The evolution of building integrated photovoltaics (BIPV) in the German and French technological innovation systems for solar cells

Master of Science Thesis in Management and Economics of Innovation

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Abstract

Building integrated photovoltaics (BIPV) are photovoltaic (PV) systems, fulfilling a function of a building and therefore allowing synergy effects by substituting the ordinary envelope of a building. The purpose of this thesis is, first, to understand and explain the evolution of BIPV technology within the German and French technological systems for solar cells and, second, to contribute to the theory on technological innovation systems by adding elements from the multi-level perspective on technological transition. We apply the structural as well as the functional analyses described in the technological innovation system (TIS) approach and complete these analyses by elements of the multi-level perspective on technological transition to investigate the evolution of BIPV. Furthermore, conclusions and policy implications are drawn out of a cross-country comparison of the German and French cases.

In Germany, a large amount of resources has been allocated to PV research since the 1970s. Furthermore, since the end of the 1970s a strong green movement emerged favouring renewable energy in general. Demonstration and market formation programmes in the 1990s lay the ground to build the biggest market for photovoltaic systems worldwide in 2007. In contrast, in France 78 percent of the electricity were produced by nuclear power in 2006 and the PV capacity installed is still very low. Photovoltaics have suffered from a low policy interest and the strong resistance of the national electricity utility Electricité de France, blocking their diffusion. Nevertheless, in July 2006, a strong feed-in tariff with a special bonus for BIPV systems was implemented, giving hope to the development of a market and an industry for PV.

First, we conclude that in Germany and France, landscape changes had different impacts on the technological innovation systems for solar cells, which resulted in different paths for their development. The German system has shifted to a growth phase, whereas the French remains in a formative phase. We underline that BIPV systems interact with and face barriers of two regimes: the electricity supply regime and the building regime. Since barriers, such as long permission procedures, from the electricity supply regime against PV remain in France, BIPV are regarded as an opportunity for market formation. Indeed, BIPV may benefit from the support of the building regime and hence overcome barriers from the electricity supply regime. In contrast, in Germany BIPV are seen as a small niche for PV to diversify into.

However, the development of BIPV is hindered by building regime's institutions such as building codes, which require long and expensive certification procedures. In addition, in France the lack of architects involved in BIPV slows down the diffusion of building integrated systems. In Germany a premature lock-in situation favouring additive on-roof systems, may hamper the growth of the BIPV market.

Second, we identified that the TIS theory may not fully cover the transition from one system to another and may lack insights regarding the origin of external forces. Therefore, we suggest that these weaknesses can be reduced by borrowing the niche, regime and landscape levels from the multi-level perspective on technological transition. Particularly, the evolution of BIPV in Germany and France shows the importance of niche-regime interaction for niche formation.

Finally, we highlight lessons for policy makers. In Germany, a premature lock-in situation may hinder the diversification of PV applications such as BIPV whereas in France the fact that the BIPV market may be too small to create an industry with a complete value-chain can be underlined.

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Finally, we want to express our thanks to all the people we interviewed. Without exception, we got helpful remarks and were provided with interesting information. The interviewees enabled us to understand deeply the topic and to come up with reliable conclusions.

Contents

List of Figures

List of Tables

Abbreviations

a-Si	Amorphous silicon
ADEME	French Environment and Energy Management Agency (Agence de l'environnement et de la maîtrise de l'énergie)
AFME	French agency for the mastery of energy (Agence Française pour la Maîtrise de l’Energie)
ANR	French National Agency for Research (Agence Nationale de la Recherche)
BIPV	Building integrated photovoltaics
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
BSW	German Solar Industry Association (Bundesverband Solarwirtschaft)
c-Si	Crystalline silicon
CdTe	Cadmium telluride
CEA	French atomic energy centre (Commissariat à l’Energie Atomique)
CIS	Copper indium diselenide
CLER	French professional association for renewable energy (Comité de Liaison des Energies Renouvelables)
CNRS	French national scientific research centre (Centre National de la Recherche Scientifique)
CO_2	Carbon dioxide
CDU	Christian Democratic Union of Germany (Christlich-Demokratische Union Deutschlands)
COMES	French solar energy authority (Commissariat à l’Energie Solaire)
CSPE	French contribution for electricity public service (Contribution au Service Publique de l’Electricité)
CSS	Creative Solar Systems
CSTB	French Scientific and Technical Centre for Building

	(Centre Scientifique et Technique du Bâtiment)
CSU	Christian Social Union of Bavaria (Christlich-Soziale Union in Bayern e.V.)
Cu_2S/CdS	Copper sulphide/cadmium sulphide
DAB	Deutsches Architektenblatt
dena	German Energy Agency (Deutsche Energie-Agentur)
DGEMP	French general directorate for energy and raw materials (Direction Générale de l'Énergie et des Matières Premières)
DGS	German Society for Solar Energy (Deutsche Gesellschaft für Sonnenenergie)
Dideme	French directorate for energy demand and energy markets (Direction de la Demande et des Marchés Énergétiques)
DRIRE	French regional representation of the ministry of industry (Direction Régional de l'Industrie, de la Recherche et de l'Environnement)
EDF	Electricité de France
EEG	German Renewable Energy Sources Act (Eneuerbare-Energien-Gesetz)
EU	European Union
FACE fund	French fund for amortization of electrification costs (Fonds d'Amortissement des Charges d'Electrification)
FIT	Feed-in tariff
FVS	German Research Association for Solar Energy (ForschungsVerbund Sonnenenergie)
GW_p	Giga Watt peak
HBO	Building regulation of Hesse (Hessische Bauordnung)
INES	French National Institute for Solar Energy (Institut National de l'Energie Solaire)
IEA	International Energy Agency
ISE	Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg (Germany)
kW_p	kilo Watt peak
MW_p	Mega Watt peak
NGO	Non-governmental organisation

POPE	Energy framework policy law (Loi de Programmation fixant les Orientations de la Politique Énergetique de la France)
PV	Photovoltaics
PVPS	Photovoltaic Power Systems Programme of the IEA
RDD	Research, Development and Demonstration
RST	Ribbon Silicon Technology
RTD	Research and Technology Development
SER	French syndicate representative of the PV industry (Syndicat des Energies Renouvelables)
SPD	Social Democratic Party of Germany (Sozialdemokratische Partei Deutschlands)
Sqm	Square meter
TIS	Technological innovation system
US	United States of America
VAT	Value-Added Tax
W_p	Watt peak
ZSW	Centre of Solar Energy and Hydrogen Research in Stuttgart (Germany) (Zentrum für Sonnenenergie- und Wasserstoff-Forschung)

1. Introduction

The ongoing discussion on climate change, supported by the recently published Intergovernmental Panel on Climate Change's fourth assessment report (IPCC, 2007a; IPCC, 2007b; IPCC, 2007c), imposes pressure upon CO_2 releasing energy technologies. Moreover in March 2007, the European Union (EU) established a mandatory target that 20 percent of the energy consumed in the EU should come from renewable energy sources by 2020 (Commission of the European Communities Brussels, 2007). In order to build an energy system that is based on CO_2 neutral renewable energy, lock-in mechanisms supporting carbon-based technologies have to be overcome (Unruh, 2000; Unruh, 2002). Consequently, building a sustainable energy system necessitates an improved understanding of key processes in development, diffusion and utilisation of new technologies, and associated emergence and growth of new technical systems.

Buildings account for at least 40 percent of energy usage in the world and 84 percent of the life cycle energy requirement of a building are spent during its use phase for heating, air conditioning, ventilation, lighting, hot water, etc. (World Business Council for Sustainable Development, 2007). Energy efficiency of buildings is thus a major challenge both for actors from the energy sector and the building industry. One solution is the integration of renewable energy into buildings. Particularly, the vision of zero net energy buildings has emerged, which means that the building as a whole produces as much energy as it consumes over a one year period (World Business Council for Sustainable Development, 2007).

One technology, which is particularly regarded as promising is solar cells to produce electricity, also called photovoltaics (PV). The *photovoltaic principle* is the production of electricity out of sunlight. One special application for PV is the integration into a building. These systems are called building integrated photovoltaics (BIPV) and give the possibility to use synergy effects by substituting the ordinary envelope of a building by an electricity producing unit: photovoltaics replace normal construction materials (tiles, slates, windows, sun shades, etc.). Thus, BIPV can be regarded as a great opportunity for PV to find a broad market.

BIPV's first appearance worldwide was as roof integration in Germany in 1985 (Stark et al., 2005). Again in Germany, the first facade integration took place in 1991 (Benemann et al., 2001). In recent years, Germany was still seen as the world leader in roof-integrated solar cells (Maycock, 2000), and has developed the biggest world market for solar systems (see *Appendix A*).[1] On the contrary, in France the PV market is less developed. Nevertheless, in 2006 France was the first country to implement policies favouring BIPV in general, resulting in a fast rising interest in BIPV. Thus, both Germany and France are of particular interest for the evolution of BIPV.

However, PV and therefore BIPV still rely on subsidies in order to be competitive. Indeed, the diffusion of PV on larger markets is required to reduce costs. Yet, this diffusion is also hampered by high production costs (Sanden, 2005). As a result, subsidies serve to increase sales and therefore companies' learning, which allow cost reduction.

Scholars suggest different approaches to study emerging technologies. In particular, the innovation system approach is used to analyse the development of an industry. Several concepts have been developed in the literature; however, this study deals with the technological innovation system (TIS) approach. TISs focus on networks of agents for the creation, diffusion and utilisation of knowledge, and can be used to analyse one or several technologies or products simultaneously (Carlsson et al., 2002). Bergek et al. (2006) emphasize in particular a set of functions that shape the TIS. A functional analysis can be used in order to assess the performance of emerging TIS. Furthermore, policy challenges to foster a special technology or product can be identified.

However, the TIS approach has weaknesses. In particular, the technological transition from one system to another is not sufficiently developed. In order to overcome these drawbacks we borrow elements from the multi-level perspective on technological transition, which is notably suitable to study shifts from one technical system to another and helpful to understand the origin of external forces (Geels, 2002; Geels, 2004).

The purpose of this thesis is twofold. First, it aims at understanding and explaining the evolution of building integrated photovoltaics technology within two different countries – Germany and France. The performance of the technological innovation systems of solar cells and the evolution of BIPV are analysed. We apply structural as well as functional analyses described in the technological innovation system approach completed by the multi-level perspective on technological transition. In addition, a cross-country comparison of Germany and France is used to provide recommendations for policy makers. The goal of these

[1] The German market is the biggest world wide in 2007, taking all PV solutions into account where BIPV represents only a fraction. Most systems are installed as so called additional systems on the roof or on an open space.

recommendations is notably to help policy makers to identify critical inducing and blocking mechanisms and define priorities for the development of PV and especially BIPV. Second, this thesis aims at contributing to the theory on innovation system analysis by identifying weaknesses in the TIS framework, comparing the TIS approach with the multi-level perspective on technological transition and proposing improvements. Thereby, elements from the multi-level perspective are added to the TIS theory. Implications will be drawn out of the case-studies of building integrated photovoltaics in Germany and France.

The thesis is organised as follows. Section 2 introduces a theoretical framework based on technological innovation systems and the multi-level perspective on system innovation by describing and comparing both. Afterwards, elements from the multi-level perspective are added to the TIS approach. Section 3 contains the methodology used to gather data and discusses the reliability of this investigation. In section 4, the evolution of BIPV within the technological innovation systems for solar cells in Germany and France is portrayed and compared. Finally, section 5 concludes and discusses the results.

2. Theoretical framework

In order to understand and explain the evolution of solar cells in Germany and France a model of the system and how systems change needs to be developed. In the following section the theoretical framework consisting of the technological innovation system, introduced by Carlsson et al. (1991) and advanced by Carlsson et al. (2002) and Bergek et al. (2007), and the multi-level approach on system innovation, presented by Rip et al. (1998), Geels (2002) and Geels (2004), is introduced.

2.1. Technological innovation system[2]

An innovation system can be seen as a system in a general sense, in regard to a configuration of parts linked and combined together by relationships (Bergek et al., 2007). The Oxford English Dictionary (2007c) defines a *system* as *"a set or assemblage of things connected, associated, or interdependent, so as to form a complex unity."*

Several innovation system approaches can be found in the literature: national innovation system, regional innovation system, sectoral innovation system and technological innovation system. National innovation systems focus on national boundaries, the importance of non-firms organisations and institutions, and can include a cross-sector study (Freeman, 1987; Lundvall, 1992; Nelson, 1993). Regional innovation systems are similar to national ones but target a special region (Cooke et al., 1997). Sectoral innovation systems can be used to analyse a sector or an industry, sharing a particular technological regime, which can change over time (Malerba, 2002). Technological innovation systems, introduced by Carlsson (1995) and Carlsson (1997), focus on networks of agents for the creation, diffusion and utilisation of knowledge, and can be used to analyse one or several technologies or products simultaneously (Carlsson et al., 2002).

The technological innovation system is chosen since this approach is particularly appropriate to assess the performance of young industries (Bergek et al., 2006). In order to achieve industry growth and knowledge diffusion, a combination of the strengths of different actors is needed, which can be estimated using the TIS. Furthermore, the TIS enables an investigation that focuses on only one product or technology (Johnson and Jacobsson, 2003). In contrast, the national, regional or sectoral innovation system approaches can deal with a broader scope and are more appropriate to study general economic growth.

[2] This section draws heavily on Bergek et al. (2007), Bergek et al. (2006) and Carlsson et al. (2002).

2.1.1. Structural level of the system

Any kind of geographical boundaries can be determined for a TIS, e.g. a regional or national boundary can be chosen (Carlsson et al., 2002). Carlsson et al. (1991, p. 111) define a technological innovation system as 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."* This implies the existence of at least three components within a technological innovation system: *actors*, *networks* and *institutions* (Jacobsson and Bergek, 2004). Additionally, the *technology* itself and in particular artefacts can be added as another component (Bergek et al., 2006). An explanation of the elements follows:

- *Technology* combines knowledge and artefacts (Bergek et al., 2006). Knowledge can either be located as competence within *actors*, which is called tacit, or be codified as well as embedded in artefacts, which refers to explicit knowledge (Polanyi, 1967).

- The *actors* within a TIS cover all firms within the whole value-chain as well as other organisations (Bergek et al., 2007). For instance *actors* are: companies, individuals, banks, universities, research organisations, government bodies, industry associations and interest organisations (Carlsson et al., 2002). The entry of firms into various stages of the value-chain is considered as the central process of an emerging system (Jacobsson et al., 2004).

- *Institutions* regulate the *actors'* interrelation (Edquist and Johnson, 1997), define the value base of various systems in society and structure learning processes like guiding principles and ways to do business (Bergek et al., 2007). They appear as hard regulations controlled by juridical systems and as norms and cognitive rules controlled by social systems (Bergek et al., 2006). Since *institutional* change is fundamental for new *technologies* gaining ground, companies in competing TIS compete not only in the market but also to increase influence over *institutions* (Bergek et al., 2007).

- *Networks* emerge when links, which turn separated components into a system, are built (Bergek et al., 2006). As their appearance follows not automatically from the entry of organisations into the TIS, the *actors* have to foster the formation of valuable *networks*. Different types of *networks* stand out: *learning networks* connect suppliers and users, related firms or competitors as well as universities to industry in order to transfer tacit and explicit knowledge and guide future expectations and possibilities; *political networks* aim at influencing the political agenda, based on shared beliefs, in competition with other advocacy coalitions (Bergek et al., 2007). Smaller *technolog*y specific coalitions need to be formed, to enlarge the resource base of the individual company in terms of knowledge and information, accompanied by an engagement in broader non-*technology* specific alliances for a wider political voice, e.g. PV advocates and a coalition for renewable energy in general (Bergek et al., 2007).

Some of the mentioned components belong exclusively to the TIS; others may be shared by several systems simultaneously. In general, the younger a TIS, the more elements are overlapping and thereby the higher the dependence on other systems (Bergek et al., 2006).

Nevertheless, during the emergence of a radically new *technology*, only few of the structural components are established (Bergek et al., 2007). The TIS has to go through a formative phase where all the elements emerge (van de Ven, 1993). Hence, according to Jacobsson and Bergek (2004) three structural processes are outstanding in this phase: the entry of firms and other organisations, the formation of *networks* and *institutional* alignment. This phase is particularly characterised by: high uncertainty for all *actors* in terms of technologies, markets and regulations; and, many small changes resulting in a cumulative process, possibly lasting for decades (Bergek et al., 2006). In a formative phase TISs are mainly influenced by external forces since the components are less developed (Bergek et al., 2006), therefore identifying blocking and inducing mechanisms is of great importance. However, the more a system grows, the more endogenous factors are strengthened (Sandén and Jonasson, 2005) and the more the system can overcome blocking mechanisms or foster inducing mechanisms on its own.

When all the components of a TIS are put in place, a shift to a growth phase is possible (Carlsson, 1997). Caused by a change in any element in the system such as a technological breakthrough or *institutional* changes favouring the new TIS, a self sustained evolution may occur. A series of reactions of positive feedbacks can arise, which leads to cumulative causation (Myrdal, 1957); thus, virtuous circles strengthen the TIS like new entrants generating positive externalities and thereby reducing the entry costs for following entrants (Bergek et al., 2007). The TIS as a whole is boosted; however, each single *actor* does not necessarily benefit from the positive evolution.

Further positive feedback can finally lead to a mature TIS, which is based on a steady structure and is stable against external forces (Bergek et al., 2006). Nevertheless, stable systems need to be aware of lock-in mechanisms hampering further evolution (Unruh, 2000).

The introduced level of analysis was solely structural. A second level helps to assess the performance of a system and to explain the dynamics driving a TIS by introducing eight functions, which are directly related to the development, diffusion and utilisation of innovations (Bergek et al., 2006). However, they are not directly connected to a special component; each function may have an impact on several components and vice versa (Bergek et al., 2007).

2.1.2. Functional level of the system

This functional level of analysis aims at identifying strengths and weaknesses of the system, i.e. inducement and blocking mechanisms (Bergek et al., 2006; Bergek et al., 2007). Functions are created and influenced by the different elements of the innovation system mentioned in *2.1.1.* and by exogenous factors. Hence, functions of TISs are described as *"key processes driving the dynamics of any TIS"* (Bergek et al., 2006, p. 6). They help to capture the dynamics within the system. In addition, it is vital that policy makers try to influence the functions in order to strengthen a system and to overcome barriers to development.

There are two main reasons for analyzing the TIS in both functional and structural terms. First, it helps to define the borders of the system, i.e. until where we consider an element as a part of the system. Second, as mechanisms within the system are hard to identify, it is often necessary to add the functional level of analysis in order to understand the relation between the structure of a system and its performance (Jacobsson and Bergek, 2004; Jacobsson et al., 2004).

Eight functions are described by Bergek et al. (2006):[3]

- **Function 1:** ***Development of formal knowledge***

  This function deals with the size of the *knowledge* base and the diffusion of this *knowledge* within the TIS (Bergek et al., 2006). The *development of formal knowledge* is directly influenced by academic research, and applied research at the firms level as well as indirectly by processes of learning by doing, learning by using or imitation

[3] The description of the functions is largely based on Bergek (2006).

(Bergek et al., 2007). This function also refers to how the *knowledge* is combined in the system and exploited by the system.

- **Function 2: *Entrepreneurial experimentation***

Entrepreneurial experimentation is the transformation of *knowledge* into concrete actions, business opportunities or technical experiments. This function is strongly related to the first function since it represents the tacit dimension (Polanyi, 1967) of *formal knowledge*, and therefore, generates *knowledge* in a more explorative way (Bergek et al., 2006).

This function is of particular interest when it comes to technological development. Indeed, technological change is characterised by high uncertainty at both early and later phases (Rosenberg, 1996) and *entrepreneurial experimentation* is a way of handling uncertainty (Bergek et al., 2007). Feedbacks from different *actors* (Raven, 2005) about experiments can improve the *knowledge* base and hence decrease uncertainty. Of course, entrepreneurship involves risks and it is likely that some firms fail in developing technologies.

- **Function 3: *Materialisation***

Materialisation refers to the development of artefacts, e.g. products, production processes and complementary products. Complementary products can include prototypes, products and components, production technology and infrastructure (Bergek et al., 2006).

- **Function 4: *Influence on the direction of search***

Firms and other organisations' vision may be influenced by factors such as incentives, pressures, and blocking and inducing mechanisms. These hinder or foster the entrance of new firms into the system and firm's perceptions of entrepreneurial opportunities. According to Bergek et al. (2007), the factors' strength is the combination of several points: visions and belief in growth potential, *actors'* perceptions of the relevance of different types and sources of *knowledge*, regulations and policy, articulation of demand from leading customers, and technical bottlenecks. Both *actors* within or outside the system can be influenced by the *direction of search*.

- **Function 5: *Market formation***

During the emergence of the TIS there might not be a market big enough to develop the system. The early phase of a TIS is usually characterised by a lack of demand from customers and a lack of advantages like poor technical performance or low economic benefits. As a result, there is a need for a nursing market (Bergek et al., 2007). Such protected spaces allow firms and organisations to start a learning process and expectations for *technologies* can be generated (Kemp et al., 1998). We identified two ways of protecting spaces. The first one is a technological protection. Firms or organisations identify niche markets (Schot et al., 1994) or market segments in which the *technology* has a competitive advantage which compensates the disadvantages (Bergek et al., 2007). The second one is institutional protection. Policy makers create a competitive advantage for the *technology* through regulations (Bergek et al., 2007). One particularity of the institutional protection is its focus on the short term: governments usually implement regulations for a limited period of time, e.g. the 1 000 Rooftops Solar Electricity Programme in Germany from 1990 to 1994.

Later on, nursing markets may be followed by bridging markets (Andersson and Jacobsson, 2000) in which volumes increase and the TIS can grow. Eventually, if the TIS is successful, a mass market might be reached. It is important to notice that such a process may take several decades (Bergek et al., 2007).

- **Function 6: *Resource mobilisation***

Resource mobilisation assesses the ability of a TIS to develop human capital (scientific and technological education, entrepreneurship, management and finance), financial capital (investments in ventures, subsidies, special loans, etc.) and complementary assets (complementary products, services, etc.) which are needed for the TIS's development (Bergek et al., 2007).

- **Function 7: *Legitimation***

Legitimacy is a condition required to create a new TIS (Bergek et al., 2007). In other words, there is a need for recognition from relevant *actors* in order to *develop resources*, demand, political strength of *actors* in the new TIS and expectations among managers (Bergek et al., 2006; Bergek et al., 2007).

Hence, a process of *legitimation* helps the TIS to overcome barriers to change. However, this process might take a long time since the new TIS is embedded in an established broader environment and has to compete with established technologies. The new TIS might meet strong resistance from incumbent systems and parties with vested interests (Bergek et al., 2007).

At the emergence of the TIS, new *actors* stand alone and have almost no lobby or political power. In order to reach success and political strength, *actors* have to create advocacy coalitions (Aldrich and Fiol, 1994; Suchman, 1995). These advocacy coalitions should be able to balance incumbent political forces and foster the process of *legitimation*.

Finally, standardisation procedures can strengthen *legitimation* of a TIS. In particular, it is argued that governments may participate in standardisation procedures (Sandén and Azar, 2005). Standardisation occurs when one design among several competing ones becomes dominant and reaches a mass market. Standardisation enables economies of scale, faster diffusion and learning, and reduces uncertainty (Sandén and Azar, 2005).[4] As a result, standardisation helps systems to shift from the formative phase to the growth phase. Nevertheless, there are downsides to standardisation which might hinder the development of a system. It could be advocated that systems should generate product variety in high uncertainty environments (Jacobsson et al., 2004). Indeed, on the one hand, product variety fosters *technology* development and performance. On the other hand, product variety involves low volume production and thereby less economies of scale (Jacobsson et al., 2004). Thus, there is a need in every system to balance the conflict between volume and variety.

- **Function 8:** ***Development of positive externalities ("free utilities")***

Positive externalities are defined as benefits generated by activities that the investor cannot fully appropriate. These benefits could for example be in terms of *knowledge development*, reduction of uncertainty and strengthened *legitimacy* (Bergek et al., 2007). Furthermore, the more new entrants get into the TIS, the more *positive externalities* arise.

[4] Economies of scale allow for high volumes and cost savings for production.

It is important to notice that these functions are not independent of one another. Indeed, the evolution of a function might influence another function (Johnson and Jacobsson, 2003). For instance, the *entrepreneurial experimentation* upon a particular *technology* will certainly influence the *development of knowledge* through feedbacks. In addition, virtuous circles, which are central to a development process, may appear in the functions and hence result in cumulative causation (Myrdal, 1957). This may lead to a self sustained technological innovation system (Jacobsson and Bergek, 2004).

Thus, the TIS approach helps us to explain the development, diffusion and utilisation of new *technologies* by giving a structured framework to analyse an emerging system. Furthermore, it provides guidelines to assess the system's performance.

Nevertheless, the TIS approach has drawbacks. Firstly, it lacks the description of the transition from one system to another. The TIS theory focuses on the growth of the system itself and the importance of substituting other systems is not highlighted. Secondly, although external forces are mentioned in the TIS framework, this theory does not direct attention on these forces' origin. It is particularly difficult to locate the TIS within a broader environment. Thus, the TIS framework aims at explaining dynamics within the system and does not centre on its surroundings.

Therefore, to overcome weaknesses of the TIS approach the multi-level perspective is introduced in the following.

2.2. Multi-level approach[5]

When studying the dynamics of an innovation system and the emergence of a new *technology*, it is important to understand *why* and *how* a transition from one system to another could happen. The TIS framework described above refers to this by the shift from a formative phase to a growth phase which may lead to a mass market (Bergek et al., 2007). Nevertheless, the TIS framework lacks of deep information regarding the process of transition from one system to another.

Consequently, we add aspects of the multi-level approach, developed by Rip, Kemp and Geels (Rip and Kemp, 1998; Geels, 2002; Geels, 2004), to our theoretical framework. Geels defines three levels: *regimes*, *niches* and the *landscape* (see *Figure 1)*.

[5] This section draws heavily on Geels (2002) and Geels (2004).

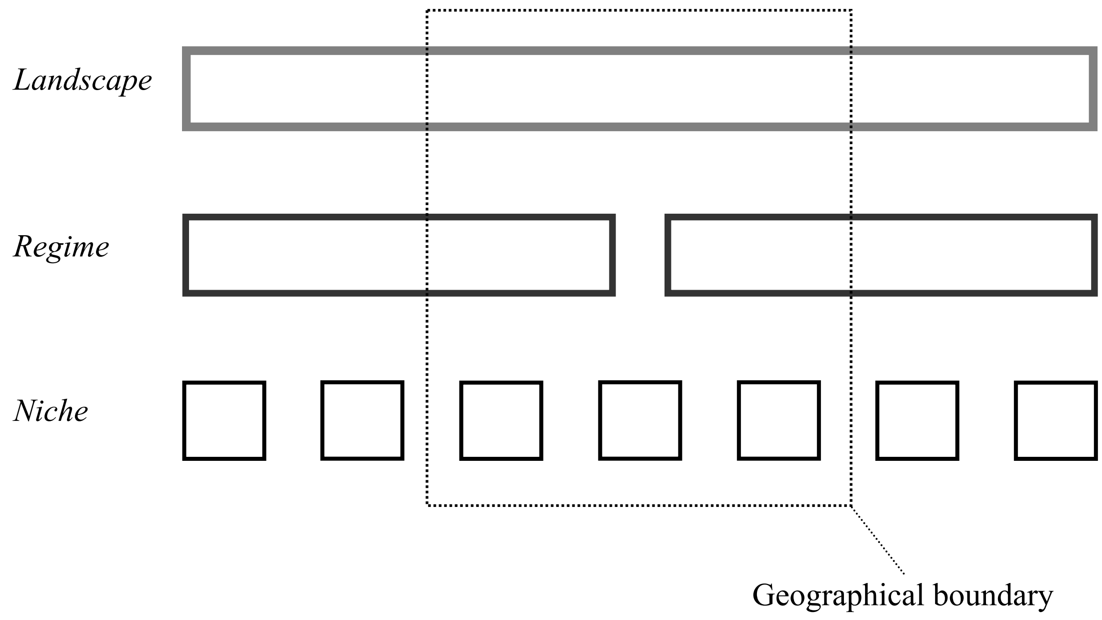

Figure 1: **The multi-level perspective adopted from Sandén and Jonasson (2005)**

The *landscape* is a broader view of systems and consists of a set of deeper structural trends and changes (Rip and Kemp, 1998). The *landscape* includes various factors which are not directly controllable by *actors*, e.g. macro-economic factors (oil prices, economic growth), wars, emigration, broad political coalitions, cultural and normative values, global warming, environmental issues, or accidents such as Chernobyl (Geels, 2002).

According to Rip and Kemp (1998), a technological *regime* is a set of rules integrated to a complex technological environment (engineering practices, production process technologies, product characteristics, skills and procedures, etc.) and embedded in a broader environment composed of *institutions* and infrastructures.[6]

Niches are defined as specific and usually small application domains protected by producers and users against *regimes'* pressure, e.g. competition or behaviour of incumbent firms. There are two ways of creating these *niches*: market niches and technological niches (Geels, 2002). Geels (2002) defines technological niches as protected spaces where the *technology* benefits from special regulations, e.g. subsidies, or alignment between various *actors*.[7] Market niches are defined as regular markets where the *technology* has a specific application which provides the *technolog*y with a competitive advantage (Geels, 2002). The definition of these two forms of *niches* can be compared to the classification outlined in section *2.1.2. ,* technological

[6] In compliance, Geels (2004) defines *"regimes as semi-coherent sets of rules, which are linked together"*.
[7] The term protected spaces refers to Schot et al. (1994).

protection and institutional protection. Technological protection refers to market niches and institutional protection refers to technological niches.

The first question the multi-level approach answers is *why* transition from one system to another happens. Geels (2004) argues that this transition is explained by instability of a system. Indeed, dynamics internal to the system might vary. These variations may lead to misalignment within a system and generate tensions, thereby weakening the *regime*'s stability (Geels, 2004). We add that instability might also come from fluctuations at the *landscape* level which may drive internal changes and misalignments.

The second question the multi-level approach answers is *how* transition from one system to another happens. Geels (2002) underlines three mechanisms in technological transition. The first mechanism is niche-cumulation which means that *technologies* first develop in succeeding applications or *niches*. One example of niche-cumulation is the use of solar cells at first in satellites, later in calculators and then for isolated emergency phones on highways. The second mechanism is hybridisation, an intermediate phase where the *"new technology links up physically with the old technology"* (Geels, 2002, p. 32). The third mechanism is the niche break out where the *technology* gets out of its *niche* to evolve and grow in bigger markets.

Nevertheless, the multi-level perspective has weaknesses. First, this approach is quite theoretical and may therefore be difficult to apply in case-studies. Hence, a structured method may be necessary. Second, the multi-level approach has a broad scope where *niches*, *regimes* but also *landscapes* are taken under consideration. As a result, this approach may lack insights concerning the mechanisms within the different levels. It is particularly difficult to describe precisely the internal evolution of a system. Third, the multi-level perspective may have a weakness when it comes to systems' performance assessment. Indeed, some systems' characteristics such as social aspects may be difficult to identify. Furthermore, one could face problems to identify policy challenges or priorities within a particular industry. In the TIS theory, these aspects that are still difficult to analyse are more stressed which makes it easier to put into practice.

2.3. Comparison and Synthesis between the TIS and the multi-level perspective

We suggest that similarities can be identified and therefore a parallel be drawn between the TIS theory and the multi-level perspective. In the following we will describe these similarities in terms of, first uncertainty, second stability and third the evolution of a system. Later on, differences between the two theories will be underlined and a synthesis proposed.

First, early phases of a technological development are characterised by high uncertainty, e.g. about technical designs. As a result *niches* are particularly important since they provide a space where learning processes can be developed and uncertainty decreased (Kemp et al., 1998). Comparatively, the significance of learning processes is underlined by Bergek et al. (2007) in the formative phase of a TIS.[8] Although they are protected spaces, *niches* are not totally independent from *regimes'* rules (Geels, 2004). Hence, a key challenge for entrepreneurs exploiting a new *niche* is not to get stuck to these rules and manage to adapt them to their specific applications. This challenge refers to *institutional* alignment (Jacobsson and Bergek, 2004) described previously in the TIS theory.[9]

Second, the evolution of a system may be described by a change in its degree of stability. A *regime* is defined as a stable system whereas a *niche* is unstable, which can be compared to a stable mature phase and an unstable formative phase of a TIS.[10] Stability and instability of systems are the origin of technological transition (Geels, 2004). Authors have analysed systems' stability using the concepts of path dependence and lock-in (Geels, 2004). Path dependence could be described as a succession of inescapable events that lead to lock-in where timing, strategy and historic circumstances determine the winner (Unruh, 2000). An example is carbon lock-in in the energy sector which generates high barriers, difficult to overcome by new entrants. According to Geels (2004) there are three ways of creating stability. First, rules and *regime*s lead to routines which orient perceptions and actions. By way of comparison firms and organisations' vision is influenced by factors such as regulations and policy.[11] Four different types of rules creating stability can be distinguished: cognitive rules, normative rules, regulative rules and the alignment between these rules.[12] This is clearly

[8] See function of *market formation* in *2.1.2.* .
[9] See *2.1.2.*
[10] See *2.1.1.*
[11] See influence on the *direction of search* function in *2.1.2.*
[12] See Geels (2004) for further explanation about these four types of rules.

linked to *institutions* and their alignment in the TIS theory.[13] Second, *actors* and organisations are involved in interdependent *networks* resistant to change because of *"organisational deep structures"* (Geels, 2004, p. 911) and strong vested interests. In particular, *legitimacy* for a new *technology* is difficult to gain when these *networks* contain strong lobbying groups and political forces.[14] Third, artefacts might have a certain *"hardness"* due to inertia of systems. This leads to a resistance to change (Geels, 2004). This refers to the trade-off between volume and variety described by Bergek et al. (2007).[15] Stability is also reinforced by network externalities: the more a *technology* is used, the larger the range of products and artefacts associated with this *technology* and the harder the emergence of a competing *technology*. In particular, stability is reinforced by the reduction of uncertainty and the strengthening of *legitimation* due to the benefits from *positive externalities*.[16]

Third, the formative phase, the growth phase and the mass-market (Bergek et al., 2007) can be respectively compared to the *niche*, the transition between a *niche* and a *regime*, and the *regime* (Geels, 2002; Geels, 2004) shown in *Figure 2*.

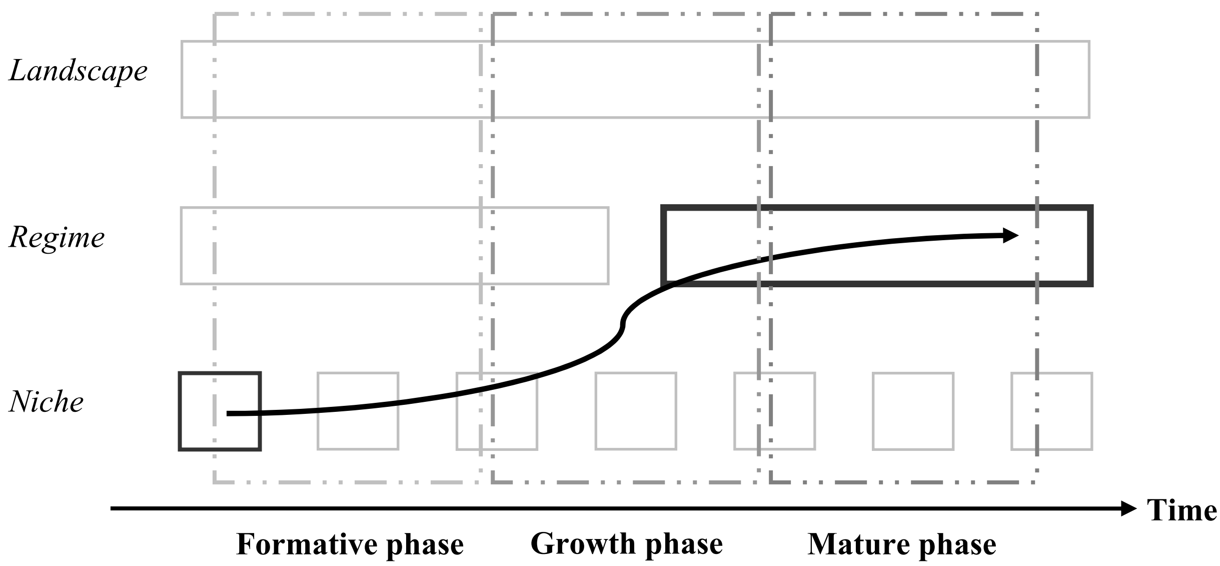

Figure 2: **Evolution of a TIS applied to the multi-level perspective**

Previously, we have shown similarities of both approaches. Subsequently, we highlight their differences.

[13] See *2.1.1.*
[14] See *2.1.1. networks* in the TIS theory and the function of *legitimation* in *2.1.2.*
[15] See standardisation in the function *legitimation* in *2.1.2.*
[16] See function of development of *positive externalities* in *2.1.2.*

On the one hand, the analysis of a TIS can be divided in two levels: the structural level, which identifies the *technology*, *actors*, *institutions* and *networks*, is a prerequisite to understand the industries' dynamics since the current picture of the system can be defined; the functional level incorporates the key processes more directly related to developing, diffusing and utilising the *technology* and can therefore describe the system's performance and what creates dynamics (Bergek et al., 2006). On the other hand, the multi-level perspective on technological transition allows us to understand the shift from one system to another. This theory enables us to highlight the interdependencies of the system with different *regimes* or *niches*, and therefore the origin of inducing and blocking mechanisms outside the system.

Finally, a synthesis outlines the strength of adding elements from the multi-level perspective on technological transition to the technological innovation system approach.

First, the notion of transition from one system to another is strengthened in the TIS approach by the multi-level perspective. Second, the TIS framework may not be precise regarding the origin of external forces. On the contrary, the multi-level perspective helps to identify these by incorporating the *landscape* and potentially several *regimes* in the analysis, which may influence the evolution of a new *niche* by inducing and blocking mechanisms. Third, the TIS approach gives a clear concept how to analyse and to explain the dynamics within a system, whereas the multi-level perspective is harder to apply to practical studies because of its broadness. Therefore, the TIS framework is more appropriate when it comes to the identification of policy challenges or priorities within a particular industry. However, the multi-level perspective assists to explain the TIS's place within a broad environment.

2.4. Co-evolution and competition between systems

Finally, some general remarks about co-evolution and competition are given since these terms are particularly relevant for the case-studies. Indeed, the borders of these two notions may not be easy to define and could sometimes overlap and co-exist in the energy field, particularly in renewable energy.

As discussed earlier, blocking and inducement mechanisms are highly important during the formative phase of a TIS since the components are still less developed and external forces mainly driving the system (see *2.1.1.*). Blocking mechanisms could come from other TIS competing in the same market and political arena. Especially, incumbent firms may try to hinder the evolution of *niches* competing with themselves (Geels, 2004). Particularly, in the energy field powerful coalitions are built up and dependence on established suppliers is generated, therefore so called lock-in mechanisms or macro-level barriers have to be overcome (Unruh, 2000). Thus, there is competition between different TIS but co-evolution is possible as well, e.g. *knowledge* to produce silicon was *developed* in order to produce semiconductors but is beneficial to manufacture solar cells as well.

Other possible interactions between different TIS are spillovers, not only in the *knowledge* dimension (Bergek et al., 2006). For instance a coalition between advocates for solar cells and wind power is very likely to have shared interest such as favourable *institutions* or *legitimation* of renewable power. Since emerging TIS most likely share structural elements, one TIS may be influenced by functions of another. Hence, boosting the function of one system could generate *positive externalities* that foster the building of the structural components of the other systems. Similarly, negative effects can be transferred as well.

Thus, not only competition takes place within a system on the firm level and between systems as a whole but co-evolution as well.[17]

Finally, we discuss the ability to generalise the conclusions about the theory. Since the study is based on two established approaches, a strong framework is used. Indeed, common known weaknesses of the TIS framework and the multi-level perspective on technological transition can be overcome when they are combined instead of using them exclusively. Nevertheless, further studies should be conducted in order to confirm the appropriateness of the analytical framework used.

Hence, the theoretical framework is based on a literature review. The chosen approaches are widely known and their general appropriateness for studying an emerging system shown in several studies (Geels, 2004; Bergek et al., 2007). The combination of the TIS and the multi-level perspective on technological transition is made to improve the understanding of the different phases of an emerging industry and to explain the interdependence of the emerging TIS with other *niches* and *regimes*.

3. Methodology

This section deals with the methodology used for the case-studies about the TIS in Germany and France. The reliability of the study is justified.

[17] Or like Geels (2004) puts it: There are games within groups and games between groups. In this context groups refer to firms, industries, public authorities etc.

The empirical part of the report (see *section 4*) contains two case-studies. The case-studies performed in this thesis deal with building integrated photovoltaics in Germany and France. Hekkert et al. (2007) argue that a process or historic event analysis is particularly suitable to study development and change processes, i.e. technological transition. We follow this rationale and base the description of the evolution of BIPV within the German and French technological innovation systems for solar cells on the order of events, which are analysed using structural and functional approaches simultaneously.

The separate case-studies allowed us to assess the usefulness of the theoretical framework developed. Indeed, Yin (1994) emphasises the relevance of case-studies to develop or to test theory. Moreover, testing the theory with a single case-study may be seen as a limit (Yin, 1994). Conducting two case-studies and applying the same theoretical framework to both of them allowed us to reduce uncertainty regarding the validity of our results since a cross country comparison helps to draw reliable conclusions and to identify relevant policy challenges. In particular, not only absolute valuation is possible, a relative comparison between the two countries assists to interpret the findings correctly.

The German and French industries were chosen according to their importance for BIPV. Indeed, Germany and France are interesting countries in the European Union for our study since they have two different approaches implementing the *technology*, notably two different policies. Furthermore, the study and analysis of these two countries is pertinent since German and French are our native languages.

A preliminary study was performed to identify the different *actors* of the TIS and to understand the *technology*. Therefore, PV magazines like Photon were read, Internet search engines such as www.google.com or www.scopus.com used and a trip to Europe's largest PV trade fair, InterSolar 2007, in Freiburg (Germany) was made. Especially, this trip made it possible to establish first contacts with companies, industry associations and governmental organisations in our respective countries. Short interviews performed at InterSolar 2007 helped to understand the available *technology*, identify important *actors* and to test as well as improve the appropriateness of a preliminary questionnaire.

Later on, contacts with several informants were intensified and interviews performed. Fabien Crassard interviewed 12 people in France and Johannes Rode 24 in Germany. Most of the interviews were made face-to-face. Details about the interviews can be found in *Appendix B*. Notably, the authors conducted the interviews in their native language in order to avoid misunderstandings. Initial contacts at the French Environment and Energy Management Agency (ADEME) and the German Energy Agency (dena) were provided by Andrew Machirant, working at Switchpower (Sweden) and being a member of the PV policy group. The interviewees were chosen from contacts made at InterSolar, experts found through magazines or the Internet, and further contact recommendations from interviews performed in the early stage of the investigation; thus, a snowball-method was partly used. Since several *actors* of the system had already been identified and grouped in the preliminary study, we were able to contact and interview various types of *actors*.

Every interview was semi-structured (Remenyi et al., 2000); hence, open-ended questions were asked and the conversations guided in the right direction by the interviewers. For the purpose of reducing bias (Remenyi et al., 2000) notes were taken during the interviews, which were translated into English later on. In order to verify the information provided by the interviews and used in the report, the interviewees were contacted again before finishing the thesis to review their statements.

The statements of the interviewees were tested by asking the same questions to several interviewees. Thus, by using triangulation, that is evidences from multiple sources (Remenyi et al., 2000), the data gathered was verified. The triangulation was further enhanced by interviewing people from different *actors* in the system such as architects, industry organisations, researchers at Universities, companies producing BIPV products as well as political *actors*. Finally, triangulation allowed us to decrease subjectivity. Indeed, we used multiple sources: interviews, research papers and books, media, and the Internet.

Nevertheless, this study faces uncertainties that constitute limitations to our results and therefore need to be highlighted. However, being aware of these uncertainties, we made the necessary arrangements to decrease them and hence reach valuable and trustable results. In the following, these uncertainties are described and discussed.

In Germany and France the monitoring of installed BIPV systems is clearly weak. The French law favouring BIPV just came into force in July 2006. Official data for PV in general can be found until 2006 but not for BIPV. The further impacts of the new legislation can be estimated but not be taken for granted since official statistics about its impacts are lacking. In Germany, verified data for BIPV is only available until 2003, when an evaluation of the 100 000 rooftops solar electricity programme took place. However, with the adjustment of the Renewable Energy Sources Act in November 2006, an improved data collection was implemented (Bundesgesetzblatt Teil I Nr. 52, 2006). This should enable the calculation of the exact power produced by facade, roof and open space systems.[18] Although this will provide no detailed data for BIPV in total, it could clarify the impact of the German 5 EURCent/kWh facade bonus. Nevertheless, the lack of official data and the novelty of the French feed-in-tariff in favour of BIPV call for studies about BIPV in Germany and France in coming years. In order to face the uncertainty, data and figures about the PV power installed or the estimated BIPV power installed were verified by several experts.

Finally, the last limitation is the short time period of around five months dedicated to this study. However, in order to gather reliable information efficiently, we interviewed key persons in Germany and France.

To conclude, the case-studies have to be regarded as explorative research (Remenyi et al., 2000) since the existing knowledge was limited. Nonetheless, great effort was carried out to secure the reliability of the sources. In contrast, the knowledge about the frameworks is well developed. Therefore, a framework combining two approaches is built, helping to overcome weaknesses of each exclusive framework and to clarify the characteristics of the studied systems.

4. Empirical study

In the following, two case-studies about the evolution of BIPV within the German and French technological innovation systems for solar cells are outlined. At first, a general overview of the history of the worldwide PV industry is given. Thereafter, BIPV are defined and some technical background explained. Subsequently, the German and French TISs for solar cells are described separately. Finally, the development in both countries is compared and policy implications are outlined.

1839 French physician A. E. Becquerel discovered the photovoltaic effect

1877 First solar cell out of selenium (England)

1921 German physician Albert Einstein won the Nobel Prize for his theories explaining the photoelectric effect published in 1904

1954 First patent of a silicon solar cell by Bell Laboratories (USA)

1958 Vaguard 1, the first satellite with solar power supply (USA)

1973 First oil crisis

1976 Development of solar cells out of amorphous silicon (USA)

1986 Chernobyl disaster

Figure 3: **Time-line early development of PV worldwide (U.S. Department of Energy, 2004; Stark et al., 2005)**

[18] Unfortunately, during the creation of this thesis the law has still been in its realisation; thus, the data has not yet been published by the electric power supply industry, although already been provided by statute.

4.1. Definition and background

4.1.1. Overview about the PV history

A general overview of the different materials and technologies used for solar cells can be found in *Appendix D*.

Jacobsson et al. (2004) divide the diffusion of solar cells in five periods with several shifts from policy driven markets to commercial ones and vice versa shown in *Figure 4*.

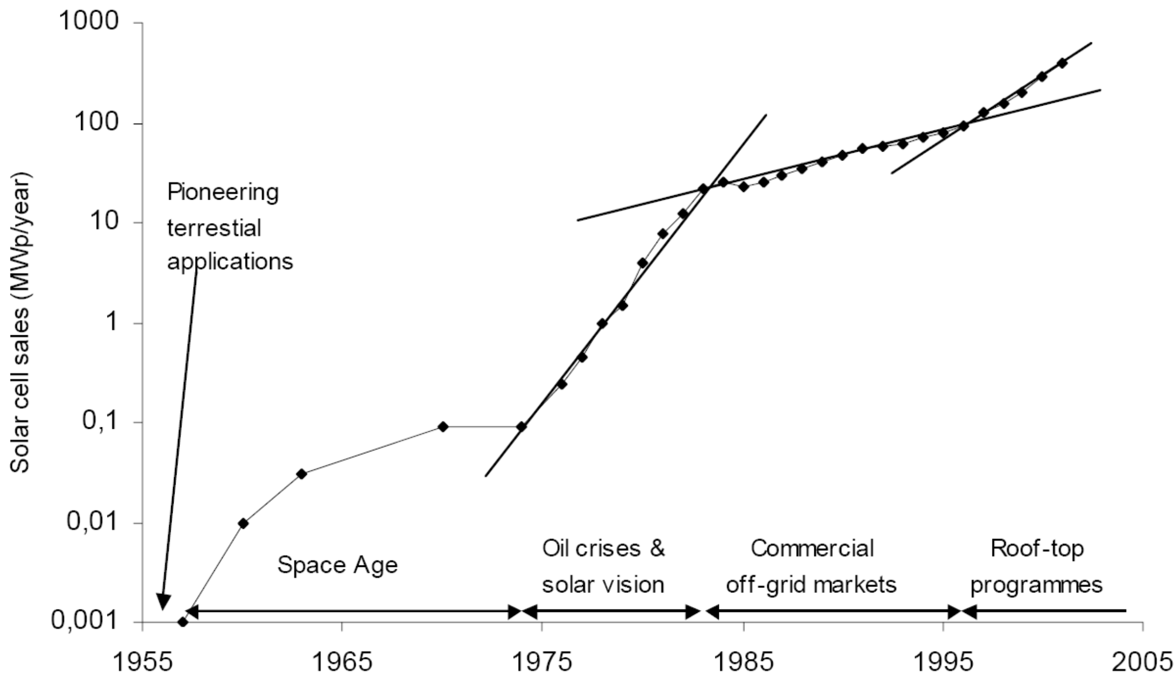

Figure 4: **Five phases of solar cell diffusion (Jacobsson et al., 2004, p. 8)**

The photovoltaic effect was discovered by the French physician Becquerel in 1839 (hwp & ISET, 2006). Afterwards several attempts were made to produce solar cells.[19] However, it took more than one hundred years until the first solar cell was turned into a product. This cell, developed by Bell Laboratories in 1954 (see

), was made out of crystalline silicon (c-Si) and reached an efficiency of 6 percent; thus 6 percent of the irradiation (incoming energy from the sun) was converted into electricity (Jacobsson et al., 2004). In this period sales remained very small, only some pioneering utilisations for toys or stand-alone power supply in remote places were tried (Jacobsson et al., 2004).

[19] See U.S. Department of Energy (2004).

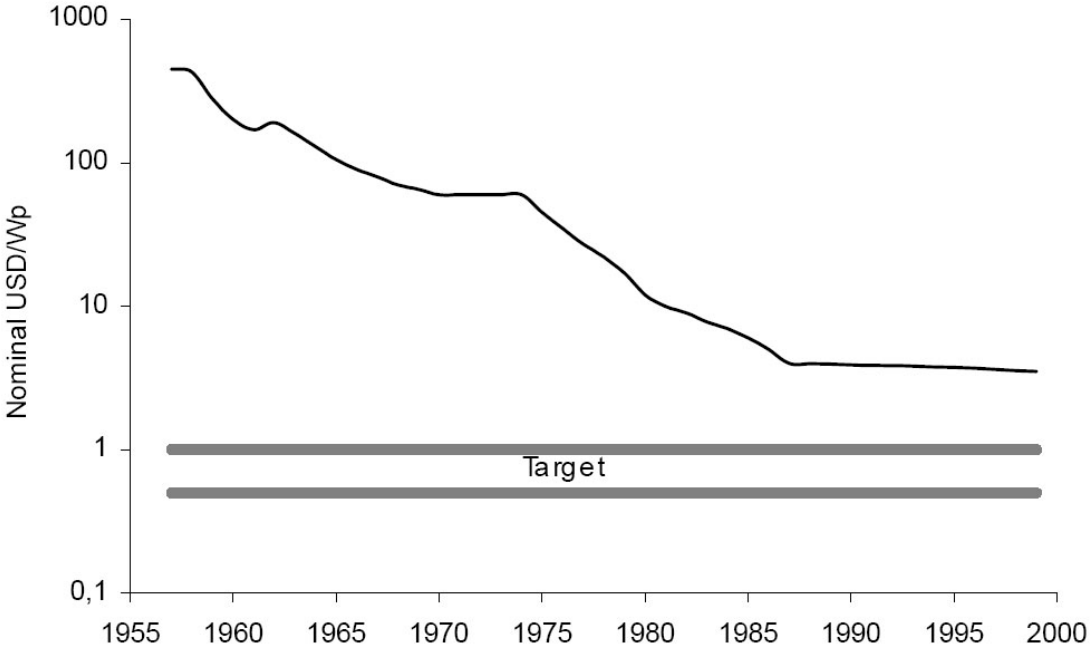

Figure 5: **Solar cell price set in relation to target price (Jacobsson et al., 2004, p. 11)**

The first real application found was satellites (Stark et al., 2005). The power supply from solar cells was essential for satellites but on earth the high costs of several hundred USD/W_p per module shown in *Figure 5*, prevented other applications in these days.[20] By the end of the 1960s the annual production reached 0.1 MW_p/year (see *Figure 4*).

During the mid 1970s, the first oil crisis led to efforts to become independent from energy imports, and growing environmental awareness. This resulted in governmental Research, Development and Demonstration (RDD) programmes in several countries (Jacobsson et al., 2004), especially in the USA, followed by Japan and Germany, shown in *Figure 6*. This period was characterised by a rapid increase in solar cell production and very optimistic forecasts about a solar cell powered world (Jacobsson et al., 2004).

[20] Several cells are combined into a module. Solarbuzz (2006) defines Watt peak (W_p) as follows: *"Watt Power output of a Solar module is the number of Watts Output when it is illuminated under standard conditions of 1000 Watts/meter^2 intensity, 25°C ambient temperature and a spectrum that relates to sunlight that has passed through the atmosphere (AM or Air Mass 1.5)."*

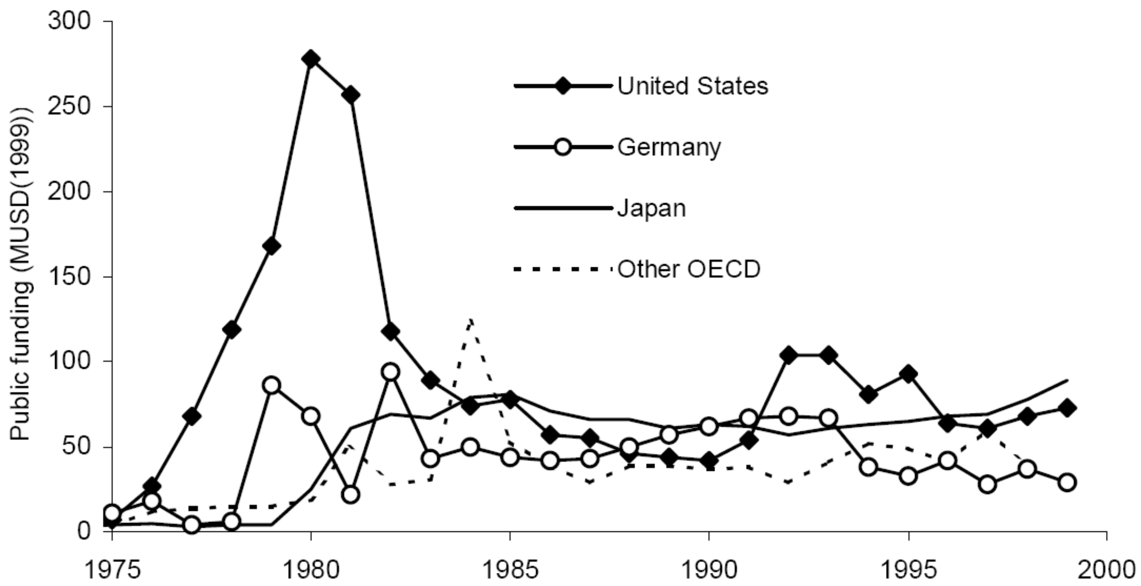

Figure 6: **Public solar cell research, development and demonstration funding in OECD, 1975-1999 (in million 1999 USD); (Jacobsson et al., 2004, p. 9)**

In 1983, the annual production reached 22 MW_p, where most of the systems were tax-credit financed large-scale grid-connected plants in California (Jacobsson et al., 2004). However, the situation for fossil fuels eased up and PV were still not competitive (Stark et al., 2005) with prices around 10 USD/W_p per module shown in *Figure 5*. Furthermore, in the U.S. the Reagan administration changed the RDD and tax policies; therefore large-scale solar cell plants were not pushed further (Jacobsson et al., 2004). Nevertheless, during the same time new *markets* were *found*; especially, consumer electronics products, such as pocket calculators using amorphous silicon (a-Si) solar cells, generated a new demand (Jacobsson et al., 2004). Amorphous silicon was particularly regarded as a promising low cost alternative, but until 2006 the market share fell under 5 percent again. In the late 1980s and at the beginning of the 1990s, the demand for solar cells came mainly from developing countries; the off-grid market using crystalline silicon was the most important (Jacobsson et al., 2004). However, the optimism of the late 1970s was lost and the growth slowed down. The *market grew* only by an average of 12 percent per year between 1983 and 1996 (Sanden, 2005).

A new growth period based on *market formatio*n programmes in developed countries began during the mid 1990s and still continues (Jacobsson et al., 2004; Stark et al., 2005): since 1994 the Japanese government has subsidised rooftop mounted grid-connected systems;[21] Germany started its 100 000 rooftops solar electricity programme in 1999 followed by an ambitious feed-in-tariff; and a few years later many other countries such as Spain, Italy or

[21] The Japanese subsidies phased out in 2005 (IEA PVPS, 2006a).

France installed similar guaranteed payments for feeding electricity produced by solar cells into the grid. These policies allowed the PV *market* to *grow* rapidly in recent years despite not being competitive without subsidies against established technologies to produce electricity. More than 2.5 GW_p of solar cells were produced in 2006 compared to 0.2 GW_p in 1999 (Hirshman et al., 2007). Hence, between 1999 and 2006 the production grew by more than 40 percent every year.

Still, crystalline silicon remains the most important solar cell technology in 2006 with about 90 percent of the total cells produced (see *Figure 23* in *Appendix D*). Nevertheless, the sales of cells made of amorphous silicon, which had a share of less than 5 percent in 2006, will probably increase rapidly in the coming years since the production capacities are greatly expanded (Kreutzmann, 2007).[22]

To sum up, the evolution of PV is characterised by deploying market niches as well as technological niches later on, referring to *niche-cumulation*, and the further dominance of silicon solar cells. Cost reductions and efficiency improvements are still not sufficient to be competitive without subsidies. However, policy interventions such as *market formation* programmes have led to rapid growth (Jacobsson et al., 2004).

4.1.2. BIPV

BIPV can be described as an application of PV, which is functionally, aesthetically and / or energy technically integrated into a building (Hagemann, 2002). However, there is no official definition for building integrated photovoltaics and still there has been no clear consensus about which systems fall into the category and which not (Hagemann, 2002).[23]

According to the Oxford English Dictionary (2007b) the word *integrated* is defined as *"…combined into an whole; united; undivided"*. Furthermore, a *building* is described as *"…a structure of the nature of a house built where it is to stand" (Oxford English Dictionary, 2007a)*. Thus, BIPV stands for photovoltaic systems, which are combined into a building, as a house. Furthermore, this combination cannot easily be disunited again: when the BIPV system is removed the house is not complete anymore. Consequently, this refers to the functional aspect of a BIPV system. According to our definition, a BIPV system has to undertake a function in the building such as weather protection, sun protection or the integration as a

[22] Within the last years, the silicon shortage caused an increasing interest in the silicon-based thin film technologies since they require fewer raw materials.
[23] However, in France criteria were defined by the Ministry of Economy, Finance and Industry to assess if a system refers to BIPV (DGEMP and Dideme, 2007).

design element (see *Appendix E* for an overview of functions of BIPV systems). Thus, two basic aspects for PV systems can be distinguished:[24] the constructional and the aesthetic aspect, which can either solely or both be met.[25]

If a PV system is integrated into a building, a compromise between solar technical requirements for a PV system, conventional functions which the envelope of a building has to fulfill, and the aesthetic demand of a building has to be found (Hagemann, 2002).[26] However, the degree of integration can be very different and is hard to assess (see *Figure 25* in *Appendix F*). Finally, apart from some products, such as solar tiles or windows including a semitransparent solar cell, the decision if a PV system falls into the category of BIPV or not, has often to be done case-by-case.

As shown in *Figure 25* in *Appendix F* there are three levels of integration: application, which refers only to visual integration; constructive addition; and constructive integration. Nevertheless, in this thesis the primary condition of a PV system to be regarded as BIPV is the functional aspect.[27] Hence, a BIPV system can either substitute an ordinary part of a building and fulfill its function or bring a new functional aspect to the building.[28] To make it clear, in our definition additive solutions on stilts, which are called on-roof or roof-mounted systems, are typically not regarded as BIPV (see *Appendix G* for some examples of BIPV systems), but if they are appropriately integrated in the visual concept of the building, we still regard them as BIPV.[29]

Two main subcategories of BIPV systems exist: roof integration and facade integration. Furthermore, there is a big difference, particularly in the effort to install and expenditure, between standardised and customized products.[30] Especially, roof and facade systems differ

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[24] This applies for every other building material as well.
[25] We are well aware of the fact that the aesthetic aspect is subjective. However, architectural aestheticism is surely a part of every building and has therefore to be included.
[26] The optimal outcome of a PV system is reached by an inclination of about 30° turning to the south in Europe; see *Figure 24* in *Appendix F*.
[27] Including both the constructional and the aesthetic aspect, which can either solely or both be met, as explained above. This is in compliance with the French guide defining the BIPV character of a system (DGEMP and Dideme, 2007) and partly with the German requirements to receive the facade bonus for a PV system (Altrock et al., 2006). However, the German facade bonus requires a function besides the aesthetic aspect such as weather protection.
[28] This can again either be constructional or aesthetic.
[29] Such integration may be subjective and has to be assessed case by case. We are well aware of the fact that we cannot assess the aesthetic integration case-by-case for this thesis. However, solely visually integrated systems are rare and therefore do not play a major role until today.
[30] For instance a missing building permit can hinder the installation of a system.

greatly in the regulations they have to fulfill and in the German case also in their feed-in-tariff.[31]

4.1.3. General barriers and inducement mechanisms for BIPV

The usage of solar cells to produce electricity comes with several advantages, to mention only few: sun irradiation is inexhaustible and free of charge; during the usage time no fossil fuels are consumed; the production of electricity by solar cells is environmentally friendly;[32] PV modules are almost wear-free;[33] and the amount of maintenance is comparatively low (Hagemann, 2002). However, PV faces several drawbacks as well: the initial investment costs are high; continuous current produced by the cells has to be transformed into alternating current by an inverter; and above all, electricity production is dependent on sunlight (Hagemann, 2002) and difficult to store. In the long-term perspective, substantial cost reductions have to be reached by improving PV-technology's efficiency and achieving economies of scale so that electricity production from solar cells becomes directly competitive with established technologies to generate electricity (grid parity) (Wenzel, 2007).

Especially, the integration of PV into a building provides opportunities to use PV *technology* and to compensate system inherent drawbacks: compared to open space PV systems, ones integrated into or on a building exploit previously unused surfaces; costs for substructures can be reduced or completely abandoned; and zero net energy houses can cover the complete energy consumed from electronic devices in the house (Hagemann, 2002). From the perspective of buildings, BIPV solutions fulfil a function on the building exterior besides energy production and can replace conventional building materials (Hagemann, 2002); thereby, cost savings are possible. Additionally, compared to other energy sources PV does not benefit from scale effects when it comes to electricity production (Ricaud, 2007): wind turbines benefit from exponentially growing electricity output with increased size; in contrast, PV systems only allow linear growth of output per sqm for increasing plant size. Thus, small scale plants on or in houses are as efficient as large scale plants on open spaces.

Nevertheless, BIPV solutions face problems to get widely spread. Due to poor insulation values of the existing building stock, it is presently more important - with regard to cost and energy efficiency - to increase the energy efficiency of the building shell and its energy

[31] The differences are explained in detail in the sections about France and Germany later on.
[32] By environmentally friendly we mean that the production of electricity from solar cells does not generate carbon emission, waste or noise.
[33] Depending on the manufacturer usually between 80 and 90 percent of the initial efficiency are guaranteed for 15 to 20 years.

systems (Hagemann, 2002).[34] Using PV as a building component to generate solar electricity might not be the first step to convert an existing building into an energy efficient home. Nonetheless, based on an overall energy efficient design BIPV are regarded as a promising *technology* to produce the electricity needed. To allow for a smart integration of BIPV into the building fabric, it is necessary to integrate the BIPV-planning into the overall energy and design concept of a building from the beginning of a new building project. A pre-requisite to carry out such a holistic design approach, which considers design-, structural- and energy issues of a new building project right from the start, is an intensive communication and collaboration between the people involved into the building design process (Hagemann, 2002). However, such collaboration is based on trust in the project partners' expertise and the openness for reconsidering once own point of view. Due to a lack of information users are sceptical about the reliability of BIPV products regarding e.g. weather protection as well as electricity generation. In addition, overlapping trade areas between the people involved in the realisation of a BIPV system cause problems regarding legal liability responsibilities (Hagemann, 2007). In general, building regulations can hinder the diffusion of BIPV products. Especially, PV systems integrated into or added on a building have to fulfil construction norms like the building codes for Europe, albeit the higher the integration degree of a solar system, the more requirements have to be met.[35]

Particularly, BIPV systems require certain boundary conditions to perform well. Crystalline solar cells substituting the ordinary envelope of a building have to be rear ventilated in order to avoid efficiency losses through heating up the PV modules.[36] Furthermore, as shown in *Figure 24* in *Appendix F*, PV systems can produce the most electricity when they are orientated to the south and inclined of about thirty degrees.[37] Therefore, already during the planning phase of a building these conditions have to be taken into consideration.

In general, the market for BIPV is only a fraction of the total PV market. Most PV systems are installed on the open space or as additive systems on the roof. There are several reasons for that. Firstly, on the open space larger systems can be installed, which can have a capacity

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[34] For example: thermal insulation of windows and walls, more efficient heating systems etc.

[35] Surely, all building components have to fulfil these norms. However, the certification process can be time consuming and cost intensive.

[36] The efficiency of PV modules, hence the electricity produced, decreases with increased temperatures for mono and poly silicon cells, but not for amorphous silicon cells (Reijenga, 2003). Mono and poly silicon cells together have a market share of 90 percent, compared to less than 5 percent of amorphous silicon cells in 2006, see *Figure 23* in *Appendix D*. However, the production capacity of amorphous cells will probably increase rapidly in 2007 (Kreutzmann, 2007).

[37] Thirty degrees are roughly correct for Germany and France. However, the exact inclination depends on the place where the system is installed.

of several $MW_{p.}$[38] However, these systems usually do not receive the same feed-in-tariff as roof systems.[39] Secondly, BIPV systems are normally most appropriate to install during the construction phase of a building or during a reconstruction phase. In contrast, to a completed building an additional solution can easily be added. Thirdly, facade systems as one part of BIPV systems are not interesting for private residential buildings since the solar irradiation is less on facades compared to roofs.

However, BIPV stand for more aesthetic solutions and is regarded as a future market (IEA PVPS, 2004). Furthermore, the production capacity of a-Si solar cells will be largely expanded until the end of 2007 (Kreutzmann, 2007). Particularly, this technology is regarded as very interesting for BIPV since it offers material saving potentials and therefore cost saving potentials (Hagemann, 2007). In addition, it can be used to produce semitransparent cells (Reijenga, 2003) and as a flexible bendable material offering many potential applications, e.g. see *Figure 33* in *Appendix G*.[40] This may give BIPV systems a strong rise in demand (Schwarzburger, 2007).

4.1.4. The systems studied

In the following, the outcomes of two case-studies are described. The case-studies deal with the technological innovation systems for solar cells and the evolution of grid-connected BIPV in Germany and France. As the electricity produced by PV is not competitive without subsidies, it needs to be supported by strong incentives given by national policies (Jacobsson et al., 2004). Therefore, national boundaries are chosen since many characteristics of the TIS for solar cells are country specific.[41]

We described BIPV as an application of PV products. Therefore, BIPV are a part of the *niche* of PV. Furthermore, according to its definition, BIPV in Germany and France mainly interact with two *regimes*: the one of the building industry and the one of the electricity supply industry.[42] This implies to place BIPV as shown in *Figure 7*.

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[38] In summer 2007, the biggest PV plant in the world was located in Beneixama in Spain with a power of 20 MW_p (PVresources, 2007).
[39] For instance in Germany open space systems receive a lower remuneration. See *Appendix I* for details about the German feed-in tariff.
[40] Other PV technologies can also be used to produce semitransparent modules.
[41] For instance, the French and German *networks*, norms, *knowledge* and political environment differ.
[42] Since BIPV involves the adaptation of two *regimes*, i.e. building and electricity supply industry, barriers to *legitimation* of both *regimes* have to be overcome. As a result, *legitimation* is particularly complicated to develop.

Both the PV industry and the building industry are important to understand the evolution of BIPV. However, we chose to focus on the PV part of the technological innovation systems since BIPV are one possible application of the PV *technology* and therefore an opportunity for PV to be widely spread. Hence, BIPV are mainly shaped by the evolution of the PV industry. As a result, in order to explain the evolution of BIPV, the development of photovoltaics in general is described in the analyses as well.

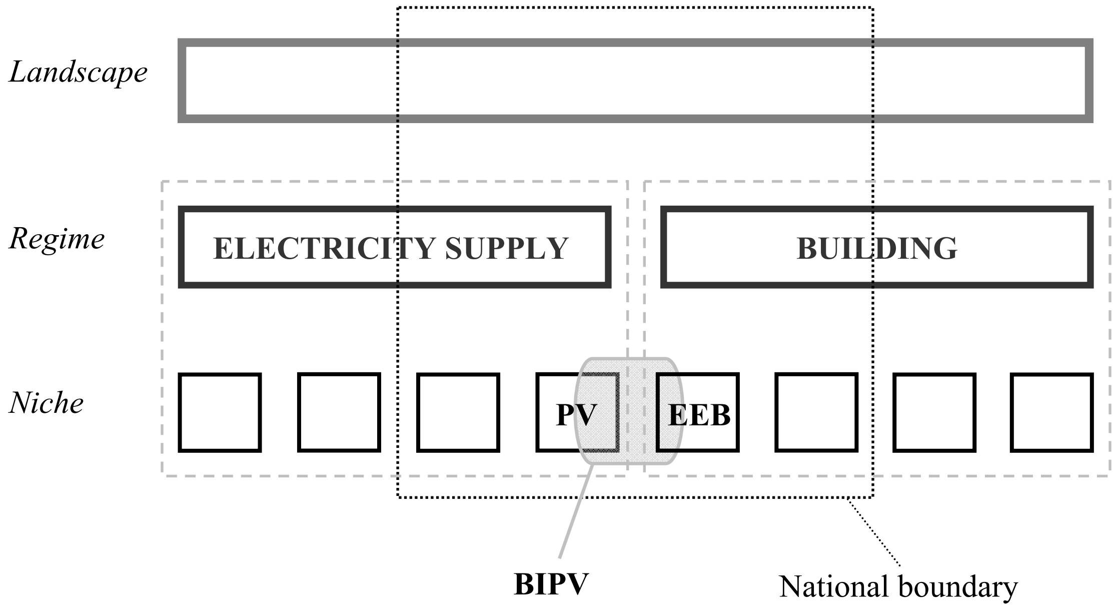


Figure 7: **BIPV placed in the multi-level perspective (PV: photovoltaics, EEB: energy efficient buildings)**

In the following sections, the analyses of Germany and France are performed separately. Afterwards they are compared and policy implications drawn.

4.2. Germany

An overview about the evolution of PV and BIPV in Germany is given in *Figure 8*.

Jacobsson et al. (2004) divide the evolution of the German technological innovation system for solar cells into two periods: one ending in 1989, which mainly contained basic research, demonstration programmes and therefore *knowledge creation*, as well as the formation of advocacy coalitions; the second period from 1990 until about 2003 was characterised by *market formation* based on incentives created by policies, a strengthening of the *actors* in the industry, an enlargement of the whole system and finally of a self sustained development.[43] We suggest that a third period starting in 2004 shows a shift to a growth phase of the TIS for

[43] Jacobsson et al. (2004) actually schedule the second phase between 1990 and about 2001 when their study was finished. However, there was an increase in the annually installed photovoltaics capacity of more than 300 percent in Germany between the years 2003 and 2004 (see *Figure 9*). Therefore, we extend this second period until 2003.

solar cells in Germany and therefore further rapid market growth. Moreover, the production capacity is enlarged and several *actors* entered the value-chain at various stages; potentially turning the system from an import into an export industry.

In compliance with the time periods introduced, we argue that two development phases for building integrated photovoltaics in Germany can be distinguished. The first period, ending in 2003 is again mainly characterised by basic research, demonstration projects and establishment of the idea that PV can be integrated into a building, substituting conventional materials, and can simultaneously be used as an aesthetic element. This first period particularly consists of *resource mobilisation*, *legitimation*, and *knowledge generation* activities; these activities helped to form *networks*. Starting in 2004 and lasting until today, the second phase was characterised by financial incentives for some BIPV solutions created by policies, therefore a decoupling from the standard PV market was aimed and an independent small *niche market formed*.

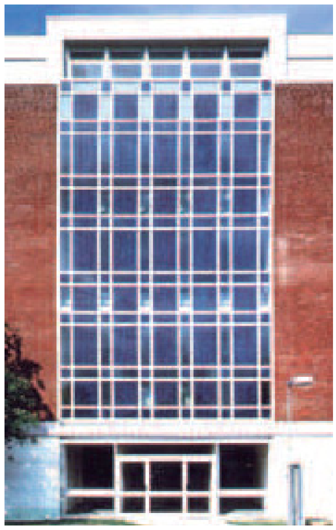
In order to capture the evolution of BIPV and PV in general in Germany, the description is split up in three different phases using the periods introduced before.

a) Until 1989: A preparation phase for PV – hardly any BIPV activity[44]

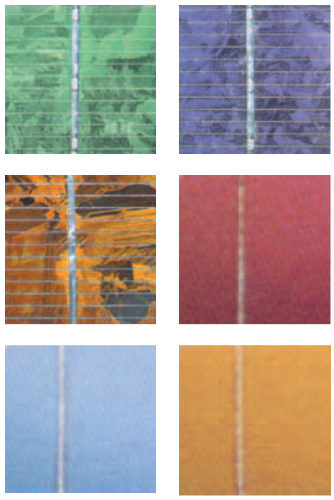
During the mid 1960s, Telefunken and Siemens started to develop solar cells by reacting to the USA’s export restrictions on the European Space Agency (Jacobsson et al., 2004). However, the first real interest in this *technology* arose in the time of the first and second oil crisis in 1973 and 1979 (hwp & ISET, 2006). During this period a change in the *landscape* took place in Germany: a strong Green movement was formed, which disapproved of nuclear power and fossil fuels in the long run (Jacobsson et al., 2004). This was in compliance with the government’s aim to become less dependent on energy imports. Thus, in a coherent step the federal government raised its expenditures on solar cell RDD as shown in *Figure 6*. Remarkably, compared to other countries Germany’s RDD spending on PV was continuously high in absolute as well as relative terms (Jacobsson et al., 2004).[45]

[44] The evolution of PV in general in this period draws heavily on Jacobsson et al. (2004) and Stark et al. (2005).
[45] In 1978 Germany became the second largest spender on solar cells RDD in absolute terms and since then has been ranked among the top three (with the U.S. and Japan) until today (Jacobsson et al., 2004).

PV in general			BIPV specific
Foundation of German Society for Solar Energy (DGS)	1975		
Federal program (technologies to utilize solar energy)	1977		
Foundation of Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg	1981		
First PV power plant in Germany on the island Pellworm	1983		
		1985	First PV roof integration in Germany
Foundation of Centre of Solar Energy and Hydrogen Research (ZSW) in Stuttgart	1988		
Launch of 1 000 rooftops solar electricity programme (until 1994)	1990		
Launch of first feed-in-tariff (90 percent of average electricity cost)	1991	1991	First PV facade Integration worldwide in Aachen, Germany (1)
Energy self sufficient house in Freiburg inaugurated	1992		
		1993	First structural glazing PV facade
		1993	PV integration with holographic elements at IGA in Stuttgart
First local feed-in-tariff in Aachen; followed by many other cities	1994	1994	First facade integration with amorphous solar cells
		1996	Launch of coloured solar cells on the market (2)
Launch of 100 000 rooftops solar electricity programme (until 2003)	1999	1999	1 MW_p PV system Mont-Cenis in Herne integrated in roof and facade, 10000 sqm of modules (3)
Launch of Renewable Energy Sources Act (EEG)	2000	2000	First integration of transparent crystalline cells
		2002	Brochures about BIPV in North Rhine-Westphalia and Baden-Württemberg
Amendment of Renewable Energy Sources Act (EEG)	2004	2004	5 EURCent/kWh facade bonus since 2nd revision of Renewable Energy Sources Act (EEG); (not for BIPV in general)



(1) First PV facade integration worldwide: Stadtwerke Aachen (Stark et al., 2005)



(2) Coloured solar cells (Stark et al., 2005)

(3) 1 MW_p BIPV system in Herne (Scheuten, 2007b)

Figure 8: **Time-line of the development of PV and BIPV in Germany (Stark et al., 2005; BMU, 2007a)**

In line with these efforts the federal German government started the programme on "technologies to utilize solar energy" in 1977. Furthermore, the Fraunhofer Institute for Solar Energy (ISE) was founded in Freiburg in 1981.[46] In 2007 it is still Europe's largest solar research institute with a staff of approximately 500 people (Fraunhofer ISE, 2007).[47] According to Jacobsson et al. (2004) 18 universities, 39 firms and 12 research institutes were working on solar cells between 1977 and 1989 which resulted in the emergence of a *"broad academic cum industrial knowledge base"* (Jacobsson et al., 2004, p. 13) including complementary products like inverters but still focusing on cells and modules. Most effort was directed onto improving crystalline silicon cells; however, a-Si and CIS technologies were explored as well. Thus, federal RDD funding *supplied resources* causing a *creation of knowledge* in various fields and firms and research institutes were *influenced in their search* to enter into the development of solar cells (Jacobsson et al., 2004).

In 1983, the first German PV plant was installed on the island Pellworm (Stark et al., 2005). The plant had a capacity of 300 kW_p and was therefore the biggest in Europe at that time (Jacobsson et al., 2004). Only two years later, the first BIPV systems in Germany appeared, e.g. the Solarhaus next to Saarbrücken with a roof integrated PV system (Stark et al., 2005). Then, in 1986 a demonstration programme, which enabled more than 70 larger plants to be built by the mid-1990s, was started including a two years monitoring programme (Jacobsson et al., 2004). However, the total PV power installed was still only 2 MW_p by 1990. Thus, the demonstration projects cannot be regarded as important for *market creation* but created *application knowledge* (Jacobsson et al., 2004). By testing how to integrate a plant into the landscape or testing the integration into a building, different applications were evaluated. Furthermore, in another project, two participants, Bayernwerk and Siemens, founded Siemens solar, growing into one of the largest PV firms in the world and buying itself into the US market by acquiring ARCO in order to get access to CIS and a-Si technology.

However, during the mid of the 1980s the supply of fossil energy resources has eased up and photovoltaics were still far from being competitive against established energy technologies.

[46] Later on, the Centre of Solar Energy and Hydrogen Research (ZSW) was founded in Stuttgart in 1988 (Stark et al., 2005). Then in 1990, the Research Association for Solar Energy (FVS) was built as an umbrella organisation for all the research institutes dealing with solar cells. Today, eight research institutes work together under the FVS, building a *learning network,* and include research for renewable energy in general, still focusing on solar cells (FVS, 2007).

[47] The budget for the ISE alone accounted for 33 MEUR in 2006 (Fraunhofer ISE, 2007).

According to Jacobsson et al. (2004) three types of organisations were founded early on in this period to support renewable energy and particularly solar energy in order to induce *institutional* change by promoting their potential: professional societies, industry associations and a lobby organisation within the political structure. The German Society for Solar Energy (DGS) is an example for a wide based professional society including 3600 members today while founded in 1975 (Jacobsson et al., 2004). Scientists and other participants are combined under one umbrella, diffusing information to industry and politicians through advisory groups and writing position papers. Another organisation in this category is "Förderverein Solarenergie", which was established in 1986 and invented the cost covering refunding, which gave the idea for feed-in-tariffs later on (Jacobsson et al., 2004; Altrock et al., 2006).[48] Conventional industry associations like the German Solar Energy Industries Association (UVS) started in 1978 or the German Professional Association of Solar Energy (BSi) founded in 1979, which merged into the German Solar Industry Association (BSW) in 2006, are besides spreading information mainly responsible for lobbying politicians. The last and rather unusual type of organisation is Eurosolar founded in 1988. It consists of politicians from all political parties, excluding Liberals, in the federal, the Länder and the local level (Jacobsson et al., 2004).[49] Thereby, most importantly party wide support for solar cells and renewable energy in general was accomplished; additionally, an awareness of the potential of renewable energy was promoted and specific policies designed.

The creation of organisations came along with the formation of *networks* within the organisations and among them (Jacobsson et al., 2004). Most importantly, policy makers were involved early on in *political networks*, which gave the possibility to change the *institutions* directly in favour of solar power and renewables in general. Furthermore, the basis for the *development of positive externalities* was laid, having major impacts in the following period (Jacobsson et al., 2004).

Thus, the period until 1989 was primarily characterised by a *supply of resources* by federal RDD programmes, which influenced the *direction of search* in order to *generate new knowledge* (Jacobsson et al., 2004). Many organisations were established promoting solar cells and a wide spectrum of technologies was explored. Furthermore, the first applications

[48] Cost covering refunding refers to a remuneration of the electricity fed into the grid by facilities using renewable energy sources, which covers besides the costs of the facility and its installation, all running costs, cost of funds and an adequate return after a time period of usually 20 years (Altrock et al., 2006).

[49] The German country is a federal republic, which consists of 16 federal states. These states are called Länder in German. Examples for Länder are Bavaria or Hesse.

for PV were tested including few BIPV solutions, respectively in-roof systems. Nevertheless, no self sustained development could be identified (Jacobsson et al., 2004).

b) 1999-2004: Towards self sustained growth for PV – Identification of BIPV as an application, resource mobilisation and demonstration[50]

The period described in the following includes policy efforts to strengthen the *formation of markets* while simultaneously *supplying resource*s to guide *the direction of search* into solar cells in general. Most effort was still given to silicon cells but thin film technologies were funded as well (Jacobsson et al., 2004).[51]

Between 1990 and 1994, the 1 000 rooftops solar electricity programme, "*a demonstration cum market formation programme*" (Jacobsson et al., 2004, p. 16) of small grid-connected solar cell installations, was launched.[52] The aid of PV systems resulted in the installation of more than 2200 roof-mounted systems with a capacity of 5.3 MW_p (Rindelhardt et al., 1995). The programme led mainly to the installation of systems on the roof. However, approximately 400 kW_p of in-roof systems were installed during the programme as well.[53] Besides the integration of normal PV modules into the roof by using special installation techniques in order to use them as a roof, some PV tiles of the Swiss manufacturer Newtec using Siemens modules were also installed (Rindelhardt et al., 1995).

The 1 000 rooftops solar electricity programme arose out of a Parliamentary resolution demanding for higher efforts in developing renewables in 1988, which was a consequence of the Chernobyl disaster in 1986 leading to SPD's decision to abandon nuclear power (Jacobsson et al., 2004). This refers to a profound change in the political *landscape*. In spite of SPD not being in power during this period, its policy change still encouraged the coalition

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[50] The evolution of PV in general in this period draws heavily on Jacobsson et al. (2004) and Stark et al. (2005).
[51] As explained in *4.1.3.* amorphous silicon is regarded as very promising for BIPV since it is a flexible material and enables to produce semi-transparent cells.
[52] The off-grid connected market was never really important in Germany. The 1 000 rooftops programme laid the ground for systems connected to the grid and since then the vast majority of systems have been grid connected. The reasons for this are mainly the comparatively dense population in Germany and the absence of islands far away from the mainland. Thus, only few applications for off-grid systems exist.
[53] According to Rindelhardt et al. (1995) 11 out of 123 PV systems realised in Sachsen during the 1 000 rooftops solar electricity programme were in-roof and thereby BIPV systems. The total capacity installed in Sachsen within the programme accounted for 521 kW_p, where 43.4 kW_p were in-roof systems; thus, 8.3 percent were BIPV systems. This amount extrapolated to the total 5.5 MW_p installed during the programme country wide, makes an estimation of 400 kW_p of BIPV power installed in whole Germany during the 1 000 rooftops solar electricity programme reasonable. However, one has to consider that this capacity comes only from in-roof systems and no facade systems.

of CDU and Liberals to launch the 1 000 rooftops programme.[54] This shows the increasing awareness of the necessity of finding alternatives to the established energy resources in these days in Germany.[55] The idea to install PV systems on roofs made the main disadvantage of PV, the low energy density, less important (hwp & ISET, 2006) since many roofs are available and the production capacity of one roof can be adequate for the electricity consumption of one house.[56] The 1 000 rooftops solar electricity programme was accompanied by measurement and analysis of the PV systems installed.[57] The programme mainly aimed at developing installation know-how and an installation standard, which de-facto became the installation on a roof. A *knowledge formation downstream* among installers was achieved and new inverters were developed as an act of *entrepreneurial experimentation* and *materialisation* leading to *knowledge generation*: many electrical installers entered the market and conditions to feed decentralized power into the grid were tested (Jacobsson et al., 2004).

Furthermore, in 1991 the first feed-in-tariff was implemented in Germany. Förderverein Solarenergie and Eurosolar joined with the young German wind turbine industry and an industry association of owners of hydro power plants (Jacobsson et al., 2004); therefore, a feed-in-tariff giving 90 percent of the domestic market price, which was about 8.5 EURCent/kWh at that time, to suppliers of electricity from renewable energy technology, was implemented. Hence, the electricity utilities were forced by an obligation to accept the electricity produced by renewable energy to be fed into the grid (hwp & ISET, 2006). This tariff made it possible that not only the electricity produced by renewables had to be used by the producer itself but that the surplus in electricity was sold to a price not competing with established technologies to produce electricity but to a price close to the price to which electricity was sold by the utilities.[58] Yet, for solar power this amount was not high enough to be cost covering and therefore the feed-in-tariff did not create rapid diffusion; still, the idea

[54] We use CDU to describe the fraction of CDU and CSU in the German parliament. The CSU only exists in Bavaria, where the CDU does not run for elections. The CDU is present in all other Länder.
[55] Thus, a tension, the increasing awareness of the necessity to find alternative energy resources, weakening the electricity supply *regime* emerged.
[56] Compared to technologies utilising fossil fuels a lot of space is needed to produce the electricity for a densely populated region. However, this comparison does of course not take the genesis of the fossil fuels into account.
[57] For instance see Hoffmann et al. (1998) and Rindelhardt et al. (1995).
[58] We assume that the electricity utilities sell the electricity they produce for a higher price than their production price in order to make profits.

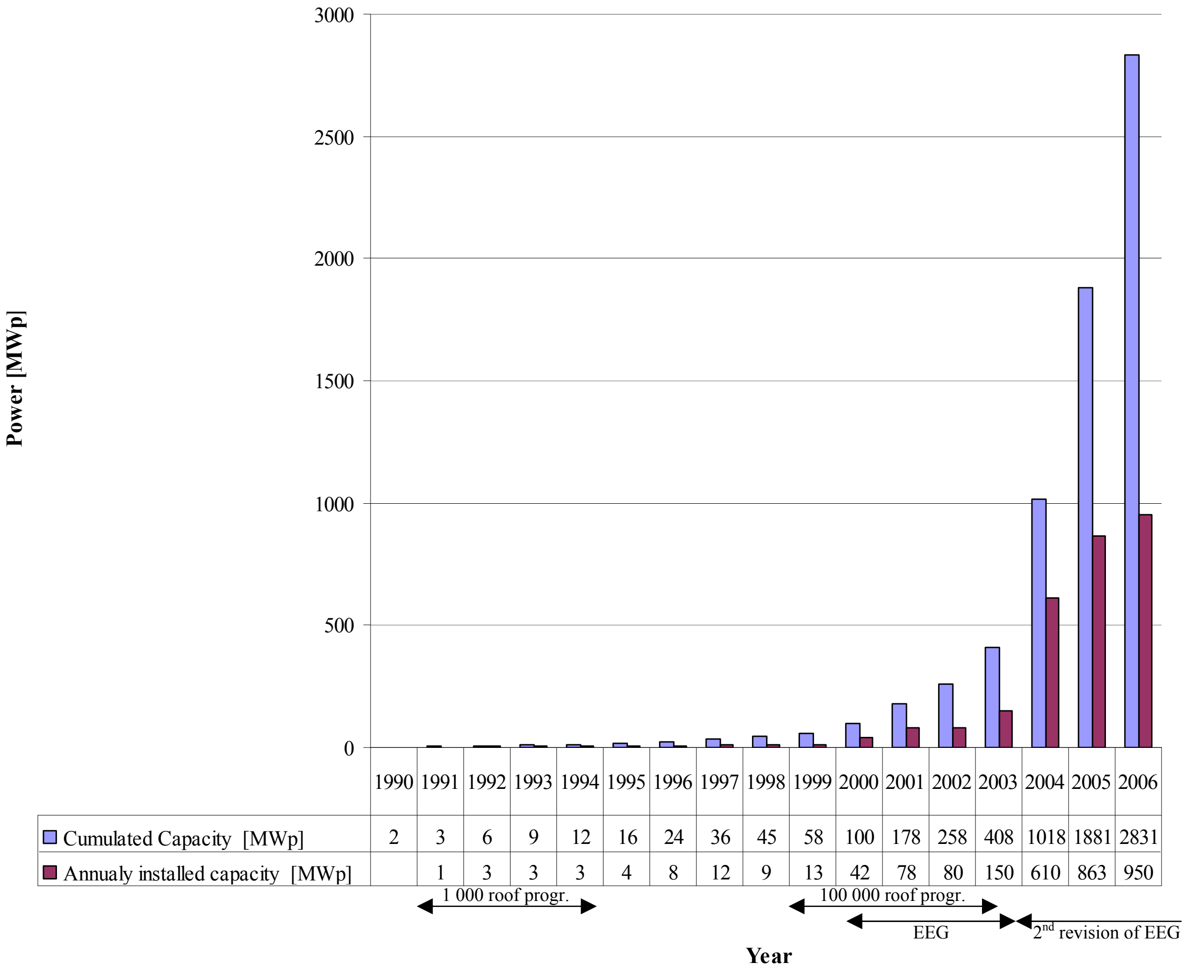
that electricity from renewable energy needs to be brought closer to the market by supportive prices was diffused.[59]

Thus, the identification of PV as efficient enough to produce electricity for one house on its roof, the Chernobyl accident resulting in higher environmental awareness, the search for alternatives for nuclear power, and the first feed-in-tariff shifting the price competition from production prices to demand prices for electricity produced from PV, gave *legitimation* to PV systems. Hence favourable changes on the *niche* as well as *regime* and *landscape* level showed a combined effect, helping to establish photovoltaics.

In 1991, independent from the 1 000 rooftops programme, the first facade integration worldwide took place in Aachen (Hagemann, 2002; Stark et al., 2005).[60] It was built by the local utility in Aachen and had a capacity of 4 kW_p. According to Jacobsson et al. (2004), before the facade system was realised an architect had participated in a meeting about solar cells and was convinced that he had already seen a PV facade. Another person involved in the meeting, Oussama Chehab from Flachglass, had worked with PV tiles before and was able to convince the architect that PV facades had not existed until then but could be built. After Chehab had persuaded his management, the system was built and a completely new segment born. The installation was realised without federal funding, since the common perception was to put solar cells onto a roof to maximize the electricity produced.[61] For the local utility in Aachen, the image function of the facade seemed to be more important than the supply of electricity. This opened up a new market opportunity for PV: systems integrated into a building in an architecturally interesting way. However, it would take years until awareness for PV was achieved among architects. The project in Aachen and some more following in the early 1990s made people aware of PV solutions and may have helped to prepare for more advanced programmes like the 100 000 rooftops programme later on (Jacobsson et al., 2004).[62] Flachglass, which became insolvent and was acquired by Scheuten Solar in 2003 (Photon, 2007b), even invited architects and politicians and offered training programmes for electricians, facade makers and building companies (Jacobsson et al., 2004) in order to make their new facade product public but thereby promoting a new PV application as well. Hence, first efforts to *legitimise* BIPV facade systems were made. Furthermore, *knowledge* was *built*

[59] Subsidies are necessary to overcome a Catch-22 situation: the diffusion of PV on larger markets, which is needed to decrease costs, is hampered by high costs (Sanden, 2005).
[60] In the following, the word facade refers to systems integrated into a building but not integrated in the roof.
[61] As explained in the paragraphs before, the efficiency loss of a PV system depending on its orientation can be seen in *Figure 24* in *Appendix F*.
[62] By building the first PV facade as an act of *materialisation*, *legitimation* was given and the *direction of search influenced* to BIPV facades and to PV in general.

by installing the first facade in Aachen and attempts to *influence* architects to consider PV facades as a possibility were made. Moreover, the new application of PV as a facade material was an act of *entrepreneurial experimentation*, and tacit *knowledge* was created.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Cumulated Capacity [MWp]	2	3	6	9	12	16	24	36	45	58	100	178	258	408	1018	1881	2831
Annualy installed capacity [MWp]		1	3	3	3	4	8	12	9	13	42	78	80	150	610	863	950

Figure 9: **Grid connected capacity from Photovoltaic installations for electricity generation in Germany from 1990 to 2006 (BMU, 2007b) and important federal legislations to foster the diffusion of solar cells**

Nevertheless, during the beginning of the 1990s the market for solar cells was still very small in Germany (see *Figure 9*); since the industry was running with high losses, investments in production facilities were hard to justify (Jacobsson et al., 2004). Siemens produced cells in the US as they bought the American company ARCO and the rest of the German producers merged under the firm ASE (Jacobsson et al., 2004). In 1996, the production within Germany dropped to less than 0.2 MW_p (see *Figure 10*), indicating that the former investments in RDD could not be exploited, neither in *market development* nor in production capacity (Jacobsson et al., 2004).

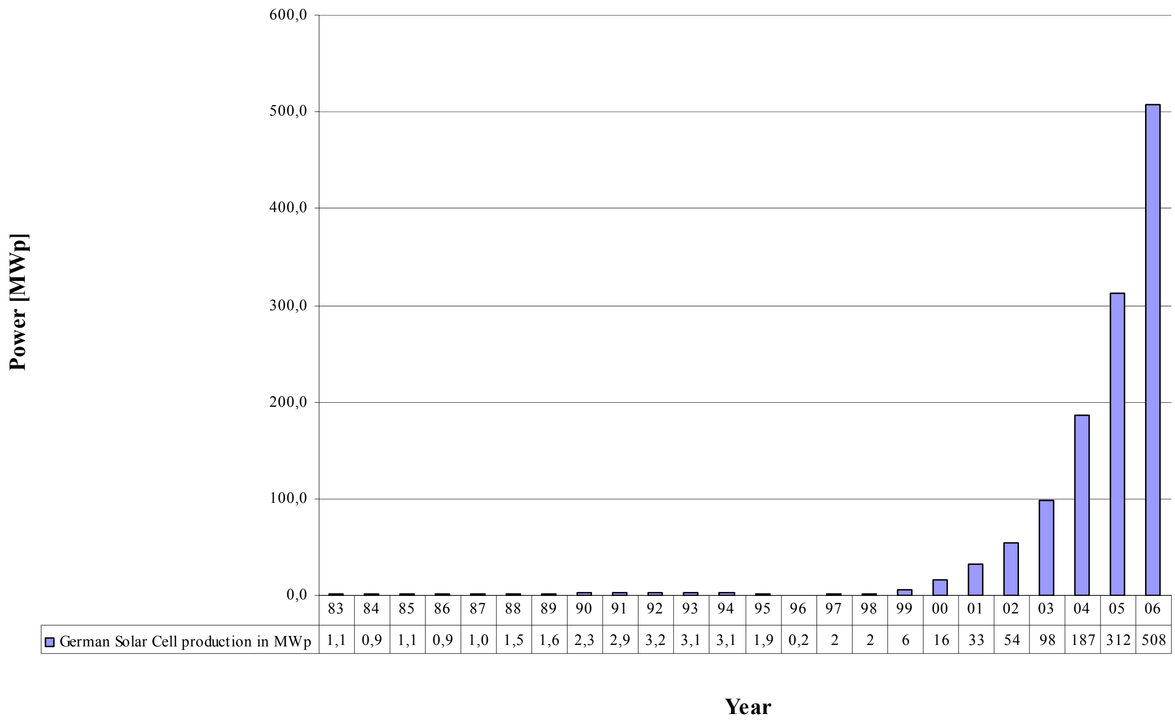


Figure 10: **German solar cell production in MW_p from 1983 to 2006; Sources: 1983-1997: Jacobsson et al. (2004); 1998-2005: BSW (2007b); 2006: Hirshman et al. (2007)**

When the 1 000 rooftops programme expired, no succeeding federal funding besides the low feed-in-tariff of about 8.5 EURCent/kWh was left. According to Jacobsson et al. (2004), in the German parliament where the CDU/Liberal coalition was still in power, a 100 000 rooftops programme proposed by EuroSolar in 1993, and included into SPD's political programme in 1994, was rejected. Nevertheless, other *actors* stepped into the breaches. Firstly, Förderverein Solarenergie successfully convinced local governments to install local feed-in-tariffs. In 1994, about when the 1 000 rooftops programme phased out, Aachen implemented a local tariff followed by 40-45 other cities (Jacobsson et al., 2004).[63] Secondly, electricity utilities started offering special tariffs for electricity from renewable energy: Bayernwerk offered a green pricing scheme, including an investment in a 50 kW_p plant and

[63] Initially, a remuneration of 1.02 EUR (2 DM) was paid in Aachen. In 1997 the remuneration was reduced to 96 EURCent/kWh (1.89 DM/kWh) since costs for solar systems had dropped (Püttner, 1997). Other examples for cities where local feed-in-tariffs were implemented in 1994 are Hammelburg and Freising. Later on, other cities followed, e.g. Darmstadt, where the local utility, HEAG, implemented a remuneration of 65 EURCent/kWh (1.28 DM/kWh) in 1998 (Leuschner, 2007). Furthermore, a 30 percent investment grant was given by the Länder government in Hesse where Darmstadt is located. However, the utilities working on a national level did not adopt the tariffs. Furthermore, different tariffs in different cities and therefore a lacking general legislation prohibited rapid market growth for solar cells. Nevertheless, a small *niche* could survive under these conditions. In addition, the local feed-in tariffs have probably helped to set the range of the remuneration of the Renewable Energy Sources Act later on (Jacobsson et al., 2004).

buying electricity for more than 10 EURCent/kWh, in 1994; RWE implemented an eco-tariff, which 15 000 subscribers switched to, for electricity solely produced by renewable energy costing twice as much as the normal tariff in 1996 (Jacobsson et al., 2004). Thirdly, research efforts were continued; e.g. between 1995 and 1999 the research project "development of photovoltaic compact systems" was carried out, including intensive university-industry cooperation (hwp & ISET, 2006), helping to keep companies in the market and to improve products.[64] Fourthly, new organisations promoting solar energy appeared. Their work was primarily on the local public level and supported by volunteers. One example may be the "Solarpfennig e.V." (respectively "Solar penny") founded in 1994 in Spandau next to Berlin, which helped to diffuse *knowledge* and built demonstration projects (Ludewig, 2007). Solarpfennig was founded by an environmentally aware pastor. Every member paid 1.5 EURCent per kWh he or she consumed into a fund in order to improve the awareness about consumed electricity and to encourage to save energy. The collected money was used later on to finance small PV projects in the region.[65] The impacts from organisations on the public level should not be underestimated especially regarding the demonstration of solar cells and the long-term promotion convincing people one by one, hence *legitimating* photovoltaics as a whole.

As explained, thanks to the mentioned points the market for solar cells kept on growing when the 1 000 rooftops programme ran out. In the mid 1990s, lobbying for more generous solar policies got more intensive. According to Jacobsson et al. (2004) Eurosolar had already suggested a 100 000 rooftops programme in 1993; then, in 1996, the German Solar Energy Industries Association (UVS) lobbied for such a programme as well. However, the energy utilities worked against the existing feed-in-tariff, which was high enough to create rapid growth of wind power. Again the wind power lobby and other organisations favouring particular renewables or renewable energy in general joined forces. Eventually, a commission of the German parliament barely decided to keep the legislation in 1997 (Jacobsson et al., 2004).

Only one year later, the political conditions and thereby the political *landscape* changed. The coalition of SPD and the Green party came to power and favourable policies for renewable energy were foreseeable, since both parties agreed to dismantle nuclear power and to install a

[64] 80 percent of all the power inverters developed during this research project came from university-industry cooperation (hwp & ISET, 2006), indicating a *learning network*.

[65] Eight projects were realised by the Solarpfennig e.V. in total. Finally, after the Renewable Energy Sources Act was implemented the society's target, to ask for better promotion and sponsorship for renewable energy, was reached and therefore the Solarpfennig e.V. closed (Krüßmann, 2007).

follow-up programme of the 1 000 roof programme (Altrock et al., 2006). In addition, the German solar cell industry reinforced their lobbying accompanied by the decisions of ASE and Shell to build two new production plants in Germany (Jacobsson et al., 2004).[66]

Finally, in 1999 the 100 000 rooftops solar electricity programme was launched including investment subsidies and cheap loans to install solar cells. However, the programme started very slow and only about 3 500 requests were submitted while nearly twice as many were expected in 1999 (Altrock et al., 2006).[67]

In order to reach fast diffusion of PV systems, the feed-in-tariff had to be revised. The Green party was in favour of moving the local cost covering tariffs to the Federal level and arranged a lobbying process including environmental groups, the Solar industry associations, the trade union IG Metall, solar cell producers and politicians from the Länder level (Jacobsson et al., 2004). In contrast, the SPD had different incentives to change the feed-in-tariff: the liberalisation of the energy market in 1998 led to lower electricity prices, which hampered the German wind turbine industry, having grown to become one of the world leaders while still dependent on a dynamic home market (Jacobsson et al., 2004).

Therefore, a new feed-in-law called the Renewable Energy Sources Act (EEG) was introduced in March 2000. The new law abandoned the remuneration's dependence on the market price, fixed it for 20 years and introduced different remuneration amounts for different renewable energy sources. For electricity produced from solar cells 50.62 EURCent/kWh (99 Pfennig/kWh) were set, which gave in combination with the 100 000 rooftops programme for the first time an attractive payment for private investors countrywide (Altrock et al., 2006).[68] Hence, in the following years the market grew rapidly; the newly installed capacity increased from only 13 MW_p in 1998 to 150 MW_p in 2003 (see *Figure 9*). Most importantly, the remuneration is financed by an apportionment among all consumers of electricity; thus the costs are shared by all consumers.[69]

In the following years, the Renewable Energy Sources Act was changed twice and in 2004 even amended. Originally, in March 2000 a cap of 350 MW_p for the remuneration of PV

[66] ASE only built the plant in Germany after threatening to move abroad, which was finally answered by the promise of a new solar cell programme (Jacobsson et al., 2004).
[67] These accounted for nearly 9 MW_p.
[68] Every year the remuneration should decline by 5 percent for new systems. However, old systems kept their high funding, which should constrain the industry to cost reduction. *Appendix I* includes an overview of the German remuneration for electricity produced from solar cells fed into the grid from 1991 to 2008.
[69] The more electricity one consumes, the more he or she has to subsidise renewable energy. However, the state is not directly involved in this subsidy, only by setting the legal framework.

capacity was installed (Altrock et al., 2006). However, the director of the German Solar Energy Industries Association (UVS) was able to implement a formulation in the law requiring a follow-up regulation, which guaranteed economical operation of new PV systems further on (Kreutzmann, 2000).[70] The huge success of the feed-in law in combination with the 100 000 rooftops programme made an expansion of the cap to 1 000 MW_p soon necessary;[71] against the minister of economic affairs' will, the new cap was installed in June 2002.[72]

The policies described above led to new entrants into the PV industry. Besides *supplying resources* and *creating knowledge* in process technology, they diversified into new market segments, which refers to *entrepreneurial experimentatio*n (Jacobsson et al., 2004). The facade integration in Aachen in 1991 found imitators and within a few years several architects got interested in photovoltaics. *Figure 11* shows that during the 1990s BIPV projects were conducted every year. More and more architects got involved and further *knowledge* was *developed*. In addition, some seminars informing architects about BIPV were offered during the mid 1990s (Stark, 2007).[73] Thus, attempts were made to guide the *direction of search* of architects towards PV solutions. Besides, some professorships in architecture dealing with energy efficient building or solar architecture were installed in the following years (Jacobsson et al., 2004).[74] Still, the low annually installed BIPV power shown in *Figure 11* implies that the *legitimation* of BIPV facades was not sufficient and a *market hardly developed* in these days.[75] However, the process of *legitimation* continued and more and more *resources* were *mobilised*.[76]

[70] Only the reached cost reduction for PV systems should be taken into consideration for the following regulation.

[71] Already during the year 2002 some banks refused the financing of PV production facilities since they believed the cab would shortly be reached (Altrock et al., 2006).

[72] The minister of economic affairs, in these days Werner Müller, was already against increasing the feed-in law in 2000 since he feared the law would burden the consumer and the economy as a whole in future that the German Federal Constitutional Court and the European Court of Justice could jeopardise the law. However, the alternative costs caused by the remuneration of PV power accounted still only for 0.006 EURCent/kWh in 2001 (Altrock et al., 2006).

[73] However, the interest of architects decreased slowly again. According to Stark (2007) in 1995 around 25 architects participated in a seminar about BIPV, in 1996 still 20 attended and in 1997 only around 15.

[74] For instance, Prof. Manfred Hegger has incorporated the chair for energy efficient building at the University of Technology Darmstadt since 2001. Furthermore, he is member of the board of directors of HHS Planer + Architekten AG, which participated in the planning of the 1 MW_p BIPV project Mont-Cenis (Herne) installed in 1999. In addition, similar chairs in architecture or civil engineering were installed or will be installed at universities in Berlin, Konstanz, Stuttgart and Bochum (Stark, 2007).

[75] In particular, BIPV facade systems offer inferior efficiencies compared to roof systems since the angle of inclination is less optimal. However, the fact that one can earn money or cover at least a part of the cost for a facade by integrating a PV system, is seldom taken into consideration, which shows the missing *legitimation* of BIPV facade systems.

[76] More architects got in contact with the *technology* and solutions for many types of integration were available. However, a profitable operation of a BIPV system, like every other PV system, was not possible in the 1990s.

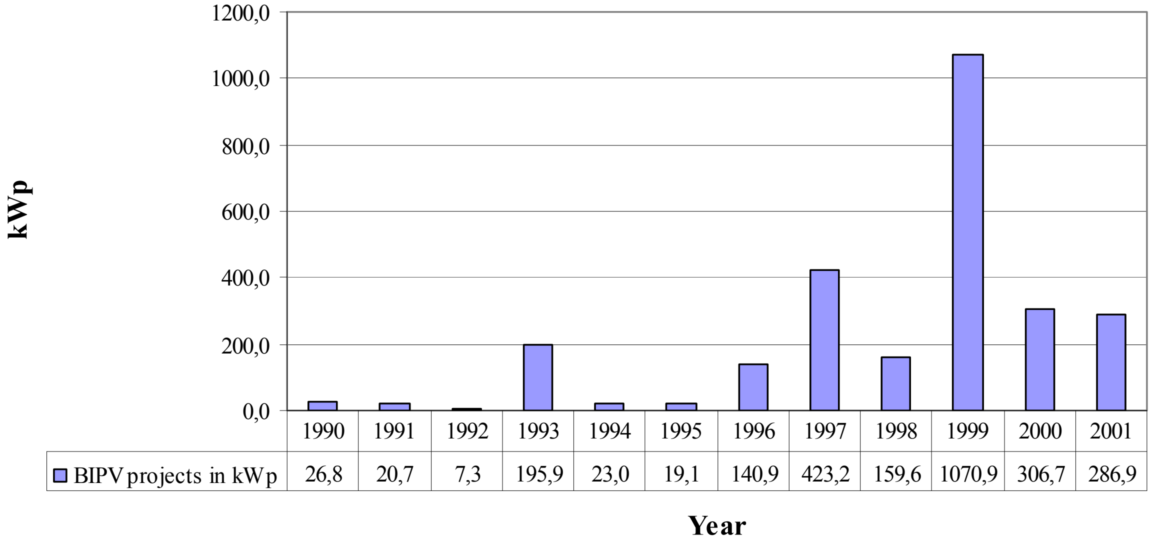


Figure 11: **BIPV facade projects in Germany according to Hagemann (2002)**[77]

BIPV projects were usually not commissioned for monetary rewards but for image and design incentives. In compliance, around the turn of the millennium fourteen BIPV projects were completed in new federal buildings in Berlin with a total capacity of 760 kW_p (Hagemann, 2003). During the same time more and more architects doing research about how to integrate photovoltaics into buildings emerged. Since 1993, several books and brochures have been published about BIPV, explaining the different technologies and illustrating case-studies, as shown in *Appendix J*.[78] Furthermore, around the year 2000, small *networks* between architects and planners doing research and working on projects were formed (Hackner, 2007). These *networks* slowly grew larger and included more and more types of *actors* dealing with BIPV.[79] The networks enable the exchange of information in order to stay up-to-date about the market development and help to *spread knowledge*. Furthermore, a more elaborate

[77] The Figure includes flat roofs, fanlights, parapets, structural glazing, sun protection and some pitched roofs (usual roof integrated systems). Thus, the integration of standard modules or solar tiles is not sufficiently included, only few of these projects are taken into consideration. The projects were found in the book Hagemann (2002) and the amount of projects cannot be regarded as complete. However, the data shows that there were continuously BIPV projects in Germany in the 1990s. In average, an increase in the capacity of project is found over the years. Furthermore, the projects are mostly commissioned by public or commercial entities. This implies that the projects were mainly built for image or design incentives and not for monetary rewards (Hagemann, 2003). According to the author of the book, the data is nearly complete until 1997 and therefore representative for this period (Hagemann, 2007). Particularly, in 2000 and 2001 the number of projects increased and several projects are thus not included in *Figure 11*.

[78] Albeit most books were published after the year 2000, at least two were published in the 1990s. The brochures were for instance published by the ministry of economics in Baden-Württemberg or North Rhine-Westphalia and included, besides other information, examples as well as legislative information for the integration of photovoltaics into buildings. Thus the brochures are attempts to *influence the direction of search* into BIPV.

[79] Several companies provide cells for BIPV projects in Germany and therefore most of the bigger companies have at least one expert in BIPV.

division of labour is achieved, the barriers between different potential participants in a BIPV project are slowly reduced and trust is built since the people involved with different backgrounds know each other. Nevertheless, the market for BIPV in facades was still comparatively small: solely, in 1999 when the 1 MW_p project in Herne was finished the market for facade systems was above 1 MW_p, as shown in *Figure 11* and *Appendix H*.[80]

Another segment, which gave the companies the possibility to diversify, was roof-integration. As explained earlier first attempts of systems integrated into roofs were made during the 1980s and during the 1 000 rooftops programme. However, in the mid of the 1990s Lafarge entered the market as a dominant *actor* of the German tile industry (Jacobsson et al., 2004). Lafarge tried to promote in-roof systems by bringing together different industry associations in order to diffuse this approach. According to Jacobsson et al. (2004), the interest grew and ten firms showed solutions for roof integration at an exhibition in 2000. Nevertheless, the products faced problem to get widely spread. Firstly, it makes mainly sense to install an in-roof system on new buildings or when the roof of an old building has to be exchanged anyway. However, the amount of old buildings with intact roofs is high and the amount of new roofs to build low (Hegger, 2007). Therefore, the market for additive on-roof systems is bigger than for in-roof systems. Secondly, the installation of on-roof systems is easier and faster, which implies a cost advantage against in-roof systems (Tönges, 2007).[81] Thirdly, for the structural integration into existing roofs, smaller solar roof tiles would be of advantage. However, small sized PV-roof tiles are more expensive than large-sized standard modules, less reliable and require costly efforts to install since many small tiles have to be wired (Hagemann, 2007).[82] Thus, products that integrate small modules into a small tile have a clear cost disadvantage. Furthermore, in Germany an extreme variety of tiles exists, which disables high economies of scale since for every specific product solar cells have to be integrated in a different way (Hackner, 2007; Tönges, 2007). Additionally, solar tiles usually need a comparatively high amount of space per kW_p. Around the year 2000, most of the solar tile

[80] The 1 MW_p project in Herne was the first BIPV system of this size worldwide. Furthermore, the installation of different semitransparent modules in a roof (between 58 and 86 percent transparency) was tested in order to keep the cooling of the transparent cells in an appropriate dimension (Hagemann, 2002). Thereby *knowledge* to install such a big integrated system was *developed*. Furthermore, the system helped again to *legitimise* BIPV since it attracted international attention.

[81] Although PV systems are always comparatively expensive, working hours for the installation can easily increase the price drastically.

[82] Alternatively standard modules can be integrated as in-roof systems as well. Nevertheless, this type of integration does not refer to tiles anymore.

manufacturers gave up and stopped the production.[83] However, the integration of standard modules into the roof still existed as an alternative.

The 100 000 rooftops programme included monitoring of the installed systems as shown in *Appendix H*. This data implies that within this *market formation* programme, a standard appeared. Facade systems are expensive and are more installed for image reasons; they build a cost intensive small *niche* helping to *legitimise* PV systems as a whole as eye-catchers. In contrast, in-roof systems were a potential solution for new buildings. However, the monitoring data of the 100 000 rooftops programme shows that the market went in a different direction. In 1999, 7.5 percent of the systems were in-roof systems, but in 2003 only 1.4 percent compared to 86.7 percent of on-roof systems in 1999 and 97.7 percent in 2003. Hence, a standard emerged: on-roof systems as the application, which is the easiest and cheapest to install mainly fostered the exponential increase in installed PV power in Germany until 2003. On-roof systems are the ones which mainly benefit from *positive externalities* to adoption in Germany: most systems are installed in this way and therefore on-roof systems are present in people’s mind.

Nevertheless, according to Jacobsson et al. (2004) Germany was still regarded as the world leader in roof-integrated solar cells around the year 2000. However, the de-facto standard of on-roof systems may have hindered the further evolution of BIPV systems, which may be seen as a premature lock-in situation.

In general, not only the PV demand grew in Germany, the production capacity was increased as well. In 1996, only two firms were manufacturing solar cells, whereas in 2000 already six companies (Jacobsson et al., 2004).[84] Hence, the degree of *materialisation* of the industry was increased by *entrepreneurial experimentation*. Particularly, the production processes were developed in cooperation with research institutes: Sunways cooperated with the University of Konstanz, Antec with the Batelle Institute and Würth Solar had a strong link with the University of Stuttgart and the Centre of Solar Energy and Hydrogen Research in Stuttgart (Jacobsson et al., 2004). Notably, transparent solar cells developed by the University of

[83] According to Hug (2006) several solar tile manufactures gave up: The aesthetically very nice tiles from the Gebrüder Laumans GmbH & Co. KG were introduced in 1999 and highly praised. However, the high installation costs increased the price by about 25 percent compared to standard modules: the wiring of nearly 400 tiles to reach 1 kW_p was very complex. In 2004 the production was stopped. Furthermore, Pfleiderer, which launched the TerraPiatta Solar in 1999, interrupted its production as well. The Pfleiderer product also suffered from its price, about 50 until 60 percent higher than standard modules’ price (Schneider, 2007). *Figure 30* and *Figure 34* include examples of solar tiles in *Appendix G*.

[84] Ersol, Sunways, Antec and Würth Solar started producing cells using many different design approaches (besides crystalline silicon, they built modules out of a-Si, CIS, CdTe etc.) in this period (Jacobsson et al., 2004).

Konstanz (Khammas, 2007) show a successful research activity in BIPV: *knowledge* offering new integration possibilities was *developed*. [85]

Following Jacobsson et al. (2004), three kinds of strong *networks* linked the growing number of *actors* within the PV industry. Firstly, the high research funding since the 1970s paid off, as close industry-academia links led to new and improved production processes. Thus, due to the *growing market,* the degree of *materialisation* could be increased since new *knowledge developed* in research institutes was exploited. Secondly, the *actors'* base of the industry got wider. New applications were found, which involved new *actors* such as architects or roof manufacturers.[86] This helped to *legitimise* PV *technology* as a whole and to *supply* new *resources*.[87] Thirdly, the increasing number of *actors* and therefore jobs generated in the industry strengthened the industry associations' lobbying power. By raising the cap for remunerated PV power for the feed-in tariff, the door was opened for new investments until the 1000 MW_p cap was reached.

To sum up, between 1990 and 2004 the political conflict about fostering the diffusion of solar cells to produce electricity was won by the groups in favour of renewable energy.[88] An ambitious *market formation* programme was installed leading to a fast market growth as well as a strengthened domestic industry. The industry's whole value chain was enlarged; diversification took place on the manufacturing as well as the application level. A self sustained growth was reached (Jacobsson et al., 2004). Particularly, demonstration projects build the first *niche market* and helped to *legitimise* the *technology*. Therefore, the *direction of search* was influenced towards solar cells and new *knowledge* was *created*. This led to *entrepreneurial experimentation* and *materialisation*, new production facilities were built partly by new *actors* and thus *resources* were *mobilised*. Furthermore, due to *positive externalities* through the availability of new demonstration projects, the *market* was *enlarged* further on. Yet, the functions *materialisation* and *positive externalities* were particularly weak. In 2003, the German PV market was still bigger than the German production capacity; therefore about one third of the PV power installed had to be imported.[89]

[85] Transparent cells are mainly interesting for sun protection or for aesthetical incentives of building integrated systems. Directly, in 1999 the production of these cells was started by Sunways. The production of the new transparent cells can be regarded as an act of *entrepreneurial experimentation* in the BIPV field.
[86] Even if solar tiles were not really established, potential applications were tested, showing the growing dynamics in the industry.
[87] E.g. the interest of architects for PV in architecture emerged slowly.
[88] This period was largely affected by the Red/Green coalition.
[89] This is clarified when *Figure 9* and *Figure 10* are compared. Additionally, this gap was increasing even more in the following years, instead of decreasing.

The role of BIPV systems was mainly to promote and *legitimise* PV as a whole. Nevertheless, *knowledge* about how to develop and install facades or in-roof systems was continuously *gained*. *Entrepreneurial experimentation* took place with the attempt to merge tiles and solar cells. This attempt failed, mainly because of high installation costs and weak exploitation of the available surface. As another act of e*ntrepreneurial experimentation*, the production of transparent modules was started by Sunways using *knowledge developed* by the University of Konstanz. In addition, the interest of architects in the *technology* was slowly, but continuously increasing. On a long-term perspective, the role of solar architecture gains importance in the education of architects; therefore *resources* have been *supplied* in the following years.[90]

c) 2004 – today: Intensive growth of PV – BIPV persists in a niche

The following period is characterised by intensive growth for PV in general and the emergence of legislative incentives for BIPV facade systems.

At the end of 2003 the legislation for PV systems was changed again, still under the coalition of the SPD and the Greens.[91] After the 100 000 rooftops programme had phased out, the second revision of the Renewable Energy Sources Act was launched on the first of January 2004.[92] According to Altrock et al. (2006), the new norm removed the 1 000 MW_p cap completely, included open-space PV systems, implemented a remuneration distinguishing between on or in roof systems, facade systems and open-space systems, and increased the remuneration in total in order to compensate the end of the 100 000 rooftops programme.[93] This change of the legislation was planned to be launched by mid 2004 when the Renewable Energy Sources Act was amended as a whole. However, the revision of the solar feed-in law was brought forward faster since the solar associations were able to convince the government that the time period between June 2003 when the 100 000 rooftops programme phased out and the Amendment of the Renewable Energy Sources Act in summer 2004 would have been too

[90] As explained earlier several chairs in architecture or civil engineering deal with solar cells as a building material.

[91] This change was still undertaken by the coalition of the SPD and the Greens, but under a slightly different distribution of power. In the re-election of the coalition the Greens gained about 2 percent reaching 8.6 percent and the SPD lost more than 2 percent reaching 38.5 percent (Bundeswahlleiter, 2002). Therefore, the influence of the Green party slightly increased.

[92] In 2005 a follow-up programme for the 100 000 rooftops programme was implemented by the KfW, which is a public corporation and its roles are therefore defined by law, giving cheap loans for solar systems until 50 000 EUR. Until September 2007 about 300 MW_p were installed through the programme and 38 400 loans approved (KfW, 2007).

[93] Before, only open space systems until 100 kW_p were refunded by the Renewable Energy Sources Act (Altrock et al., 2006). *Appendix H* contains an overview of the feed-in-tariff including a detailed description about the different types of PV systems.

long and therefore would have hampered the German solar industry.[94] By the fast legislation change, the German PV market was again able to grow massively: in 2004 more than 600 MW_p were newly installed and in 2006 even 950 MW_p as shown in *Figure 9*.

Not only the German market but also the production capacity increased: in 2004, 187 MW_p were produced and in 2006 already 508 MW_p. However, the gap between the newly installed and the produced capacity increased. The German PV industry was only able to produce about half of the capacity demanded. Therefore, the German companies could bask in a demand-driven market resulting in high profits (Geinitz, 2007). Furthermore, the German companies mainly sold standard products, there was no need for innovative applications since all the modules produced were immediately sold (Altevogt, 2007). According to the president of the German Society of Solar Energy (DGS), Jan Kai Dobelman, the too high feed-in-tariffs hinder progression and faster cost reduction (Geinitz, 2007).

Nevertheless, the generous feed-in law guided the *direction of search* into the solar field. *Entrepreneurial experimentation* was fostered as many different production technologies were deployed by many different *actors*.[95] According to Hirshman et al. (2007), there were 22 companies producing solar cells[96] and 32 companies producing modules[97] in Germany in 2006.[98] The new *actors* in the industry mostly refer to *materialisation* and *resource mobilisation* in order to exploit the rapidly *growing market* (see *Figure 12)*. Since 2000, the German production capacity seems to follow the market growth, but increases slower. Furthermore, *Figure 12* shows the importance of the German market for the worldwide market. In particular, in 2004 the strong increase in the German market corresponds to the rapid growth of the worldwide market.

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[94] The government was worried that the German PV industry, which had grown rapidly before, would still not be strong enough to put away a setback since the international market was already highly competitive: bankruptcy of firms and the loss of qualified jobs was feared (Altrock et al., 2006).

[95] As already explained earlier, particularly the capacity to produce thin film modules will be highly increased in Germany in 2007 (Kreutzmann, 2007). A production capacity of 2 GW_p is expected for the end of 2007, about 500 MW_p could be thin film.

[96] Including: Antec, Brilliant 234, Calyxo, Conergy, CSG Solar, Deutsche Cell, Ersol, EverQ, First Solar, Heckert, IXYS, Johanna, Ordersun, Q-Cells, Scheuten Solar, Schott Solar, Shell Solar, Solarion, Solarwatt, Sulfurcell Solartechnik, Sunways, Würth Solar (Hirshman et al., 2007).

[97] Including: Aleo Solar, Antec, ASS, Brilliant 234, Calyxo, Concentrix, Conergy, CSG Solar, Ersol, EverQ, First Solar, GSS, Heckert, Johanna Solar, Odersun, Scheuten, Schott Solar, Schüco, Solara, Solar-Fabrik, Solar Factory, Solarion, Solarnova, SolarTec, Solarwatt, Solon, Sulfurcell, Sunovation, Sunware, Webasto, WulfmeierSolar, Würth Solar (Hirshman et al., 2007).

[98] Furthermore, according to Kreutzmann (2007) Wacker Chemie AG, which has been Germany's only silicon producer, will probably be able to produce about 7 500 tons of silicon. Of these, approximately 4 350 will be sold to the solar sector, which should be enough for about 460 MW_p of solar modules. In 2010, the company wants to produce already 14 500 tons, which should be enough to produce 1.4 GW_p of solar modules assuming a decrease of silicon requirements per watt. In addition, City Solar AG is planning to build a plant, which will be able to produce 2 500 tons in 2008.

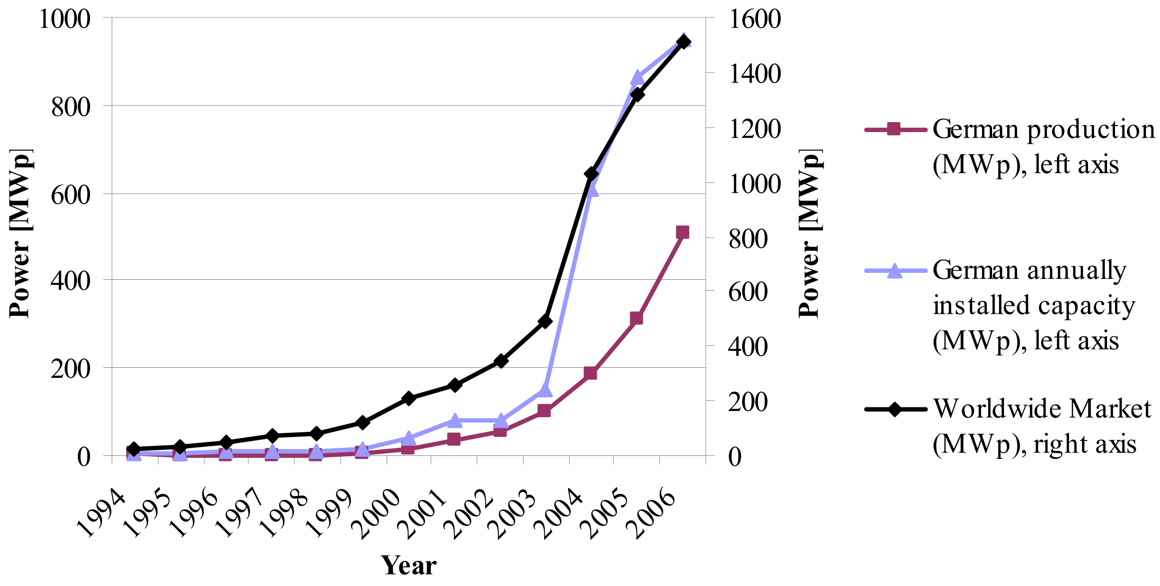

Figure 12: **German annually installed capacity of solar cells compared to the German production of solar cells (both left axis) and the worldwide market (right axis); Sources: German solar cell production: 1994-1997: Jacobsson et al. (2004); 1998-2005: BSW (2007b); 2006: Hirshman et al. (2007); German annually installed capacity: BMU (2007b); Worldwide market (IEA PVPS countries): IEA PVPS (2007)**

Although the production growth was not as fast as the market growth and therefore still only about half of the modules installed in Germany in 2006 were produced in the country, the German solar industry increased the share of exports from 14 percent in 2004 to about 34 percent in 2006 (BSW, 2007b). Since approximately 20 countries introduced similar feed-in laws as in Germany (Geinitz, 2007), the worldwide market is most probably going to grow fast in the coming years. Thus, *positive externalities* arise outside Germany increasing the demand for solar cells. If the German industry is able to expand its production capacity as fast as in recent years, it can benefit from this development and transform into an export industry (Kreutzmann, 2007).[99]

Most importantly for the development of BIPV systems, the second revision of the Renewable Energy Sources Act on the first of January 2004 included a facade bonus of 5 EURCent/kWh, which was proposed by the German Society for Solar Energy (DGS) and the German Professional Association of Solar Energy (BSi) (Hartmann, 2007; Stubner, 2007).[100]

[99] Kreutzmann (2007) estimates 656 MW_p of modules to be produced in Germany in 2007 and more than 2 GW_p in 2008.

[100] According to Stubner (2007), the DGS and BSi asked for a bonus of 10 EURCent/kWh for facades but since the remuneration for electricity produced from solar cells was already comparatively high in general only a bonus of 5 EURCent/kWh was politically achievable in 2004. The idea of a facade bonus was met by the Greens and partly by SPD politicians since the potential for facades and BIPV was regarded as big and an increased acceptance for integrated solutions was expected by implementing such a bonus. A bonus for BIPV in general was not installed since this *niche* was perceived as very young and a further subdivision of the remuneration was regarded as impracticable. Furthermore, the missing legally suable definition of BIPV discouraged from

However, the law clearly states that the facade bonus does not apply for in-roof systems.[101] Furthermore, systems have to be a substantial part of the building, which refers to the fact that systems installed on an already completed facade cannot receive the bonus (Altrock et al., 2006).[102]

As the change of the feed-in tariff was already done on the first of January 2004 the part of the Renewable Energy Sources Act dealing with solar cells was nearly untouched at the Amendment in July 2004, only a definition of the word building was added to guard against the misuse of the legislation. Then, in 2006 a small change was implemented again: the yearly decline for so called open-space systems was increased to 6.5 percent to put more pressure on the industry for cost reduction and to improve the incentives for systems integrated into or added on buildings (Altrock et al., 2006).

The early attempts in the 1990s to integrate PV into facades and the efforts to promote this *technology* finally resulted in the bonus of 5 EURCent/kWh included into the feed-in law in 2004. The facade bonus was installed to increase the incentives for architecturally ambitious solutions to integrate PV into buildings. Furthermore, it should partly compensate the lower efficiency of facade systems but should not compensate the complete cost difference between a simple facade and a PV system (Viertl, 2007).[103] The primary aim was to guide the *direction of search* into facade systems.

The performance of BIPV in Germany is described in the following. The facade bonus had no great impact and the demand for BIPV solutions did not rapidly increase (Erban, 2007; Geinitz, 2007; Neuner, 2007; Viertl, 2007). According to BSW (2007a), more than 95 percent of the total PV power installed is on roofs.[104] However, in 2006 only about 1 percent of the newly installed power connected to buildings were BIPV systems (DGS, 2007; Geinitz, 2007; Neuner, 2007).[105] A reasonable estimation for the newly installed power of different BIPV applications is 1 MW_p on facades, between 3 and 4 MW_p on flat roofs and between 6 and 7 MW_p on pitched roofs in the year 2006 (Neuner, 2007).[106] Hence, the BIPV market in

implementing a general BIPV bonus since misuse was tried to be avoided. In addition, BIPV systems are subsumed as facade systems in the political discussion in Germany; therefore the discussion is misleading and incorrect since the facade bonus does not apply for in-roof systems in general.

[101] Inclined systems, which do not only substitute tiles and have further functions for the building such as shadowing are not regarded as in-roof systems and can therefore receive the facade bonus.

[102] Of course these systems still receive the ordinary remuneration.

[103] *Figure 24* in *Appendix F* shows the efficiency loss of facade systems due to the less optimal inclination.

[104] The BSW is the German Solar Industry Association.

[105] Hence about 99 percent were additive systems on the roof; a de-facto standard appeared.

[106] Classical in-roof systems are meant by the term pitched roofs.

Germany may be relatively big to most other countries but is still a small *niche* within the fast growing PV market; the *market formation* for BIPV has been particularly weak compared to PV in general and seems to stay so.[107]

Architectural BIPV projects are still in the phase of *legitimation*. According to Stark (2007), BIPV has a generation problem: within the next years the first architects, who got in contact with PV during their studies, will enter the job market and *supply new resources* for BIPV projects. In contrast, the older architects educated several years ago have to be interested in solar architecture themselves in order to use it; thus, only few take the trouble to get to know the new *technology*.[108] However, the *formal knowledge base* for architectural BIPV is relatively high: several books have been published and researchers deal with the topic.[109] Yet, despite the *market formation* for BIPV is still weak compared to additional on-roof systems; the interest in solar architecture and the awareness of BIPV is rising. Solarenergieförderverein Bayern e.V. offered a contest for the best PV building integration for the third time in 2005; eventually 18 projects participated (SEV-Bayern, 2005). In the same year, Biohaus offered the first international exhibition of solar tiles (BIOHAUS, 2007). Additionally, in terms of *materialisation*, several new thin film plants are planned in Germany (Kreutzmann, 2007), which could be seen as an indicator for coming BIPV activity. Furthermore, the product variety in BIPV in-roof and facade systems slowly increases (Rexroth, 2007).[110] In addition, architects seem to accept PV as a building material: in 2006 the PV facade system of the fashion boutique Zara in Cologne was on the cover page of the important German Architecture magazine DAB, indicating that PV has been noticed (Rexroth, 2007).[111] Nevertheless, it seems that the incentives for BIPV have been too low until today and that

[107] Surely, the market for BIPV grew rapidly until the year 2007 as well. However, this growth was much slower than the growth for additional on-roof systems. In particular, *Appendix H* shows the relative decrease of BIPV systems in Germany between 1999 and 2003, which are divided into in-roof and facade systems in *Table 4*.
[108] According to Stark (2007), it is still too complicated for architects to gather information about BIPV. Even today, architects have to be engaged in BIPV for a long time until enough *knowledge* is built to use it as a building material. It is not sufficient to inform architects about BIPV, detailed information about solutions have to be available as well, such as account of expenditures and comparisons with other materials.
[109] Nonetheless, the research undertaken is mainly descriptive and solutions are often developed for exemplary projects (best practise). Standardised and transferable BIPV solutions have to be developed or improved in order to simplify the implementation for architects (Clemens, 2007). *Appendix J* contains an overview of books and brochures published about BIPV in Germany.
[110] Systaic launched a complete roof solution with PV integration in 2007 (Achilles, 2007). Schüco, potentially the market leader for BIPV in general in Germany, and EON founded Malibu, which wants to offer a new thin film solutions especially for facades in 2008 (Schüco / E.ON, 2007). Furthermore, Schüco developed a facade system, called E^2 Façade, in cooperation with Prof. S. Behling, who holds the chair for structural design at the University of Stuttgart (Schüco, 2007).
[111] DAB stands for Deutsches Architektenblatt. Another example for increasing awareness of BIPV is a series of three publications in the German building magazine (Deutsche Bauzeitung) about solar potentials. The first article was published on the 20th of August 2007 by Claudia Hemmerle, Susanne Rexroth and Bernhard Weller on the pages 62-67.

without greater financial incentives a market growth as intensive as for PV in general cannot be reached for BIPV shortly.

The market for PV tiles hardly existed in the years before, but found a very small revival. Although most players gave up their products around the year 2000, a couple of *actors* are in the market in 2007 referring to *entrepreneurial experimentation*. Biohaus was claimed to be the market leader for in-roof solutions in Europe in 2006 (Hug, 2006) using standard PV modules on the one hand and PV tiles out of amorphous silicon on the other hand.[112] Another player producing PV tiles is Creative Solar Systems. The PV tiles from this company correspond to 6 normal tiles, which minimises the installation costs.[113] The CEO of the company Bodo Sauerbrey states that the demand for his system is high. Until September 2007 he has sold about 6 000 modules (Sauerbrey, 2007) representing about 240 kW_p. However, he is convinced that he could have sold more than ten times as many if the prices for the modules were reduced.[114] There is nearly no competition for Creative Solar Systems in the market for PV tiles in Germany (Sauerbrey, 2007) and in the meanwhile the total PV market became big enough to provide a small *niche* for such systems.[115] Nevertheless, the market for integrated standard modules is much bigger, although still small. In order to keep prices low, BIPV solutions still have to consist of standard modules (Hackner, 2007).

After an overview of the performance of BIPV in Germany was given, three obstacles for the development are outlined below.

First, although the generous remuneration for electricity produced from PV surely caused the rapid market growth for PV in general in Germany, the feed-in tariff also changed the incentives to install PV from solely environmental idealistic to mostly financial reasons (Neuner, 2007; Tönges, 2007). Thus, to some extent the feed-in tariff does not foster as rapid market growth for BIPV as for PV in general (Erban, 2007) since the 5 EURCent/kWh facade bonus cannot fully compensate the efficiency losses from the less optimal inclination.[116]

[112] However, these systems cannot really be regarded as PV tiles. Compared to the early attempts to build PV tiles, they are much bigger in order to minimise the installation and production costs.
[113] See *Figure 30* and *Figure 34* in *Appendix G* for an example of PV tiles from Creative Solar Systems.
[114] The modules are still smaller than standard modules and the module producers are therefore not very interested in this segment (Sauerbrey, 2007). As explained earlier, the German producers face a demand-driven market where they can sell nearly everything in these days. Thus, the interest in non standard module production is small and hence the prices are high.
[115] Compared to some years ago where companies as Pfleiderer and the Gebrüder Laumans GmbH & Co resigned from the market as explained earlier, there seems to be a small *niche market* for PV tiles today.
[116] In order to cover the efficiency losses of at least 30 percent of a facade system due to the less optimal orientation, a facade bonus of approximately 15 EURCent/kWh had to be implemented (Erban, 2007).

Furthermore, facade solutions are often customized products, which are more expensive.[117] In addition, in-roof PV systems cannot save high costs by substituting tiles; therefore the saving potential is low.[118] As a result, on-roof systems emerged as a de-facto standard referring to premature lock-in, which hinders BIPV *technology* to gain ground. Additive on-roof systems come to people's mind when they think about PV and therefore BIPV are most often not regarded as an alternative.[119] Thus, to some extent there is competition between on-roof systems and in-roof or facade systems.[120] BIPV products are more complex to install, have a cost disadvantage and the industry's incentives are low to go for special applications.[121]

Second, another important barrier for facade systems is legislative problems. The permission to install PV systems is regulated by the building codes on the Länder level (hwp & ISET, 2006).[122] All 16 Länders' building codes contain the permission free installation of PV systems (Schneider, 2002).[123] Still, permission free and other systems have to fulfil the requirements of construction materials. The higher the integration degree of a solar system, the more requirements have to be met. Therefore, product lists exist which regulate if a special permission is needed or not.[124] Most often, glass is the supporting construction element for solar modules and consequently the modules have to fulfil the same requirements as usual glass (Stark et al., 2005). If the PV system has the function to bear weight, special permissions have to be given for new applications, besides a general technical approval or a

[117] Consider a customer, who heard that it is possible to earn money with PV. When the customer finds out that he or she cannot earn money with well integrated facade systems, he or she will most probably prefer a standard additive solution (Erban, 2007).

[118] Tiles are a mass product with a price of approximately 25 until 30 EUR/sqm, whereas solar modules cost about 500 EUR/sqm (Erban, 2007). In 2007, the possible savings by substituting ordinary tiles cannot compensate the higher costs of in-roof systems yet. However, through cost reduction for modules in general, cost savings will become interesting.

[119] This is in compliance with a study by the EuPD, a news service, where installers and wholesalers were interviewed (EuPD Research, 2007). The study attests on-roof systems a high potential for development and in-roof and facade systems a low potential for development in Germany. Furthermore, the potential for poly and mono crystalline silicon technology is regarded as high and the one for amorphous silicon low. Thus, the study does not foresee changes from the present situation.

[120] Furthermore, although the advocacy coalitions favouring photovoltaics in general favour BIPV as well, there is no decoupling from PV. Thus, promotion of PV is the primary focus and BIPV are only regarded as a *niche*. Therefore, the wide spread additional systems hinder the diffusion of potentially more advanced BIPV systems.

[121] Nevertheless, the *actors* engaged in BIPV have recognized France, where the role of BIPV increases, as an interesting new market and try to be present there (Erban, 2007; Neuner, 2007; Sauerbrey, 2007).

[122] Thus, 16 different legislations exist. However, they are quite similar.

[123] For instance in Hesse PV systems on or in buildings, which are no cultural relicts within the meaning of monumental protection and are not in their neighbourhood, were permission free even before the year 1994 (HBO, 1994). Later on the formulation of the regulation was more detailed and PV systems until 10 sqm have been permission free since at least 2002, compare §§ 53 I 1, 55 HBO in connexion with Annex 2 No. 3.9 (HBO, 2002).

[124] "Bauregellisten" are meant with the term product lists.

general technical certificate of inspection exists (hwp & ISET, 2006).[125] However, for usual additive on-roof systems and even for in-roof systems no permission is needed in general.[126]

Third, complex architectural BIPV projects require intensive planning.[127] The communication between potential participants of BIPV projects is essential to overcome existing barriers between the rather conservative building industry and PV system integrators.[128] In addition, warranty and liability problems are unsolved (Hagemann, 2007).[129]

In order to increase financial incentives for BIPV, the German Society for Solar Energy asks for a higher remuneration for facade systems and a special in-roof bonus for the coming Amendment of the Renewable Energy Sources Act in 2008 or 2009 and does not totally rule out a faster decline of the feed-in tariff for solar cells in general (DGS, 2007). In contrast, the German Solar Industry Association (BSW) opposes any kind of intensification of the law.[130] However, the progress report about the Renewable Energy Sources Act from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety suggests an increase in the declination for roof systems from 5 to 8 percent until 2011 and from 6.5 until 9.5 percent for open-space systems. Furthermore, the progress report asks for no new BIPV incentives. Thus, greater financial incentives for BIPV seem to be improbable on the short term.

In summary, since 2004 the demand and the production capacity for solar cells in Germany have gone through a rapid growth phase. Benefiting from the generous feed-in law and an easy permission procedure, the *market formation* was intensified. On the production side, the big domestic market, the long preparation phase based on intensive research and *positive*

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[125] However, if the permission is given in one federal state (Land), the permission process is much easier in another federal state compared to a totally new permission process since the permissions are partly accepted country wide. General technical approval and general technical certificate of inspection are the translations of “allgemeine bauaufsichtliche Zulassung” and “allgemeines bauaufsichtliches Prüfungszeugnis”. Since the amount of BIPV facade projects is still comparatively small, special permissions have to be obtained often.

[126] These systems are classified as other building products and therefore do not require any certificate to be installed (hwp & ISET, 2006). Compared to other EU member states the permission process for PV systems in general is easier and faster in Germany (Wenzel, 2007).

[127] This applies for most of the new technologies in the building sector.

[128] PV systems require the collaboration of overlapping trade areas as roofers and electricians. For example: an electrician does not usually climb on a roof to wire a roof mounted PV installation. Therefore, it would be helpful if the one, who is responsible for the roof deck, also deals with the electrical wiring. However, clearly defined tasks for different trades do not allow that one trade takes over the job of another trade in Germany. This causes difficulties in carrying out work required for the installation of BIPV systems (Hagemann, 2007).

[129] Competence and liability conflicts can easily emerge. As an example, according to Bolling (2007) at the Messe Essen, a fair complex, a BIPV roof system was installed. However, the roof was leaky but the PV modules were not the origin of the problem. Still, the liability was unclear and the responsibility open.

[130] Just recently, the German Solar Energy Industries Association (UVS) and the German Professional Association of Solar Energy (BSi) joined forces and founded the German Solar Industry Association (BSW) in 2006 in order to be more powerful to keep the generous German feed-in regulations.

externalities in form of growing export markets helped to expand the production capacity. Furthermore, new *actors* strengthened the system at all stages of the value-chain. However, the self sustained growth reached is based on incentives created by policy. Additive on-roof systems became a standard referring to an *institutional* change and premature lock-in. The BIPV market can still be classified as a very small *niche* within the PV *niche*, although several *actors* deal with this application. The facade-bonus had no real effect and projects can still be seen as attempts to *legitimise* the *technology* and guide the *direction of search* towards BIPV. However, more and more established architects get in contact with the material and new architects gather *knowledge* about PV in their education. Thus, *resources* are *supplied* for the future. Furthermore, *knowledge* has been *acquired* in a continuously existing *niche market*, which is observed by researchers. Although *entrepreneurial experimentation* is still insufficient some activity can be found. The degree of *materialisation* may improve with new thin film plants starting to produce in 2007. A self sustained growth for building integrated photovoltaics cannot be identified yet. In Germany, BIPV seem to be hindered by the strength of the market for on-roof systems emerged as a de-facto standard, the higher costs for BIPV systems compared to additive solutions, legislative problems and the intensive planning required for BIPV.[131]

4.3. France

In the following section, the history of the French TIS for solar cells is described. In particular, the influence of important events on the development of BIPV in France will be highlighted and analysed. *Figure 14* shows a brief history of PV and BIPV.

The development of PV in France can be divided into five phases between 1973 and today. The first phase, between 1973 and 1982, describes the emergence of the vision of photovoltaics as a potential source of electricity for France. The second phase, between 1983 and 1990, underlines the development of off-grid applications for French isolated sites. The third phase, between 1991 and 2001, highlights the work performed in France by associations, companies and governmental organisations to *legitimise* the development of grid-connected PV. The fourth phase, between 2002 and 2006, is marked by the growth of the grid-connected

[131] Of course, the big market for additive on-roof solutions aids to diffuse BIPV as well. The lobbying organisations are in favour of all PV applications and the legislative framework is also favourable for BIPV. However, BIPV are only regarded as a *niche* and therefore not part of the main considerations (Hackner, 2007), e.g. the German Society for Solar Energy (DGS) had an expert committee dealing with BIPV some years ago but missing funds and comparatively low importance in the total market let the initiative ebb away in recent years (Ludewig, 2007). Above all, integrated solutions are not competitive in price against simple on-roof systems and are therefore only seldom considered as an alternative.

PV market in France which partly drove the actual orientation towards building integrated photovoltaics. The fifth and last phase started in 2006 with the increase of the French feed-in tariff and the emphasis given to BIPV.

Figure 13 illustrates the market evolution in France between 1992 and 2006. In particular, one can remark the rise of grid-connected applications since 2002 which balanced the off-grid market in 2006.

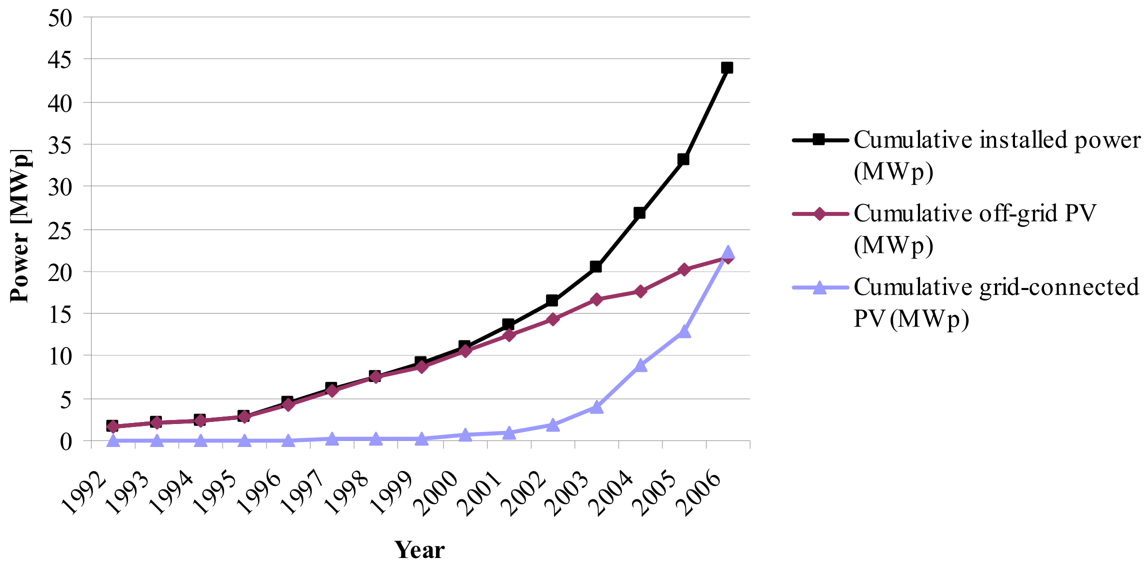

Figure 13: **Growth of cumulative installed power in France (PV installations in MW_p) between 1992 and 2006 (DGEMP, 2006; IEA PVPS, 2006b; IEA PVPS, 2007)**

a) 1973 – 1982: photovoltaics, an alternative energy source with a great potential

At the beginning of the 1970s, several events in the *landscape* influenced renewable energy. Especially, the growing concern about environmental issues and the oil crises drove an increasing interest in renewable energy in France.[132] Between 1973 and 1982, support was provided to the solar industry, starting the *development of a formal knowledge* through e.g. work groups, surveys, conferences. In particular, in 1978 the French solar energy authority (COMES) was created, reinforcing the *legitimation* of solar energy and *mobilising resources*. This authority was in charge of coordinating, managing and promoting all solar activities in France. The COMES was issued from the desire to change the French energy model including a fairly big share for renewable energy, and was presented as a symbolic competitor of the well-known Atomic Energy Commission (CEA).[133]

[132] By France, mainland – or Metropolitan – France (including Corsica) and overseas departments are meant.
[133] The CEA, created in 1945, is a public organisation in charge of the development of all applications of atomic energy (civil and military).

PV in general			BIPV specific
National interest for Renewable Energy	**1973**		
Intensification of the French Nuclear Program	**1974**		
Foundation of the French Solar Energy Authority (COMES)	**1978**		
COMES becomes the French agency for the mastery of energy (AFME)	**1982**		
Foundation of Enerplan, French professional association of solar energy	**1983**		
AFME becomes the ADEME	**1990**		
Foundation of Phebus, French association for PV (now Hespul)	**1991**		
First PV system connected to the grid (by Hespul)	**1992**		
European programmes PHEBUS in 93, 95, 97 and PV-Salsa: installation of 329 kW_p (until 2000).	**1993**		
Law allows installations to connect legally to the grid	**1995**		
Governmental decision to "diversify energy sources"	**1998**		
PV market deployment programme initiated by ADEME (until 2002)	**1999**		
Hip-Hip European programme (until 2002)	**2000**		
First Feed-in Tariff	**2002**	**2002**	The ADEME launches a first initiative for grid-connected BIPV
		2002	First solar tile developed by IMERYS Toiture
Law POPE: energy objectives	**2005**		
Foundation of the French National Institute for Solar Energy (INES)	**2006**	**2006**	New Feed-in tariff in favour of BIPV
		2007	Release of eligibility criteria for BIPV

Figure 14: **Time-line of the development of PV and BIPV in France**

At the end of the 1970s, expectations could be generated and solar solutions were planned to represent between 5 and 25 percent of the energy need (Ministry of Industry, 2001). As a result, several firms were *guided in their search process* and started developing solar cells during the end of the 1970s and beginning of the 1980s – e.g. Photowatt International, the biggest solar cell manufacturer in France in 2007, was created in 1979. Furthermore, between 1974 and 1986, other *entrepreneurial experimentations* were conducted and a few companies worked notably on the Ribbon Silicon Technology (RST) process, *developing* more *knowledge* and *mobilising resources* for the TIS for solar cells. For instance, Philips Labs LEP SARL was the first to develop the RST process, but was taken over by CGE Alcatel in 1981 with its subsidiary Photowatt International (Albers and Schmela, 2004).[134]

In 1974, after the oil crisis of 1973, the French nuclear programme was accelerated by Electricité de France (EDF)[135] and the French government, increasing the CEA's political weight (Electricité de France, 2006).[136] This change in the political *landscape* had an impact on solar energy's expectations since priority was given to nuclear development. Although photovoltaics for terrestrial applications were considered too expensive by the French government, the COMES continued its efforts and maintained *resource mobilisation*, increasing its budget by 50 percent in 1982 (Ministry of Industry, 2001). Despite the loss of *legitimation* for solar energy against nuclear power, one minister predicted a future market for solar energy and the creation of 75 000 to 90 000 jobs in this domain (Ministry of Industry, 2001). In order to *gather* more *resources* and achieve these objectives, the COMES merged with the energy economy agency to become the French agency for the mastery of energy (AFME). Later on in 1990, AFME became the French Environment and Energy Management Agency (ADEME).

[134] Photowatt International now produces multicrystalline silicon. RST was abandoned due to low silicon prices during the 1980s .Today, RST is developed in France by SolarForce that was created in 2003 by Claude Remy, the same CEO that abandoned it at Photowatt International (Albers and Schmela, 2004). SolarForce plans to produce around 1 MW_p of PV modules in 2007.

[135] EDF is the main electricity utility in France. It owns all the nuclear power plants which represented 78 percent of the French electricity production in 2006 (Ministry of Ecology Sustainable Development and Town and Country Planning and Ministry of Economy Finance and Industry, 2007a). See *Appendix K* for further information about electricity production in France.

[136] In 1974, EDF announced the construction of thirteen nuclear plants within two years in order to develop energy independence for France (Electricité de France, 2006).

b) 1983 - 1990: decrease of the interest in solar cells and development of off-grid PV systems for isolated sites

Expectations for solar energy declined in the 1980s because of two main changes in the *landscape*: the fast development of nuclear power in France and the decrease of oil prices. Only few *resources* were allocated to research in PV and entrepreneurs were no longer interested in the field. Despite all the efforts to maintain the development of PV, the French market slowed down in the middle of the 1980s.

Due to high cost and the lack of reliable technical solutions, PV were developed during the 1980s for isolated sites' solutions (rural houses, water pumps in Africa, relay stations, etc.) forming the first terrestrial applications for PV.[137] Three cell producers remained in the industry during the 1980s: Photowatt International (created in 1979), Solems (created in 1982) and Free Energy Europe (created in 1986).

In 1983, Enerplan, the French professional association for solar energy, was created. Its mission is to represent, promote and develop solar energy in France (Enerplan, 2007). In 1984, the "Comité de Liaison Energies Renouvelables" (CLER) was founded. This non-profit association aims at managing a *network* of *actors*, informing, communicating, encouraging *knowledge* sharing and creation (through seminars, workshops, studies, etc.), accompanying renewable energy projects, supporting job creation and representing professionals at both national and European levels (CLER, 2007). These organisations have worked to reinforce the *legitimation* of PV and managed to form the first *networks* wherein *knowledge* could be diffused.

c) 1991 - 2001: the fight for grid-connected PV legitimation

During the 1990s in France, the PV industry was characterised by a clear lack of *legitimation*. Indeed, neither EDF and its nuclear monopoly, nor the French government supported renewable energy. According to Alain Ricaud (Founder of Cythelia in France), it was even considered degrading to work in this field during this period in France (Ricaud, 2007).[138] As a result, *resources* for research were insufficient and the French government somehow advised the ADEME against *developing knowledge* in photovoltaics (Claverie, 2007).

[137] During the 1980s, PV systems represented a big investment. Hence it made sense to use them in exceptional cases such as isolated sites that were too far away from the grid. Furthermore, it was only at the end of the 1980s that electronics progress guaranteed a quality of current compatible with the grid's norms.
[138] Cythelia is a consultancy firm specialised in renewable energy and environmental technologies.

In 1991, Phebus, the French association for photovoltaics, was founded.[139] Phebus was later renamed into Hespul. This association is the first organisation specialised in grid-connected photovoltaics in France and aims at promoting this *technology*. Hespul was notably able to generate a *network* of *actors* in the PV industry. Furthermore, they connected the first PV system to the grid in 1992 whereas both EDF and the government were opposed to grid-connection.[140] During the 1990s, the association coordinated four programmes supported by the European Union: in 1993 (Phebus 93), in 1995 (Phebus 95), in 1997 (Phebus 97) and in 1999 (PV-Salsa). Although the French government tried to slow down the enthusiasm of the French association and to give a negative picture of grid-connected PV (Plein Soleil, 2003), Hespul maintained their efforts thanks to the European Union's support. Hespul represents the historical pioneer of grid-connected PV in France and its role was clearly decisive for the development of the French technological innovation system for PV. First, it reinforced the function of *entrepreneurial experimentation* since they connected the first PV system to the grid and pursued these installations during the 1990s.[141] Second, Hespul influenced the *direction of search* of French *actors* in the TIS (companies, users, governmental organisations, etc.), changing their perception of the *technology*. Third, Hespul fought for the *legitimation* of grid-connected PV systems, defending the *technology* at the local, national and European level. Fourth, the association fostered *market formation* of grid-connected PV. Between 1992 and 1999, the majority of the grid-connected PV systems were installed by Hespul with the support of the European Commission. Some projects were also installed by Total-Energie (today named Tenesol).

By the end of 1999, 583 kWh (ADEME, 2006) were installed, of which 529 kWh by Hespul (Hespul, 2007b). However, according to Marc Jedlizcka, these PV-systems were implemented in a "juridical no man's land" (Plein Soleil, 2003).[142] This lack of *institutional* alignment underlines the fact that by the end of the 1990s a lot of work had still to be done in order to *legitimise* grid-connected PV.

In the meantime, the behaviour of the dominant electricity company EDF regarding PV seemed to change. In 1993, the ADEME and EDF signed an agreement which allowed the installation and the financing of off-grid PV systems for houses far away from the electricity

[139] Founders: Marguerite-Marie Chichereau-Dinguirard, Paul Coste, Marc Jedliczka, Max Schneider.
[140] Actually, grid-connection was not forbidden by the law since grid-connected PV were inconceivable for the French authorities.
[141] Hespul installed the first 300 kW_p of grid-connected PV in France (Plein Soleil, 2003).
[142] Marc Jedlizcka is Hespul's founder and actual manager. He is a real pioneer in France. Jedlizcka notably equipped his house with photovoltaics in 1985 (Plein Soleil, 2003).

grid (Facé Funds[143]) (Ministry of Economy Finance and Industry, 2003). This partnership was renewed in 1996 and 2004. Furthermore, in 1996 EDF launched the ADEN programme which aimed first at improving the reliability of the PV *technology* and second at proposing a range of standardised rural electrification systems. This programme was renewed in 1999 and called ADEN2 (Claverie, 2002a).

However, the legal framework did not take under consideration the possibility to connect PV systems to the grid, hindering the development of the market. Thanks to efforts provided during the 1990s by French associations and industries as well as the pressure from the European Commission, the French government and EDF were pushed to accept grid-connected photovoltaics. As a result, in 1995, French laws authorised the connection of PV systems to the grid and for the first time, public funds were allocated to the development of grid-connected photovoltaics' *knowledge* and projects.

By the end of the 1990s, discussions regarding environmental issues gained power at both national and European levels. In this context, the French government approved of a new policy in favour of energy diversification in 1998, initiating the process of *institutional* alignment. Hence, more *resources* were *mobilised* and an annual public budget of 46 MEUR for promotion and development of renewable energy was announced for the beginning of 1999 (Claverie, 2002a). As a result, resistance from the government started to decrease which opened up new expectations concerning PV future.

In 1999, the ADEME launched a PV market deployment programme which ended in 2002 (European Renewable Energy Council, 2004). The goal of this national programme was twofold: to support Research and Technology Development (RTD) on PV components, systems and applications; and to subsidise demonstration and dissemination projects. The RTD programme involved several *actors* from the industry and the public sector, reinforcing *networks* and *knowledge sharing*.[144] The programme aimed at maintaining the granted volume of 1.2 MW_p/year for off-grid power systems and starting an initiative in favour of grid-connected building integrated photovoltaics (BIPV) (European Renewable Energy Council, 2004). In three years, 70 MEUR were invested in the ADEME RTD programme (23 MEUR

[143] FACE (Fund for amortization of electrification costs) is a public fund traditionally devoted to extending and reinforcing the electricity infrastructure in French rural areas.
[144] Examples of *actors* involved: Photowatt International, EDF, Saint Gobain Recherche, Apex BP Solar, Total-Energie, Transénergie, CNRS, CEA-GENEC, INSA Lyon, CEA-Lco, Universities, Armines, CEAC-Exide, CSTB.

from ADEME) and research was dedicated to various areas (see *Appendix L*).[145] Besides, the dissemination programme mobilised 36 MEUR (16 MEUR from ADEME, 16 MEUR from Regional Councils, and 4 MEUR from Facé Fund) (Claverie, 2003).

As a result, ADEME was able to *develop formal knowledge* in the field and *mobilise* more *resources*. The RTD programme permitted ADEME to reactivate research in PV and the dissemination programme aimed at encouraging *entrepreneurial experimentation* through demonstration projects both for off-grid and on-grid PV (Claverie, 2002b).

After the success of the first RTD programme (1999-2002), ADEME launched a three year industrial RTD project in 2004. It aimed at reducing the production costs of cells by 30 percent within 4 years and making the link between research and industry. New partners joined this programme such as EMIX (crystalline silicon) and Free Energy Europe (amorphous silicon) (Claverie, 2004). This programme developed *materialisation* in the TIS by improving the production processes, and fostered *knowledge* sharing between *actors*, and thus built up *positive externalities*.

Thanks to the involvement of many national *actors*, ADEME managed to create a French group working for the national PV interest. Hence, *networks* started to become advocacy coalitions gaining political strength and working at the international level. In 2005, the ADEME and its partners were committed in international projects such as PV era-net (since 1999), PV Policy Group, European Photovoltaic Technology Platform, or the Photovoltaic Power Systems Programme of the International Energy Agency (PVPS programme and notably Task 10 dealing with Urban Scale PV applications). However, according to Fabrice Juquois (2007) and André Claverie (2007), the participation of French firms in certain international decisions is too weak. In particular, the low participation of French *actors* in international norms' design for PV products is of great importance for the development of an industry.

In 1999, the European Commission launched the Hip-Hip project. It aimed at reducing PV systems cost from 7 EUR/W_p to 5 EUR/W_p within three years and each member country of the project had to install 450 kW_p of PV (ADEME, 2003).[146] This project focused mainly on PV in the building industry and was coordinated in France by the ADEME. Four functions were influenced by this project:

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[145] The funding had different sources, e.g. ADEME, CEA, CNRS, EDF, Regional Councils, Facé Fund.
[146] Six countries participated in this project: Austria, France, Germany, Italy, The Netherlands and Spain.

- ✓ *Resource mobilisation:* ADEME launched in 2002 a national initiative in which they created financial incentives for BIPV in collaboration with the Regional Councils. This initiative aimed at stimulating the market for grid-connected BIPV and reaching 20 MW_p installed within 5 years (European Renewable Energy Council, 2004);
- ✓ *Legitimation:* EDF and the SER (a professional syndicate representative of the PV industry) developed a feed-in contract for grid-connected PV systems;
- ✓ *Market formation:* the Hip-Hip project triggered an interesting dynamic which allowed France to increase substantially its share of PV applied to the building: from 350 kW_p installed at the end of 1999, France reached 1.5 MW_p at the end of 2002 (ADEME, 2003);
- ✓ *Institutional* alignment*:* before the launch of the Hip-Hip project, only few efforts were dedicated to the adaptation of the current technical rules to new *technologies*. This European project permitted the publication of technical specifications for grid-connected PV systems (developed by EDF and the SER) and the start of a process of certification with the Scientific and Technical Centre for Building (CSTB).[147] Furthermore, EDF was obliged since 2000 to remunerate electricity fed into the grid, opening the way for the implementation of a feed-in tariff.

Although several grid-connected systems were implemented in France during the 1990s, the main market remained off-grid PV (see *Figure 15*). Two main reasons may explain the dominance of the off-grid market in France.

First, EDF and the French government neglected PV in order to develop energy independence through nuclear power. Despite the increase of *resources* for off-grid PV development, and the work performed by EDF to improve *materialisation* and *develop knowledge* and *networks*, the market for grid-connected photovoltaics is still weak.

Second, rural and isolated site's electrification is a priority in France and off-grid PV are considered as one of the best solution to respond to this need. As a result, PV got stuck to this image of "solution for isolated sites" and *expectations* for grid-connected PV decreased. Hence, the *search* was influenced towards off-grid PV. Especially, it may be argued that EDF encouraged the development of this image in view of the fact that they financed off-grid installations, pushing research and firms in this direction. In other words, the priority given to the development of off-grid PV started to generate lock-in, and became a barrier for the

[147] CSTB is a public organisation created in 1947 which aims at improving welfare and safety in buildings and their surroundings.

emergence of grid-connected PV. In particular, overseas departments and Corsica have played an important role in the dominance of off-grid solutions rather than grid-connected (see *Figure 15*).[148] There are several reasons why PV could be fast developed in the overseas departments and Corsica, and not in metropolitan France. First, they include a big potential of isolated sites where alternative energies have to be developed (Claverie, 2007). Second, solar irradiation is higher in these islands (Claverie, 2007). Third, electricity production is more expensive in the overseas departments and Corsica than in metropolitan France because nuclear power plants cannot be installed there. However, electricity is still sold at regulated prices which do not cover electricity production costs. Hence, EDF had to develop energy diversity for overseas departments and Corsica (Claverie, 2007).

However, the role of the French overseas departments and Corsica were twofold. On the one hand, and following the previous rational, they hinder the development of grid-connected PV to a certain extent. On the other hand, they have been of great importance regarding the *formation of a market* for PV in general (Claverie, 2007). They became the first *niche market* for the French off-grid PV and have enabled the *development of formal knowledge* and a progressive *legitimation* of the *technology* by the French government (Claverie, 2007).[149] Thus, it is important to underline that the evolution of off-grid PV developed *positive externalities* that grid-connected PV were able to exploit and benefit from later on.[150]

Despite the significant market, the year 2002 was modest for off-grid PV: projects, amounting to only 90 kW in total, were funded by the FACE fund (1.62 MEUR). This can be explained by the *reduction of the potential market* for isolated sites (saturation of the market), especially in Metropolitan France. However, the number of funded projects in the overseas departments and Corsica remained stable (about 1 MW_p/year) (Claverie, 2003).

[148] By overseas departments, Guadeloupe, Martinique, Réunion and Guyane are meant.
[149] By the end of 1999, the cumulated PV power installed in France was around 5.2 MW_p with 66 percent installed in the overseas departments (Juquois, 2005).
[150] Indeed, off-grid and on-grid PV use the same *technologies* when it comes to cells and modules. The differences between the two solutions concern the components around the production of electricity. Moreover, on-grid PV could benefit from improvements in the public corporate image of photovoltaics and previous *institutional* alignment for off-grid PV.

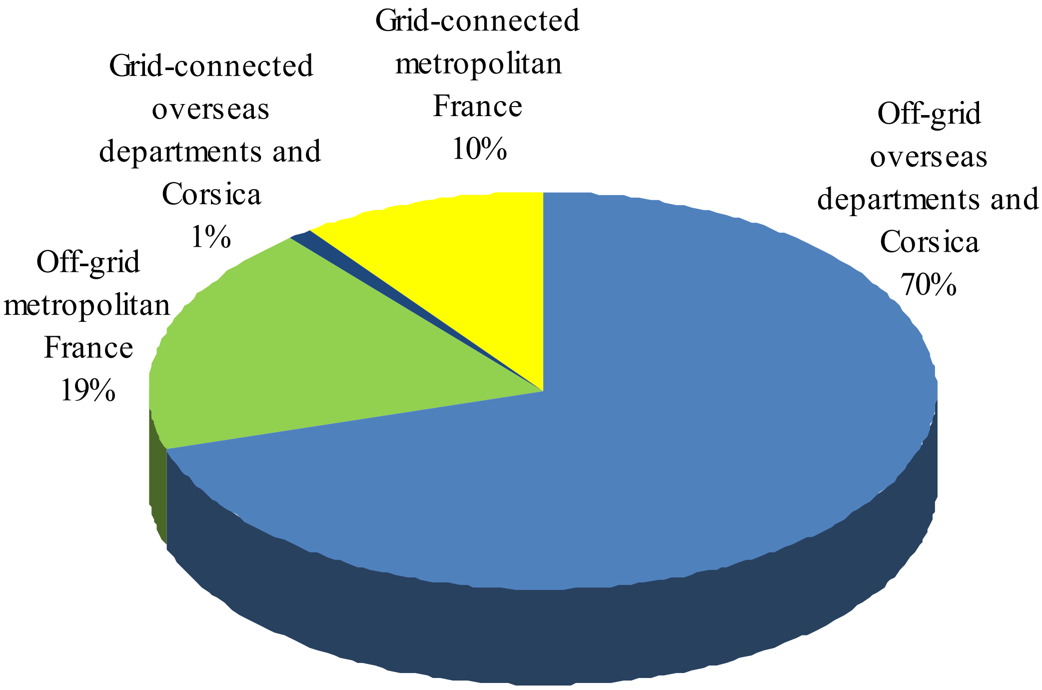

Figure 15: **Cumulative installed PV power in France in 2002 (Juquois, 2005).**

In terms of production capacity, although France was in the lead in Europe regarding cell production in 1997 with 5.7 MW_p produced by Photowatt (19 percent of the European production) whereas for instance only 2.3 MW_p were produced in Germany (Ricaud, 2005), the French industry did not grow as fast as in other European countries. Indeed, countries like Germany or Spain implemented strong incentives for grid-connected PV such as feed-in-tariffs, but France did not develop any special regulation to push the PV market. As a result, the French production was largely overtaken by Spain and Germany in 2002 with only 17.6 MW_p compared to 58 MW_p in Germany and 50.1 MW_p in Spain (Ricaud, 2005). The resistant behaviour of the electricity supply *regime*, that is nuclear power, is considered as an important reason why France did not develop any special incentives for grid-connected PV. In particular, the lobbying power of EDF is partly responsible for the difficulties to access the electricity grid (De Franclieu, 2007; Ouaida, 2007). This barrier to the development of *institutional* alignment is the main origin of the delay the French TIS for solar cells faces today. However, this blocking mechanism tends to decrease (De Franclieu, 2007; Ouaida, 2007) since EDF has understood that demand for photovoltaics is growing and tries to satisfy its customers (Barthez, 2007). This led to the emergence of a new period characterised by the development of *institutional* alignment.

d) 2002 – 2006: A pivotal period for the French PV industry

At the beginning of the 21^{st} century, renewable energy and in particular PV were finally regarded by the government as a reliable alternative that needs to be developed.

Between the years 1999 to 2002, French *actors* such as the ADEME, Hespul, the SER, Enerplan, the CLER, as well as companies and research centers, put a lot of efforts to strengthen the TIS for solar cells, implementing several mechanisms to promote the *technology* in France. In particular, they improved the cooperation between industry and public research, developed demonstration projects, helped to finance applied research for all the components of PV systems, provided information to all the *actors* of the industry (utility, regional authorities, firms, government) and tried to foster *knowledge* sharing through workshops, seminars or conferences (Claverie, 2002a; Claverie, 2002b; Claverie, 2003). Furthermore, since 2001, the ADEME developed the "*espaces info-énergie*". These independent organisations offer free information and advices (technical, legal, administrative, etc.) to private persons or companies and constitute a proximity *network* for renewable energy and energy efficiency.

In 2002, the first feed-in contract was developed by EDF in partnership with the SER, reinforcing *legitimation* and *institutional* alignment. This contract defines the conditions for the connection of PV systems to the grid. EDF and the SER also defined technical terms for grid connection of PV (European Renewable Energy Council, 2004).

Following this keen interest, the French government implemented the first feed-in tariff for photovoltaic electricity in 2002. EDF had to pay 15.25 EURCent/kWh for mainland France and 30.50 EURCent/kWh for overseas departments and Corsica (Ministry of Economy Finance and Industry, 2002).

In July 2005, policy makers designed a new energy framework policy law (called "law POPE"). The law POPE highlights in particular the necessity to diversify the energy bunch in France and sets quantitative objectives, e.g. 21 percent of the national electricity consumption should come from renewable energy by 2010 (CLER, 2006).[151] Moreover, in the framework of this law, a programme called "Plan Face-Sud" in the building sector, plans to install 50 000 rooftops PV systems by 2010 (CLER, 2006). According to André Claverie, law POPE is the

[151] This law is notably based on the recommendations drawn by the white book on energies published by the French government in 2003. This report highlighted in particular the necessity of energy management and renewable energy (Claverie, 2004).

main reason, besides the development in overseas departments, why the PV market could finally increase in France (Claverie, 2007). Indeed, this law underlines especially energy management in buildings, the use of renewable energy and emphasizes particularly the installation of rooftops PV systems, *legitimising* the use of photovoltaics in construction.

This movement led to several improvements in terms of research. From 2004 to 2005, the PV RTD public budget increased from 4 MEUR provided by ADEME to 12 MEUR in 2005. Indeed, in 2005 the National Agency for Research (ANR) was created and started a new research programme for photovoltaics. As a result, ADEME and ANR were able to join their efforts and reach a budget of 12 MEUR in 2005 (Claverie, 2006). ANR is now dedicated to the support of basic research whereas ADEME focuses on industrial and applied research (Claverie, 2007).[152] Moreover, in 2005, the ANR introduced the first call for proposals about PV in the built environment (Agence Nationale de la Recherche, 2005), developing *entrepreneurial experimentation* and *formal knowledge* for BIPV. This call for proposals is part of a programme at the ANR dedicated to photovoltaics. As a result, companies in partnership with research laboratories or universities had to elaborate projects within the framework of the topic of the call for proposals. The programme had two goals: to reduce PV cost and to improve building integration. Afterwards, a set of projects was selected and presented to investors (public or private) to be realised. In 2006 and 2007, ANR launched two other calls for proposals dealing with BIPV (Agence Nationale de la Recherche, 2006; Agence Nationale de la Recherche, 2007).

Furthermore, in July 2006, the National Institute for Solar Energy (INES) was officially created in Savoie (a French department located in the Region Rhône-Alpes). The INES aims at promoting and developing solar energy in France through three platforms: Research, Development and Industrial Innovation; Demonstration; and Education. Although INES was created in 2006, the concept is older since the first idea was already elaborated in 1998 in Savoie (Institut National de l'Energie Solaire, 2006). As a result, more *resources* were allocated to research on solar energy and more *knowledge generated*.

Finally, the European Union also supported this development. In particular, one European programme, the PV-Starlet programme was important for the *development of materialisation* in France. Indeed, in September 2002, IMERYS Toiture launched a solar tile in France. This *entrepreneurial product* received the support of the European Union and the ADEME through

[152] In August 2005, the government announced the creation of the Industrial Innovation Agency (AII) which allocates budget for applied research and in particular to SMEs (Claverie, 2006).

the PV-Starlet programme. As a result, during the period of the programme, installations of IMERYS' solar tiles received strong subsidies (around 80 percent of the cost of the installation). This programme was coordinated in France by IMERYS Toiture and Hespul.[153] The objectives were to develop interactions between two *regimes,* the PV industry and the building industry, integrating PV in construction materials. This programme ended in 2005 and allowed IMERYS to install its products on many roofs: at the end of 2004, already 130 houses (around 220 kWh) were equipped with IMERYS's solar tiles (Batiactu, 2005).

Despite the growing *legitimation and resource mobilisation* for PV in France between 2002 and 2006, the French TIS for solar cells was still underdeveloped compared to a few European neighbours. In particular, the lack of a *national market* for PV has negatively *influenced the direction of search* of French *entrepreneurs* (manufacturers) and hindered *materialisation*. One striking example is the share of exports in Photowatt's production: 90 percent was exported in 2006 (Hirshman et al., 2007).

At the end of 2005, cell production reached 33.1 MW_p in France, mainly due to the growth of markets abroad (see *Figure 16*).

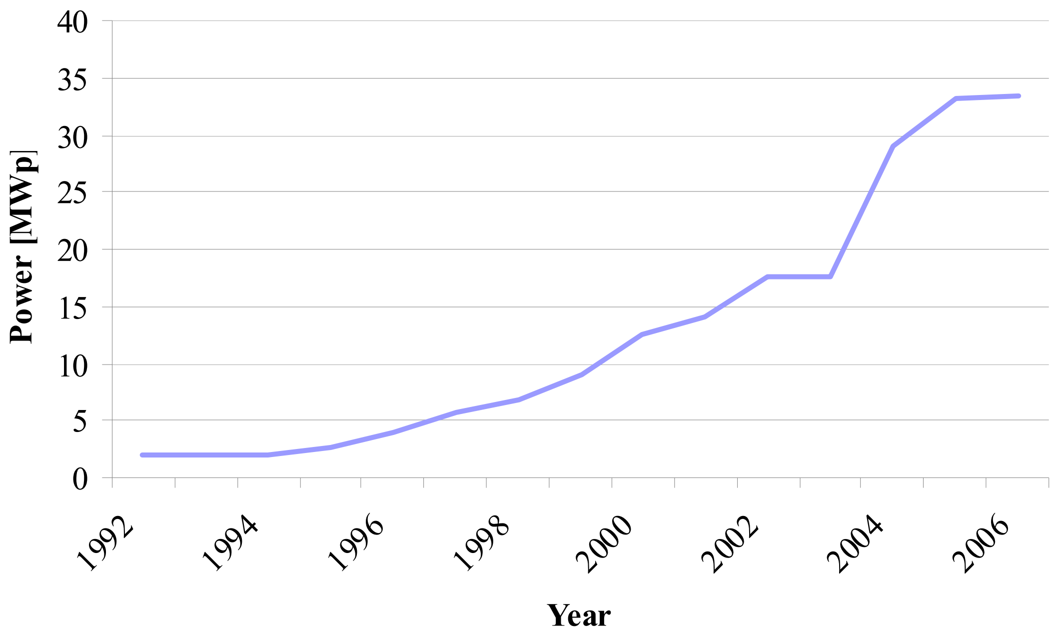

Figure 16: **French production of solar cells (European Renewable Energy Council, 2004; Ricaud, 2005; Hirshman et al., 2007)**

[153] This project involved 9 countries: France, Belgium, Holland, Germany, UK, Spain, Portugal, Italy and Switzerland.

e) 2006 – today: the BIPV choice

Pushed by the pressure put by growing advocacy coalitions composed of the ADEME, the SER, PV firms and French associations e.g. Enerplan and Hespul, the French government implemented new *regulations* to develop a *national market* (Juquois, 2007). In particular, an economically more interesting feed-in tariff should guarantee the growth of the demand. In July 2006, the French government released a new feed-in tariff strongly in favour of BIPV: 30 EURCent/kWh were offered for PV systems in metropolitan France, 40 EURCent/kWh for PV systems in Corsica and overseas departments, and a special bonus of 25 EURCent/kWh (15 EURCent/kWh for overseas and Corsica) for BIPV (rooftops and facades) was implemented. As a result, each grid-connected BIPV system is remunerated 55 EURCent/kWh for the electricity it produces (Ministry of Economy Finance and Industry, 2006b).[154] Nevertheless, it is important to highlight that EDF can compensate the purchase of electricity thanks to a public fund called "*Contribution au Service Publique de l'Electricité*" (CSPE). The CSPE, implemented in 2004, is a tax paid by all the consumers in France and which aims at supporting for instance extra-costs involved for rural electrification, or feed-in tariffs (Ministry of Ecology Sustainable Development and Town and Country Planning and Ministry of Economy Finance and Industry, 2004). According to Anthelme Eiselé (Enercoop), the CSPE compensates most of the expenditure: $1MW_p$ of PV power produced costs 300 EUR for EDF, but 84 percent is covered by the CSPE (Anthelme Eiselé interviewed in ElecMag, 2007).[155]

One reason for developing such a feed-in tariff is that the government wants to differentiate from the mass-industry and leading countries (De Franclieu, 2007; Juquois, 2007) and hence chose BIPV which are still small and not standardised in other countries yet. Another reason is that France wants to develop a non-anarchical industry, i.e. the government does not want to foster the development of non-controlled urban scattering (Courtois, 2007). This last reason refers to the cultural value of aestheticism which is an important criteria in France when it comes to the design of regulations for urban areas and the countryside (Juquois, 2007). For instance, many cities or regions in France have directives regarding the type of tiles (style, colour) private people have to follow when they build or renew a house so that the landscape looks uniform and nice. Another example is the resistance of historic building architects

[154] Feed-in contracts are signed for a 20 year period. This feed-in tariff does not decline by 5 percent every year like in other countries.
[155] Enercoop is one of the new electricity utilities that was founded after the electricity market liberalisation on July, 1st 2007. Enercoop supplies electricity entirely from renewable energy.

against BIPV who usually forbid the installation of photovoltaics on historic buildings or in its neighbourhood.[156] In addition, the French PV *actors* are convinced that within ten years, it may be economically more interesting to use building integrated photovoltaics when constructing a new building than using usual building materials (Juquois, 2007).

It is also argued that this feed-in tariff allows France to "*protect*" its national industry. Indeed, fostering the PV market would induce the entrance of foreign companies on the French market and eventually favour the development of foreign industries rather than French companies (Michel, 2007; Moschberger, 2007). BIPV are a fairly new *technology* in the PV sector and firms have not developed standards yet, neither in France nor abroad. Hence, this provides French companies a *niche market* where competition is still weak and gives them the opportunity to develop their own *technologies* and products for building integration (Michel, 2007).

However, although France may try to protect its market and industry, one can argue that this protected space may also be a way for the government to limit the number of projects (Courtois, 2007). Indeed, integration to the building could be seen as a constraint that reduces the number of solutions and the size of the market (Moschberger, 2007). Therefore, the PV potential is narrowed down to building applications and the growth of the industry is slowed down.

Beyond the debate regarding its real goal, this feed-in tariff clearly *influences the direction of search of firms* and a real *market formation* can be expected, opening the way for further *materialisation*. Finally, the process of *institutional* alignment is now engaged and the *legitimation* of the *technology* progresses.

Furthermore, other financial incentives exist such as a 50 percent tax credit on hardware for individuals[157], local investment subsidies[158], a complementary support from the ADEME[159]

[156] Historic building architects are in charge of preserving historic buildings and the area around the building (parks, villages, etc.).
[157] The cap for this tax credit is 8000 EUR per family with the possibility to add 200 EUR per child. It was implemented in 2002 with only 15% tax credit and increased in 2005 to 40% and finally 50% in 2006. The expiry date is December 2009.
[158] They usually cover up to 30 percent of the total costs depending on regional policies.
[159] This support is often up to 1 EUR/W_p and is based on bids at regional level. The cap is fixed by limited budgets.

and the reduced value-added tax (reduced VAT: 5.5 percent instead of 19.6 percent) on the system's installation cost and in particular cases (Hespul, 2007a).[160]

However, despite this strong feed-in tariff in favour of BIPV, it took several months until the *market* showed a substantial reaction. According to Marc Jedliczka, this delay in the market is due to a "*slight hiccup*" in the definition of BIPV installations which led more to a "*psychological barrier for rooftop systems than a real one*" (Hirshman, 2007). Indeed, already "*about 80 percent of BIPV components are clearly approved under the current tariff guidelines*" (Marc Jedliczka in Hirshman, 2007). As a result, this fairly low hesitation in BIPV applications definition increased uncertainty and pushed administrations and customers (industrial and individuals) to believe that one should wait for a clearer definition of BIPV applications.

In April 2007, the general directorate for energy and raw materials (DGEMP) and the directorate for energy demand and energy markets (Dideme) released a guide describing the eligibility criteria for BIPV installations (DGEMP and Dideme, 2007), strengthening the *legitimation* of BIPV.[161] This document does not provide any list of official BIPV products, but explains the situations where PV installations are considered integrated to the building and hence can benefit from the special feed-in tariff of 55 EURcent/kWh. The eligibility of systems for this BIPV bonus is decided by the DRIRE (Hespul, 2006).[162]

Also, since May 2007, reduced VAT on the system's installation cost is no longer applicable to installations that sell the totality of the electricity produced to the electricity utility. This change specifies that the reduced VAT is only applicable for installations under 3 kW_p (Hespul, 2007c). This modification of the fiscal conditions for PV systems had and will have an important impact for the PV firms' activity. Indeed, the market for private installations will certainly suffer from this change which will slow down *market formation*.

On July, 1st 2007, the French government liberalised the electricity market for private customers. Following this liberalisation of the market, one can expect the entrance of new operators with green offers in favour of renewable energy (Claverie, 2007; Loyen, 2007; Ricaud, 2007). However, it is commonly argued that this change will not have any decisive impact on photovoltaics' diffusion (Claverie, 2007; De Franclieu, 2007; Ricaud, 2007).

[160] See explanation below.
[161] Both DGEMP and Dideme were part of the Ministry of Economy, Finance and Industry but are now part of the new Ministry of Ecology, Sustainable Development and Town and Country Planning created on May, 18th 2007.
[162] The DRIRE are regional representations of the ministry of industry.

Furthermore, the liberalisation of the French market might only be seen as competition in theory (Brand, 2007). In reality, there are few advantages for the French to change their electricity supplier.[163]

Finally, in September 2007, a quality guarantee for photovoltaics called Quali'PV was implemented by an association, Qualit'EnR.[164] The first objective is to guarantee the quality of the installers' know-how. It also aims at promoting and diffusing installation techniques of grid-connected PV, and improving the quality of services delivered by installers (Tecsol, 2007).[165] Quali'PV reinforces *institutions* and will certainly strengthen BIPV' *legitimation*. Furthermore, it shows the interconnection of BIPV with two *regimes*: the building industry and the electricity supply industry. In particular, Quali'PV highlights the need of coordination between the *actors* of both *regimes*.[166] Similarly, an alignment between the *institutions* of both *regimes* is required: PV modules have to comply with construction norms.

The efforts made during the last decades in the field of PV finally permitted the TIS for PV to develop notably thanks to the emphasis given to building integrated photovoltaics. According to ADEME, between 2005 and 2006 the grid-connected PV market grew by 137 percent (see *Figure 13*). The orientation towards building integrated photovoltaics will certainly secure a future development of the market for France. However, financial incentives have to be maintained.

Previously, the history of photovoltaics in France and especially building integrated photovoltaics was described and analysed. In the following, an overview of the structure of the French PV industry in 2007 is provided. In particular, we highlight the categories of actors, the important networks and the main blocking and inducing mechanisms for the development of PV and more specifically BIPV.

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[163] For instance, customers that switch the electricity supplier cannot come back to EDF. Furthermore, EDF's prices are currently guaranteed by the government against price increases (regulated prices). Moreover, the CSPE (see previous explanation), that the historical electricity suppliers (mainly EDF) benefit from, has not been generalised to all the competitors. As a result, customers that want to produce electricity from renewable energy and benefit from the feed-in tariff have to stay under contract with EDF. Since customers may change supplier mainly for ideological reasons (against nuclear power), we easily understand that it is a fallacious liberalisation.

[164] Qualit'EnR was created in 2006 to manage Quali'Sol, a quality guarantee for solar thermal installations created by the ADEME in 1999. Qualit'EnR continued this work, implementing new quality guarantees: Quali'Bois at the beginning of 2007 and Quali'PV in September 2007.

[165] Quali'PV is divided into two different modules: Quali'PV module Elec covering the electricity part of the installation and Quali'PV module Bat concerning the integration to the building. Trainings for Quali'PV started in October 2007.

[166] For instance, coordination between a carpenter and a photovoltaics installer is needed since PV modules have a standardised size which might not match with the roof frame.

We could identify while analysing the history that several groups of *actors* were shaped. They all participate in the evolution of the TIS for PV, positively as well as negatively. In France, many *actors* could emerge, energising the TIS for PV: governmental organisations, e.g. ADEME; non-governmental organisations, e.g. Hespul, Enerplan, CLER, the SER; manufacturers of cells and modules, e.g. Photowatt International, Free Energy Europe, Solems, Tenesol (50 percent owned by EDF and 50 percent by Total), Emix, IMERYS Toiture; components manufacturers[167], e.g. Arcelor, Saint-Gobain; systems integrators, e.g. Clipsol, Sunwatt Energy, Solarcom, Apex BP Solar; research organisations, e.g. the INES, the CEA, the CNRS, the CSTB, Universities, private laboratories; and installers. In particular, Photon International included three of the French companies in its market survey on cells and modules production worldwide: Photowatt International (cells and modules), Free Energy Europe (cells and modules) and Tenesol (modules) (Hirshman et al., 2007).

In terms of production capacity of solar cells, the French industry has a particular profile. Indeed, the French production has always been higher than its national market since 1994. *Figure 17* shows in particular two interesting characteristics of the French PV industry. First, and as we described in the French history, we observe that the national market is small compared to the worldwide market and the gap has increased since 2003. The main cause for this delay is the late implementation of financial incentives for *market formation*. Second, we remark that the French production capacity growth is not driven by the growth of the national market but rather by the worldwide market, even if the production capacity is comparatively small. The main cause for this is that 90 percent of the solar cells produced in France are exported (e.g. to Germany, Greece, Italy and Spain) rather than sold on the national market (Hirshman et al., 2007).

[167] Components manufacturers do not include cells and modules production. Components can be for example glasses for modules, aluminium or steel frames, inverters, cables, etc.

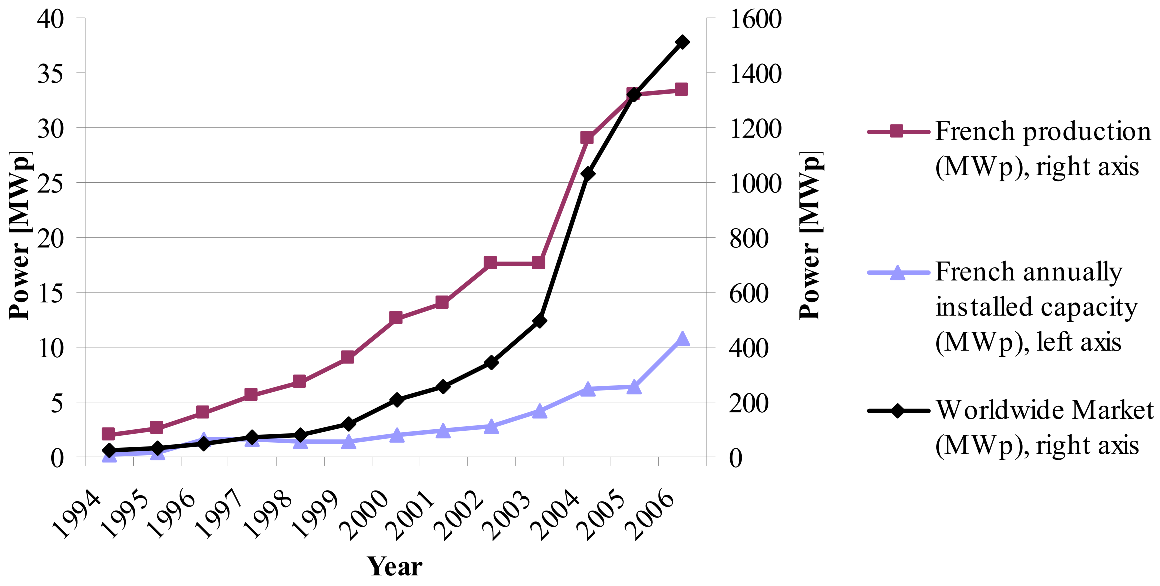

Figure 17: **French annually installed capacity of solar cells compared to the French production of solar cells and the worldwide market (IEA PVPS countries) (Ricaud, 2005; DGEMP, 2006; Hirshman et al., 2007; IEA PVPS, 2007). The left scale refers to the French production and market curves and the right scale refers to the worldwide market.**

Photowatt International is the only manufacturer that appears in the world production balances (Ministry of Ecology Sustainable Development and Town and Country Planning and Ministry of Economy Finance and Industry, 2007b). *Figure 18* shows the evolution of Photowatt's production.[168]

Furthermore, big industries in France support the development of the technological innovation system for PV: EDF (ambiguous attitude), Total and Saint-Gobain. Total is committed in various companies such as Tenesol and Photovoltech (France-Belgium) and research projects with ANR. EDF leads research projects notably in high efficiency thin film technologies and is involved in several companies, e.g. Apollon Solar, Tenesol. Saint-Gobain is involved in the whole value chain of photovoltaics particularly with the production of glass for modules and is committed in several projects with ANR, e.g. thin films, amorphous silicon (Ministry of Ecology Sustainable Development and Town and Country Planning and Ministry of Economy Finance and Industry, 2007b).

[168] Being the main manufacturer in France, Photowatt's production should be very close to the national production of solar cells. The differences between Photowatt's figures and *Figure 16* can be explained by the different annual periods taken by the sources. All sources do not necessarily take a year from January to January.

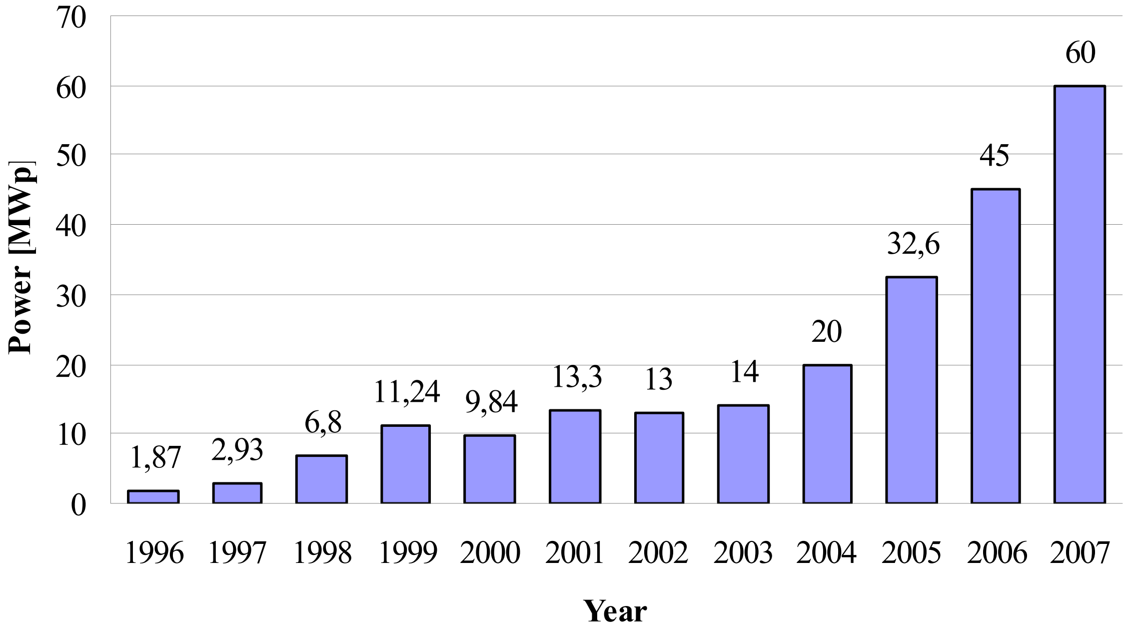

Figure 18: **Photowatt's production of solar cells (MW_p) (Photowatt International, 2007)**

Nevertheless, there are certain groups of *actors* that are missing. The main category missing is the architects. Despite a few of them that try to work with the concept of sustainable building, most of the architects do not consider energy issues as part of their job (Ricaud, 2007). This is mainly due to a lack of education in this field (Tjoyas, 2007).[169] As a result, even young graduated architects are lacking of competences regarding these issues. Then, although the category cells and modules manufacturers exist, it is still weak compared to the Japanese or German manufacturers.[170] Moreover, there is no silicon producer in France. However, a project of a silicon plant is starting in the south of France. This project called SILPRO should start its production in 2009 with 3000 tons of silicon per year and will increase this production from 5 to 10 thousand tons after 2010 (Les Echos, 2007).

Furthermore, several *networks*, especially important for BIPV, can be identified. As we could observe during the description of the history of photovoltaics in France, associations and governmental organisations such as the ADEME were able to develop *networks* within the field and make companies working together in order to develop lobbying power through the formation of advocacy coalitions. The ability to generate *networks* helped the PV *technology* to gain *legitimation* and led to the choice of BIPV development. In the meantime, the French

[169] Architecture schools giving real courses about sustainable buildings are rare in France (Tjoyas, 2007). According to Mimi Tjoyas, if architects want to specialise in renewable energy for buildings, they have to take special and expensive trainings after being graduated.

[170] Only one company, Photowatt International, has a significant production.

government developed "*competitiveness clusters*" which aim at gathering *actors* from the industry, research and training communities working in the same field and the same region (Ministry of Economy Finance and Industry, 2006c).[171] Using the technological innovation system's terminology, these "*competitiveness clusters*" are powerful *networks* developing *formal knowledge, entrepreneurial experimentation* and *positive externalities,* and *influencing the direction of search*. Four clusters are related to solar energy: Tenerrdys (region Rhône-Alpes), Capénergie (region PACA), Derbi (region Languedoc-Roussillon) and S2E2 (regions Centre-Limousin). Nevertheless, despite the formation of *networks* which foster the development of BIPV, none of them is BIPV specific.

As we saw in the history, the process of *institutional* alignment for BIPV started slowly and quantitative goals for the industry came late. Today, France has an objective of 160 MW_p for 2010 and 500 MW_p for 2015 (Ministry of Economy Finance and Industry, 2006a). *Institutional* alignment was notably manifested in financial incentives in favour of BIPV, the development of certification with the CSTB, and the development of quality guarantee with Quali'PV. As a result, it allows for more expectations regarding BIPV development and reinforces its *legitimation* as well as *resource mobilisation.* This context opens new perspectives for the *technology* which already grows fast. Indeed, according to Mozer (EDF OA[172]), 85 percent of the demands for feed-in contracts apply for the BIPV bonus.[173] Four thousand new feed-in contracts have reached EDF OA in Lyon since July 2006.[174] Given the fact that the power average of new contracts is between 2.5 and 3 kW_p (Mozer, 2007), we conclude that this amount of contracts represents between 8.5 MW_p and 10.2 MW_p of BIPV.[175] Following this estimation, we can assess that BIPV represents today between 15 percent and 20 percent of the cumulative installation of photovoltaics in France.

Besides *institutional* alignment, fostered by advocacy coalitions, other inducement mechanisms allowed BIPV to grow. In particular, the work performed in the PV field during the last decades has surely developed *positive externalities* for BIPV. For instance, the improved corporate image of the *technology* and progress in research helped BIPV to emerge

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[171] In order to stimulate the French economy, sixty six competitiveness clusters were created in 2005, dealing with many different topics, e.g. biotechnology, renewable energy, electronics, IT, medical, Bio-agronomics, transport, chemicals.

[172] Electricité de France – Purchase Obligation division (OA). They notably deal with all the feed-in contracts . There are four OA divisions in France. In 2006, EDF reorganised these divisions for the solar part specifically and gathered all the feed-in contracts' responsibility to one division, located in Lyon (Mozer, 2007).

[173] In August 2007, this figure increased to 95 percent of the contracts.

[174] These 4000 contracts include installed or not yet installed PV. Before July 2006, about 1000 feed-in contracts had been treated.

[175] This figure is an estimation and includes all the BIPV systems, installed and not installed.

and grow. Moreover, as mentioned before, overseas departments have played an important role in the *formation of a significant market*. Until 2006, they have pulled the French PV industry. Finally, BIPV were fostered by the emergence of the concept of energy efficiency in buildings which benefit from high interest among French policy makers.

Nevertheless, the TIS for PV still faces barriers in France. First, the long administrative procedure required to install and connect a BIPV system to the grid hinders the development of the market.[176] The length of the administrative procedure is due to the high number of documents involved and the high number of authorities to contact.[177] Furthermore, the supply of silicon has been a clear brake for PV worldwide within the last years but this problem has still not been overcome (De Franclieu, 2007). Despite the launch of several projects of silicon plants, the high price of this raw material is still hindering cost reduction and represents still a barrier for the production of solar cells. Then, fiscal uncertainties regarding the status of the private producer slow down the development of BIPV (Juquois, 2007).

Besides these general difficulties for PV, building integrated photovoltaics have to deal with specific barriers. The most important one is probably the long and expensive procedure for the certification of BIPV products by the CSTB (PV Policy Group, 2006). Indeed in France, each building material has to comply with a compulsory traditional ten years insurance system ("garantie décennale") which requires for every component to obtain a certification delivered by the CSTB. Although the CSTB works in order to improve products' certification, it is argued that the procedure to obtain certifications is still too slow. It can take several months and even a year before the CSTB certifies a product (Claverie, 2007). However, the companies have to respond to the market need as fast as possible. As a result, the certification procedure developed by the CSTB is not compatible with the companies' expectations. Companies such as IMERYS or Arcelor have already threatened to skip this certification if the CSTB does not shorten the procedure time (De Franclieu, 2007). Then, architects are clearly missing in the French BIPV system and this represents a significant barrier since the architectural aspect is important in BIPV projects (Tjoyas, 2007). Without the implication of architects, the promotion and diffusion of the *technology* may be slower.

[176] It can take between 2 months and one year to connect your system to the grid (Tjoyas, 2007).
[177] Around nine documents such as authorisations and diverse letters are required and between four and eight authorities (depending on the region and the type and size of the project) have to be contacted: EDF OA, DRIRE, DIDEME, the city concerned, Regional and General Councils, ADEME, Insurance.

4.4. Cross-Country comparison

In the following, we compare the evolution of BIPV within the technological innovation systems for solar cells in Germany and France. Several themes are discussed. First of all, we elaborate on changes at the *landscape* level in both countries. Then, we describe the interaction between the PV *niche* and the electricity supply *regime*. Thereafter, we underline differences regarding the PV market in Germany and France. Afterwards, we discuss interactions between the two countries. Finally, we highlight uncertainty concerning the development of PV in Germany and France.

In Germany and France, several changes in the *landscape* influenced the development of photovoltaics. Due to the oil crisis in 1973, both countries aimed at energy independence. Therefore, the first interest in solar cells emerged and the first attempts in PV research were made. However in France, the oil crisis also triggered the acceleration of the development of nuclear power which became the main source of electricity. In particular, in 1974 EDF announced the construction of thirteen nuclear plants within two years, which illustrates the *mobilisation* of *resources* into nuclear at the expense of PV. Furthermore, the French green party's influence remained relatively weak. Hence, energy production from renewable energy had only few supporters in the French political *landscape*. In contrast, in Germany a strong Green movement emerged, fostering the creation of advocacy coalitions in favour of renewable energy and in particular of PV. As a result, the German government *mobilised more resources* to the development of solar cells. Particularly, the German expenditure on RDD for solar cells was raised at the end of the 1970s and has remained one of the highest in the world. Furthermore, the Chernobyl accident in 1986 resulted in a large opposition against nuclear power and therefore *influenced the direction of search* towards alternatives in Germany. In contrast, this accident did not affect the French nuclear power programme significantly. Hence, in opposition to France, in Germany a process of *legitimation* started. Consequently, changes in the *landscape* had different impacts on the development of the TIS for solar cells and both countries followed different paths for evolution of PV.

Then, a different development can be highlighted regarding the interaction between the PV *niche* and the electricity supply *regime* in the two countries. Especially, we identified three dimensions of *niche-regime* interaction: *legitimation, market formation* and political interaction.

First, *legitimation* is essential to improve the interaction between the *niche* and the *regime.* In particular, institutional alignment between the PV *niche* and the electricity supply *regime* regulates the relations between the two levels. For instance, in Germany in 1991, a tariff enabled remuneration for electricity fed into the grid for the first time. Then, the mid 1990s were characterised by a period of intense struggle to modify the *institutional* framework regarding PV. Finally, in 1998 the SPD and the Greens got into power, changing the political *landscape.* The new coalition implemented a generous feed-in tariff in 2000 and put pressure on the electricity *regime* to adopt photovoltaics as an electricity source. In contrast, in France, despite the efforts to *legitimise* grid-connected PV systems, these systems faced strong barriers maintained by the electricity supply *regime* which blocked the process of *institutional* alignment. For instance, the difficulty to connect PV systems to the grid, due to long-lasting administrative procedures in France, hindered their diffusion. In particular, according to the PV Policy Group (2006), the permission procedure to install a PV system and connect it to the grid takes 2 months in Germany and between 4 and 12 months in France, indicating a barrier for solar cells in France. In France, the high number of documents and authorities required to connect a system to the grid, is considered to be the main cause of long-lasting procedures.

Second, *market formation* can be useful to improve interaction between the *niche* and the *regime*. For example, in Germany at the beginning of the 1990s, the first demonstration and *market formation* programme for photovoltaics, the 1 000 rooftops programme for grid-connected systems, started. Rooftops solutions interact with the electricity *regime* since they have to be connected to the grid. *Positive externalities* arose since the more systems were connected to the grid, the more grid-connection was *legitimised*. On the contrary, in France off-grid PV systems remained the main market during the 1990s since these applications were particularly interesting for isolated places such as the French overseas departments. Hence, the low market for grid-connected systems did not allow France to build up interaction with the electricity supply *regime*. As a consequence, at the end of 2002, the grid-connected PV capacity installed in Germany was 258 MW_p whereas in France this capacity was only 1.9 MW_p. To sum up, the incentives developed at the *niche* level regarding *legitimation* and *market formation* allowed the German TIS for PV to develop interaction between the *niche* and the *regime* levels, increasing *legitimation* and generating feedback loops in the German PV *niche*. In contrast, in France strong barriers hindered the development of such interaction and PV, and especially grid-connected PV, suffered from low *legitimation*.

Third, a political interaction, in particular the role of advocacy coalitions to overcome barriers to development maintained by the electricity supply *regime* can be highlighted. In Germany, strong advocacy coalitions helped to remove the main barriers raised by the electricity supply *regime*, resulting in the increase of the diffusion of photovoltaics in the 1990s. Furthermore, the new financial incentives implemented in 2000 partly resulted from the pressure of two manufacturers, ASE and Shell, within the TIS. In contrast, in France resistance by the electricity supply *regime* remained strong and prevented PV advocacy coalitions from gaining power. Thus, another path was followed for the diffusion of PV. Indeed, advocacy coalitions identified photovoltaics as a potential building component, leading to the design of a feed-in tariff with a special bonus for building integrated photovoltaics in July 2006, which *guided the direction of search* towards this technology. BIPV are regarded as a solution to sidestep electricity supply *regime*'s resistance by overcoming the building *regime*'s barriers. Nevertheless, it may also slow down the *market development* for PV in general. Indeed, when we compare this market deployment with Germany, we realise that BIPV are a constraint which may narrow down the range of PV applications and hence limits the size of the market mainly to in-roof and facade solutions. The different influence of advocacy coalitions in Germany and France is illustrated by the cumulative installed PV power by the end of 2006. In France only 44 MW_p of PV power were installed by the end of 2006, whereas in Germany the work performed by advocacy coalitions helped to overcome barriers and therefore to reach 2831 MW_p of PV power installed.

In the following, we outline differences between the German and French PV markets in terms of structure, technology's diffusion and the necessity of *market formation* to increase production capacity.

Firstly, the German and the French PV markets are structured differently. Building integrated photovoltaics can be seen as one *niche* application evolving within the PV *niche*. BIPV interact with other PV applications such as on-roof systems or open space PV plants. In Germany this interaction is more competitive than in France, since the variety in terms of installation types has decreased (*Appendix H*) and a standard application of additive on-roof systems emerged early on. Thus, premature lock-in may hinder other photovoltaic applications to gain ground. In 2007 in Germany, PV systems integrated into a building represent a market of about 1 MW_p on facades, between 3 and 4 MW_p on flat roofs and between 6 and 7 MW_p on pitched roofs in 2006 (Neuner, 2007), representing only about 1 percent of the PV market. Especially building integrated photovoltaic systems compete with cheaper and easier to install on-roof solutions. As a result, within the PV *niche* a situation appeared where BIPV systems need to diffuse on larger markets to reach cost reduction, which is hindered by high costs. In contrast, in France other PV applications did not hinder the development of BIPV, which are rather a solution for PV to overcome electricity supply *regime*'s barriers. The implementation of the feed-in tariff in favour of BIPV has opened new opportunities for PV to evolve. Hence, since July 2006, BIPV installations represent 85% of the contracts for grid-connected PV (Mozer, 2007), demonstrating the effect of the feed-in tariff regarding market formation.[178] To conclude, BIPV are only regarded as a small *niche* to diversify into in Germany whereas in France it is perceived as an opportunity for PV *market formation*.

Secondly, the mechanisms behind the diffusion of building integrated photovoltaics are different in the two countries. In particular the role of architects differs. In Germany, early attempts to use solar cells as building components have been made since the beginning of the 1990s, referring to *entrepreneurial experimentation*. Therefore, the interest of architects in the *technology* has increased. In addition, several chairs of architecture dealing with PV as a building component were created, *mobilising resources* into BIPV. Thus BIPV has been involved in the education of architects, which helps to *legitimise* the *technology* and to *develop formal knowledge*. Furthermore, since 2004 a facade bonus of 5 EURCent/kWh has been implemented, partly aligning *institutions* with BIPV. This represents a process of diffusion that might lead to self sustained growth. However, the *legitimation* of architectural BIPV projects is still weak and the *influence on the direction of search* small since BIPV represent only about one percent of the PV market in 2007 (Neuner, 2007). On the contrary in France, architects are hardly involved in the development of BIPV, representing a lack of *resource mobilisation* and *entrepreneurial experimentation*. In particular, the absence of architects can be explained by the lack of education regarding the integration of renewable energy into a building and therefore a shortage of *knowledge creation*. Nevertheless, the feed-in tariff strongly in favour of BIPV fosters its development. As a consequence, BIPV are partly diffused through architectural promotion in Germany whereas it is mainly diffused thanks to financial incentives in France.

[178] Most probably, the majority of the BIPV installations are in-roof systems.

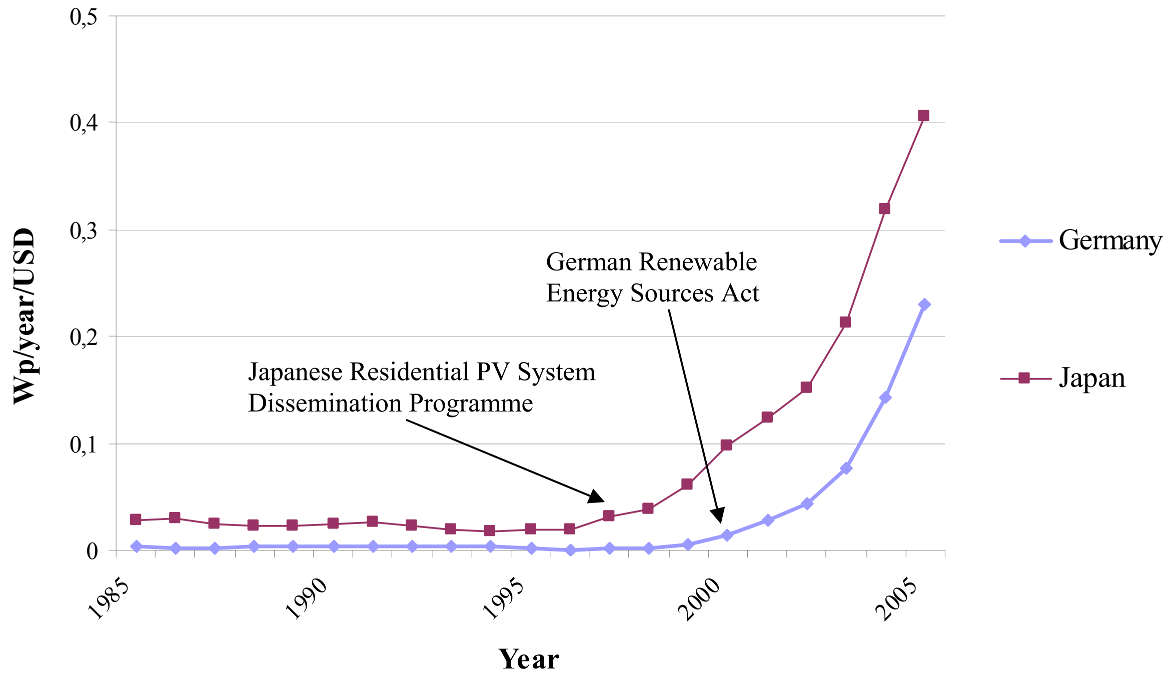

Figure 19: **Annually solar cell production in relation to the cumulative RDD investments in solar cells in Germany and Japan (Wp/year per USD); Source: German production capacity: 1983-1997: Jacobsson et al. (2004); 1998-2005: BSW (2007b); German RDD investments: 1974-1990: Jacobsson and Sandén (2005); 1991-2005: (IEA, 2006) in 2005 prices and exchange rates; Japanese production capacity: 1983-2003: (Jacobsson and Sandén, 2005); 2004: (IEA PVPS, 2005); 2005: (Hirshman et al., 2007); Japanese RDD investments: 1974-2005: (IEA, 2006) in 2005 prices and exchange rates**

Thirdly, *Figure 19* indicates that besides public RDD programmes a *market formation* is needed to strongly increase the production capacity, i.e. the ratio between production and cumulative RDD expenditures increases rapidly when *market formation* programmes are launched such as the German Renewable Energy Sources Act implemented in the year 2000. However, the French case shows a different situation. As explained earlier, until 2007 the French production capacity is less related to the French market size since the production capacity seems to be more influenced by growth of the worldwide market *(see Figure 17*). In conformity, Photowatt the dominant producer of solar cells in France exported 90 percent of its products in 2006. In contrast, in Germany, where the domestic market, as the biggest in the world, affects the world market largely, a closer interdependence between the domestic market and the domestic production capacity can be identified (see *Figure 12*). In compliance, despite high expenditures in research and *market formatio*n the German production capacity for solar cells was comparatively low until the end of the 1990s. For instance only 2 MW_p

were produced in Germany in 1997 whereas France produced 5.7 MW_p.[179] Nevertheless, in the following years, when the German domestic market grew significantly leading to a domestic market of 950 MW_p in 2006, the production capacity increased, resulting in 508 MW_p produced in 2006.[180] In contrast, the domestic market remained small with a size of 10.9 MW_p in France and only 33.5 MW_p were produced in 2006. In Germany, the PV production growth since the year 2000 was made possible by the entrance of several *actors* at all stages in the solar cells' value-chain. On the contrary, the French industry suffered from a low number of new entrants and therefore a low degree of *materialisation* due to the lack of national interest in photovoltaics and the small domestic market resulting from too low financial incentives for *market formation*. To conclude, both the German and the French PV markets can still be considered as niches but in different phases. Indeed, the German TIS for solar cells is in a growth phase since the domestic market gave strong incentives to companies to enter the industry and therefore allowed a rapid growth of the production capacity. The French TIS for solar cells is still in a formative phase since the domestic market has been too small to attract new entrants and therefore the production capacity remained comparatively low.

Then, we highlight that interaction between countries on the *niche* level is possible. On the one hand, the French decision to foster especially BIPV was influenced by the German TIS since BIPV are comparatively less developed and may give France the opportunity to build up its own industry. Thus the decision for BIPV protects the French industry and therefore reduces the risk that e.g. German companies invade the French market. On the other hand, the French system may influence the German to identify the opportunities BIPV offers and increase the *direction of search* in Germany into BIPV. Hence, interaction between countries on the *niche* level can foster or hinder the development of a technology.

Finally, uncertainty regarding the development of PV is higher in France than in Germany. Indeed, *networks* with a strong lobbying power and influential advocacy coalitions are more established in Germany than in France. As a result, the German TIS may be able to cope with and prevent *institutional* changes unfavourable for PV. On the contrary in France, it may be difficult to win a fight against a potential abandonment of the feed-in tariff, which would certainly lead to a slow down of the diffusion of PV.

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[179] During this time, two German companies were manufacturing solar cells and in France only Photowatt produced PV.

[180] Notably, many production facilities were built in the eastern part of Germany where policy incentives help to attract business.

5. Conclusions and Discussion

This thesis aimed first at understanding and explaining the evolution of BIPV within the German and French technological innovation systems for solar cells and second at drawing implications for the TIS theory. Therefore, we developed an analytical framework based on the TIS theory and completed by elements borrowed from the multi-level perspective on technological transition. Afterwards, we applied the framework to the German and the French technological innovation systems for solar cells, with a particular interest on the evolution of building integrated photovoltaics. Finally, we compared the development in the two countries.

First, we draw conclusions concerning the evolution of BIPV within the German and the French TISs for solar cells. BIPV interact with two separate *regimes*: the electricity supply *regime* and the building *regime*. Thus, barriers from both *regimes* have to be overcome and BIPV projects involve difficulties regarding coordination issues of several *actors*. We identified that changes at the *landscape* level had different impacts in Germany and France. Therefore, divergent paths were followed regarding the evolution of PV. In both countries, photovoltaics remain a *niche market*. However, the German TIS has shifted to a growth phase whereas the French system is still in a formative phase. Indeed, in Germany the main barriers to the diffusion of photovoltaics were overcome, while in France resistance from the electricity supply *regime* remains in 2007. In particular, the long administrative procedure to obtain permissions to install and connect PV to the grid hinders its diffusion and needs to be shortened. In this context, building integrated photovoltaics evolve differently in both countries. On the one hand in Germany, BIPV are considered as a small *niche* within the PV *niche*, and is therefore a possibility for photovoltaics to diversify. On the other hand, in France BIPV are regarded as an opportunity to increase *market formation*. Especially, BIPV may help the French technological innovation system for PV to overcome the electricity supply *regime*'s barriers. Indeed, by overcoming resistance of the building *regime*, the BIPV market may grow and strengthen advocacy coalitions' influence, allowing the development of PV on a broader scale. Nevertheless, we underlined specific barriers to the diffusion of BIPV. In general, building integrated photovoltaics have to face misalignments with the building *regime*'s *institutions*, e.g. BIPV have to comply with building codes. Furthermore, in France the lack of involvement of architects hinders the diffusion of BIPV. In Germany, a premature lock-in situation for additive on-roof systems emerged, blocking the diffusion of BIPV. Therefore, to some extent, building integrated photovoltaics compete with other PV applications in Germany.

Second, we set out with the identification of weaknesses in the TIS theory and suggested to add elements from the multi-level perspective on technological transition to overcome these drawbacks. The TIS approach may not cover the transition from one system to another sufficiently. Yet, the emerging photovoltaics system is not ready to substitute established *regimes* but interacts with them. Particularly, the TIS theory does not direct attention on the origin of external forces. Furthermore, the TIS theory may not be helpful to explain where a system is located in its broader environment. We suggest that these weaknesses can be overcome by borrowing the *landscape*, *regime* and *niche* level of the multi-level perspective on technological transition. Particularly, the case-studies of building integrated photovoltaics in Germany and France show how important *niche-regime* interaction is for *niche* formation.

In the following, we highlight implications for policy makers. In Germany, premature lock-in hinders application variety but supports fast *market growth*. Therefore, in terms of variety, missing incentives for in-roof systems hinder the diversification of PV applications and represent a weakness in the German *institutional* framework for photovoltaics since new opportunities could be missed. Thus, German policy makers have to be aware of the German *institutional* framework favouring only one particular application. Although, this allows high volumes and economies of scale, it decreases application variety. In contrast, in France BIPV may not be able to create a domestic PV market big enough to build up an industry with a complete value-chain. In particular, in order to enlarge an industry a growing domestic market may be necessary. Furthermore, uncertainty regarding the support of the institutional framework on the long-term may hinder industry growth. Thus, in France new PV manufacturers may have difficulties to develop. Finally, due to the strength of the technological innovation system for solar cells in Germany, the French TIS has to develop fast and the length of administrative procedures has to be shortened.

In general, policy makers should be aware of the long-term perspective needed to foster and establish a new system. In particular, *institutional* alignment can take decades and barriers to diffusion may not be overcome fast. This is illustrated by the long time span between the first efforts in PV research and photovoltaics' existence in a *niche* today. Furthermore, not only financial incentives as a generous feed-in tariff are necessary to diffuse a new *technology*, the improvement of administrative procedures as in the case of photovoltaics in France stands out as well.

The effect of the implementation of *institutions* favouring BIPV in terms of future market and growth is uncertain. Nevertheless, given the few data published on BIPV, one can expect that the French market for in-roof solutions will grow rapidly within the next years. Nevertheless, we highlight the lack of architects in France which hinders the development of architectural BIPV solutions. In contrast, the German BIPV market has a low growth potential on the short-term. However, the increasing awareness of architects in Germany may generate a favourable environment leading to a progressive adoption of the *technology*. In general, building integrated photovoltaics may have the potential to break out of the *niche* and allow PV *technology* to diffuse widely. When cost-reduction for solar cells is reached, valuable cost savings will be possible by replacing the ordinary envelope of a building by BIPV.

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Appendix

Appendix A)

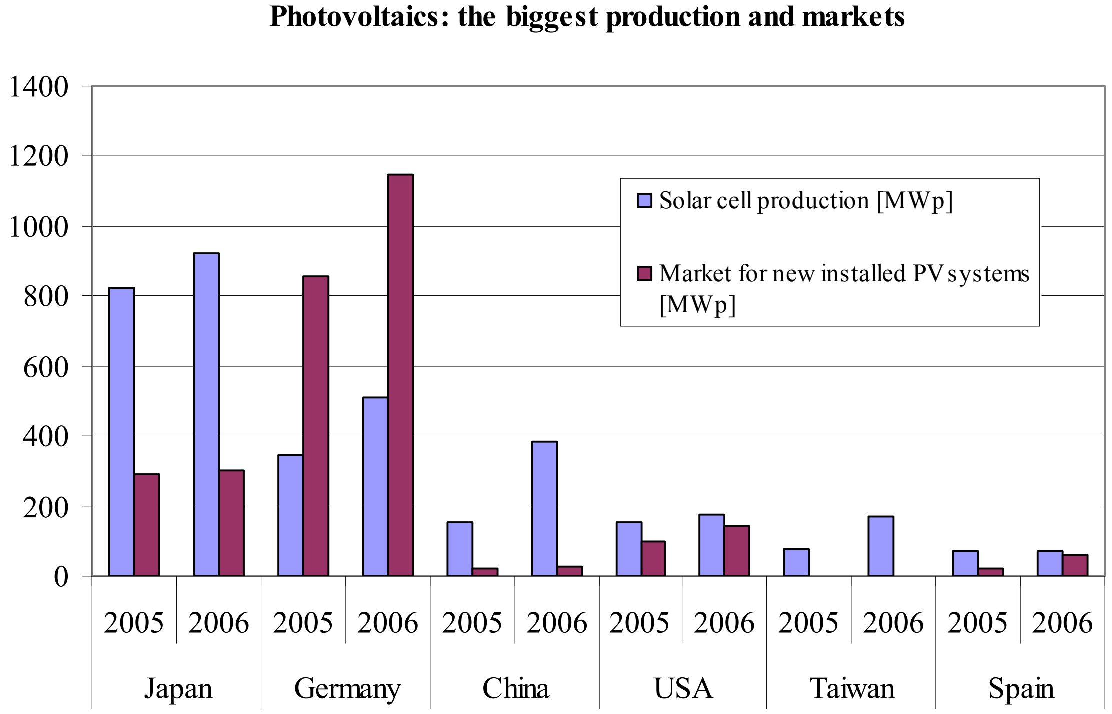


Figure 20: **Photovoltaics the biggest production and markets. Source: Photon (2007a), translated into English by the authors. Below detailed information about the data gathering of Photon is given.**

Data in Megawatt, date: May 2007

Sources:

Data for cell production: estimation, based on PHOTON market surveys.

Data about annually installed solar power in Germany: secured data for the years 2004 and 2005. Only proved installations were included, the data can be regarded as conservative and the real installed power may have been slightly higher.

Details about the survey method can be found at: www.photon.de/photon/photon-aktion_install-leistung.htm

Data about installations in Germany for 2006: prognosis, based on production of the producers of power inverters conducted by PHOTON.

Data about installations of other countries: estimation, based on different secondary sources.

Appendix B)

Interviews in France conducted by Fabien Crassard

Date	Interviewee	Firm/Organisation/Function	Place	Interview Type
21/06/2007	Sébastien Michel	Invest Languedoc-Roussillon Project Manager	InterSolar 2007 Freiburg	face-to-face
09/07/2007	Christophe Moschberger	Alsace International Cluster Energivie Cluster's manager	Colmar	face-to-face
16/07/2007	Bassam Ouaida	Transénergie CEO	Ecully	face-to-face
16/07/2007	Roland Barthez	Photon Power Industries General Manager	Ecully	face-to-face
18/07/2007	Fabrice Juquois	ADEME Renewable Energy Department Renewable Energy Programme Manager	Sophia-Antipolis	face-to-face
18/07/2007	André Claverie	ADEME Renewable Energy Division Engineer	Sophia-Antipolis	face-to-face
19/07/2007	Alain Ricaud	Cythelia CEO	Le Bouget du Lac	face-to-face
20/07/2007	Richard Loyen	ENERPLAN French professional association for solar energy Managing Director	Marseille	face-to-face

23/07/2007	Mimi Tjoyas	Architect Graduated by the Government (DPLG) Specialised in environmental issues	Perpignan	face-to-face
23/07/2007	Christophe Courtois	Chamber of Commerce and industry of Perpignan Environment and New Technologies	Perpignan	face-to-face
01/08/2007	Robert De Franclieu	Apollon Solar Director – General Manager	Lyon	face-to-face
20/08/2007	Cécile Mozer	EDF Agence Obligation d'Achat Responsible for the South-East Agency	Lyon	telephone

***Table 1:* Interviews in France taken by Fabien Crassard**

Interviews in Germany conducted by Johannes Rode

Date	Interviewee	Firm/Organisation/Function	Place	Interview Type
21/06/2007	Frederik Moch	Service Centre at the German Solar Industry Associaton (Bundesverband Solarwirtschaft, BSW)	InterSolar 2007 Freiburg	face-to-face
21/06/2007	Ilona Eisenschmid	Project Engineer BIPV (Optisol) at Schott Solar Germany GmbH	InterSolar 2007 Freiburg	face-to-face
21/06/2007	Robert Buschmann	Product Manager Solar Division, Head of Development PV-Modules at Schüco International AG	InterSolar 2007 Freiburg	face-to-face
22/06/2007	Hartmut Haverland	Sales at ThyssenKrupp Solartec	InterSolar 2007 Freiburg	face-to-face
22/06/2007	Olaf Achilles	Board of directors of systaic AG	InterSolar 2007 Freiburg	face-to-face
27/06/2007	Corlenia Viertl	Senior Advisor, Division for “Solar Energy, Biomass, Geothermal Energy, Market Introduction Programmes for Renewable Energy”, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	Berlin	e-mail
02/07/2007	Heiko Schwarzburger	Chief editor of the magazine “photovoltaik – Das Magazin für Profis”	Berlin	e-mail
03/07/2007	Thomas Wenzel	dena, renewable energy	Berlin	telephone
04/07/2007	Prof. Manfred Hegger	chair for energy efficient building at the department for architecture, University of Technology Darmstadt, and member of the board of directors of HHS Planer + Architekten AG	Darmstadt	face-to-face

04/07/2007	Roland Neuner	head of sales for PV building solutions at Schott Solar	Alzenau	telephone
06/07/2007	Karl-Heinz Tönges	vice-president sales & marketing, Europe at United Solar Ovonic Europe	Frankfurt	face-to-face
11/07/2007	Dr. Thomas Stark	scientific assistant of Prof. Hegger at the chair of energy efficient building at the department for architecture, University of Technology Darmstadt	Darmstadt	face-to-face
11/07/2007	Dr. Ingo Hagemann	architect and author of the book "Gebäudeintegrierte Photovoltaik", see Hagemann (2002)	Aachen	face-to-face
19/07/2007	Markus Hackner	key account manager at Sharp Electronics Germany / Solar Business Group	Munich	face-to-face
23/07/2007	Dr. Susanne Rexroth	scientific assistant of Prof. Weller at the chair of structural design at the department for architecture, University of Technology Dresden; editor of the book "Gestalten mit Solarzellen", see Rexroth (2002)	Berlin	face-to-face
23/07/2007	Jens Altevogt Christiana Clemens	dena; renewable energy	Berlin	face-to-face
24/07/2007	Heiko Stubner	assistant of Dr. Hermann Scheer and Marco Bülow, both members of the German parliament	Berlin	face-to-face
25/07/2007	Dr. Günther Ludewig	architect and member of the DGS (German association for solar energy)	Berlin	face-to-face
31/07/2007	Britta Bolling	project leader, Abacus Energiesysteme	Cologn	face-to-face
02/08/2007	Astrid Schneider	architect and author of the book "Solararchitektur für Europa", see Schneider (1996)	Berlin	Telephone

21/09/2007	Bodo Sauerbrey	CEO, Creative Solar Systems GmbH	Suhl-Wichtshausen	Telephone
21/09/2007	Christoph Erban	BIPV expert, Schüco International KG	Bielefeld	Telephone
26/09/2007	Uwe Hartmann	First vice president, German Society for Solar Energy (DGS)	Berlin	Telephone

Table 2: **Interviews in Germany taken by Johannes Rode**

Appendix C)

Comparison of the French and German TISs for BIPV placed in the multi-level perspective

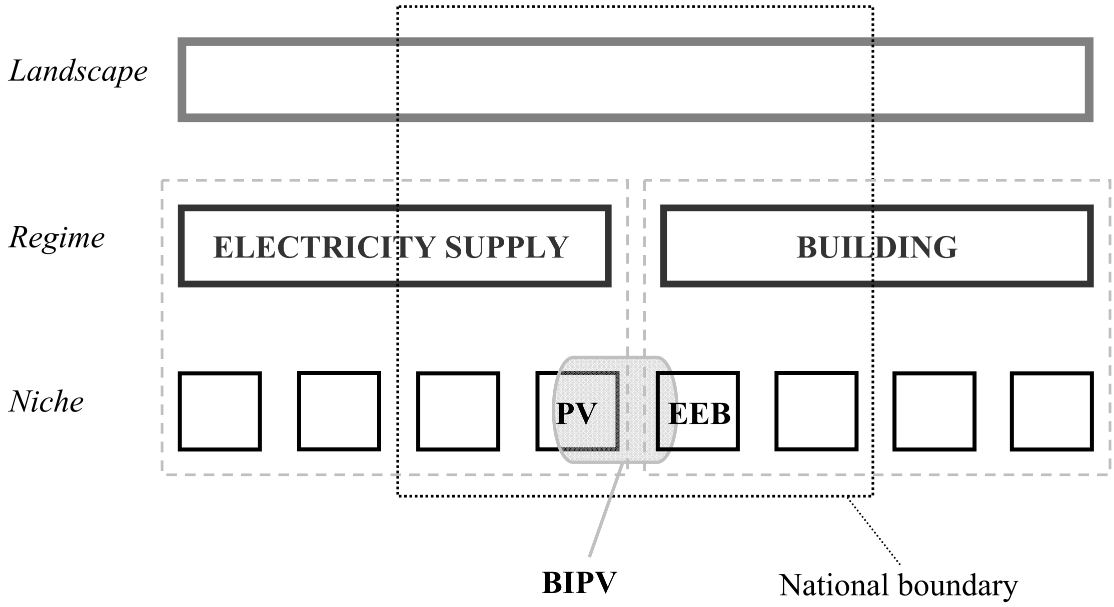


Figure 21: **BIPV in France placed in the multi-level perspective (PV: photovoltaics, EEB: energy efficient buildings)**

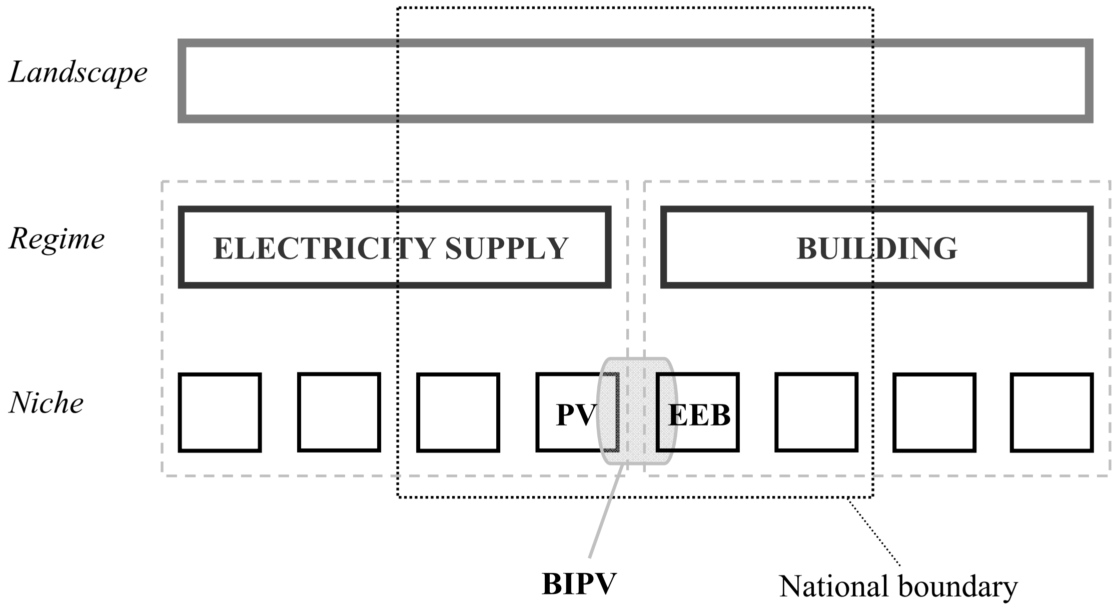


Figure 22: **BIPV in Germany placed in the multi-level perspective (PV: photovoltaics, EEB: energy efficient buildings)**

BIPV in France include nearly the whole PV *niche* since the French regulations favour BIPV strongly and therefore most projects are BIPV projects since July 2006. Contrarily, in Germany BIPV are only a small fragment of the PV *niche*.

Appendix D)

Overview of solar cell technologies[181]

Most of the solar cells are made of silicon. However, there are still several designs competing. *Figure 23* shows the cell technology shares in percent and *Table 3* typical and maximum efficiencies of cells. A short description of the most often used solar cell designs follows:

***Figure 23:* Cell technology shares (in percent) of total cells produced (Hirshman et al., 2007, p.148)**

Bulk technologies (wafers) are mainly made of silicon (90 percent of the technologies).

- ✓ *Single crystalline silicon cells (sc-Si)* are made of a single-crystal and are more expensive than multicrystalline silicon cells. Furthermore, sc-Si cells have a uniform appearance since only one colour is visible (single-crystal). Single crystalline silicon is also called mono-crystalline.
- ✓ *Multicrystalline silicon cells (mc-Si)* are less expensive to produce but are also less efficient than sc-Si.

Thin films are thinner cells (100x thinner) and therefore allow for material cost savings. However, they are usually less efficient.

- ✓ *Amorphous silicon cells (a-Si)* tend to be less efficient than bulk silicon but are cheaper to produce since they require less material and have a lower amortisation period in terms of energy. In addition, a-Si cells are more suitable for curved surfaces and have a better performance at higher temperature, which often occurs in BIPV applications.
- ✓ *Cadmium Telluride cells (CdTe)* are one of the most efficient thin films. In particular, CdTe and a-Si are more suitable for large-scale production.
- ✓ *Copper Indium Diselenide cells (CIS)* are quite efficient (13.5 percent) compared to other thin films. However CIS is still expensive.

[181] This appendix is mainly based on (Reijenga, 2003).

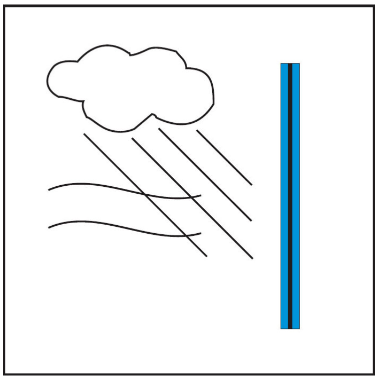
These technologies are the main designs for solar cells. Thus, there is still a large variety of products competing with silicon solar cells. Among them, we can also identify Ribbon silicon (wafers), Ormosil (wafers), thin film Copper Indium Gallium Diselenide (CIGS), Gallium Arsenide (GaAs), light absorbing dyes, organic/polymer solar cells, nanocrystalline silicon, protocrystalline silicon or Crystalline Silicon on Glass (CSG).

Type	Typical module efficiency [percent]	Maximum recorded module efficiency [percent]	Maximum recorded laboratory efficiency [percent]
Single crystalline silicon	12-15	22,7	24,7
Multicrystalline silicon	11-14	15,3	19,8
Amorphous silicon	5-7	-	12,7
Cadmium Telluride	-	10,5	16,0
Copper Indium Diselenide	-	12,1	18,2

Table 3: **Typical and maximum module and cell efficiency (IEA PVPS, 2002)**

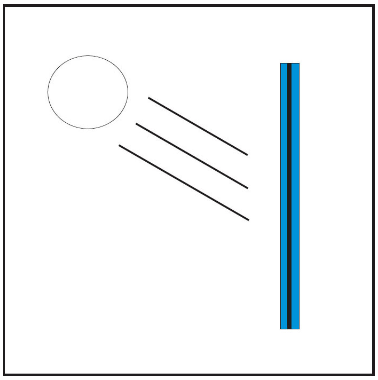
Appendix E)

Functions of BIPV systems



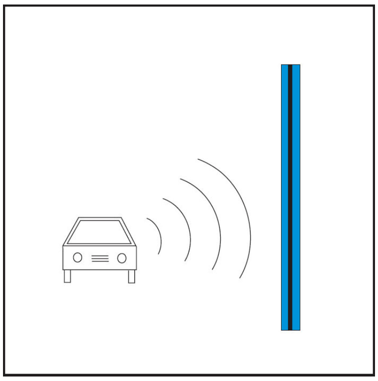
Weather protection

Waterproofed and windproofed facade or roof of a building.



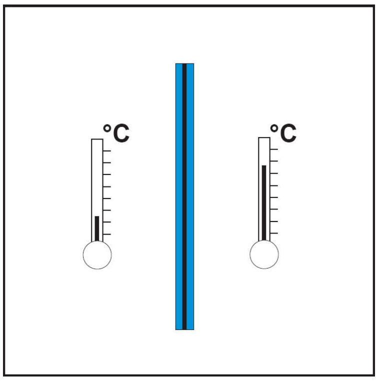
Sun protection / shadowing

Degree of shadowing is eligible through positioning and degree of transparency.



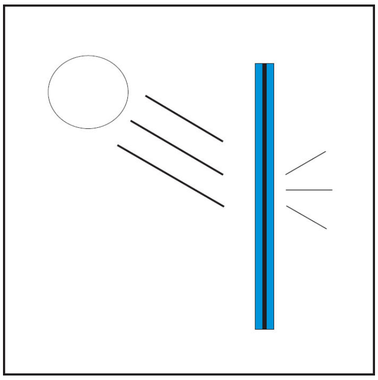
Noise protection

Up to 25 db sound damping is possible.



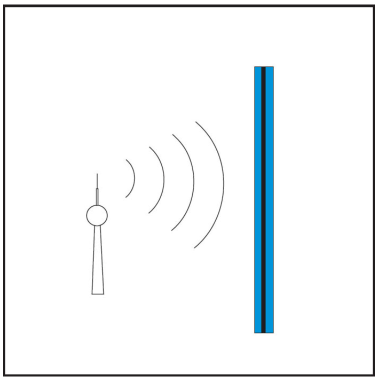
Thermal insulation (heating as well as cooling)

Improving the efficiency of cells by cooling through rear ventilation. Isolation function is possible as well.



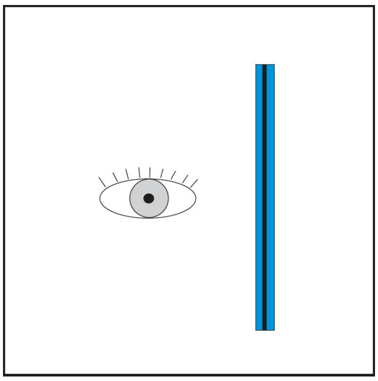
Visual cover / refraction

One-way mirroring visual cover.



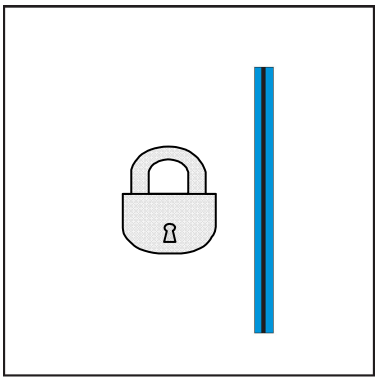
Electromagnetic shielding

Can be used as a faraday cage but also as repeating antennas.



Aesthetic quality

Integration in a building as a design element.



Safety

Safety glass function is possible.

Source: Pictures from Stark et al. (2005). Descriptions from hwp & ISET (2006). Translated and described by the authors.

Appendix F)

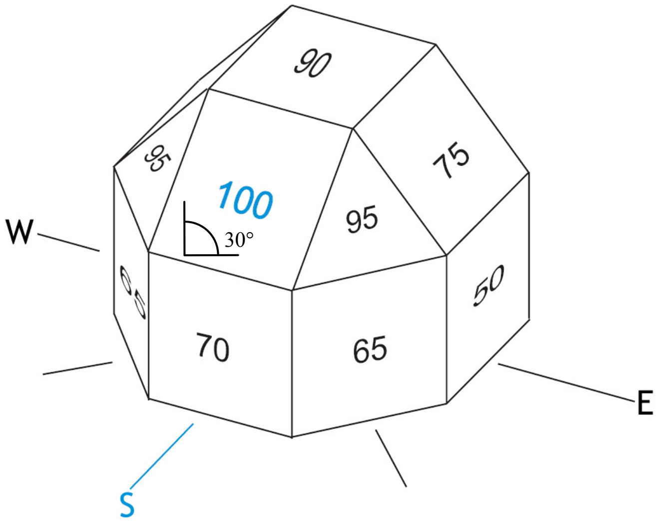


Figure 24: **Angle of inclination effect on yearly amount of irradiation in percent in Europe (Stark et al., 2005)**

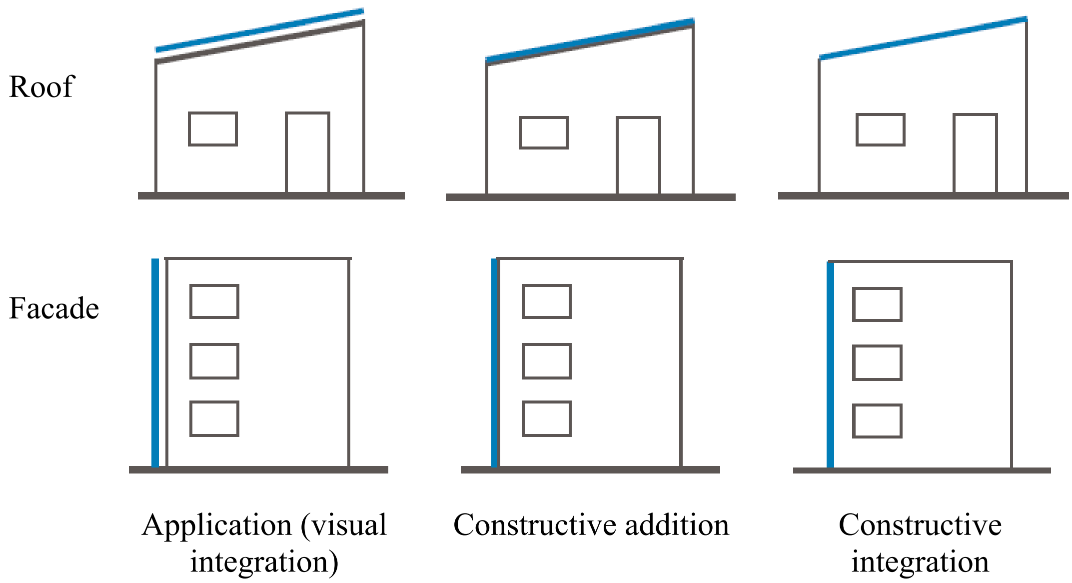


Figure 25: **Three levels of integration adopted from (Stark et al., 2005)**

Description of different integration levels according to (Stark et al., 2005)

The application (visual integration) level refers to modules, which are placed additive over or on the actual envelope of a building. This is particularly suitable for subsequent installations on an existing building. These systems can only be regarded as BIPV, if they are appropriately aesthetically integrated as shown in *Figure 28* and *Figure 37* in *Appendix G*. However, additive systems do usually not fall under the BIPV category as *Figure 26* or *Figure 27* in *Appendix G*.

The level of constructive addition contains modules which replace the outer envelope of the building and are therefore necessary for the building as they cover the functions of the material replaced. Examples are shown in *Figure 29*, *Figure 30*, *Figure 31*, *Figure 33*, *Figure 34* and *Figure 36* in *Appendix G*.

In the furthest integration level, the constructive integration, the modules represent the whole envelope of the building and consequently have to fulfil all attributes of a roof or a facade as shown in *Figure 35* in *Appendix G*.

Appendix G)

Examples of BIPV

Figure 26: **Typical on-roof PV system (Stark et al., 2005)**

The PV system is installed on stilts; there is space between the modules and the roof. Usually these systems are not regarded as BIPV since they are most often not aesthetically integrated into the building.

Figure 27: **On-roof PV system (Scheuten, 2007a)**

The picture shows that on-roof systems can be installed with little space between the roof and the modules. However, according to our definition this system cannot be regarded as BIPV since it is not aesthetically integrated.

Figure 28: **Aesthetically integrated on-roof PV system (Rexroth, 2005, p. 195)**

Since the system of *Figure 28* is appropriately aesthetically integrated we regard the system as BIPV. Although it is an additive on-roof system, it is visually integrated.

Figure 29: **Integration of PV tiles into a roof (Stark et al., 2005)**

The PV tiles substitute ordinary tiles. PV tiles and normal tiles are on the same plane. This is clearly a BIPV system, referring to constructive addition.

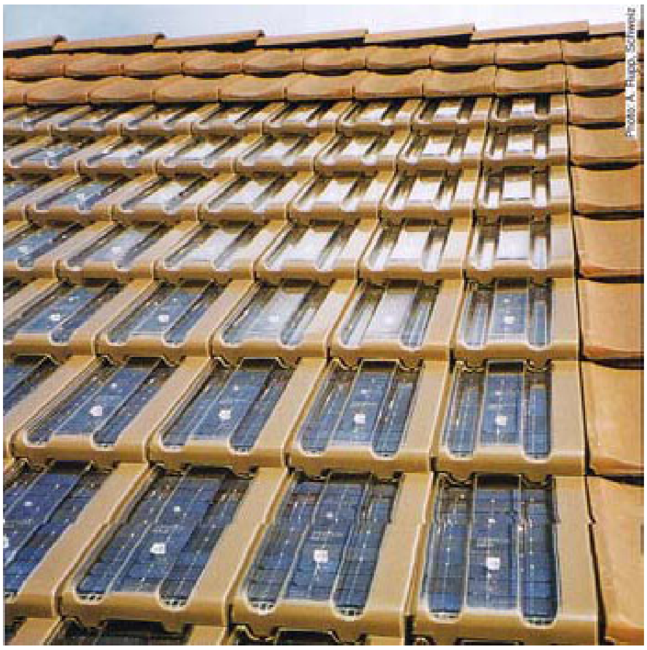


Figure 30: **Example of PV tiles (Blumenberg and Spinnler, 2007)**

The tiles have a similar size as usual tiles but small PV modules are integrated. Some surface to produce electricity is lost since the tiles do not completely consist of PV modules. PV tiles are regarded as BIPV (constructive addition).

Figure 31: **Example of PV in-roof system (Blumenberg and Spinnler, 2007)**

Standard modules are integrated into a roof and substitute usual tiles. The system withstands the BIPV definition for constructive addition.

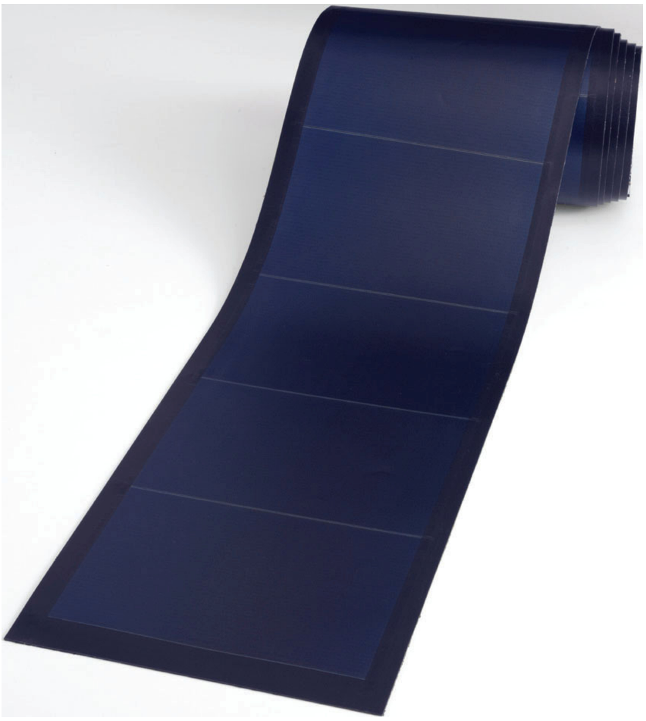


Figure 32: **Flexible and bendable PV module out of amorphous silicon from Uni-Solar (Uni-Solar, 2007)**
These thin film modules are especially interesting for BIPV applications.

Figure 33: **Application of amorphous silicon modules from alwitra (Alwitra, 2007)**
Alwitra's BIPV system made of thin film modules produced by Uni-Solar. The modules refer to constructive addition.

Figure 34: **Creative Solar Systems solar tiles (CSS, 2007)**
One solar tile replaces 6 usual tiles and has a capacity of 40 or 53 kW_p per tile. The system is regarded as constructive addition and therefore as BIPV.

Figure 35: **Semitransparent modules as glass roof (Scheuten, 2007b)**

The PV modules are constructively integrated into the building; therefore they fulfil the highest integration criteria and clearly belong to BIPV.

Figure 36: **PV facade integration of the fashion boutique Zara in Cologne (Blumenberg and Spinnler, 2007)**

The BIPV system demonstrates the possibility to integrated modules into the complete facade (besides windows).

Figure 37: **Aesthetically integrated on-roof solar system (Volz and Stark, 2005)**

Although it is an on-roof system, it won a special prize at a contest of the Bavarian solarenergy development association (Solarenergieförderverein Bayern e.V.) for BIPV products in 2005. The system is aesthetically well integrated and can thus be regarded as BIPV.

Appendix H)

BIPV data for Germany from 1999 until 2003

Development of types of systems in percentages of all approved applications in Germany of the 100.000 rooftops solar electricity programme (KfW, 2004)							
year	1999	2000	2001	2002	2003		*total*
on roof	86,7%	93,5%	91,8%	95,3%	97,7%		*92,9%*
in roof	7,5%	2,4%	5,7%	3,4%	1,4%		*4,3%*
facade	2,3%	1,1%	0,9%	0,6%	0,4%		*1,1%*
rest	3,5%	3,0%	1,6%	0,7%	0,5%		*1,7%*
sum	*100,0%*	*100,0%*	*100,0%*	*100,0%*	*100,0%*		*100,0%*

Newly power installed in the 100.000 rooftops solar electricity programme (KfW, 2004)							
year	1999	2000	2001	2002	2003		total
Power (MW_p)	9	37	76	78	146		348

Own calculation in absolute numbers based on the percentages and power above (in MW_p)							
year	1999	2000	2001	2002	2003	*total (the sum of the data from 1999 until 2003)*	*total (by using percentages)*
on roof	7,8	34,6	69,8	74,3	142,6	*329,1*	*321,4*
in roof	0,7	0,9	4,3	2,7	2,0	*10,6*	*14,9*
facade[182]	0,2	0,4	0,7	0,5	0,6	*2,4*	*3,8*
rest	0,3	1,1	1,2	0,5	0,7	*3,9*	*5,9*
sum	*9*	*37*	*76*	*78*	*146*	*346,0*	*346,0*
newly BIPV power installed in Germany (in MW_p)							
year	**1999**	**2000**	**2001**	**2002**	**2003**	***total (the sum of the data from 1999 until 2003)***	***total (by using percentages)***
BIPV (in roof + facade)	**0,9**	**1,3**	**5,0**	**3,1**	**2,6**	***12,9***	***18,7***

Table 4: **BIPV data for Germany of the 100.000 rooftops electricity programme**

This calculation bases on the assumption that the average power of all installed types of systems (on roof, in roof, facade and rest) are the same, which is surely not correct, but sufficient to give a reliable tendency.

[182] According to Rexroth (2005) the BIPV power installed can be estimated slightly higher since not all systems were covered under the 100 000 rooftops programme.

Appendix I)

Remuneration for electricity produced from solar cells from 1991 until 2008 in Germany (Altrock et al., 2006)

- *1991 until 2001 (calculated according to the Act on the Sale of Electricity to the Grid on the 7th of December 1990, 90 percent of the average market price of electricity)*

year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Pfennig/kWh	16,61	16,53	16,57	16,93	17,28	17,21	17,15	16,79	16,52	16,13
EURCent/kWh	8,49	8,45	8,47	8,66	8,84	8,8	8,77	8,58	8,45	8,25

Table 5: **Remuneration for PV systems in Germany between 1991 and 2000**

- *2000 until 2008 (calculated according to the Renewable Energy Sources Act on the 29th of March 2000, the change on the 31st of December 2003 and its amendment on the 21st of July 2004)*

systems in or on buildings/sound-proof walls			
year of installation	until incl. 30 kW_p in EURCent/kWh	from 30 kW_p in EURCent/kWh	from 100 kW_p in EURCent/kWh
before 2002	50,62	50,62	50,62
2002	48,10	48,10	48,10
2003	45,70	45,70	45,70
2004	57,40	54,60	54,00
2005	54,53	51,87	51,30
2006	51,80	49,28	48,74
2007	49,21	46,82	46,30
2008	46,75	44,48	43,99
…	5 % decline every year for all the systems		

Table 6: **Remuneration for PV systems on buildings in Germany between 2000 and 2008**

systems in facades and other systems				
year of installation	until incl. 30 kW_p in EURCent/kWh	from 30 kW_p in EURCent/kWh	from 100 kW_p in EURCent/kWh	other systems in EURCent/kWh[183]
before 2002	50,62	50,62	50,62	50,62
2002	48,10	48,10	48,10	48,10
2003	45,70	45,70	45,70	45,70
2004	62,40	59,60	59,00	45,70
2005	59,53	56,87	56,30	43,42
2006	56,80	54,28	53,74	40,60
2007	54,21	51,28	51,30	37,96
2008	51,75	49,48	48,99	35,49
…	5 % decline every year for all the systems besides			6,5 % decline every year

Table 7: **Remuneration for PV facades and other systems in Germany between 2000 and 2008**

[183] Until 2003 other systems were only refunded until 100 kW_p.

Further years are not listed since an amendment of the Renewable Energy Sources Act is again planned for 2008 or 2009.

Description of different categories of systems according to the Renewable Energy Sources Act from the 21st of July 2007 (Altrock et al., 2006)

According to § 11 paragraph 2 clause 1 EEG[184], all substantial parts of the PV system have to be completely mounted on or upon a building or a sound-proof walls.[185] The amount of remuneration depends on the capacity of the system. However, the remuneration of systems, which exceed one of the limits (30 kW_p or 100 kW_p), occurs proportionate according to § 12 paragraph 2 EEG. Furthermore, the building must not primarily be constructed to produce electricity from solar cells.

The bonus for facade systems, outlined in § 11 paragraph 2 clause 2 EEG, of 5 EURCent/kWh does not decline every year[186] and applies for system, which are installed at the outer envelope of a building, cover a function[187] for the building and represent a substantial part of the building. However, the facade bonus is not valid for in-roof systems.

Other systems refer to open-space systems, e.g. in fields. According to § 11 paragraph 3 EEG they have to fulfil special requirements in order to prohibit the installation on ecological sensitive areas and to reach a wide acceptance in the local population.

[184] The translation of EEG is Renewable Energy Sources Act.
[185] This refers to the category “systems in or on buildings/sound-proof walls” from the page before.
[186] Only the bonus does not decline, the basic remuneration does. However, the decline applies only for new systems. Thus, if a system is once installed the amount of remuneration is constant for 20 years.
[187] This could for instance be weather protection or shadowing.

Appendix J)

Overview of books and brochures published about BIPV in Germany

- books

1993, Othmar Humm, Peter Toggweiler: "Photovoltaik und Architektur / Photovoltaics and Architecture". Birkhäuser.

1996, Schneider, Astrid: Solararchitektur für Europa.

2000, Lüling, Claudia / Auer, Gerhard / Dimmler, Bernhard: Architektur unter Strom - Photovoltaik gestalten.

2002, Hagemann, Ingo: Gebäudeintegrierte Photovoltaik – Architektonische Integration der Photovoltaik in die Gebäudehülle.

2002, Rexroth, Susanne: Gestalten mit Solarzellen – Photovoltaik in der Gebäudehülle.

2003, DGS Deutsche Gesellschaft für Sonnenenergie Landesverband Berlin Brandenburg e.V.: Photovoltaische Anlagen.

2005, Hermannsdörfer Ingrid / Rüb, Christine: Solar Design: Old Buildings, Urban Space, Landscapes.

- brochures

2000-2005 (different editions), Stark, T., Lutz, H.-P., Schneider, H. and Schneider, S. Wirtschaftsministerium Baden-Württemberg: Architektonische Integration von Photovoltaik-Anlagen.

2001, Landesgewerbeamt Baden-Württemberg, Informationszentrum Energie: Architektenkammer Baden-Württemberg.

2005 (2nd edition), Photovoltaik in der Gebäudegestaltung, Ministerium für Wirtschaft, Mittelstand und Energie des Landes Nordrhein-Westfalen (MWE).

2006, hwp & ISET: Multifunktionale Photovoltaik – Photovoltaik in der Gebäudehülle.

This list should not be regarded as complete. Nevertheless, it shoes the continuous research and the information prepared by different institutes.

Appendix K)

Electricity production in France (Ministry of Ecology Sustainable Development and Town and Country Planning and Ministry of Economy Finance and Industry, 2007a)

Type of power	1973	1979	1985	1990	2000	2004	2005	2006
Nuclear	15	40	224	314	415	448	452	450
Thermal	119	134	56	48	53	60	67	60
Renewable energy*	48	68	64	58	72	66	58	64
Total	182	241	344	420	541	574	576	574

Table 8: **Electricity production in France between 1973 and 2006 (simplified electricity balance)**

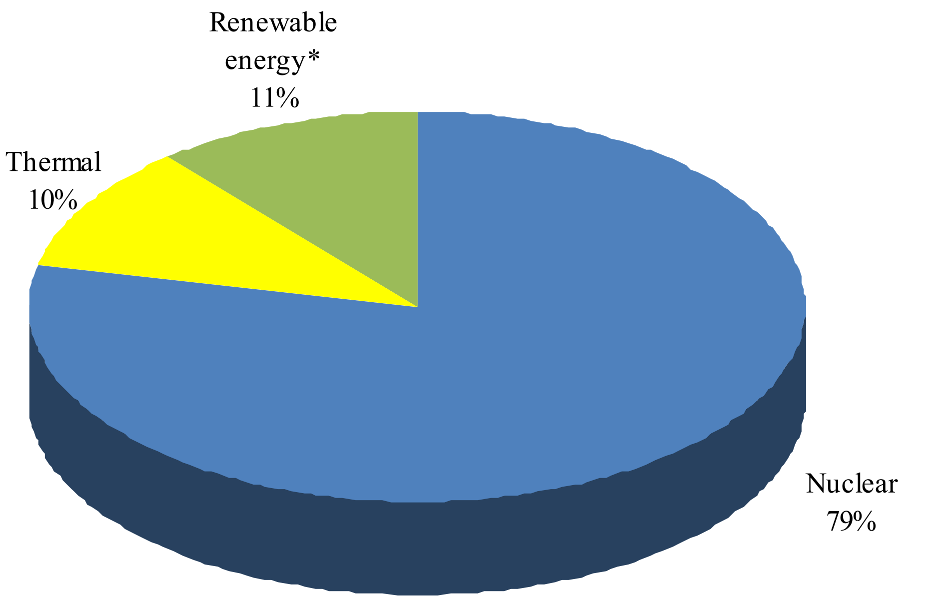


Figure 38: **Electricity production in France in 2006 (Ministry of Ecology Sustainable Development and Town and Country Planning and Ministry of Economy Finance and Industry, 2007a)**

* Renewable energy includes: hydraulic, wind power and photovoltaics.

Appendix L)

Description of the RTD programme (Claverie, 2002b)

Research in the RTD programme was conducted in different fields:

- Mono-crystalline Silicon PV cells: "PV-16" project (Photowatt and CNRS)
- Thin films:
  - Mono-crystalline silicon films: "Succès" project (CEA-GENEC and INSA Lyon)
  - Heterojunctions based on amorphous and crystalline silicon: "Hermes" project (Cea–Genec and CNRS)
  - Cells based on Cu-In-Ga-Se prepared by electrodeposition: "Cisel" project (EDF-EMA, CNRS and Saint-Gobain Recherche)
  - Cells based on organic polymers (Cea-Lco, CNRS and Universities)
- Engineering of PV systems: management and control of the energy flows, converters, inverters (Apex Bp solar, Total-Énergie, Transénergie, Cea-Genec, Armines, CNRS)
- Storage batteries (Ceac, Apex Bp Solar, Cea-Genec, CNRS)
- Multisource, stand alone village electrification systems for individual uses, water pumping (Transénergie, Total Energie, Armines, Cea-Genec)
- Accompanying studies on tests, return of field experiences, global management of the of PV systems network, granting of a concession, reliability of the systems and development of standards (Cea-Genec, Armines, PHK, IED, FONDEM, SERT, Costic, etc.)