PV innovation system were asked to describe the public perception of PV in Portugal (see Appendix A). According to these interviews, the mainstream considers PV as a promising future energy source. However, it is perceived as being currently too expensive. Only, the beneficial FiT within the microgeneration scheme (introduced in 2008) created a demand for small scale PV installations. For most of the owners of small scale PV installations the feeling to generate their own energy is the most important argument to invest in PV aside of financial benefits. In addition, some of these investors have environmental concerns.

Legitimisation of the PV technology for actors within the innovation system

The increasing number of installers which signed up for the registration as official installers within the microgeneration framework illustrates the increasing importance of the PV innovation system for installers in Portugal since 2007 (Certiel 2009 a). In addition, an increasing number of entrants in the association APISOLAR and a high demand for technical trainings of installers have been reported. The entrance of the PV innovation system into the bridging phase in 2007 can be correlated to an increasing legitimation of the PV innovation system for installers. On the wholesaler side a similar development occurred. Several former wholesalers of other household and installation equipment enlarged their portfolio with PV installations and related products (e.g. Resul).

Within the last two years many of the largest Portuguese engineering corporations (namely Martifer, DST, EFAECEC) have started activities in the PV TIS. They have been involved in the promotion of several PV power sites [Prado 2009]. DST and Martifer even invested in Portuguese module assembling factories. Also EDP, the former state owned electrical energy company created activities on the service side (Maciel 2009). In 2009, EDP was temporarily involved in the promotion of a first Portuguese wafer production which in the end was not realized (Felismoni e Gonçalves 2009). These investments and the interest of the above mentioned corporations in the PV innovation system show an increasing legitimation of the PV technology in the Portuguese economy in general. In addition, an increasing political impact in favour of the PV innovation system is generated.

Some actors of the PV innovation system in Portugal, especially wholesalers and installers, mentioned a strong wind lobby within the renewable energy sector in Portugal. On the one hand this lobby pushes the renewable energy sector in general. On the other side it attracts all the intention on its own technology and suppresses national engagement in the PV innovation system (Joyce 2009, Herbers). Highly influential national corporations like EDP and Martifer are active in the field since the market-take of in 2003 (IEA Wind Energy 2009). Due to the much larger support and allocated licensed under the IPP framework the wind innovation system in Portugal developed much quicker than the PV TIS. Large production sites of wind power components are today located in Portugal creating economical benefits as well as political impact of the sector (IEA Wind Energy 2009).

General aspects of the legitimisation of the PV technology

The PV innovation system in Portugal deals with several intrinsic technological aspects. One hand Portugal has some of the regions with the highest annual solar irradiation in Europe, creating excellent geographical conditions for the use of solar energy (see Section 2.1). Also the success and reliability of the PV technology in neighbouring markets like Spain and Germany induces technological legitimacy (IEA PVPS 2009 b). On the other hand some technical aspects of PV do not match with the current specifications and requirements of the Portuguese electricity sector.

- The amount of electricity generated from a solar cell depends on the intensity of the irradiated solar light. Due to the diurnal circle and a variation of the weather the electricity generated from solar cells fluctuates. Although a seasonable and annual average is well predictable, the short-term electricity generation potential strongly fluctuates in comparison to the fossil fuel or hydro based electricity generation. As no promising technology for the efficient electricity storage is currently available, gaps between the demand side and supply side of electricity generated with PV occurs.
- The price of electricity generated from PV remains currently expensive in comparison to electricity generated from fossil fuels, wind and hydro. The highest FiT tariff for electricity generated from renewable sources is allocated to electricity generated from solar cells in Portugal (MEAT 2005, MEI 2007). The

high costs are often used by opposing lobby groups in Portugal to argue against PV technology (Lusa 2009). Explicitly, the strong wind lobby was mentioned by some actors of the PV innovation system in Portugal which suppresses national engagement in the PV innovation system (Joyce 2009, Rodrigues 2005). Within the last years, however, the prices for PV equipment and modules decreased strongly. Various sources expect the point of grid parity, when electricity generated from PV is as expensive as the electricity generated in the grid, will be reached within the next ten years (IEA PVPS 2009 b).

- In contrast to fossil fuel based electricity generation, PV installations can be highly efficient even in decentralized installations of only a few kWp power capacity. Therefore, PV power supply is often used in stand alone systems. The market segment of stand alone systems provided the initial nursing market for the technology in Portugal. In order to connect a large quantity of on grid PV installations to the Portuguese national electricity grid, the latter needs to be enforced. The Portuguese grid is historically aligned for centralized power generation. In the past, especially the increasing number of wind farms in Portugal created a need for new grid concepts (INESC 2008, REN 2009).

Strengths and weaknesses of the function *legitimation*

Financial incentives and the corresponding growth of the PV market induced a favourable legitimation of the PV innovation system in Portugal for different groups of actors. Regarding installers and wholesalers, especially the microgeneration scheme created prospects for a sustainable market. The long-term prospects related to this subsidy framework strongly increased the legitimacy and attractiveness of the PV innovation system. More and more installers and wholesalers generate essential technological knowledge for the overall increase of the PV innovation system. This way, both, the total amount of electricity generation capacity based on PV as well as economic benefits increase. Furthermore, the increasing activities of large corporations within the PV innovation system shows a generally increasing legitimacy of the PV innovation system in the Portuguese economy, generating essential investments and political impact of the sector. This leads to new manufacturing sites and economic benefits in Portugal.

Solar energy enjoys excellent geographical conditions in Portugal. Especially some regions in the south of Portugal have the highest annual solar irradiation in Europe. In addition, the success of the PV technology in neighbouring European markets generates legitimacy.

The PV innovation system has to deal with some general intrinsic technology specifications which do not match to the current electricity grids and demands. These technological specifications as well as the current high costs lower the overall legitimation of the PV technology. In particular, the current high costs for electricity generated from solar cells are criticised by adverse lobby groups. Of high importance in Portugal is the strong wind lobby, which supports on the one hand the use of renewable energy in general but criticises und suppresses the PV innovation system development.

3.2.8 Development of Positive Externalities

Free utilities are usually developed within a TIS. They increase the attractiveness of the TIS for current actors and new entrants. The availability and number of positive externalities itself is an indicator for the dynamics of a TIS.

Networks:

Aside from a number of international and European associations, currently three associations (APISOLAR, SPES, APESF) exist in Portugal which promote the PV technology and national PV TIS. The associations' general objective is to enduringly increase the use of PV and solar energy in Portugal by raising the public awareness, actively taking part in political negotiations and legislative aspects, supporting research, collaborating with international associations and providing a platform for communication and discussion within the industrial sector (Freitas 2009, Herbers 2009, Mendes and Carvalho 2006 SPES).

- The Sociedade Portuguesa de Energia Solar (SPES) is the oldest association founded in 1980. Initially it was mainly driven by individual interest and commitment to solar energy. Since the beginning many relevant and powerful people in the Portuguese renewable energy sector were member of the SPES, including business men, researchers, professors, engineers, architects and politicians (Mendes and Carvalho 2006)
- The Associação Portuguesa de Indústria Solar (APISOLAR) was founded in 1998 during the nursing phase of the Portuguese PV TIS. This Portuguese industry association consists of companies with manufacturing sites and service bureaus in Portugal. APISOLAR was preliminary mostly oriented towards the solar thermal sector. Only when photovoltaic started to take projection in Portugal, some companies from the PV sector (e.g. Lobo Group) joined.
- The Associação Portuguesa de Empresas de Solar Fotovoltaico (APESF) was founded in 2008. This association focuses explicitly on the PV sector and is open to companies from outside of Portugal. APESF was founded, mainly because some PV companies of medium size did not felt represented themselves by APISOLAR. Both, APISOLAR and APESF are members of the European Photovoltaic Industry Association (EPIA) (Herbers 2009).

In addition the Associação Portuguese de Energies Renováveis (APREN), which was originated in 1988, promotes all different kinds of renewable energy sources in Portugal. The association is a non-profit institution of public interest. However, some actors from the PV TIS state that it is dominated by the hydro and wind sector (Herbers 2009).

Pooled labour market:

As mentioned before, the increasing relevance of the PV TIS in Portugal creates an increasing attention from the employees and education side of this sector. Especially the microgeneration scheme and the small scale installations created a demand for installers with advanced technological and application specific knowledge. New courses for installers have been started in the last years and master program have been started at universities (Joyce 2009).These activities are expected to increase the number of skilled labour in the PV sector in Portugal and generate a pooled labour market.

Specialized suppliers:

As Portugal is a late developing market and neighboured to more advanced markets in Germany and Spain, specialized products are often imported from these TIS if they are not at hand or more expensive within the Portuguese TIS itself. Some specialized wholesalers for PV equipment and installations have emerged in the last years in Portugal (e.g. FFSolar, Bright Solar, Resul). Within this study no products PV related which was explicitly developed for the Portuguese market has been observed. In general, the components of PV installations are mass produced internationally.

Non tradable inputs:

A national technical committee was created which monitors and induced the European and international Photovoltaic standardization (CTE 82). The committee is hosted by the Instituto Electrotéchnico Portugês (IEP).

Strengths and weaknesses of the function *development of positive externalities*

The emerging PV TIS in Portugal has created three associations which promote solar energy in Portugal and create a platform for interaction between the actors in the PV TIS. The diversification of the associations illustrates on the one hand an increasing relevance of the PV TIS. On the other hand the PV TIS faces contradictory interest in the solar thermal and wind power sector. The associations are connected with PV industry associations on the European and international level.

On the supply side of specialized products, the Portuguese TIS profits from connected other international PV innovation systems.

3.3 Summary

In previous sections the functions of the Portuguese PV innovation system were mapped. The section of each function finishes with a short paragraph on the strengths and weaknesses of a function regarding the functionality and the predefined system goals of Section 3.1. In Table 3-3, the strengths and weaknesses are summarized. The relevance and impact of the strengths and weaknesses on the functionality are evaluated for both system goals by +,0 and – representing a strong, somewhat and little impact, respectively.

Function	Strengths and Weaknesses	Relevance	
		system goal 1	system goal 2
Knowledge Development and Diffusion	**Weaknesses:**		
	- low transfer rate of scientific knowledge to industrialized products	+	-
	- lack of production knowledge in industries and R&D units	+	+
	- low capacity of training and institutional platforms for new installers	-	+
	Strengths:		
	- high scientific knowledge base in R&D units	+	-
	- combined investigations on smart grids	+	0
Influence on the direction of search	**Weaknesses:**		
	- politics favour wind more than PV	+	+
	- lack of timelines in past incentive frameworks	0	+
	- large PV power plants have been favoured instead of small PV installations	0	+
	Strengths:		
	- politics generally support renewable energies	+	+
Promoting entrepreneurial experimentation	**Weaknesses:**		
	- lack of variety of manufacturers	+	-
	- most manufacturers bought their entire production equipment and production knowledge from abroad	+	-
	Strengths:		
	- strong increase of installers and wholesalers for PV components	0	+
Market formation	**Weaknesses:**		
	- low political support for PV until 2002	-	0
	- despite the IPP framework was started in 2002 no significant impact on the market until 2007	0	+
	Strengths:		
	- increasing intention to support renewable energies after 2002	+	+
	- strong and immediate impact of the microgeneration framework on the market	0	+
Mobilization of resources	**Weaknesses:**		
	- depends in all segments on financial incentives	0	+
	Strengths:		
	- no considerable lack of resources was identified	+	0
Legitimisation	**Strengths:**		
	- financial prospects and long term orientation of the financial incentives create high legitimisation of PV technology	0	+
	- nation wide economical prospects through entrepreneurs create legitimisation within politicians and the public interest	+	0
	- excellent geographical conditions for PV technology in Portugal	+	+
	- success of PV technology in other European countries	0	+
Development of positive externalities	**Strengths:**		
	- three national associations support PV technology in Portugal	+	0
	- specialized suppliers available in neighbouring markets	0	+

Table 3-3: Summarized strengths and weaknesses of each function.

4. Discussion and Conclusion

4.1 Performance of the Portuguese PV Innovation System

This section reviews the inducement and blocking mechanism which induce, accelerate, delay or obstruct the functions of the Portuguese PV innovation system. The blocking and inducement mechanisms and their impact on the functions are illustrated in Figure 4-1. They have been derived from the strengths and weaknesses of the functional patterns which are described in the previous section.

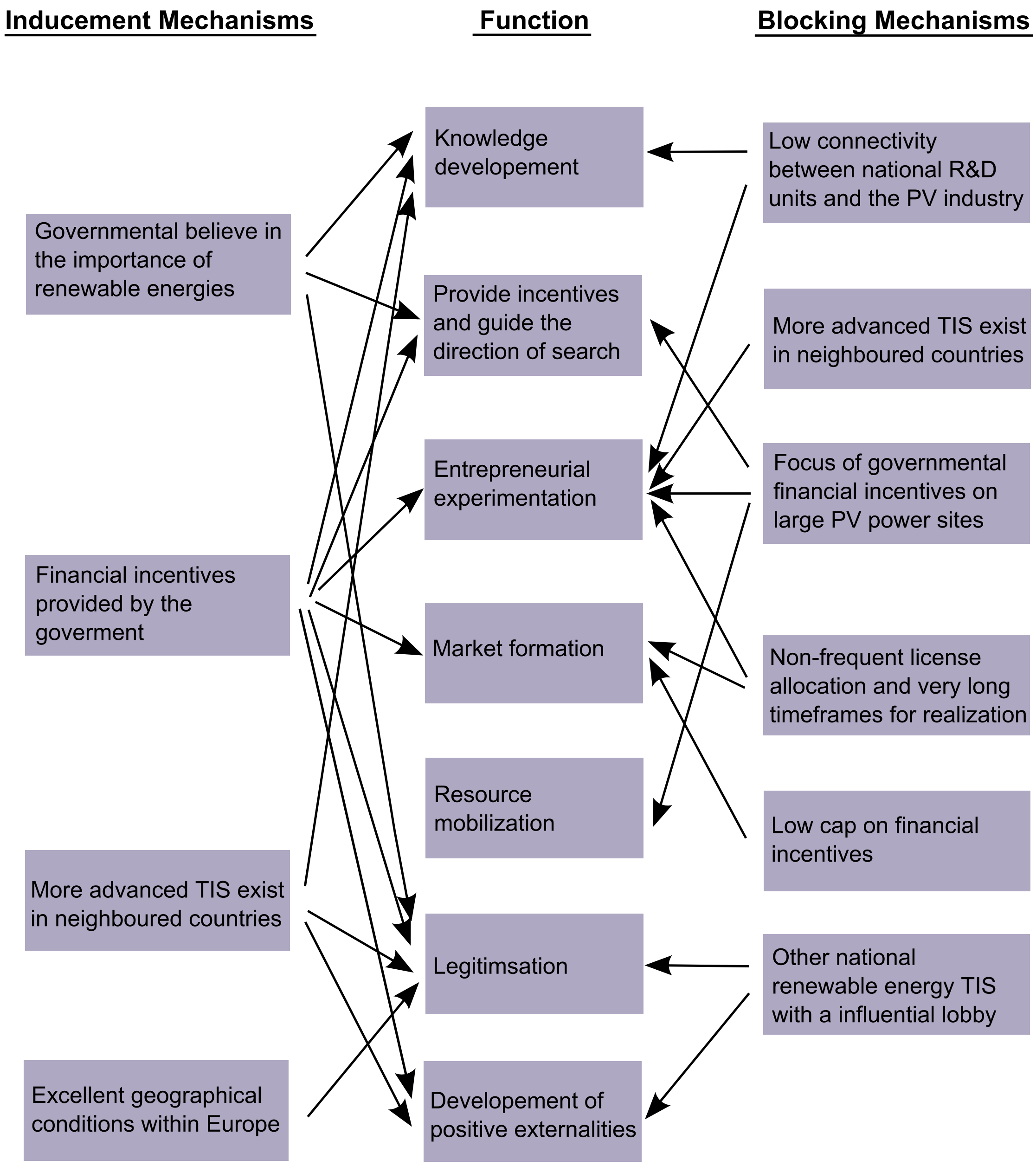


Figure 4-1: Inducement and blocking mechanisms in the Portuguese PV innovation system

Inducement Mechanisms

Four fundamental inducement mechanisms have been identified (see Figure 6-1). Two of them, *"More advanced innovation system exists in neighbouring countries"* and *"Excellent geographical conditions"* are closely related to the initial situation of Portugal being an economy of high application potential and emerging industries in photovoltaic technologies. The other inducement mechanisms, *"Governmental believe in the importance of renewable energies"* and *"Financial incentives provided by the government"* are created by the governmental support of the PV innovation system in Portugal.

More advanced innovation system exists in neighbouring countries

The Portugal PV innovation system is connected to more advanced and developed innovation system in neighbouring countries. The success of the PV technology and the economical benefits of the PV innovation system in these countries generate legitimacy. In addition, the neighbouring innovation systems provide free utilities like specialized products and services to the Portuguese PV innovation system. In this context, these products are free utilities in the sense that they are commercially available and do not need to be developed at high economical expenses within Portugal. Also, the European networks and industry associations are accessible for Portuguese actors. Production as well as technological knowledge which are generated in connected PV innovation system can be transferred to the Portuguese PV innovation system. However, the transformation or purchasing of knowledge will most likely transfer economical benefits outside of Portugal.

Excellent geographical conditions

The south of Portugal is one of the regions in Europe with the highest levels of solar radiation, causing excellent conditions for PV energy conversion. Portugal is most likely one of the first places in Europe where the prices for electricity produced from PV will reach the point of grid parity. Due to the high geographical potential, the PV technology in Portugal enjoys a high legitimacy from politicians.

Governmental belief in the importance of renewable energies

Changing a national energy system is a major alteration. As PV technology remains currently expensive in comparison to conventional energy sources in Portugal, governmental actions are needed to create favourable circumstances for the development of a robust PV innovation system. Within the last 10 years, both on the European and national level, renewable energies have gained attention with politicians. Renewable energies are perceived as a way to decrease the GHG emission and energy dependency. In general, the Portuguese PV innovation system profits from this attention which results for example in financial incentives for the PV innovation system. In addition, due to the increasing national relevance of renewable energies and PV technology several universities and national research institutes started fundamental and applied research on PV technology and system integration in Portugal.

Financial incentives provided by the government

The financial incentives provided by the government are the main inducing mechanisms of the Portuguese PV innovation system. Without financial incentives, PV technology would remain a niche product for a small number of off grid applications of less than 200 kWp annual installed power capacity. The subsidy frameworks introduced by the Portuguese government from 2001 on created favourable economical circumstances for various actors of the PV innovation system and induced the formation of a PV market. The increasing relevance of the PV innovation system for installer, wholesaler manufacturer as well as other economic entities caused the market to enter the bridging market phase. Within the IPP framework and the microgeneration scheme about 128 MWp and 22 MWp of installed capacity will be installed until the end of 2010, respectively. While the IPP favours large PV power sites, small installations (> 3.68 kWp) are supported within the microgeneration framework. This way the financial incentives induce different market segments and guide the direction of search within the PV innovation system. Another market segment is BIPV systems which are currently of no relevance.

With increasing size of the market its legitimacy increases and more actors (e.g. wholesalers, installers and large engineering corporations) directed their attention on the PV innovation system in Portugal. The entrepreneurial experimentation was enforced and financial and human resources became available for the PV innovation system. A couple of module assembling manufacturers and various installers, wholesalers and civil engineering companies entered the PV innovation system. These new actors generated application and technological knowledge. Positive externalities were developed as industry associations and national technical certification committees were founded.

Blocking Mechanisms

More advanced innovation system exists in neighbouring countries

This mechanism is both an inducement and a blocking mechanism. The blocking mechanism affects mostly the entrepreneurial experimentation of manufacturers and the development of production knowledge within the Portuguese PV innovation system. As components of PV installations such as PV modules and inverters are easily transportable at low costs, Portuguese manufacturers face international competition. Being an emerging economy in PV technologies, whose market size developed more than 5 years after advances innovation system (e.g. in comparison to Germany, Japan and China) most of the Portuguese manufacturers lack the time to develop their own production and technological knowledge base. Little production of PV technology components exists currently in Portugal. No production of inverters and wafers, the core element of a crystalline solar cell, exists in Portugal. Aside from one exception (Lobo Group) all module assembling manufacturers in Portugal purchased the production knowledge in foreign countries. In summary, Portugal is missing the production knowledge and manufacturers lack the time and capacity to develop such. Much of the

PV technology needs to be imported and generation of technological and production knowledge is blocked. Consequently, much of the economic benefits are generated outside of Portugal.

Low connectivity between national R&D units and PV industry

PV technology and complementary components of a PV installation are high-tech products. Thus, in order to sustain a strong Portuguese PV innovation system innovative products and services generated in Portugal are essential. Several Portuguese R&D units research on PV technologies, providing a rather high level of fundamental scientific knowledge on PV technologies in Portugal. The transfer rate of this scientific knowledge into the Portuguese PV industry and to manufacturers is rather low. Only a very small number of R&D projects resulted in commercial products. In addition, no knowledge on production processes is developed in national R&D units, creating a lack of production knowledge. The lack of cooperation between R&D units and industry affects the entrepreneurial experimentation of PC component manufacturers in Portugal, resulting in a small number of the latter.

Focus of governmental financial incentives on large PV power sites

In 2003 the Portuguese government enhanced the national target of installed PV power capacity to 150 MWp (by 2010). Within the IPP framework and microgeneration framework 128 MWp and 22MWp of licenses for a favourable FiT were allocated, respectively. Out of the 128 MWp licensed under the IPP framework over 120 MWp were allocated to large photovoltaic power plants (> 1MWp). In addition, the IPP framework was launched in 2002, six years earlier than the microgeneration framework. Thus, the governmental financial incentives were mainly focused on large PV power sites. Due to a missing potential of Portuguese actors within the national PV innovation system, the large PV power sites were in most cases promoted, financed and build with foreign expertise and companies (e.g. Moura power site, Serpa power site). Most of the components were imported and economical benefits were generated outside of Portugal. Only, in the case of the Moura power plant, the foreign promoter of the project did built a back-end PV assembly facility within Portugal, generating some economical benefit in Portugal. In summary, the inducing effect of the financial incentives on the development of the Portuguese PV innovation system is low for large PV power plants. The entrepreneurial experimentation of Portuguese installers, wholesalers, manufacturers and civil engineering companies within the national PV innovation system was obstructed. In contrast the microgeneration scheme which is focused on small size installations formed a long-term PV market for installers, wholesalers and Portuguese manufacturers. An enhanced mobilization of financial and human resources as well as entrepreneurial experimentation was observed.

Non-frequent license allocation and very long timeframes for realization

In 2001 within the E4 Program the Portuguese government set the first fixed targets for installed PV power capacity in Portugal. In 2003 this target was enhanced to 150 MWp of installed PV power capacity by 2010. From 2002 on licenses for a favourable FiT of grid-connected PV installations were allocated under the IPP framework. The high FiT kept the demand high, which exceeded the maximum target by 2004 and the allocation process was stopped. Despite the early allocation of the licenses, only from 2007 has the grid-connected PV power capacity increased. The timeframes for the completion of the licensed PV power capacity were set too long. The market formation was delayed for three to four years. Moreover, no licenses for a favourable FiT were available form 2005 to 2008. Due to the overall cap, all licenses within the IPP framework were allocated until the end of 2004. The microgeneration scheme was only introduced in 2008. Thus, a stop-and-go effect was created. No licenses were available for new entrants in the PV innovation system during 2005 and 2008, decreasing the entrepreneurial experimentation and the mobilization of human resources.

<u>Stronger national renewable energy innovation systems</u>

Within the renewable energy policy of the Portuguese government since 2001 the wind energy sector gained the largest attention in terms of total financial incentives and allocated total grid-connected power capacity. Thus, the wind innovation system in Portugal has developed much quicker than the Portuguese PV innovation system and generated an influential lobby. Although, this lobby supports in general the renewable energy sector in Portugal, it criticises the current high costs for electricity generated from solar cells which decreases the legitimacy of the PV innovation system. As a matter of fact the wind innovation system and the PV innovation system fight for the shares of the financial incentives addressed towards the renewable energy sector. This, within political networks and renewable energy associations, the wind lobby as well as the solar thermal lobby have partly contradictory interests.

4.2 Lessons for economies of high application potential and emerging industries in photovoltaic technologies

In the previous sections of this work, the functionality of the Portuguese PV innovation system has been traced in detail. Blocking and inducement mechanisms were identified. In this section, lessons from these mechanisms are drawn. Furthermore, it is discussed to which extent these lessons can be generalized for other economies of high application potential and emerging industries in photovoltaic technologies. The lessons are sorted in three categories, namely *Lessons related to the initial situation of Portugal being an economy of high application potential and emerging industries in PV technologies*, *Lessons related to the governmental support of the PV innovation system in Portugal* and *Other Lessons from the Portuguese PV innovation system.*

Lessons related to the initial situation of Portugal being an economy of high application potential and emerging industries in photovoltaic technologies.

In Section 4.1 it is shown that the condition of being an economy of high application potential and emerging industries in photovoltaic technologies has produced both inducement and blocking mechanisms for the Portuguese PV innovation system. Due to the intrinsic character of these mechanisms they are transferable directly to other economies of high application potential and emerging industries in PV technologies. Unfortunately, due to the general character, these lessons provide less specific lessons in terms of what to do and what not to do. Nevertheless, the understanding of the mode of operation of these mechanisms provides helpful insights.

The high application potential creates a strong legitimacy of the PV technology.

On the one hand, the good geography for PV applications in Portugal proved to create political legitimacy for the potential and economic prospects of the PV technology in Portugal. On the other hand, the success of the PV technology in other national innovation systems created technological legitimacy which is enforced by the availability of international networks and an accessible knowledge base. In summary, the Portuguese case illustrates well that already the initial situation of being an economy of high application potential and emerging industries in photovoltaic technologies likely enforces the legitimacy of the PV technology. The PV technology is likely perceived in many economies of high application potential and emerging industries in photovoltaic technologies as a promising source for energy and economical benefits. This applies in particular to those countries that can easily link their PV innovation system to advanced foreign PV innovation systems.

The late development of economies with emerging industries in the PV sector induces a particular shortage of time to generate technological and production knowledge

Components of PV installations are easily transportable at low cost. Thus, in times of linked markets, international competition for PV technology related goods is apparent in any PV market. With regard to economies of high application potential and emerging industries in photovoltaic technologies, on one side the knowledge base of international specialists and suppliers is needed and on the other side national actors (e.g. manufacturers) face highly experienced international competition from more advanced foreign PV innovation systems. Thus, the late development of economies of high application potential and emerging industries in photovoltaic technologies is a threat. In particular, the development of a technological and production knowledge base is short on time as the case of Portugal illustrates. Despite a relatively high scientific knowledge base, the lack of time to develop production and technological knowledge was observed to be a threat for many emerging Portuguese actors, in particular manufacturers, with the PV innovation system.

A lack of manufacturing companies within only emerging PV economies decreases the prospects for national economical benefits and reduces the self enforcing mechanisms which are crucial for the development of a strong innovation system. In addition the willingness of politicians to provide financial incentives for an emerging PV innovation system depends very much on the prospects for national (or even regional) economical benefits (for comparison see Bergek et al. 2008).

Lessons related to the governmental support of the PV innovation system in Portugal

A strong national political willingness to support the PV innovation system is indispensable.

The Portuguese case as well as most strong national PV innovation systems (e.g. Germany, Japan) illustrate well that a national political willingness to support the PV innovation system is indispensable. Aside from visions and specific targets, in the case of Portugal financial incentives are needed to develop a PV innovation system as long as the point of grid parity is not yet surpassed. Also numerous institutional barriers (e.g. the connection to the conventional grid, or technical certifications) are difficult to overcome without political support. In the case of Portugal the Section 3.2.5 points out that without political support the PV innovation system would still be restricted to niche markets in Portugal.

This lesson is very general and can be drawn from many national PV innovation systems. The Portuguese case is only one example. Therefore, it is valid for any economy of high application potential and emerging industries in photovoltaic technologies.

Large PV reference projects in the early phase of the innovation system development are less favourable for the development of the national PV innovation system than small PV installations (of similar market size).

In the early phase of the development of the Portuguese PV innovation system the financial and technical capability of Portuguese actors to promote large projects was missing. Thus, foreign companies promote the large reference projects which were supported by governmental incentives. Most of the needed services and products were imported and much of the economical benefits have been lost for the development of the Portuguese PV innovation system. As a result, little application specific, production and market knowledge was generated in the national Portuguese PV innovation system. In contrast the financial incentives for small installations formed a PV market for local installers, wholesalers and manufacturers. Technological and application specific knowledge was generated and legitimacy increased. In conclusion, the study of the Portuguese PV innovation system shows that financial incentives shall be directed towards small PV installations rather that large reference projects.

This lesson is most likely applicable to all economies of high application potential and emerging industries in photovoltaic technologies. All of them face strong foreign PV innovation system. In contrast to small installations, large projects can be processed by foreign companies with very low interaction and employment of the national PV innovation system.

Financial incentives need to be attributed regularly and sustainable.

Within the last described period of development of the Portuguese PV innovation system various political frameworks for financial incentives have been applied. In Section 3.2.3 it is explained that the Portuguese PV innovation system would not have been developed without these incentives. Especially the feed in tariff proved to provide a good framework for the belief of the investors in the continuation of benefits. A detailed study of different frameworks showed that they differ in their success. A sustainable impact on the Portuguese PV innovation system was achieved with such frameworks which allocated the financial incentives regularly and of sufficient extent at low bureaucratic complexity. A severe mistake in the first Portuguese incentive frameworks has been a lack of time–limits for the completions of a PV installation as well as stop- and go-effects in the allocation of licenses.

The lessons drawn in this paragraph from the Portuguese case are well transferable to other economies of high application potential and emerging industries in photovoltaic technologies. First of all the study of the Portuguese PV innovation system demonstrates that the feed in tariff is a very suitable financial incentive scheme. In addition some more specific lessons are extracted which can serve as guidelines for other economies of high application potential and emerging industries in photovoltaic technologies.

Other unique lessons from the Portuguese PV innovation system

A good connection between R&D units and industries is needed

Looking at the Portuguese case, the low connectivity between R&D units and industries was found to inhibit a strong diffusion of innovations into the business segments in the Portugal PV innovation system. This is very counterproductive as a high level of research on PV technologies at national research institutes and universities has been found in Portugal. Thus, in general good basis for the generation of skilled labour and new innovative products exists within the Portuguese PV innovation system.

This lesson is rather specific for the Portuguese case. In general, it might not be the case that economies of high application potential and emerging industries in photovoltaic technologies have strong R&D units. Therefore, this lesson will not generally apply. However, for several Southern European countries it might still be valid.

Stronger renewable innovation system can block the diffusion of the PV innovation system

The case of Portugal nicely illustrates the bipolar relation between the PV innovation system and other renewable innovation systems. On the one side stronger innovation systems in the field of renewable energies helped to advocate renewable energies. In addition, the need for enforced national electricity grids capable of accommodating decentralized power generation as well as the public awareness and political influence is increased. On the other side, stronger innovation systems compete with PV for the amount of financial resources addressed to renewable energies. This can be a major drawback for the PV technology if measures are mainly correlated to current electricity production costs. Today, wind power and hydro power is commonly cheaper than electricity generated with PV technologies.

This lesson is very important for economies of high application potential and emerging industries in photovoltaic technologies. In most cases also other renewable energy sources technologies (e.g. wind and hydro) are of interest for the national energy strategy.

Lessons related to system goals

The two system goals of "generating economical prospects" and "increasing the electricity production capacity based on PV" can be conflicting.

In this work the functionality of the Portuguese PV innovation system was measured on behalf of two system goals which have been derived from the vision of the Portuguese government on the PV technology in Portugal. These two goals are namely "*generating economical prospect for Portugal"* and *"increasing the electricity production capacity based on PV in Portugal"*. They are expected to be of general interest for most economies of high application potential and emerging industries in photovoltaic technologies, as the willingness of any society and government to invest and support PV technology relies very much on the prospects of these two system goals.

In some sense, especially when financial incentives need to be allocated, these system goals can be conflicting. Although, both goals support the PV technology in general, they emphasise different aspects. The first goals, "*generating economic prospects for Portugal from a PV innovation system"* focuses on the economic prospects and opportunities. The second goal "*increasing the electricity production capacity based on PV in Portugal*" focuses on the amount of electricity generated from PV technology.

The analysis of the Portuguese PV innovation system provides one illustrative example for the conflict between the two system goals. Mostly large reference projects have been supported by the Portuguese government in the early phase of the development of the innovation system. Although these projects increased strongly the electricity production capacity based on PV in Portugal, they have generated little prospects for Portugal to develop a long term economical prospects for the PV innovation system in Portugal. The latter conclusion holds in particular, when regarding the amount of financial support which was directed towards these reference projects.

4. 3 Recommendations for the Portuguese PV Innovation System

From the analysis of the blockage and inducement mechanisms of the Portuguese innovation system, three major recommendations have been derived which are suggested to the Portuguese policy makers.

Reinforcement of the applied research institutes and network

A low connectivity between fundamental research and industry has been observed in Portugal. Therefore, in order to make use of the innovation potential and excellent human capital that is generated at fundamental research institutes, the connectivity between industry and research needs to be increased. A well suitable interconnection point can be applied research networks and institutes. These entities help to transfer the knowledge.

In addition, applied research meets more directly the need of the existing manufacturers. Most of the existing manufacturers are active in the field of the module assembling. They face strong international competition with large production capacities and production knowledge. Therefore, in order to support the national manufacturers, production related and more applied research in the field of module assembling is needed.

New long term targets for renewable electricity generation differentiated by technology

In order to decrease uncertainties about future market sizes and economical prospects of the PV technology in Portugal new long term growth oriented targets are needed. Furthermore, once fixed targets for each renewable technology are established in Portugal the common interests of the renewable sector can be aligned and help to overcome common barriers (e.g. the common interest in flexible and strong national electricity grids).

Financial incentives shall be directed more towards small scale installations

The governmental financial incentives directed on large PV power sites induced much less economical benefits for the Portuguese PV TIS than those incentives directed on small scale installations. Therefore a change in the future allocation schemes is needed. Small and medium scale installations shall benefit from much more form the total amount of the allocated licenses.

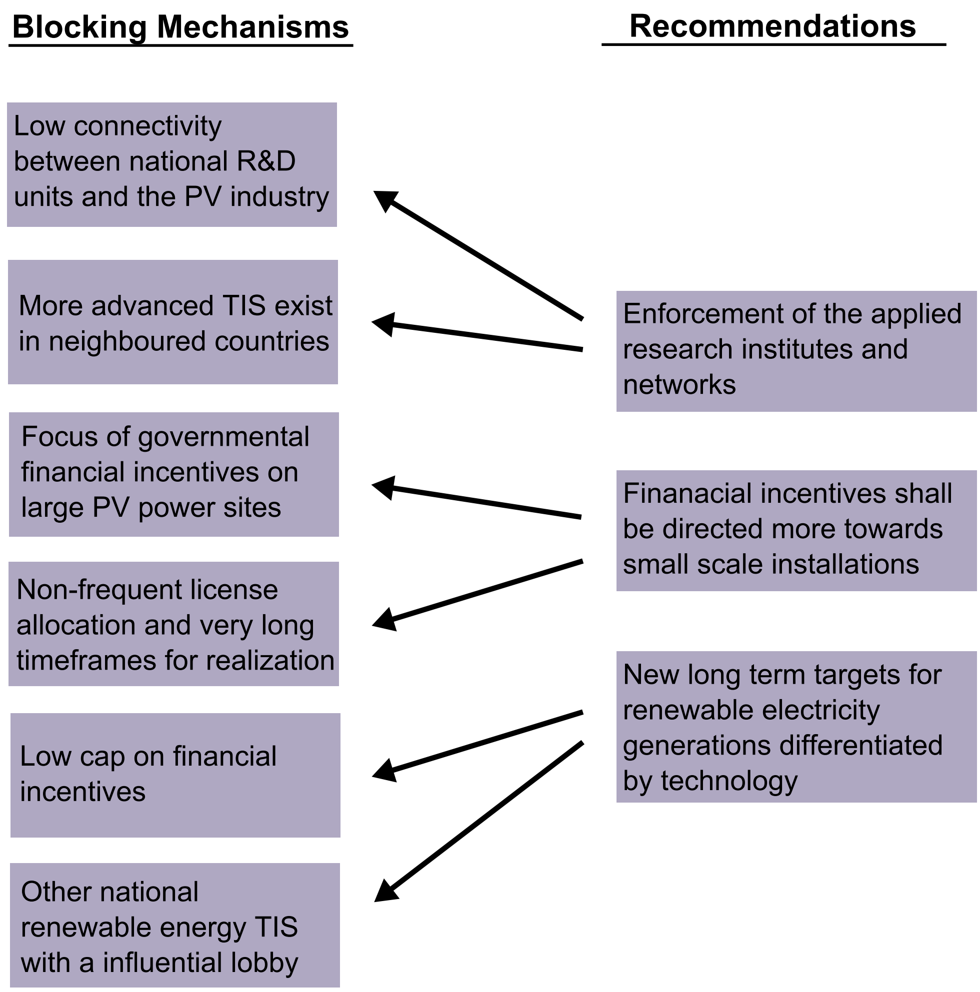


Figure 4-2: Recommendations for the Portuguese PV innovation system.

4.4 Discussion of the Applied Framework and Methodology

In this work the Technology Innovation System framework was applied in order to study the performance of the Portuguese PV innovation system. In a second subsequent step it was analysed whether the analysis of the Portuguese PV innovation system provides lessons to other economies of high application potential and emerging industries in photovoltaic technologies.

Following the TIS analysis step by step, several blocking and inducement mechanisms have been derived for the strengths of important functions within the Portuguese PV innovation system. To the author's perception, the framework provided a very good guideline, both for the process of collection and sorting information and for the analysis. Especially the paper of Bergek et al. (2008), which was written as a practical guideline for analysts, was found very useful. The cross disciplinary view of the TIS on the Portuguese PV innovation system suited well to the snowball principle applied to collect the data. Especially, when considering the rather short time of three month for the data collection, the snowball principle suited well to obtain an as deep as possible insight into the Portuguese PV innovation system.

The identified inducement and blocking mechanisms of the Portuguese PV innovation system lead to some lessons which were sorted in three groups. In a rather heuristic way it was discussed to which extent these lessons apply to other economies of high application potential and emerging industries in photovoltaic technologies. Surprisingly, almost all of the lessons drawn can be generalized at least to some extent to the more general case of economies of high application potential and emerging industries in photovoltaic technologies. Thus, at first sight, the TIS of the Portuguese innovation system suited well to provide lessons for other economies of high application potential and emerging industries in photovoltaic technologies. Nevertheless, in order to prove the general validity of the drawn lessons additional other economies of high application potential and emerging industries shall be studied intensively and the outcomes shall be compared to the presented findings.

Overall, to the author's perception the TIS provides a very good framework to trace the functionality of PV innovation systems in economies of high application potential and emerging industries. Furthermore, it is a good framework to derive more generalized lessons for related markets.

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Appendix

A Attended Events and Performed Interviews

Event	Dates	Location	Organiser
GENERA (Energy and environment trade fair)	12 May 2009	Madrid (Spain)	Instution ferial de Madrid
TEKTONIKA (International construction Fair)	19–23 May 2009	Lisbon (Portugal)	Feira internacional de Lisboa
TECNOFIL (International fair for industry, technology and innovation)	17-21 June 2009	Lisbon (Portugal)	Associação Industrial Portuguesa - Confederação Empresarial (AIP-CE) and Feira internacional de Lisboa
4 journadas da inovação (Workshop on innovations in Portugal, including a subsection (1 day) on solar energy in Portugal)	18-20 June 2009	Lisbon (Portugal)	Agência de inovação (ADI) (Innovation Agenency)

Interviewee	Position	Date	Location	Company / Organisation
Paulo Soares	Commercial manager, assessor of APISOLAR	12 May	GENERA, Madris	Egreen's – Energia e Ambiente, Lda
Pedro Alves	Logistics and Procurement manager	12 May	GENERA, Madrid	Martifer Solar
Pedro Campos Costa	Architect	19 May 2009	Lisbon	Autonomous architect
Miguel Orneias	Project manager	12 Mai 2009	GENERA Madrid	Asunim Portugal
Carlos Jesus	CEO	19 May 2009	TECTONIKA, Lisbon	Bright Solar
Prof. António Moura Joyce	Director	19 May 2009	Lisbon	LNEG / INETI
Pablo David González	Commercial manager	19 May 2009	Lisbon	AS Solar Iberica
Daniel Paulos	Engeneer	19 May 2009	TECTONIKA	Jayme da Costa
Birgit Herbers	Assessor	12 Mai 2009, 20 June 2009	GENERA Madrid, TECTONIKA Lisbon,	APESF and FFSolar

Ana Christina Arnedo	Engineer	20 May 200	Vena do Pinheiro, Potugal	DONAUER Portugal
PhD. Eng. Gianfranco Sorasio	Leading position (CTE)	20 June 2009	Tauguspark, Porto Salvo, Libon	WS Energia Lda
Joana Freitas	Assessor	19 May 2009, 18 June 2009	TECNOFIL, TECTONIKA Lisbon	APISOLAR
Dr. Elvira Fortunato	Associate Professor and Director	19 June 2009	TECNOFIL	Research Centre of Materials (CENIMAT) from New University of Lisbon
Marco Tibéro	Engineer	19 June 2009	TECNOFIL Lisbon	Energias Renovais Lda, LOBOSOLAR
Joaquim Santos	Commercial manager	19 June 2009	TECTONICA Lisbon	Resul
Iolanda Sousa	Head of department energy and environment	19 June 2009	TECNOFIL Lisbon	Net Plan – Telecommunicações e Energia S.A.
Pedro Monteiro	Manager	19 May 2009	TECTONICA Lisbon	DST Solar
Renato Romano	Director of Department	20 June 2009	TECNOFIL Lisbon	DGGE
João Gonçalo Maciel	Head of technology development	19 June 2009	TECNOFIL Lisbon	EDP inovação
Ana Bicho	Engineer	19 June 2009	TECNOFIL Lisbon	Solarplus

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