



## ANALYSIS OF PV SYSTEM'S VALUES BEYOND ENERGY - by Country and Stakeholder



PVPS

PHOTOVOLTAIC  
POWER SYSTEMS  
PROGRAMME

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INTERNATIONAL ENERGY AGENCY  
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

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-by Country and Stakeholder**

IEA PVPS Task 10, Activity 1.1  
Report IEA-PVPS T10-02:2008  
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This report has been prepared under the supervision of  
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## FOREWORD

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its member countries. The European Commission also participates in the work of the IEA.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D Agreements established within the IEA. Since 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The mission of the Photovoltaic Power Systems Programme is "to enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option". The underlying assumption is that the market for PV systems is gradually expanding from the present niche markets of remote applications and consumer products, to the rapidly growing markets for building-integrated and other diffused and centralised PV generation systems.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By the end of 2007, 12 Tasks were established within the PVPS programme.

The objective of Task 10 is to enhance the opportunities for wide-scale, solution-oriented application of photovoltaics (PV) in the urban environment as part of an integrated approach that maximizes building energy efficiency and solar thermal and photovoltaics usage. The Task's long term goal is for urban-scale PV to be a desirable and commonplace feature of the urban environment in IEA PVPS member countries.

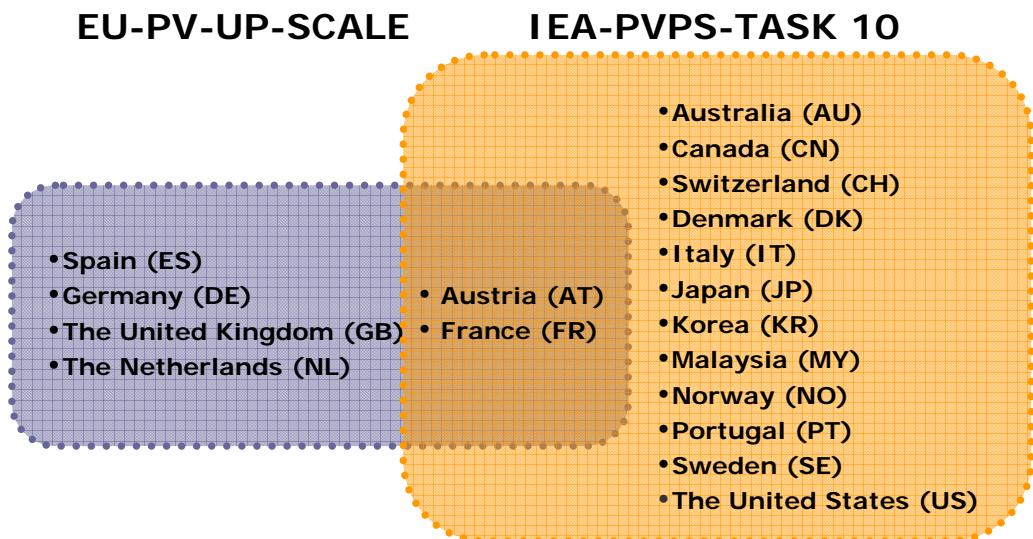
This report has been prepared by EEG (Energy Economics Group- Austria) for IEA-PVPS Task 10 under the corresponding supervision within this programme and the European research project PV UP-SCALE which both comprise closely linked activities. Both research activities complement each other by involving partners from differing countries with differing characteristics of and viewpoints on PV. The list of countries involved is provided in Figure 1 which depicts all partners by their country of origin for both research activities. It is especially the aim and duty of those few partners who participate in both activities to strengthen cooperation in order to meet the common objectives of both activities. This report represents a first result of this collective work on Value Analysis and has been prepared based on contribution of both IEA-PVPS-Task 10 and PV UP-SCALE partners.

More information of the activities of Task 10 and PV-Up-Scale can be found on:

- [www.iea-pvps-task10.org](http://www.iea-pvps-task10.org)
- [www.pvupscale.org](http://www.pvupscale.org)

Within this report, a geographical focus was applied using the following countries:

Austria (AT), Canada (CA) Denmark (DK), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Spain (ES), Sweden (SE), Switzerland (CH), The United Kingdom (GB), California / The United States (US)



**Figure 1.** Overview on countries participating in the European research project EU-PV Up Scale and the activities as set in the frame of IEA-PVPS Task 10.

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## SUMMARY OF REPORT

Although PV currently appears an expensive option for producing electricity compared to other energy sources, many countries support this technology because of its promising future potential and the additional benefits, besides generating electricity, associated with PV. These benefits need to be, firstly, identified and, secondly, quantified (especially for the demand side) in order to affect decision making in urban planning.

**The major stakeholders for PV comprise policy makers and governments, utilities and customers.** Despite each stakeholder having different preferences and interests; each added value contributes to society's welfare. In this context ***the core objective of this report is to identify, evaluate and quantify the major values and benefits of Urban Scale PV*** based on country specifics. The evaluated and / or quantified values have been categorised under the following groups.

- Avoiding fossil fuels
- Environmental benefits
- Electric utilities benefits
- Industry development and employment benefits and
- Customer's individual benefits.

### ***Avoiding fossil fuels and corresponding environmental benefits***

The great importance of renewable energies in general and PV in particular is due to the expected environmental benefits, namely:

- avoided risks of disruption in fossil fuel supply and associated price instability;
- a significant contribution towards sustainability;
- reduction of greenhouse gas emissions;
- the potential to greatly reduce, and perhaps eventually eliminate pollution associated with electricity services;
- avoided external costs.

As a first step in this respect, the contribution of PV to avoiding primary energy has been quantified taking into account the country specifics. For this report there is a geographical focus on the following countries:

Austria (AT), Canada (CA), Denmark (DK), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Spain (ES), Sweden (SE), Switzerland (CH), The United Kingdom (GB), California / The United States (US)

Using the "partial substitution methods" the primary energy equivalent of each generated kWh of PV electricity has been calculated. Investigation of the country-specific electricity supply portfolio has allowed us to determine which fuel would be replaced and was also of core importance for the follow-up analysis on reduction of greenhouse gas (GHG) emissions (CO<sub>2</sub>-e) and air pollutants (NO<sub>x</sub> and SO<sub>2</sub>).

The fossil fuels identified as likely to be avoided differ from country to country. In the case of Japan, PV would replace oil because the peak demand is typically met by oil-based power plants. In European countries, the avoided fuel is mostly natural gas or coal depending on the countries peak demand profiles, emission factors or fuel expenses. By replacing conventional

fossil-based power supply, PV contributes also to the avoidance of corresponding greenhouse gas emissions ( $\text{CO}_2\text{-e}$ ) and air pollutants such as sulphur ( $\text{SO}_2$ ) and nitrogen oxides ( $\text{NO}_x$ ). For the quantification of reduced emissions, a net balance was derived by taking into account country-specific (life-cycle) emissions factors by fossil fuel as well as (life-cycle) emissions factors of PV relating to the manufacture of PV cells. As a result, for each generated kWh of PV electricity, reduced emissions factors could be calculated on a country level.

The results indicate that the highest GHG emission reduction factors occur for United Kingdom (GB) where 1 kWh PV electricity contributes to the avoidance of 1 048 g  $\text{CO}_2\text{-e}$  from hard coal-fired power plants, while in the case of Spain the highest reduction with respect to the air pollutant  $\text{NO}_x$  is feasible (1 kWh PV contributes to the avoidance of 6,89 g  $\text{NO}_x$ ).

The analysis shows that in European countries where PV possibly replaces natural gas higher  $\text{SO}_2$  emissions occur – due to comparatively high emissions that refer to the manufacturing of solar cells but this may change in the future when PV or other renewable electricity can also be used for power supply in PV manufacturing. In contrast, in California where again natural gas represents the marginal option, this negative effect of an enhanced PV deployment cannot be observed since the upstream air pollutant emissions in the life-cycle of natural gas power plants are comparatively high.

PV can also contribute to reducing water consumption for cooling in thermal power plants. As data was not available for all countries, this value has been exemplarily quantified for California where each MWh of PV electricity contributes to save about 0,19 m<sup>3</sup> water.

The external cost of energy supply is another intensively discussed topic. Based on the outcomes of a recently conducted evaluation report of several external cost studies indicators can be derived for the avoided external cost due to PV electricity. The total potential with regard to reducing external costs of fossil power generation – referring to  $\text{CO}_2$ ,  $\text{NO}_x$  and  $\text{SO}_2$  emissions - by PV electricity was calculated. For instance in the case of Spain, where coal represents the avoided marginal conventional supply option, a high value of 9,95 EUR-Cent/kWh occurs, whilst in the Netherlands with its gas-based peak supply, only 2,86 EUR-Cent/kWh occurs. Consequently, we can assume that where PV replaces coal the external cost reduction is higher than in the case of avoiding natural gas.

### **Utilities benefits**

Values for utilities depend largely on country-specific supply and climatic conditions. The influencing factors can be classified as follows.

- The relevance of PV to meet peak demand
- Market values more precisely earning revenues on the spot market
- The relevance of PV for reducing the environmental cost burden –  $\text{CO}_2$  certificate prices applied within the European Union's Emission trading scheme.

The relevance of PV for meeting peak demand depends on the daily and seasonal load characteristics, e.g. the time of daily peaks and the correlation with solar generation. In this context, the following question appeared: To what extent can PV contribute to peak supply? Based on country-specific load profiles we classify European countries as typical "winter peak" countries, but the recent hot and dry summer conditions have clearly shown that ***there is a need to reduce peak electricity demand or supply shortage***, even during summer. In this season many thermal power plants undergo maintenance or have to reduce their generation due to a lack of cooling water.

As studies on "capacity credit of PV" indicate, PV as an option to reduce supply shortage in peak load periods has mainly been considered a topic for "summer peaking" countries like Japan and, in the USA, California - where the main literature is coming from. However, recent summers in Europe have shown that this value may become more important for European countries as electricity from Photovoltaic systems is generally produced during times of peak demand when electricity is most expensive in summer months.

The hourly average correlation between PV output and spot prices for summer and winter months confirms that PV generation matches best to peak prices during summer in central European countries. In Spain, representing southern Europe, the peak prices during summer months continue from midday on until night hours. The analysis for Sweden has shown that the spot prices do not correlate to PV output as there is a constant price level over the whole day. The value of PV from utilities point of view in Sweden therefore has to be evaluated from the revenue earned in the spot market and reduced CO<sub>2</sub> certificate prices.

Calculations of earned revenues have been undertaken for differing European countries and power markets for several years – depending also on the availability of data on PV output. A reference system (as installed in Germany) with specific PV output 982 kWh/kW<sub>p</sub> would offer an earning revenue of 56 EUR/kW<sub>p</sub> on the EEX within July 2005 to June 2006 while a reference system from Sweden during 2004 would offer a value of 21 Euro/kW<sub>p</sub> on the Nord Pool.

Within the European Union an emission trading scheme has been implemented since the end of 2004. The utilities had to pay 18 Euro on average (EEX) (from 2005 to October 2006) for each tonne of emitted CO<sub>2</sub>. Taking into account this value the monetary benefits for utilities using PV instead of fossil power generation could be calculated for reported European countries. In the Netherlands a utility can reduce its cost burden by about 0,62 EUR-Cent for each kWh generated PV electricity, whilst the highest value in size of 1,86 EUR-Cent /kWh occurs for United Kingdom where avoidance of hard coal was assumed.

### ***Industry development and employment benefits***

New job opportunities are another benefit for decision makers which are mostly considered for new energy policies (Watt, 2001). In comparison with conventional energy technologies renewable energy technologies create more jobs. The PV market is growing rapidly and offers jobs from manufacturing to installation. The numbers from Germany underpin this argument.

Germany was the largest single PV market in 2005 and had a turnover of three billion Euros. It is estimated that by 2020 market turnover will reach 15,2 billion Euros. At present, jobs in the PV sector are estimated to be around 30 000. The second largest PV market within Europe – Spain – also offers good conditions for PV industry with about 6 300 direct and indirect created jobs.

Despite other European countries not having significant PV markets they also have successful companies like Photowatt in France or Fronius in Austria which concentrate on exporting their products.

### ***Customer's individual benefits***

Beside the environmental benefits, green image and the contribution to an individual's supply security, building integrated PV systems offer other decisive individual values. In this report the major customers groups are classified into three groups: residential, commercial customers and architects & building developers as a special group which influence the decisions of others. In this context, the multi functional building construction features of

building integrated PV, as well as the contribution of PV systems to improving the thermal performance of buildings, are discussed from the architects and building developers' point of view.

Building integrated PV systems can avoid some costs of building materials which would be used instead. The cost savings are especially high when comparing PV investment cost with other decorative materials for facades. In this case, material savings are illustrated as a value which represents a monetary benefit for customers.

**Table 1. Summary of perceived PV values in this report**

		The main Stakeholders				
Environmental Benefits	Policy Makers & Governments	Utilities	Customers			Transmitters*
			Residential	Commercial	Architects & Building Developers	
	CO <sub>2</sub> savings (emissions or targets)	Reduce environmental price risk (high capacity of upgrade)	Environmental friendly technology	Environmental friendly technology	Green image - prestige	Meeting building energy standards
	NO <sub>x</sub> and SO <sub>2</sub> saving	Reduced Cost of CO <sub>2</sub> certificate				
Supply Security Benefits	Water saving	Green image-prestige	Green image-prestige	Green image - prestige	Green image - prestige	
	Avoided external costs					
	Avoiding fossil fuels	Peak shaving	Energy independence	Energy independence	Electricity savings	Reduced electricity infrastructure
Individual Benefits	Capacity credit					
	Decentralised generation	Availability/outage protection				
		Earning revenue by selling PV electricity	Reliability	Reliability	Innovative multi-functional building construction element (roofing, shading)	
		Reduced transmission and distribution costs and losses	Material saving	Material saving	Innovative design features (e.g. colour, shape and transparency)	
		Reduced fuel price risk	Modularity	Modularity	Non intrusive features (noiseless, maintenance)	Improving the thermal performance (heating, ventilation, insulation)
Industry Development & Employment Benefits	Industry development					
	Export value	New business opportunity				
	General and local employment					Sound proofing

\* Who may influence the decision-making process of a potential PV generator (Haas, 2002)

# 1 INTRODUCTION

The need for urbanisation, driven by population growth in the past and even today, goes hand in hand with increasing energy consumption. Therefore, sustainable urban development is essential. Energy efficiency and the use of renewable energy play a significant role.

The increasing problem of greenhouse gases, air pollution associated with fossil fuel electricity generation, rising oil prices and the recent gas crisis with Russia have all demonstrated the importance of forming diversified energy profiles largely based on clean and indigenous energy sources. Photovoltaic (PV) is one of the most prominent renewable energy technologies, characterised by a worldwide abundant available fuel source – the sun.

Today, approximately 75% of the European population live in urban areas (EEA, 2006). Building integrated PV systems are an integral part of a building and are able to generate electricity in urban areas where electricity is needed. Sustainable urban planning is the responsibility of major actors such as federal and local governments (municipalities), communities, architects, urban designers and people who are willing to contribute to sustainability at their urban scale. *"Whilst people all over the world enjoy their dynamic and privileged urban lives, there are major downsides to be considered: in the developed world, urban dwellers are discharging anything between 9 and 25 tonnes of CO<sub>2</sub>-e per capita per year"* (Girardet, 2004).

Over the last five years, the global PV industry has grown more than 40% each year.(IEA, 2006) Although PV is currently an expensive option for producing electricity compared to other energy sources, many countries support this novel technology because of its promising future potential and the additional benefits besides electricity generation associated with PV. The global leaders with regard to PV are currently Japan and Germany. However, many other countries follow this path – e.g. Spain and Portugal, but also emerging economies such as China. The benefits of PV, currently in effect, need to be, firstly identified, and secondly quantified, (especially for the demand side) in order to understand the potential impact on the decision making processes.

Accordingly, it is one of the major objectives of the IEA PVPS Task 10 project to conduct a comprehensive added value analysis of decentralised PV.

However, the offered benefits or values of building integrated PV at an urban level do not markedly differ at a country (federal) level because the problems of security of supply and environmental sustainability are essential at the national as well as at the local (regional) level. Furthermore, building integrated PV systems contribute as an innovative part of a building with multifunctional features.

Within the added value analysis of PV, this report aims to clarify;

**On the one hand why governments and policy makers should set strong market incentives and on the other hand why different customers groups and electricity utilities should invest in PV systems or PV electricity.**

This report aims to contribute to achieving the goal by outlining, in a concise manner, the outcomes of the value analysis.

Many possible values of Photovoltaics are very difficult to quantify because of a lack of data and the multidimensionality of several topics. This study intends to derive a basic approach based on a simple but stable argument that is easy to understand for all types of stakeholders.

## 1.1 Core Objectives

The major purpose of this document is to identify, quantify and evaluate the values and benefits of Urban Scale PV. The analysis of each value includes deriving a general methodology which is applicable for all countries/regions analysed, whilst the quantifiable examples aim to demonstrate country specific differences and perceptions.

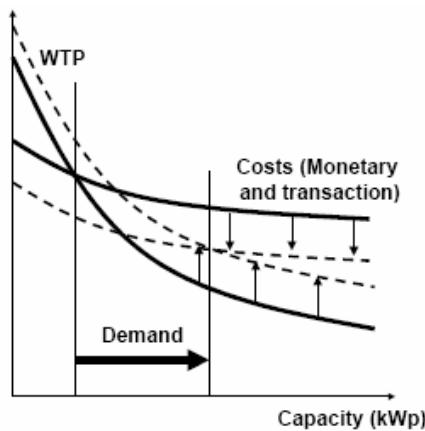
From a geographical viewpoint, this report focuses on: Austria (AT), Canada (CA), Denmark (DK), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Spain (ES), Sweden (SE), Switzerland (CH), The United Kingdom (GB) and California / The United States (US). These are the countries of the IEA Task 10 and PV-Up-Scale partners (see Figure 1) as this report is a mutual activity of both projects.

Furthermore, the identification of values will provide at least some justification with regard to PV supporting strategies to remove financial barriers, which are discussed in detail in this report, and present the benefits to diverse stakeholders which are necessary for a wider market penetration of PV technology.

Despite that there are some inconsistencies in the data, this report aims to provide guidance for other related studies.

## 1.2 Definitions - Values, Benefits and Perceptions

Two issues are of core relevance in order to achieve an increased demand for PV systems: On the one hand, to increase the customer's voluntary willingness to pay<sup>1</sup> (WTP), and, on the other hand, to reduce the (monetary and transaction) costs for customers. Figure 2 shows the effects of the WTP in a traditional supply and demand diagram. A detailed analysis of the customer's willingness to pay and the conditions influencing the WTP for PV systems is given in Haas (2002). As WTP is directly influenced by perceived added values which affect the individual's perceptions, there is a need to identify these added values for different groups of customers.



**Figure 2. How enhancement in customers WTP and decreases in costs influence the demand for PV**

Source: (Haas, 2002)

<sup>1</sup> WTP: Willingness to pay: How much is a customer ready to pay for PV electricity or invest in PV systems, respectively, - due to personal preferences or, in other words, due to added values of PV

Currently, PV appears an expensive option for producing electricity compared to other energy sources and, consequently, requires financial support – i.e. effective and efficient energy policy instruments – in order to achieve an accelerated deployment on the market. Accordingly, policy makers and governments influence the market penetration of PV technology with their decisions. As a consequence, this report aims to answer why the policy makers and local or federal governments have to set financial incentives and market deployment strategies for PV.

In this study we focus this value analysis on decentralised grid connected (building integrated) PV systems. With such PV systems, an indirect energy conservation effect can be identified due to the direct involvement of customers in their own electricity supply – see (Haas, 1995). We can define PV customers as the group of people who purchase a PV system and /or purchase PV electricity. Consequently, two markets appear: A market for PV systems and a market for PV electricity (Haas, 2002). In other words, an electricity utility can also purchase a PV system or give subsidy to households in order to purchase PV electricity. In the later case the household owner, also the PV system owner acts as a purchaser. Therefore, the main stakeholders influencing the demand for decentralized, grid-connected PV are:

- Customers
- Utilities
- Policy Makers and Governments

**Customers:** In a first step, it is important to identify the different types of Customers and their main concerns or preferences.

1. **Residential customers** (individual households): The purchase of a PV system depends on customers WTP which is largely influenced by the recognized added values and affordability. (Haas, 2002). The most important values for private customers are environmental aspects, image/prestige, reliability of PV systems, system modularity, independence with regard to their power supply and the corresponding price developments.
2. **Commercial customers:** At a first glance, we hypothesize that this customer group is mainly interested in making profits. Consequently, demand for PV systems exists within this group if they can make money with PV or if PV systems offer additional values, like prestige, image or supply security.
3. **Architects and building developers:** This is a specific group of customers who use PV for other purposes than electricity production. (Haas, 1995). Accordingly, architects identify PV mainly as a building element with multifunctional characteristics such as shading, roofing or material saving. The innovative design features – e.g. color, shape or transparency – or the thermal performance characteristics of PV such as heating, ventilation or insulation may cause this group to make use of PV systems. Another important value is the prestige associated with a PV system (Reijenga T.H., 2002).

**Utilities:** Some attributes of photovoltaics could become crucially important for electricity suppliers or distributors in the future – e.g. PV as an opportunity for new markets and business or PV to improve the image and prestige of utilities. Both affirmations seem to be evident, considering the increasing amount of utilities offering green power products as a distinguishing element in liberalized and competitive markets. The contribution of PV to reduce peak electricity demand is also an important value from utilities point of view.

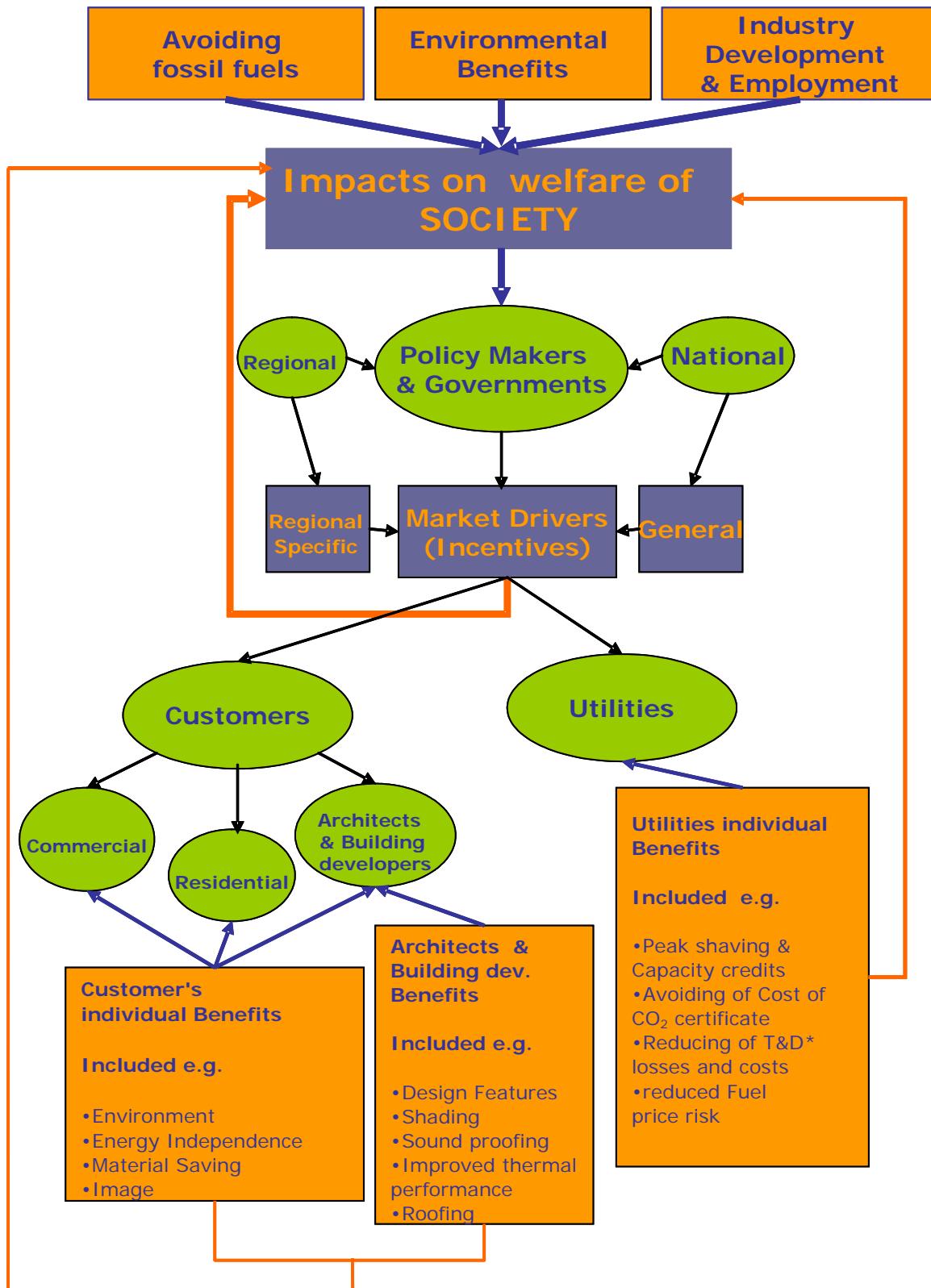
**Policy Makers and Governments:** Local or federal policy makers and governments have the obligation to contribute in increasing societal welfare. The benefits of PV for each interest

group, as discussed above, are in fact a part of the whole sum of societal benefits as illustrated in Figure 4. Societal benefits summarise the whole set of values and, consequently, they shall determine if financial incentives, as provided by energy policy for PV systems, are justified. Hence, policy makers and government can not be seen separately from the demand side and also have to be considered as an important stakeholder representing the whole society.

Figure 3 aims to clarify the relationship between values, stakeholders and market drivers on the demand side. As can be seen in this figure, the added values and market drivers have strong impacts on societal welfare.

In this respect, the most decisive values which justify the market drivers set by policy makers and governments are:

- Avoiding fossil fuels in order to contribute to supply security, and accordingly the import dependence price risks are reduced;
- Environmental benefits, which are the main conditional topic for sustainable development at local as well as at a global level; and,
- Industry development and creation of new job opportunities.



**Figure 3. Relationship between values, stakeholders and market drivers**  
 \* T&D – transmission and distribution

### 1.3 Structure of This Report

Figure 4 shows the major value categories which indicate the structure of this report.

In section 2, the basic elements of the applied methodologies, with regard to quantifying and identifying PV values are described.

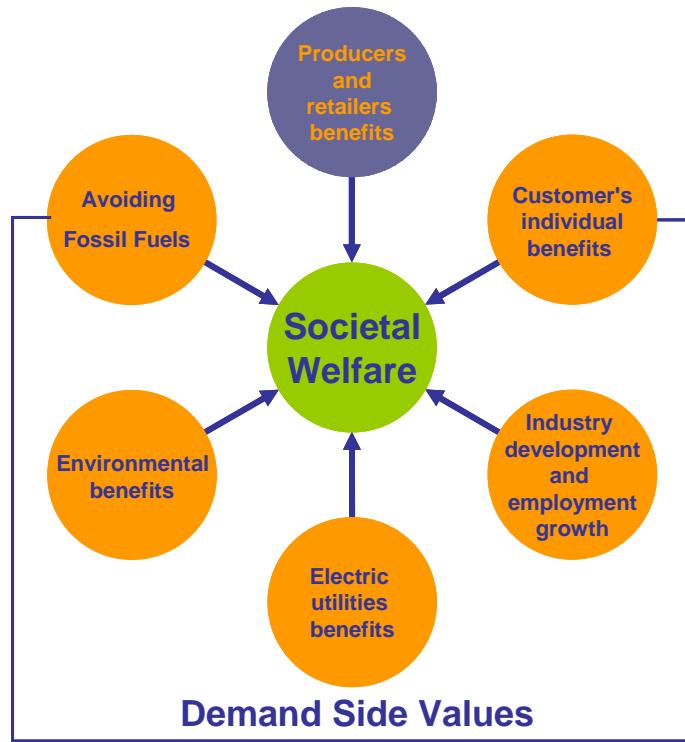
Section 3 is dedicated to the quantifying process and results of avoiding fossil fuels while in Section 4 the most important environmental values are treated based on country characteristics.

The relevance of PV to meeting peak demand, market values and reduction of CO<sub>2</sub> cost burden are discussed in Section 5 from the utilities point of view.

The value category "industry development and employment effect" is analyzed in Section 6, which is a core argument having impacts on the decision making process in energy policy.

In Section 7 the most relevant customer benefits are explained and the monetary value of "Material Saving" is illustrated as a Customer's individual benefit.

Finally in Section 8 important conclusions are derived.



**Figure 4. Classification of added values / benefits**

## 2 METHODOLOGY

Major added values of PV have been quantified and analyzed with a geographical focus based on the following countries:

Austria (AT), Canada (CA), Denmark (DK), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Spain (ES), Sweden (SE), Switzerland, CH), The United Kingdom (GB), California / The United States (US)

The method and assumptions, with regard to the identification and quantification of values were summarised according to the structure of this report. More details on applied methodologies and assumptions can be found in each related section.

### ***Avoiding fossil fuels and environmental benefits***

#### **Determining the substituted fuel:**

Base load capacities (must-run capacities) like hydropower, wind and nuclear would never be replaced by additional PV<sup>2</sup>; consequently the unneeded generation has to be exported abroad. Accordingly, for this study, country-specific data on the yearly electricity generation portfolio as well as information on the technology-specific contribution in meeting base- intermediate and peak-demand has been collected in cooperation with the project partners.

#### **Quantifying the substituted fuel:**

The primary energy equivalent of PV electricity has been calculated according to the partial substitution method which can be summarised by the equation below.

$$\begin{aligned} & \text{Replaced thermal fuel in terms of primary energy (kWh)} = \\ & \text{PV generation (1 kWh) / Average generation efficiency (\%)} [1] \end{aligned}$$

In order to quantify the amount of yearly replaced thermal fossil fuels by installing one peak kW of PV capacity; the country specific average solar yield in **kWh/kW<sub>p</sub>** has been collected. This data was provided by project partners and is based on practical experiences rather than theoretical<sup>3</sup> calculations.

#### **Quantifying avoided emissions:**

The life-cycle emissions considered were: CO<sub>2</sub>– (greenhouse gas emissions), NO<sub>x</sub> and SO<sub>2</sub> (air pollutants).

Emission reduction is reported in terms of *grams of avoided emissions for each kWh of PV electricity generated*.

<sup>2</sup> This statement can be argued at least for the near future – as long as corresponding technologies such as efficient storage technologies or demand response measurements are not commercially available on the market.

<sup>3</sup> The theoretical equation is

$$E_{out} = H_i \times P_o \times PR/Gs$$

*E<sub>out</sub>:* annual energy output in kWh/year

*H<sub>i</sub>:* global in plane irradiation in kWh/m<sup>2</sup>/year

*P<sub>o</sub>:* nominal power of the PV systems in kW<sub>p</sub>

*PR:* Performance ratio

*Gs:* Reference irradiance

The applied methodology can be summarized as follows:

- Emissions factors of replaced fuel (in end use energy basis)
- Country specific emissions factors of PV systems – for sc-Si (single crystalline) and mc-Si (multi crystalline)
- Classification of used PV cells

#### **Emissions factors of replaced fuel**

The derived country-specific emission factors refer to the (possibly) replaced fossil fuel and are expressed on an end energy basis – i.e. per kWh electricity. These factors are based, where applicable, on life-cycle analysis (LCA)<sup>4</sup> data. LCA was chosen as environmental impacts depend not only on the power generation facility itself, but on the upstream processes as well. For European countries harmonised data was derived from (Fritsche et al., 2006). In addition to the avoided emissions which indicate the gross avoided emissions, net avoidance is also expressed considering the LCA emissions of PV systems as well.

#### **Estimation of emissions factors for solar systems**

First, the life-cycle emissions for a reference system from the data inventory, as undertaken within the CrystalClear<sup>5</sup> research project, were derived – for details we refer to (Alsema et al., 2006) and (de Wild Scholten et al., 2005). Thereby, both single-crystalline (sc-Si) and multi-crystalline silicon cells (mc-Si) were analysed for a reference plant – i.e. a rooftop PV application consisting of frameless modules located in Southern Europe (reference solar insolation of 1 700 kWh·m<sup>-2</sup>·year<sup>-1</sup>), with a performance ratio (PR) of 0,75 and a plant life time of 30 years.

In the next step, the reference emissions were transferred to the country-specific circumstances, which are briefly explained in the related section:

Summing up, the following equation occurs for deriving country-specific emission factors from the reference system:

$$\text{Country\_emission\_factor} = \text{reference\_emission\_factor} \times \frac{\text{reference\_solar\_yield}}{\text{country\_solar\_yield}} \quad [2]$$

Here,

$$\text{reference solar yield} = 1\,700 \times 0,75$$

*country solar yield* = the country specific average solar yield

The emissions factors of solar cells technologies differ. Today most installed and produced modules are based on crystalline silicon cells. Accordingly, we focused on these solar cells. For the technology-specific shares of installed PV systems the average historic data (Photon, 4/2006) for produced PV crystalline silicon technologies was considered and in case of other produced cells equivalent shares of multi and single crystalline were assumed. The

<sup>4</sup> LCA is a data intensive approach including not just the direct emissions values but also indirect ones stemming from "upstream" activities like mining, processing and transport are included, as well as the materials (and energy) needed to manufacture all processes.

<sup>5</sup> In the framework of the project CristalClear data on a Life Cycle Inventory has been collected from eleven major PV companies from Europe and the USA. These data represent the status of production technology for crystalline silicon modules, comprising 94% of all 1 200 MW produced solar cell modules as of 2004 (Alsema et al., 2006).

The CrystalClear project was funded by the European Commission. More information on this project can be found at [www.ipcrystalclear.info](http://www.ipcrystalclear.info).

classification used for all reported countries is: 43% single crystalline silicon cells, 57% multi crystalline silicon cells.

### **Quantifying avoided external costs**

GHG and air pollutant emissions due to energy generation damage a wide range of receptors, such as human health, natural ecosystems and the built environment. These external effects give rise to external costs to society.

The total potential for reducing external costs by PV electricity is calculated based on derived factors (in g/kWh) with regard to emission avoidance. Additionally, the outcomes (in EUR/t CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub>) of a recently conducted conscientious evaluation of several external cost studies (see Krewitt et al., 2006) are applied to express indicators in terms of EUR-Cent saved external cost per kWh PV electricity.

### **Utilities benefits**

Besides an in-depth literature investigation on the relevance of PV to meet peak demand, the load profiles of central and southern European countries are investigated. Load profiles have been derived according to data on hourly load values for the year 2005.

The hourly average correlation between PV output and spot prices for summer and winter months has been analysed based on country-specific data on PV generation (as derived for a reference PV system) and spot market prices. Calculations of earning revenues have been undertaken for differing European countries and power markets for several years – depending also on the availability of data on PV output and spot market prices.

The average CO<sub>2</sub> certificate costs in the EU's Emission Trading scheme have been estimated at 18 Euro/t CO<sub>2</sub> according to the CO<sub>2</sub> index (EEX), representing the average for the years 2005 and 2006. Taking into account this value the monetary benefits for utilities using PV instead of fossil power generation could be calculated for reported European countries.

### **Industry development and employment**

A literature survey on created jobs and industry deployment regarding reported countries was undertaken and examples are reported.

### **Customer's individual values**

The cost comparison of PV with some roof and façade elements based on a country-specific data collection has been shown. It is assumed that one peak kW PV capacity equals 10m<sup>2</sup>. The PV system/turnkey prices have been collected and material savings were taken into account for expressing the reduction of installation shares on turnkey prices.

The other customer's individual values have been documented based on an in-depth literature investigation where (Watt, 2001) and (Reijenga T.H., 2002) provided most valuable inputs.

### 3 AVOIDING FOSSIL FUELS

PV, as a renewable energy technology, may substitute for thermal power generation based on fossil fuels and hence avoid risks of disruption in fossil fuel supply and associated price instability. In a competitive and liberalised power market it is difficult to determine which kind of energy is actually displaced by adding another power plant to the system. However, in the following we present an approach suitable for a quantification based on a few key assumptions.

As it is beyond the scope of this study to analyse in detail which conventional power plant would actually be replaced by a PV plant installed in a certain year in a certain country (e.g. in Germany either a less efficient existing coal-fired plant or a possibly new high-efficient combined cycle gas turbine), the following assumptions are made: Keeping in mind that fossil energy represents the marginal generation option that determines the prices on energy markets<sup>6</sup>, a closer look on the conventional supply portfolio on a country level will assist in deriving assumptions for fuel replacement. Next, country-specific conversion efficiencies are used to get a sound proxy to calculate from PV generation figures back to the amount of avoided primary energy.

#### 3.1 Determining the substituted fuel

For determining the replaced fuel(s), the investigation of the country-specific electricity generation portfolio is the starting point. Furthermore, it is of core importance for the follow-up analysis of fuel avoidance as well as emission reduction. More precisely, it is required in order to derive a sound assumption whether a certain fuel such as coal or a mix of different fuels would be substituted.

For this study we have collected country specific data on the yearly electricity generation portfolio as well as information on the technology-specific contribution in meeting base- and peak-demand and the opinion of project partners in this topical area has been asked.

In this context, data on the monthly portfolio would ideally be used to identify if there is enough thermal power generation (based on fossil fuels) which could be replaced by PV within each month. This is especially relevant in countries with less fossil fuel based generation, in other words – where power generation is largely based on hydro or nuclear (i.e. countries such as Austria, Norway or France).<sup>7</sup> For instance in Austria's summer months hydropower shares are rising (see Figure 6), while PV generation also increases. Consequently, less fossil fuel based generation is needed. Nevertheless, PV generation today is on such a small level that it is acceptable to stick to yearly data in order to simplify the analysis as done in this study.

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<sup>6</sup> Please note that PV, like most other renewable energies, is part of a sort of protected market. I.e. they are installed either by private individuals willing to pay more or, more commonly, due to financial support provided by an applied energy policy. Additionally, the short-run marginal costs (comprising fuel costs and operation and maintenance costs) of PV and most other renewable energies are lower than those of thermal power plants based on fossil fuels.

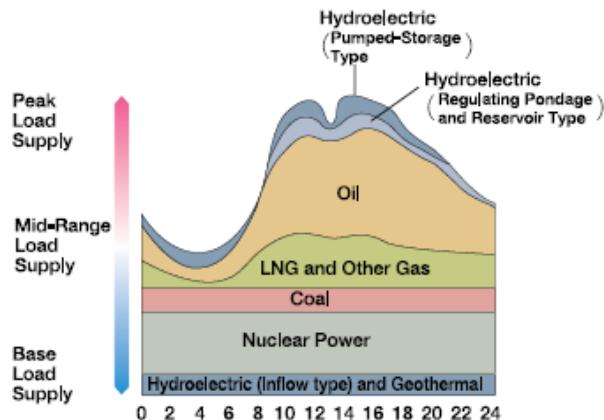
<sup>7</sup> This point will increasingly become relevant in the future as PV provides a substantially larger share of gross electricity generation. Today each country includes thermal power as a supply contribution every month - even Norway with about 99% hydro power. From today's perspective it can be concluded that "must-run capacities" (i.e. hydropower, wind, nuclear) would not be replaced in the near-term by additional PV. However, at some point of time PV generation may become bigger than thermal electricity. Then the question would appear what happens with the additional PV generation.

In most countries thermal power generation is dominated by natural gas and / or coal. As these have comparatively high fuel costs and, as far as relevant, additional expenses for CO<sub>2</sub> emissions, it could be concluded that one of these power generation options would be replaced. However, the final decision was taken country by country. A comparison of country-specific daily load profiles against PV generation profiles shows the comparatively high contribution of PV in meeting peak demands. For a detailed discussion of this topical area we refer to section 5 of this report.

In the following the detailed approach on a country level is outlined for Japan, Austria and California.

## *Japan*

It is worth mentioning that Japan, along with Germany, has become the leading PV national market worldwide, associated with their long-term PV research and development programmes as well as measures for market implementation which started in 1994. An overall picture of Japan's electricity supply is given in Figure 5 which shows a typical daily load profile and a proxy of the corresponding supply mix by energy carrier. It is evident that hydropower and nuclear cover the base load, while coal and LNG are the dominant mid-range supply options. As demand reaches the peak, power from oil and hydro (pumped-storage plant) is used to consistently maintain a stable supply of power (FEPC, 2006). It is worth emphasizing that worldwide Japan is the second largest user of oil for generating electricity, oil-based generation accounted for 133 TWh in 2004 (IEA, 2006). In the case of Japan, it can be concluded that oil-fired power plants are the marginal option and, consequently, we assume that PV would replace this fuel type.



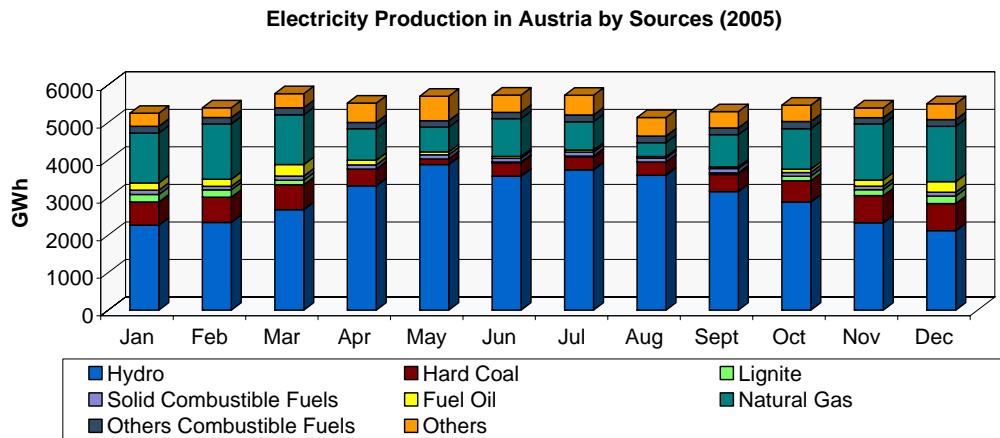
**Figure 5. Example of a Japanese daily load profile indicating the combination of power sources (based on ten major utility companies)**

Source: (FEPC, 2006)

## *Austria*

Figure 6 provides a breakdown for 2005 of Austria's monthly electricity generation by energy source. Although natural gas holds the biggest share among thermal fuels, coal (i.e. hard coal) is considered as the fuel replaced by PV. Due to the increasing relevance of the CO<sub>2</sub>

emissions trading scheme, coal with its high specific CO<sub>2</sub> emissions, represents an expensive fuel, especially as most Austrian coal fired power plants are old and have low conversion efficiency compared to other generation options.

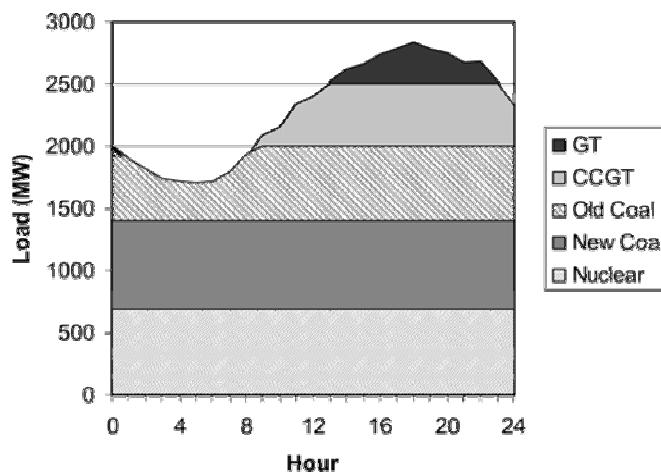


**Figure 6. Electricity production of Austria in 2005**

Source: (E-Control, 2006)

### *California*

The US is the leading consumer of coal, gas and oil for electricity generation worldwide (see e.g. IEA, 2006). The US consists of many states and conditions with regard to power supply in general and PV in particular differ from state to state. We focus in this analysis on California due to the fact that by far the most grid connected PV systems are actually installed there, and, compared to other states, the political willingness to promote PV and the financial support provided is still best in this state.



**Figure 7. Representative daily load profile for a utility in the US**

Source: (Denholm et al., 2005)

Note: GT: Gas turbines, CCGT: Combined cycle gas turbine

"California has a diverse portfolio of power supplies including hydroelectric, nuclear, geothermal, wind, biomass, and solar thermal as well as natural gas-fired power plants, however, for almost all of the hours of a year natural gas power plants are "on the margin" (Smellof, 2005) while coal and gas plants consist intermediate-load capacity. Therefore a new solar power plant would displace the use of natural gas during the time of feeding power into the grid" (Smellof, 2005).

### 3.2 Quantification of the amount of substituted fuel

In statistics, two essential methods are applied to calculate the primary energy equivalent of renewable electricity such as PV:<sup>8</sup>

#### The partial substitution method

*In this method, the primary energy equivalent of the renewable sources of electricity generation represents the amount of energy that would be necessary to generate a similar amount of electricity in conventional thermal power plants. The primary energy equivalent is calculated using an average generation efficiency of these plants. For example, assuming an average thermal efficiency of 33%, one unit of PV electricity would be equal to three units in terms of primary energy.*

#### The physical energy content method

*This method aims to be based on the physical energy content and the physical conversion efficiency to derive the primary energy equivalent. For renewables like hydro, wind or PV the efficiency has been set to one, so one unit of PV electricity would be equal to one unit in terms of primary energy.*

As can be seen, these methods generate quite different results for the treatment of electricity from renewable energies in energy balances / statistics. The physical energy content method, as commonly used in recent IEA statistics, is an unsuitable approach from the perspective of renewable energies.

Accordingly, for the calculation of the primary energy equivalent or the indicator "**avoided primary energy**", the **substitution method** was applied in this study.

For this calculation **there is a need to know the average generation efficiency of the replaced fossil fuel power plants**.

$$\text{Replaced thermal fuel in terms of primary energy (kWh)} = \\ \text{PV generation (1 kWh)}/\text{Average generation efficiency (\%)} [1]$$

Using this equation for the Austrian case, where PV would replace thermal power plants based on hard coal with approx. 39% generation efficiency, we can assume that 1 kWh PV electricity replaces 2,56 kWh hard coal in terms of primary energy. This approach means for Japan 2,63 kWh oil saved as primary fuel energy equivalents (assumed efficiency factor of oil fired power plants in Japan is 38%). Comparing the countries investigated, it is apparent that the highest specific avoidance occurs for Spain – due to the fact that the assumed average thermal conversion efficiency of the replaced thermal fuel is the lowest among all countries. On the lower end, we can find Germany, where efficient thermal plants would be replaced by PV.

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<sup>8</sup> For a brief explanation of this issue see (IEA, 2003).

Beside the choice of replaced fuel and the assumed average conversion efficiency factor data has been collected on the country-specific average solar yield. Accordingly, the amount of *yearly replaced thermal fuels by installing one peak kW PV capacity is quantified*. Obviously, this changes the whole picture for several countries: A comparison of the Netherlands and California, both characterised by equal generation-based indicators – i.e. 2,56 kWh natural gas would be replaced by 1 kWh PV electricity – shows that in the Netherlands 2 105 kWh natural gas would be saved yearly due to a one peak kW PV plant, whilst for California 3,430 kWh of natural gas would be avoided yearly – a 63% higher figure compared to the Dutch case.

**Table 2. Collected data and calculated avoided thermal fuel for various countries**

Country	Yearly average solar yield based on roof integrated PV (kWh/kW <sub>p</sub> )	Replaced Fuel (Assumed)	Generation Efficiency Factor	Avoiding of thermal fuel by 1 kWh PV (kWh)	Yearly replaced fuel by 1 kW <sub>p</sub> PV capacity (kWh)
AT	945	Hard Coal	0,39	2,56	2 423
CA	1 100	Coal	0,40	2,50	2 750
CH	950	Natural Gas	0,55	1,28	1 727
DE	950	Hard Coal & Lignite	0,43	2,33	2 209
DK	850	Hard Coal	0,41	2,44	2 073
ES	1 300	Hard Coal	0,36	2,78	3 611
FR	1 000	Hard Coal	0,40	2,50	2 500
GB	750	Hard Coal	0,42	2,41	1 807
JP	1 051	Oil	0,38	2,63	2 766
NL	821	Natural Gas	0,39	2,56	2 105
SE	850	Natural Gas	0,39	2,56	2 179
<b>US (California)</b>	<b>1 338</b>	<b>Natural Gas</b>	<b>0,39</b>	<b>2,56</b>	<b>3 430</b>

Notes:

- Data on yearly average solar yields has been provided by project partners. These figures refer to roof-based PV plants installed on suitable sites – of course, theoretical calculations based on country-specific average solar insolation data would be lower.
- For Canada, it is assumed that PV would replace coal generated electricity. Although thermal fuels vary significantly from region to region and include natural gas, refined petroleum products, biomass and coal, coal was chosen since it the most dominant fuel for thermal electricity generation. Specific regional analysis could be carried out to address specific regional concerns.
- For Sweden it is assumed that PV would replace electricity imports from Denmark, representing the marginal option in the Nordic market. Accordingly, fuel avoidance (natural gas) and conversion efficiency refer to the Danish circumstances.
- For Switzerland it is assumed that PV would replace natural gas which powers the combined cycle plants with an average efficiency factor of 55%.

Table 2 summarises the selected country information regarding the choice of replaced fuel, the average conversion efficiency (of the corresponding thermal power plants) as well as

applied solar yield factors and derived indicators on fuel avoidance (generation and capacity based). It is notable that the thermal conversion efficiency factors differ by country due to differing fuel-dependent technologies or average plant ages. In general, these data refer to the country-specific average based on a suitable mixture of old and new power plants.

## 4 ENVIRONMENTAL BENEFITS

The great importance of renewable energies is due to their considerable associated environmental benefits, namely:

- reduction of greenhouse gas emissions;
- the potential to greatly reduce, and perhaps eventually eliminate, pollution associated with electricity services;
- a significant contribution towards *sustainability*.

Let us focus on the latter point more closely – i.e. what do we mean by *sustainability*?

In relation to energy systems, i.e. the exploitation of primary energy resources for energy utilization, sustainability is commonly quoted as the ability of the particular production system to sustain the production level over long times, i.e. for continuing future generations. This implies that the sustainable system will not cause significant ecological damage.

Accordingly, environmental benefits are also societal benefits – i.e. it is not the single PV producer or any other actor in the supply chain that may take these benefits on his account, it is the whole society. But societal benefits may involve more than these environmental bonuses as we will see in the following sections.

In the following, we discuss the environmental benefits for PV as one of the key representatives of renewable energy technologies in a detailed manner, based on the country specific situation derived quantified indicators suitable for identified groups of countries. Thereby, from a methodological viewpoint the analysis of avoided primary energy (see section 3) represents the starting point for the quantification of other aspects such as avoided emissions.

### 4.1 Emission Reduction

The contribution of renewable energy sources in reducing greenhouse gas emissions and air pollutants is well known. In the following, we present a method to quantify the reduced emissions for PV. Thereby, we aim to provide a net balance by subtracting the life-cycle emissions associated with the production of PV cells from the calculated avoided direct & life-cycle emissions. We exemplify this derivation for the most prominent representatives in environmental concerns: Greenhouse gas (GHG) emissions in terms of carbon dioxide equivalent ( $\text{CO}_2\text{e}$ ), and sulphur ( $\text{SO}_2$ ) as well as nitrogen oxides ( $\text{NO}_x$ ) as major air pollutants occurring during thermal combustion.

#### 4.1.1 Avoided emissions – a gross balance

This approach directly builds on the avoided primary energy as discussed in the previous section of this report. *In other words: If electricity generated from PV plant replaces thermal power, the emissions "caused by fossil fuels" are avoided as well.*

For the quantification of the *net* reduced emissions there is a need to know country specific data on emissions factors for the replaced fossil fuels as well as for PV which occur during manufacturing of the solar cells.

Table 3 below summarises the country specific life-cycle emissions factors (except for Japan where  $\text{NO}_x$  and  $\text{SO}_2$  refer solely to direct combustion) with respect to the replaced fossil fuels. Data is expressed in end use energy basis – i.e. per kWh electricity. These data differ from

country to country according to differing average conversion efficiencies (of the corresponding thermal power plants) and the country-specific typically applied additional equipment for reducing air pollutants as well as differences within the upstream processes. The application of solely these factors in order to calculate avoided emissions for PV electricity would deliver a gross balance as it does not take into account emissions resulting from manufacturing of PV.

**Table 3. Summary of collected data on emissions factors for replaced fossil fuels**

Country	Replaced Fuel (Assumed)	Emissions Factors of Replaced Fuel (g/kWh)		
		CO <sub>2</sub> -eq	NO <sub>x</sub>	SO <sub>2</sub>
AT	Hard Coal	949	0,85	0,82
CA	Coal	1 004	1,26	5,20
CH	Natural gas	429	1,37	0,01
DE	Hard coal & Lignite	1 094	0,64	0,53
DK	Hard coal	949	0,85	0,82
ES	Hard coal	960	3,81	7,00
FR	Hard coal	949	0,85	0,82
GB	Hard coal	1 115	3,49	1,09
JP	Oil	742	0,30	0,20
NL	Natural Gas	411	1,50	0,01
SE	Natural gas	429	1,37	0,01
<b>US (California)</b>	Natural gas	499	0,57	0,32

Data sources on Emissions Factors of Assumed Fuel: <sup>9</sup>

For DE, ES, GB and NL: country specific life-cycle emissions data from (Fritzsche et al., 2006)

AT, DK, FR: an average Life-cycle emissions data of imported hard coal to the European Union (Fritzsche et al., 2006)

CH, SE<sup>10</sup>: an average value of countries DE, ES, NL, GB life-cycle emissions for natural gas

CA<sup>11</sup>: Data for CO<sub>2</sub>-e (NIR, 2006) refer to the whole power sector, comprising utilities and industrial auto-producers for the year 2004. SO<sub>2</sub> and NO<sub>x</sub> (OPG, 2005) are based on fuel combustion for 2004, representing the average specific emissions of 5 major coal power stations in Ontario.

JP: Life cycle analysis on CO<sub>2</sub>-e (Hondo et al., 2000) and

\*SO<sub>2</sub> and NO<sub>x</sub> emissions factors for Japan are based on fuel-combustion for Japanese fiscal year (FY) 2004 (FEPC, En. & Env, 2006)

US (California): (NREL, 2000): All emissions factors are life cycle

<sup>9</sup> In some cases, besides a lack of data, an inconsistency was observed - especially regarding emissions factors (i.e. if emissions indicate the life-cycle analysis (LCA), if expressed greenhouse gas emissions comprise CO<sub>2</sub>-e or solely CO<sub>2</sub>, if data refer to end or primary energy, etc.). In the case of Europe the most harmonised data were implied by (Fritzsche et al., 2006). Consequently, data for all European countries has been based on this study – referring to the year 2000. This LCA is based on GEMIS, developed by Öko-Institut – for details see (Öko, 2006).

<sup>10</sup> In Sweden natural gas would be replaced which is produced in Denmark.

<sup>11</sup> Emissions Factors from the Province of Ontario are used as proxy for Canada.

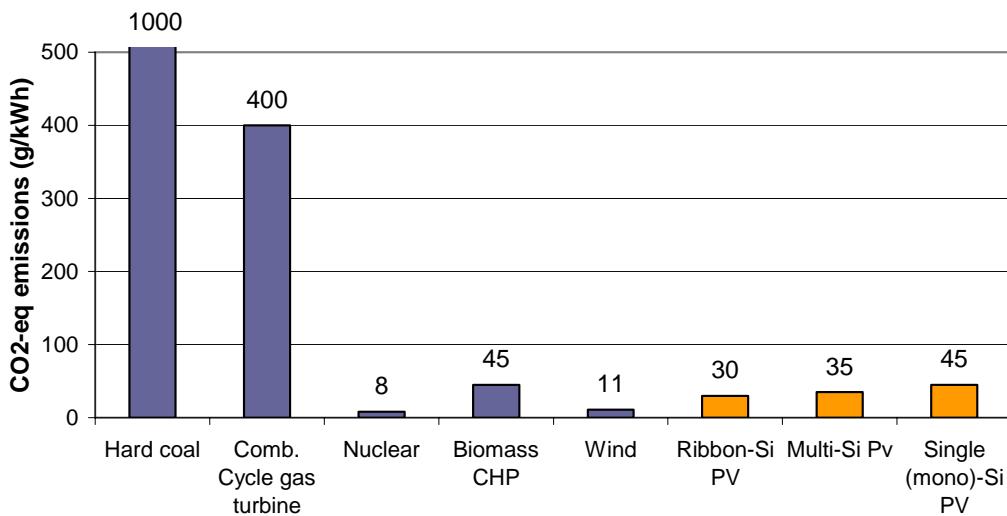
#### 4.1.2 Energy Pay Back Time and LCA emissions of PV systems

In addition to the avoided emissions as discussed above it is important to consider the life cycle emissions factors of PV in order to derive a net balance. These emissions refer to the manufacturing of the PV systems. This analysis requires a comparison of used energy for PV manufacturing compared to the energy generated during the system lifetime namely "Energy Pay Back Time (EPBT)".

According to (T10- 01: 2006), EPBT is defined as the ratio of the total energy input during the system life cycle compared to the yearly energy generation during system operation and is expressed in years.

The EPBT and related greenhouse gas emissions of PV systems are investigated in Alsema et al. (2006) based on the current status of production technology for crystalline silicon modules. The results of this paper indicate that for a roof top integrated PV system with a performance ratio of 0,75 values for EPBT based on three silicon technologies are in the range of 1,7-2,7 years for Southern European countries (irradiation  $1\ 700\ \text{kWh}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ), while in Central Europe EPBTs of 2,8 to 4,6 years occur (referring to a reference irradiation of  $1\ 000\ \text{kWh}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ).

More recent studies indicate that EPBT and related greenhouse gas emissions are declining due to technological progress – see e.g. Alsema et al., (Sep.-2006). EPBT for roof and façade integrated PV systems and the potential for GHG mitigation by using PV systems are given in T10- 01 (2006) for some selected OECD cities.



**Figure 8. Greenhouse gas emissions of PV systems based on three silicon technologies, compared to a number of other energy technologies.**

Source: (Alsema et al., 2006)<sup>12</sup>

<sup>12</sup> Data derived for Coal, Comb. Cycle gas, nuclear, biomass and wind from EcoInvent database (version 1.2. see <http://www.ecoinvent.ch/>). Note that the expressed GHG emissions of 8 g/kWh for nuclear power is "best case" comparison to other studies – e.g. a recent study conducted by (Fthenakis et al., 2006) indicates for the US an average value of 25 g/kWh.

Figure 8 shows a comparison of three PV systems (based on silicon technologies) to other selected energy technologies. The PV systems are installed on a roof top in Southern Europe with irradiation of  $1\ 700\ \text{kWh}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$  and have a 30 year life time.

As data on emissions associated with manufacturing is not consistently available for every country possessing a PV industry, it was decided to define a reference system. Based on this, country-specific emissions can be calculated according to the geographical circumstances where the PV plant would actually be installed. In the following, we illustrate this approach – based on LCA performed in the Crystal-Clear (Alsema et al., 2006) and (de Wild Scholten et al., 2005). The emissions data for a reference PV system has been conducted in collaboration with 11 PV manufacturing companies from Europe and the USA.

1. First, the life-cycle emissions for the reference system were derived. In particular, Table 4 indicates the life-cycle emissions factors for both single-crystalline (sc-Si) and multi-crystalline silicon PV-systems (mc-Si) for the reference plant – i.e. a rooftop PV application located in Southern Europe, consisting of frameless modules, with a performance ratio (PR) of 0,75 and a plant life time of 30 years.

**Table 4. LCA emissions factors of solar systems for the defined reference system  
(Performance Ratio =0,75 and Plant life time=30 years)**

Yearly Solar Irradiation	sc-Si			mc-Si		
	CO <sub>2</sub> -eq	NO <sub>x</sub>	SO <sub>2</sub>	CO <sub>2</sub> -eq	NO <sub>x</sub>	SO <sub>2</sub>
kWh/m <sup>2</sup>	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
1 700	45	0,08	0,13	35	0,07	0,10

2. In the next step, the reference emissions had to be transferred to the country-specific circumstances, which is briefly explained below:

Multiplying the performance ratio (0,75) with the yearly solar irradiation ( $1\ 700\ \text{kWh}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ) we receive an electricity generation potential of our reference system of 1 275 kWh/kW<sub>p</sub> yearly. Accordingly, within the 30 year life time a total amount of 38,25 MWh would be generated.

The total greenhouse gas emissions as CO<sub>2</sub>-e occurring during manufacturing are 1 721 kg if single-crystalline silicon cells are used, simply derived by multiplying total electricity generation with the specific emission factor. Consequently, data on actual country specific solar yield (provided by partners) allows us to estimate how much electricity could be generated with such a reference system during its life time in other locations and how much would be the corresponding emission factors in g/kWh.

In other words, if this system was installed in Germany (with a yearly average solar yield of 950 kWh/kW<sub>p</sub>) 28 500 MWh would be generated in 30 years and the corresponding emission factor for CO<sub>2</sub>-e is 60 g/kWh in case of a sc-Si.

Summing up, the following equation occurs for deriving country-specific emission factors from the reference system:

$$\text{Country\_emission\_factor} = \text{reference\_emission\_factor} \times \frac{\text{reference\_solar\_yield}}{\text{country\_solar\_yield}} \quad [2]$$

Finally, Table 5 lists the derived emissions factors of PV electricity for several countries, expressing life cycle emissions per kWh generated PV electricity for commonly used PV systems based on country specific average solar irradiation data.

**Table 5. Derived country specific LCA emission factors of PV- systems**

Country	Yearly Solar yield kWh/kW <sub>p</sub>	sc-Si			mc-Si		
		CO <sub>2</sub> -eq g/kWh	NO <sub>x</sub> g/kWh	SO <sub>2</sub> g/kWh	CO <sub>2</sub> g/kWh	NO <sub>x</sub> g/kWh	SO <sub>2</sub> g/kWh
AT	945	61	0,11	0,18	47	0,09	0,13
CA	1 100	52	0,09	0,15	41	0,08	0,11
CH	950	60	0,11	0,18	47	0,09	0,13
DE	950	60	0,11	0,18	47	0,09	0,13
DK	850	68	0,12	0,20	53	0,10	0,14
ES	1 300	44	0,08	0,13	34	0,06	0,09
FR	1 000	57	0,10	0,17	45	0,08	0,12
GB	750	77	0,14	0,22	60	0,11	0,16
JP	1 051	55	0,10	0,16	42	0,08	0,12
NL	821	70	0,12	0,21	54	0,10	0,15
SE	850	68	0,12	0,20	53	0,10	0,14
<b>US (California)</b>	<b>1 338</b>	<b>43</b>	<b>0,08</b>	<b>0,13</b>	<b>33</b>	<b>0,06</b>	<b>0,09</b>

Please keep in mind that we have to see this approach in a global context as the PV systems are not always installed where they are produced (or where all components are manufactured). They cause emissions where the components are produced but they avoid the fossil fuels and the corresponding emissions where they are installed.

Finally, Table 5 lists the derived emissions factors of PV electricity for several countries, expressing life cycle emissions per kWh generated PV electricity for commonly used PV systems based on country specific average solar irradiation data.

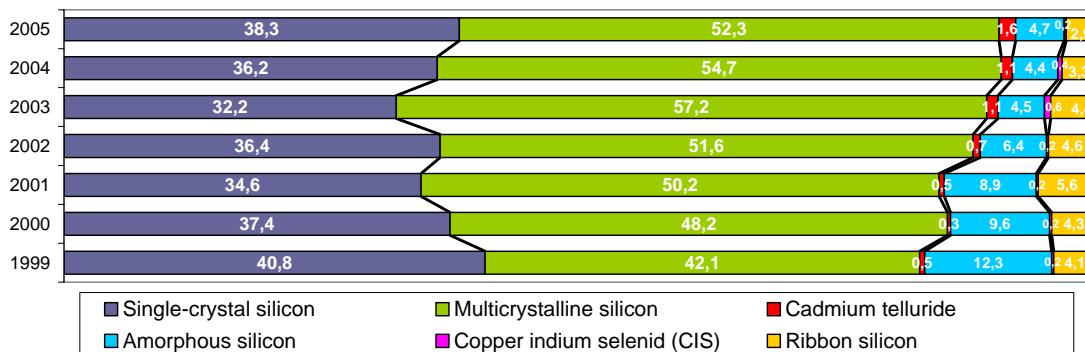
Table 5 indicates that different PV systems cause different amounts of emissions. Consequently, there is also a need to estimate the classification of the used cells in a country.

It is important to have a closer look on the country-specific PV market. The research aimed to determine, by country, the technology-specific shares for installed PV systems. In principle, this information could be derived for the following countries in detail, Austria, Japan, Sweden and United Kingdom. However, as only a small proportion of all reported countries was covered, it was decided to take the global market and use it as a proxy for applied cell types. In particular, the classification of world cell production as expressed in Figure 9 has been used.

From today's point of view most PV cells and modules sold are crystalline silicon. Therefore, for the quantification of life-cycle emissions as derived above, we focussed solely on crystalline silicon.

As illustrated in Figure 9 from 1999 to 2005 on average 37% of globally produced solar cells were single crystal and 51% multi crystalline, whilst 12% of produced cells belong to others categories. Of course the used cell technologies differ from country to country and year to

year. As country-specific data on installed cell types are difficult to derive, as a general approach for each country the historic data on global level was used. Consequently, in the case of other used cells equivalent shares of multi crystalline and single crystalline were assumed for the follow-up calculation of life-cycle emissions of PV cells and, finally, net factors for emission avoidance. More precisely, for this calculation 12% equally shared to single and multi crystalline. Accordingly, the resulting final classification is 43% single and 57% multi crystalline.



**Figure 9. Breakdown of produced PV cells by technology on global scale for the period 1999 to 2005**

Source: (Photon, 4/2006)

#### 4.1.3 Avoided emissions – a net balance

**Table 6. Country specific net reduced emissions factors based on fuel and used solar cells in g/kWh**

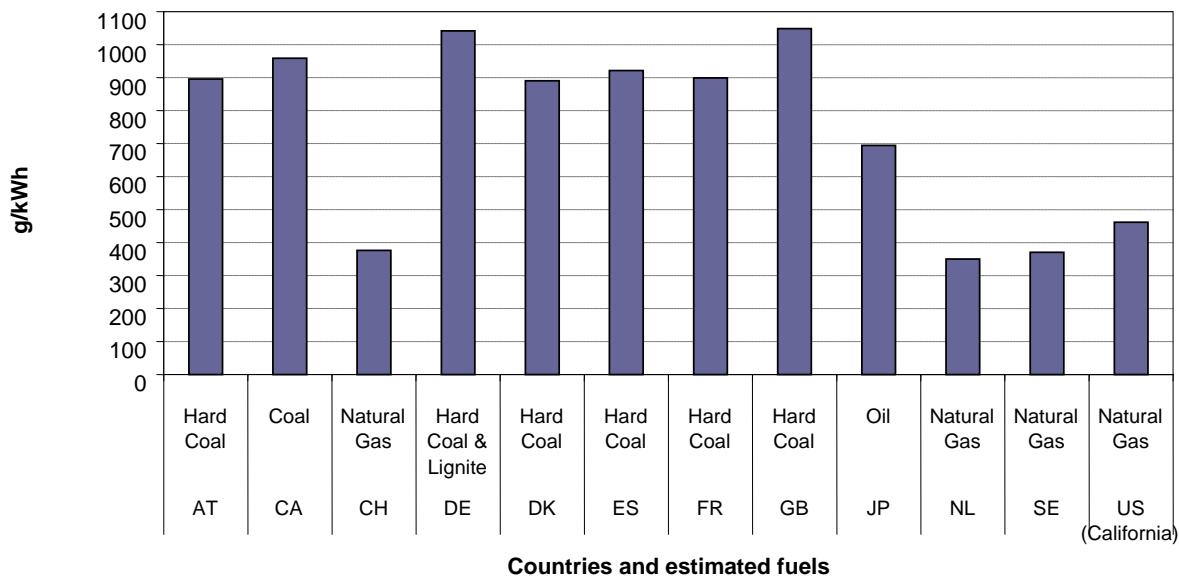
Net reduced emissions factors based on replaced fuel and used solar cells (g/kWh)				
Country	Replaced fuel	CO <sub>2</sub> -e	NO <sub>x</sub>	SO <sub>2</sub>
AT	Hard Coal	896	0,75	0,67
CA	Coal	959	1,18	5,07
CH	Natural Gas	377	1,27	-0,14
DE	Hard Coal & Lignite	1 042	0,55	0,38
DK	Hard Coal	890	0,74	0,65
ES	Hard Coal	921	3,74	6,89
FR	Hard Coal	899	0,76	0,68
GB	Hard Coal	1 048	3,37	0,90
JP	Oil	694	0,21	0,07
NL	Natural Gas	350	1,39	-0,16
SE	Natural Gas	370	1,26	-0,16
US (California)	Natural Gas	462	0,50	0,22

Note: In some countries with comparatively low sulphur emissions associated with the replaced fossil fuel a negative figure occurs with regard to net avoided sulphur emissions. This means that emissions referring to the manufacturing of PV cells (in the

country where manufactured) are higher than the avoided (in the country where the plant is installed) <sup>13</sup>. If we assume that the PV system is manufactured in Europe and, furthermore, that it replaces in a European country natural gas, higher SO<sub>2</sub> occur in the net balancing. In contrast, for the USA this is not the case: According to NREL (2000) natural gas upstream NO<sub>x</sub> and SO<sub>2</sub> emissions are much larger than those from the power plant. Consequently, a positive effect can be observed – i.e. PV electricity actually contributes to reduce SO<sub>2</sub> emissions.

Table 6 depicts the derived net emissions factors by country – i.e. indicating the reduction of CO<sub>2</sub>-e, SO<sub>2</sub>, and NO<sub>x</sub> emissions for each kWh PV electricity. The figures are derived by subtracting from gross avoided emissions (due to the substitution of fossil fuels) the life-cycle emissions of the PV generation. <sup>14</sup> Obviously, these indicators on specific emission reductions can be applied to calculate (yearly) total avoided emissions etc. as well.

For example, 1 kWh of electricity generated in a PV plant in the United Kingdom (GB) reduces approx. 1 048 g CO<sub>2</sub>-eq, 3,37 g NO<sub>x</sub> and 0,90 g SO<sub>2</sub>.



**Figure 10. Net reduced life cycle CO<sub>2</sub>-eq emissions by 1 kWh generated PV electricity based on country specific data and estimated fossil fuel replacing**

<sup>13</sup> We should keep in mind that the negative environmental impacts of PV manufacturing –due to the fossil energy used in the production of cell and module materials- can change if the used energy is also provided by PV electricity or other renewable energies. Some PV manufacturers have already their own building integrated PV systems in order to cause fewer environmental impacts.

<sup>14</sup> As mentioned above, in this study solely crystalline silicon cells have been considered as these cells dominate the market at present. Conducting a similar assessment also for thin film solar cells would alter the outcomes in terms of net emission avoidance: These types of solar cells are characterised by significantly lower life-cycle emissions, and, consequently, also net avoidance of GHG and air pollutant emissions would increase.

It is worth to mention that thin film technologies (a-Si, CIS, and CdTe) increased their share on global production from about 6.3% in 2005 to approx. 7.5 % in 2006 (Photon, 4/2007). Moreover, they comprise at present about 50% of the US production.

Figure 10 provides a graphical illustration of reduced CO<sub>2</sub>-eq emissions data as listed in Table 6. It can be seen that 1 kWh PV can reduce CO<sub>2</sub>-e emissions the most in the United Kingdom (GB) and Germany (DE). This shows that PV represents an important option for GHG reductions even in countries where the solar yields are comparatively low - see results for United Kingdom or Germany.

## 4.2 Water Saving

Thermal power plants evaporate water during cooling which has environmental impacts. "If cooling water is recycled through cooling towers or cooling ponds, water consumption is high. Conversely, if the water is used once from a nearby river then returned to the flow, the evaporation at the site is low, but the added heat to the stream increases the evaporation rate of the river, thus increasing the overall evaporation" (Torcellini, 2003).

"How much the water evaporation of power plants disrupts the natural water balance depends on the climate of the region and the source of the cooling water." (von Uexküll, 2004). It is out of the scope of this study to determine by region the environmental impacts. In contrast, we simply aim to illustrate an approach to estimate the added value offered by PV with regard to water saving.

**Table 7. Consumptive water use for electricity production**

Source: (Gleick, 1994)

Energy technology Consumptive use (m<sup>3</sup> per MWh<sub>el</sub>)

<b>Conventional coal combustion</b>	
Once-through cooling	1,2
Cooling towers	2,6
<b>Oil and natural gas combustion</b>	
Once-through cooling	1,1
Cooling towers	2,6
<b>Nuclear generation (LWR)</b>	
Cooling towers	3,2
<b>Renewable energy systems</b>	
Photovoltaics: residential	-a
Photovoltaics: central utility	0,1b
Solar thermal: Luz system	4,0
Wind power	-a

Abbreviations:

a = Negligible.

b = Maximum water use for array washing and potable water needs.

The determination of this value on a country level requires information on the water flow used for cooling in thermal power plants. Consequently, it was not feasible to derive such heavily country specific data within the framework of this project. Furthermore, as there is also a lack of information about "which kind of water is used" we exemplify this added value by discussing a case study as conducted for California.

Torcellini et al., (2003) provides data on water consumption for thermal power plants in California. A specific figure of 0,05 gallons per kWh of electricity produced was derived (equivalent to 0,19m<sup>3</sup>/MWh). This figure represents the added value offered by PV with regard to water saving in specific terms – i.e. by unit of PV electricity generation.

Finally we aim to illustrate the importance of such an indicator on water saving: Table 7, based on Gleick (1994) indicates a general view on the consumptive water use for electricity production.

### 4.3 Avoided external costs

Emissions caused by energy generation damage a wide range of receptors, including human health, natural ecosystems and the built environment. These are external effects of energy supply. These external effects cause costs to society as they are typically not paid by the polluter itself. (Re-Xpansion, 2005) If the polluter does pay adequately for the damage caused, then this is referred to as the "internalisation of external costs" which has been exemplified in section 5.3.

External costs are a widely discussed topic with regard to energy supply. In this study we base our references, to a large extent, on the outcomes of a recently conducted evaluation of several external costs studies, namely "Externe Kosten der Stromerzeugung aus erneuerbaren Energien im Vergleich zur Stromerzeugung aus fossilen Energieträgern" (in German) (Krewitt et al., 2006).

In this study, the following major analysis have been evaluated comprehensively:

- ExternE
- NewExt 2004
- Downing et al., 2005
- Nakicenovic, N., Riahi, K., 2003

Table 8 lists the final outcomes of this evaluation with regard to a monetary valuation of loss expenses (in EUR/t CO<sub>2</sub>) due to the emission of green house gases.

**Table 8. Recommended valuations for the loss expenses of green house gas emission**

Recommended valuations for the loss expenses of the climate change (EUR/t CO <sub>2</sub> )		
Low valuation	Median valuation	High valuation
15	70	280

Besides greenhouse gas emissions, in accordance with the elaborations on emission avoidance (see section 4.1), also most prominent air pollutants (SO<sub>2</sub>, NO<sub>x</sub>) were considered in the following as expressed in Table 9. More precisely, with regard to these air pollutants, the following studies serve as key reference material:

- ExternE 1999 and
- EcoSenseLE, 2006

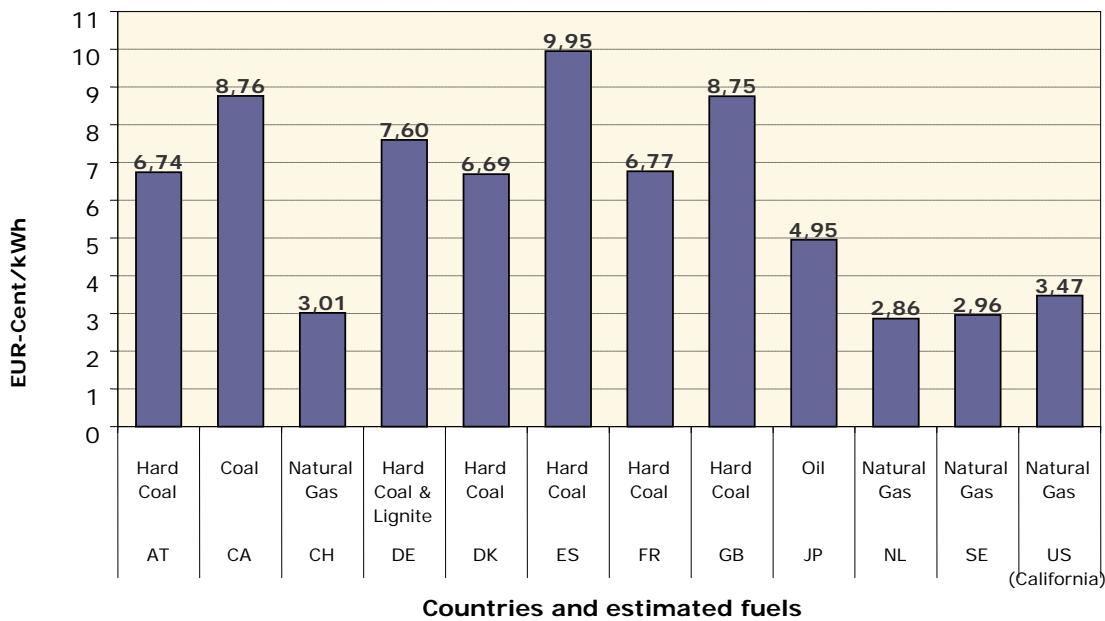
**Table 9. Summary of applied indicators on external cost**

Quantifiable Loss expenses of several air pollutants and greenhouse gas emissions (EUR/t)			
	CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>
Climate Change	70		
Health Damage		3 060	3 120
Crop losses		-10	130
Material Damage		230	70
<b>Total</b>	<b>70</b>	<b>3 280</b>	<b>3 320</b>

Table 10 lists the derived indicators with respect to avoided external costs due to PV electricity. As can be seen, loss expenses have been estimated for all reported countries, but it is important to bear in mind that the reference study used was prepared for EU 25 countries but in our report it also applied to Japan and California. The total potential, with regard to reducing external costs by PV electricity, is calculated for the recommended median value of 70 EUR/t CO<sub>2</sub> with regard to CO<sub>2</sub>-e. Therefore, we can assume that where PV replaces coal, the external cost reduction is higher than when natural gas is replaced.

**Table 10. Summary of avoided External costs by PV electricity**

Country	Avoided External Costs by PV (EUR-Cent/kWh)					
	CO <sub>2</sub> -e (low valuation)	CO <sub>2</sub> -e (median - recommended -valuation)	CO <sub>2</sub> -e (High Valuation)	NO <sub>x</sub>	SO <sub>2</sub>	Total (with median CO <sub>2</sub> -e valuation)
AT	1,34	6,27	25,09	0,25	0,22	<b>6,74</b>
CA	1,44	6,71	26,84	0,39	1,66	<b>8,76</b>
CH	0,56	2,64	10,55	0,42	-0,05	<b>3,01</b>
DE	1,56	7,29	29,17	0,18	0,12	<b>7,60</b>
DK	1,34	6,23	24,92	0,25	0,21	<b>6,69</b>
ES	1,38	6,45	25,80	1,24	2,26	<b>9,95</b>
FR	1,35	6,29	25,17	0,25	0,22	<b>6,77</b>
GB	1,57	7,34	29,36	1,12	0,29	<b>8,75</b>
JP	1,04	4,86	19,44	0,07	0,02	<b>4,95</b>
NL	0,53	2,45	9,80	0,46	-0,05	<b>2,86</b>
SE	0,56	2,59	10,37	0,42	-0,05	<b>2,96</b>
<b>US (California)</b>	<b>0,69</b>	<b>3,23</b>	<b>12,93</b>	<b>0,17</b>	<b>0,07</b>	<b>3,47</b>



**Figure 11. Total avoided external costs with median CO<sub>2</sub> valuation**

Figure 11 gives a country comparison regarding possible avoidable external costs based on country specific results derived from Table 10. Spain shows the highest value due to a high NO<sub>x</sub> and SO<sub>2</sub> reduction potential for PV electricity – assuming that hard coal is replaced.

## 5 UTILITY BENEFITS

The value of PV to utilities depends largely on country-specific supply and climate conditions. The influencing factors can be classified as follows.

- The relevance of PV to meeting peak demand
- The market value of PV compared to spot market prices
- The relevance of PV for reducing the environmental cost burden – CO<sub>2</sub> certificate prices applied within the European Union's Emission trading scheme.

A utility may also have an interest in:

- The relevance of PV to reducing transmission and distribution costs and losses
- Reduction of fossil fuel price risk
- Availability of outage protection.

These values could also be important for investment decisions in PV, but they have not been quantified in this report as they are beyond its scope.

### 5.1 The relevance of PV to meeting peak demand

The relevance of PV to meeting peak demand depends on the correlation between daily and seasonal load characteristics and peak solar generation. Therefore, it must be investigated if PV really can contribute to peak demand, and to what extent. Can PV reduce Peak Capacity for each country or each region?

#### 5.1.1 Potential of PV to reduce peak demand

This issue is related to the so-called "**capacity credit**" that can be given by PV generation, i.e. what capacity reduction can be made in the conventional power plant mix by the addition of PV capacity or, in other words, to what extent can PV provide power when a utility needs it.

In order to determine the amount of capacity credit, it is necessary to determine what part of the peak demand can be met by an appropriate value of solar energy. According to studies in the US, this value will depend on the time of system peak demand, as well as the orientation of the solar electric system and is called "Effective Load Carrying Capability" (ELCC) (Smellof, 2005).

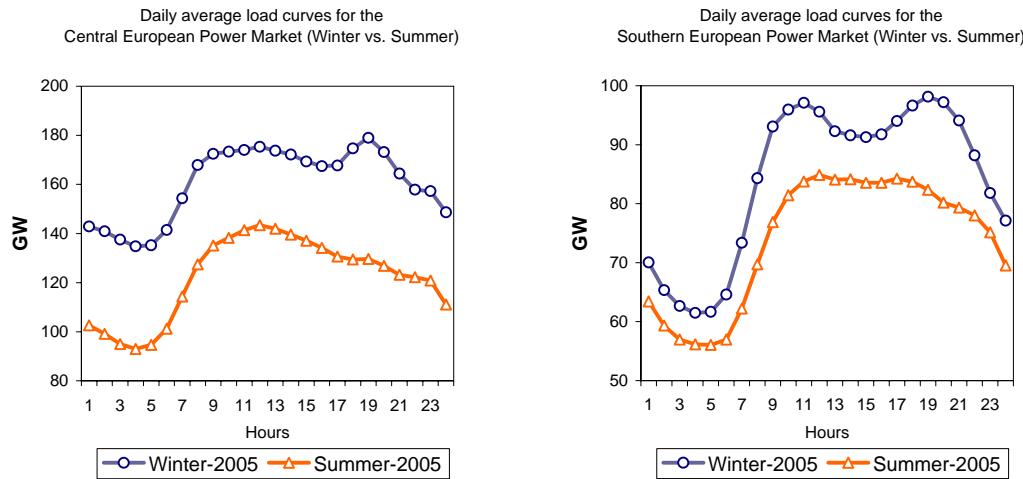
*"In general, ELCC is the ability of a power system to effectively contribute to a utility's capacity, or system output, to meet its load. In determining PV's value to a utility, the magnitude of the sun's intensity is less important than its relationship to load requirements. A typical example of high ELCC for PV occurs when the utility system load reflects commercial customers' demand for midday air-conditioning; this load is a good match to PV's power output. The PV ELCC is lower for residential customers who have a high air-conditioning demand in the late afternoon; the load is not matched as well to the intensity of the solar resource." (US DOE, 1996)*

*"Studies in the U.S. have shown that the correlation between summer to winter peak load and effective load carrying capacity is higher than that between average irradiance levels and ELCC [US DoE, 1996]. The ELCC can exceed 80 % of PV rated output when the ratio of summer to winter peak load is greater than 1.5 (US DOE, 1996). Hence, a 1 kW<sub>p</sub> PV system*

could be considered to have a dispatchable rating of 800 W<sub>p</sub>. Using this approach, the US DoE has published a map showing the different PV ELCC across the US [ibid]. This map allows planners to target areas where PV would have a high value. These areas are not necessarily those with high solar radiation levels" (Watt, 2001).

As indicated above, the ability of PV to meet peak demand differs by location and, at first glance, it can be suggested that it is more substantial for summer peak countries than for countries that have their highest peak loads during winter. Hence, in the following, the research explores if the reported countries are summer or winter peak countries, based on the identification of their typical yearly "bottleneck time".

Figure 12 and Figure 13 depict the average load curve of central (AT+ CH+ DE+ FR (left)) and southern (ES+ IT+ PR (right)) European countries for winter months (December to February) and summer months (June to August) in 2005. Both cases indicate that the "bottleneck time" is in the winter evenings – a time when there is no PV electricity available. Based on their country-specific load curves all European countries - even southern European - can be characterised as "winter peak" countries and the electricity supply security is typically focussing on winter peak demands. However, in Southern Europe there is also an increased demand observable for summer months (as Spanish data for July 2005 indicate; see Annex A –Load Curves) – due to air conditioning and the influence of tourism.



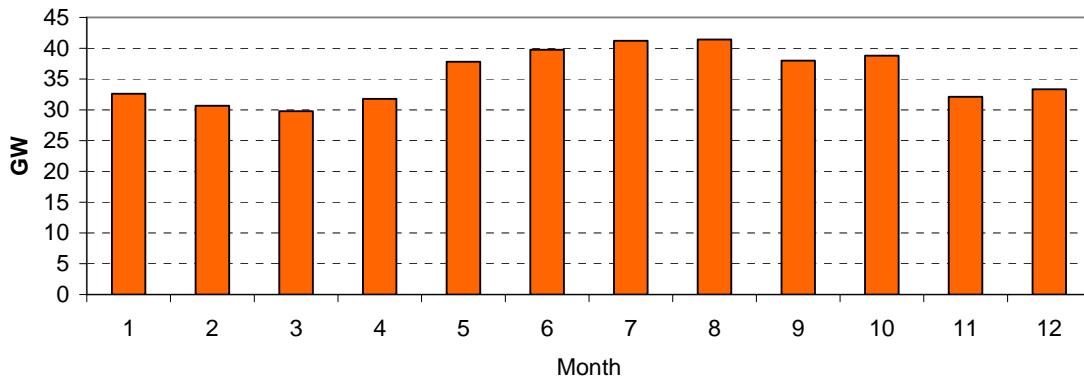
Source: UCTE, Union for the Co-ordination of Transmission of Electricity,  
<http://www.ucte.org>

**Figure 12. Daily average load curves for the central European Power market (AT+CH+DE+FR)**

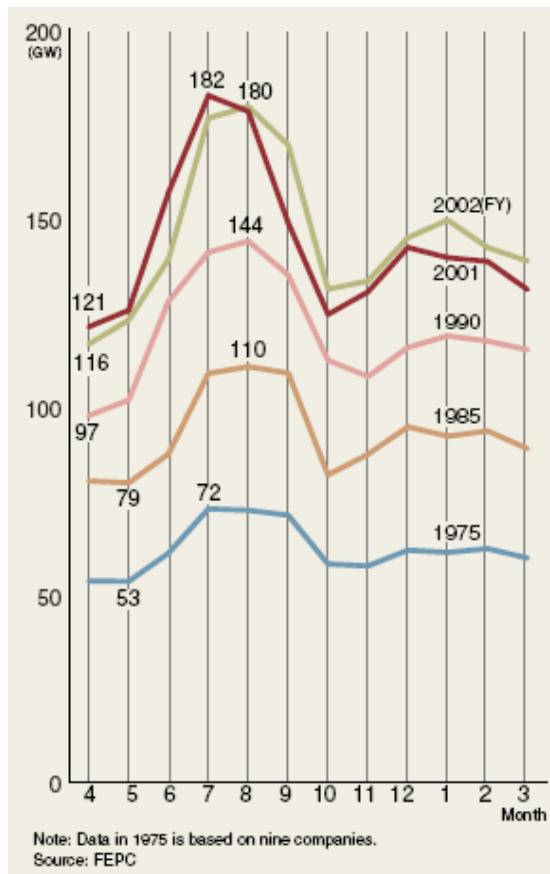
**Figure 13. Daily average load curves for the southern European Power market (ES+IT+PR)**

In California and Japan, in contrast to Europe, "bottleneck time" is typically in the summer (see Figure 14 and Figure 15).

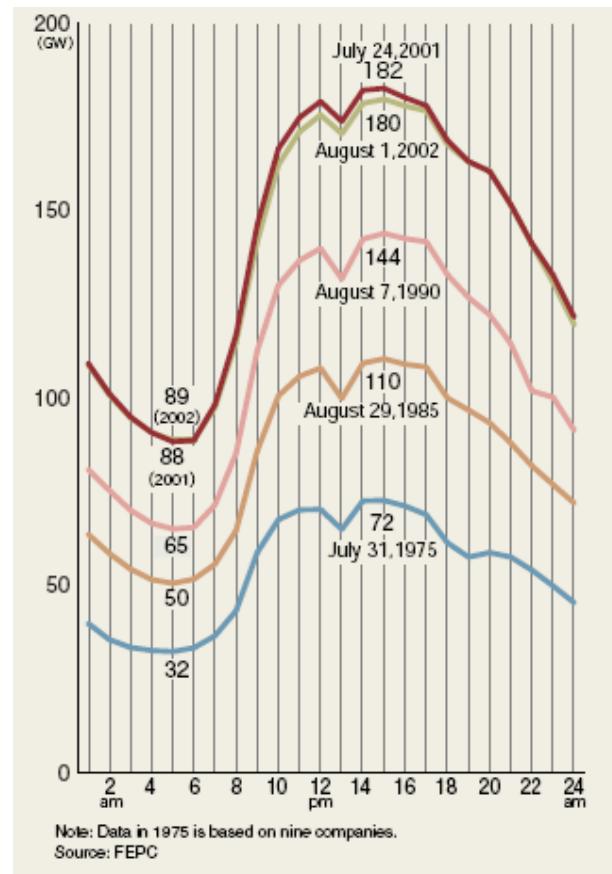
Monthly Peak Electricity Demand in California - 2001

**Figure 14. Monthly peak electricity demand in California in 2002**

Source: (Brown, 2002).

**Figure 15. Annual electric use for ten Japanese utility companies**

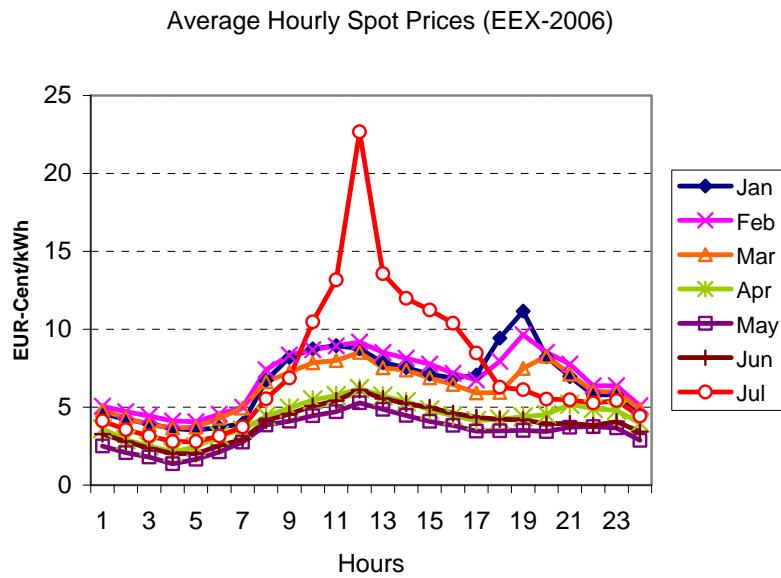
Source: (FEPC, 2004)

**Figure 16. Example of Japanese daily load-curve in summer.**

Source: (FEPC, 2004)

Despite that for "winter peak" countries the capacity credit of PV is not high during this time of year, the recent hot and dry summer experiences in Europe have clearly shown that ***there is a need to reduce peak electricity demand in the summer*** from a utility's point of view. This is influenced by the fact that many thermal power plants are maintained during the summer months or have to reduce their generation due to a lack of cooling water as needed for thermal (incl. nuclear) power generation.

In general, demand is rising during the summer season with increasing numbers of air conditioners installed. According to a local utility in Austria, Energie AG, recent experiences in Austria have shown that demand rises by 5% during extreme hot days. From 25<sup>th</sup> to 27<sup>th</sup> of July 2006, all days with temperatures above 32° Celsius, the daily energy consumption was on average 5-8% higher than the previous year when the temperature was around 25° Celsius. The peak demand hours during summer typically occurred around midday and in the afternoon – a trend which is even more relevant for southern European countries (see Figure 13). In order to meet this high demand, a shut down thermal power plant had to be put in operation again. This caused environmental impacts and also a monetary burden for this utility – including additional costs for fuel and CO<sub>2</sub> emission allowances (see section 5.3)<sup>15</sup>.



**Figure 17. Average hourly spot prices in EEX (Germany's energy exchange) from January until July 2006**

Source: EEX- European Energy Exchange (<http://www.eex.de>)

Figure 17 shows that the spot market prices were very high in July 2006 at German's energy exchange EEX which indicates a lack of supply from utilities point of view. *"During the extreme heat wave in July 2006, peak prices paid at the European Electricity Exchange spot market exceed the feed in tariff paid in Germany"* (Jäger Waldau, 2006).

In conclusion, recent incidences have shown that the contribution of PV to reducing peak demand during the summer will become increasingly important for all European countries. In

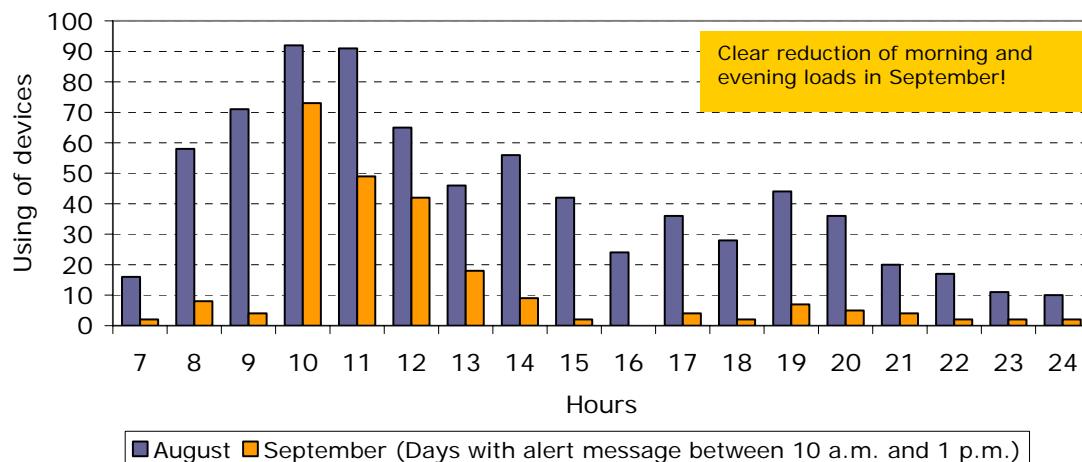
<sup>15</sup> For further details on this illustrated incident we refer to (Energie AG, 2006).

summer, Photovoltaic electricity is generally produced during times of peak demand when electricity is most expensive.

Deriving a country-based capacity credit value for PV requires a detailed timely analysis matching PV output to utility's peak demand at the local level. This comprehensive analysis is beyond the scope of this report.

### 5.1.2 Load Management

With an intelligent load management utilities can control their loads. A local project example from Germany, namely "Waschen mit der Sonne"<sup>16</sup> (roughly translated as "washing laundry based on solar energy"), shows how PV production with its natural volatility can be used more efficiently. Local customers who were willing to contribute to this case received an alert message by cell phone at times when a substantial amount of solar energy was produced (typically between 10 a.m. and 1 p.m.). Anyone who responded to this call to smooth out peaks in power demand was rewarded with a small financial incentive (i.e. about 50 EUR-Cent per respond) (Fraunhofer, 2006). Consequently, as a broad set of consumers followed the request, and, consequently, used for example their washing machines at the preferable hours, a clear reduction in peak load demand than usually observed in morning and evening hours could be achieved (see Figure 18<sup>17</sup>).



**Figure 18. Case study "Waschen mit der Sonne": The impact of intelligent load management on daily load curves as observed in months with (September 2006) and without management service (August 2006)**

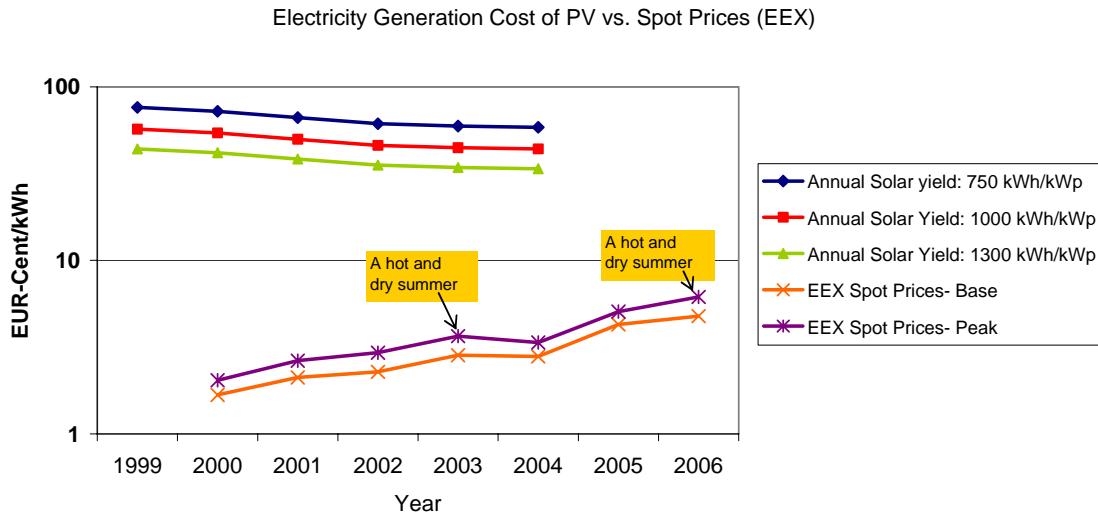
Source: (MVV, 2007)

<sup>16</sup> This project has been implemented by the local utility of Mannheim MVV in cooperation with Fraunhofer Institute for Solar Energy Systems (ISE).

<sup>17</sup> Figure 18 shows that in September the customers received this alert message and used mostly their devices between 10 a.m. and 1 p.m. in comparison to August when there was no alert message.

## 5.2 Market Value of PV

The simplest way to identify the market value of PV electricity is a comparison with spot market prices. To do so, firstly, the correlation between PV output and spot market prices will be exemplified in order to investigate the possible contribution of PV during high price periods. The impact of weather conditions on peak prices will be shown for reported countries.



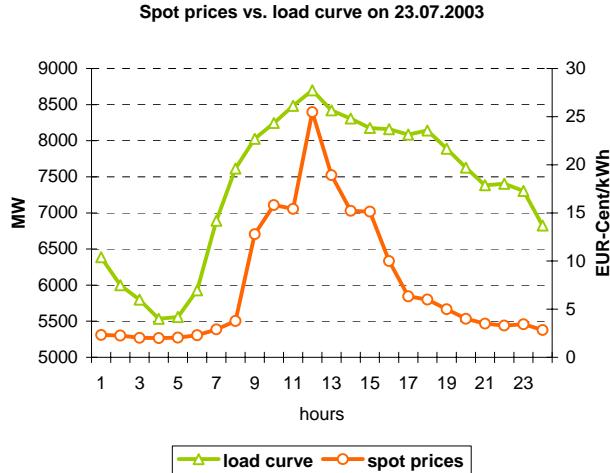
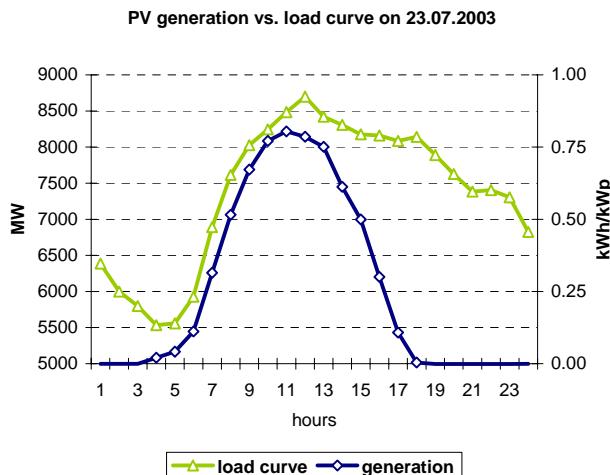
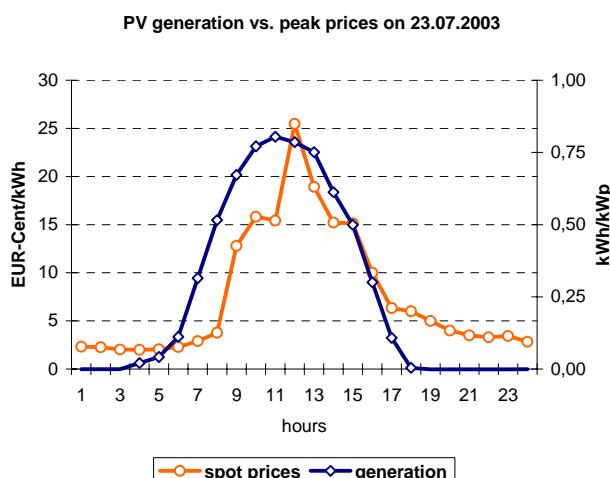
**Figure 19. Electricity generation cost of PV compared with spot prices**

Figure 19 illustrates the development of electricity generation costs for PV and spot prices. It can be seen that spot prices are rising year by year while PV generation costs are decreasing.

### 5.2.1 Correlation between PV generation and magnitude of peak spot prices

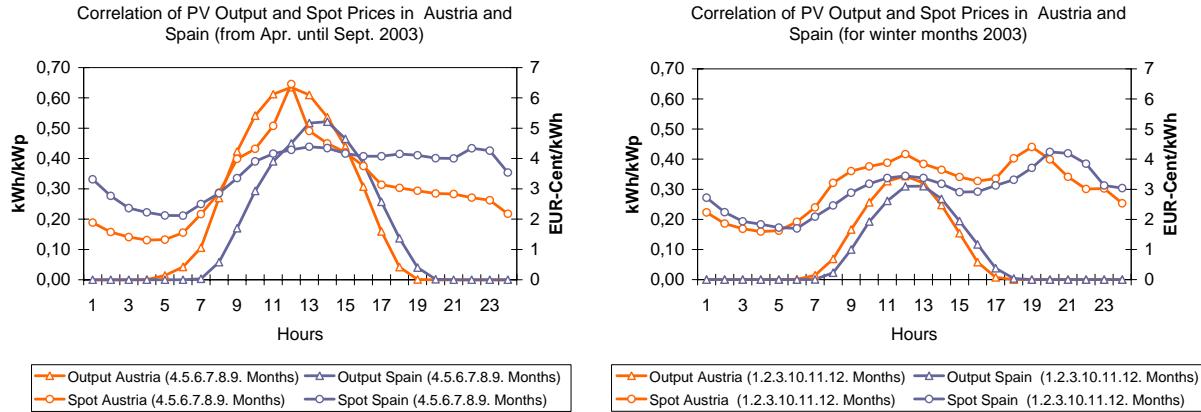
In order to identify correctly the competitiveness (in monetary terms) of PV electricity in the power market there is a need to investigate the correlation between PV generation and spot market prices. This analysis will also provide information about the contribution of PV to periods of peak load because spot prices are mostly dependent on load i.e. spot prices increase when demand rises.

Figure 20 illustrates the correlation between spot prices and load curve for a typical hot summer day in Austria – i.e. the 23<sup>rd</sup> of July 2003. Next, Figure 21 shows the correlation between PV generation and the load curve, whilst Figure 22 depicts the correlation between PV generation and spot prices for this representative day. All figures indicate that PV generation, spot prices and load curve are correlating well on this day.

**Figure 20. Spot prices vs. load curve (in Austria on 23 July 2003)****Figure 21. PV generation profiles vs. load curve (in Austria on 23 July 2003)****Figure 22. PV generation profiles vs. spot prices (in Austria on 23 July 2003)**

In the following we derive the correlations between PV generation and spot prices in a detailed manner, observing the developments in the years 2003 to 2006 for various countries.

## **2003: Austria and Spain**



**Figure 23. Correlation of PV output and spot prices in Austria and Spain in 2003 during warm season (April to September – left) and cold season (October to March - right)**

Figure 23 shows the correlation between PV output and spot prices for Austria and Spain for the year 2003. The correlations were derived from data on hourly spot prices for the corresponding electricity markets and data on PV output for a reference system. In more detail, the Austrian PV reference system is located in Vienna whilst the reference system for Spain refers to the city Tarragona<sup>18</sup>. Data on spot market prices have been taken from EXAA (Energy exchange Austria) for Austria and for Spain from OMEL (Operador del Mercado Iberico de Energia). Please note that the results are also summarised in Table 11 – listing data for all investigated countries.

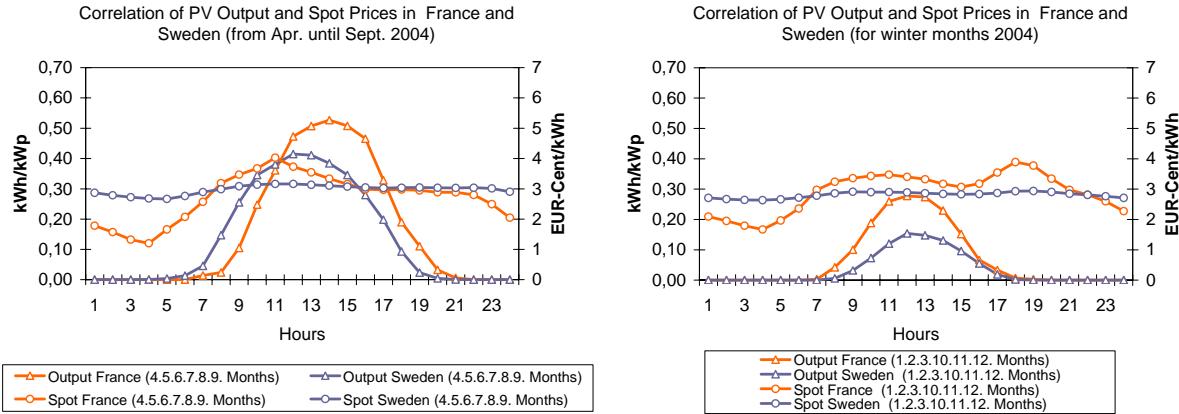
Spain is the one of the fastest growing economies in Europe and rising electricity demand is coupled with comparatively high fuel prices and, in general, less efficient power plants. Therefore, the average price level is high<sup>19</sup> compared to central European countries. In the summer period, i.e. the months April to September, PV electricity is produced during times of highest demand when conventional electricity prices are also highest.

In Austria the impact of the weather on the electricity demand can be clearly observed, in contrast to Spain. The reason is that Austria is a typical “winter peak” country like Germany (see Figure 25) and its supply portfolio is not especially designed to meet summer peaks. In summary, PV offers the possibility in both countries to reduce midday peak demand during summer and, in the case of Spain, PV can additionally contribute for longer daily periods. During the winter season peak prices occur typically in the evening but as the midday price levels indicate the (small) contribution of PV during this time is also valuable.

<sup>18</sup> Please note that these reference systems represent a country just in terms of correlations, i.e. by delivering representative generation profiles. The PV output of the reference system in Spain is very low compared to Austria. This can be explained by the hot summer of 2003 in Austria and a low performance ratio for the Spanish system. The average yearly solar irradiation for Tarragona is actually high – a figure of 1 498 kWh/m<sup>2</sup>/a occurs based on PVGIS

<sup>19</sup> The average spot price for the year 2003 in Spain was 3,25 EUR-Cent/kWh while in Austria it was approx. 3,07 EUR-Cent/kWh.

## 2004: France and Sweden

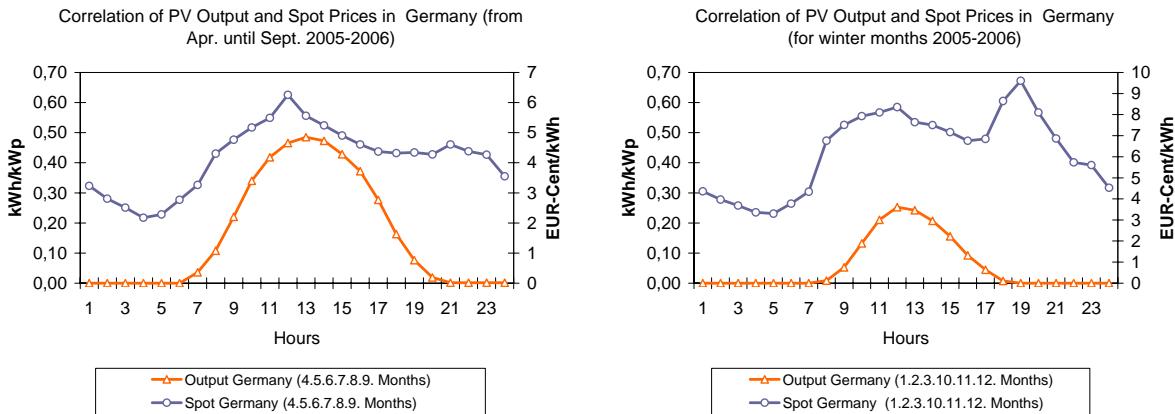


**Figure 24. Correlation of PV output and spot prices in France and Sweden in 2004 during warm season (April to September – left) and cold season (October to March - right)**

Figure 24 shows the correlation of PV output and spot prices for France and Sweden for the year 2004. The reference PV systems used are located in Lyon (France) and Stockholm (Sweden) and spot prices were derived from Powernext (France exchange) and Nord Pool (exchange for Denmark, Sweden, Finland and Norway).

Due to the dominance of hydropower the price levels in the Nordic market are low. France, being the largest nuclear generator in Europe and a major electricity exporter, also has low price levels in comparison to central and southern European countries. For Sweden it can be suggested that there is no correlation between PV output and spot prices. In the case of France it is possible to say that the peak price in the summer occurs at 12 o'clock midday which means demand is high and PV output also typically peaks.

## July 2005 to June 2006: Germany



**Figure 25. Correlation of PV output and spot prices in Germany from July 2005 to June 2006 during warm season (April to September – left) and cold season (October to March - right)**

Figure 25 depicts the correlation between the spot market prices from EEX (German electricity exchange Market) and the PV output of a reference system installed in Bonn (Germany) in the period July 2005 to June 2006. Since Austrian and German spot prices are rather similar this is a good example illustrating that the average spot prices rose in 2005-2006 in comparison to 2004 (see Austrian case study for 2004). Similar to France it can be observed that the peak price in the summer occurs around midday when PV output also typically peaks. Even during winter a low contribution of PV to the midday peak (which is lower than the typical evening peak) is apparent.

Table 11 shows the results of the calculations on earning revenues which have been made for different European countries and power markets for several years – depending also on the availability of data on PV output. A reference system in Germany with 982 kWh/kW<sub>p</sub> within 2005-2006 would offer an earned revenue of 56 EUR/kW<sub>p</sub> on the EEX while a reference system in Sweden during 2004 would offer a value of 21 Euro/kW<sub>p</sub> on the Nord Pool.

**Table 11. Summary of revenues from selling PV electricity respectively used country data on PV output and spot market prices.**

Country	NL	AT	ES	DK	FR	SE	DE
Location of Reference Systems	Simulation Results-1999	Vienna	Tarragona	Brædstrup	Lyon	Stockholm	Bonn
Year of Data	2000-2001	2003	2003	2004	2004	2004	July 2005 to June 2006
Spot Market	APX	EXAA	OMEL	Nord Pool	Powernext	Nord Pool	EEX
System Capacity (kW <sub>p</sub> )	1	2	100	4	1	6	23
Yearly Yield of Ref. System (kWh/kW <sub>p</sub> )	822	1 224	1 010	793	1 012	765	982
Revenues from selling PV electricity per year (EUR/kW <sub>p</sub> )	39 - 51	50	51	23	30	21	56

### 5.3 Cost of CO<sub>2</sub>-Certificates

Green house gas reduction is becoming a key energy policy issue for most industrialised countries, and especially for Europe. In this context, within the framework of the Kyoto Protocol, the European Union has committed to reducing its greenhouse gas emissions to 8% below 1990 levels by 2008-2012.

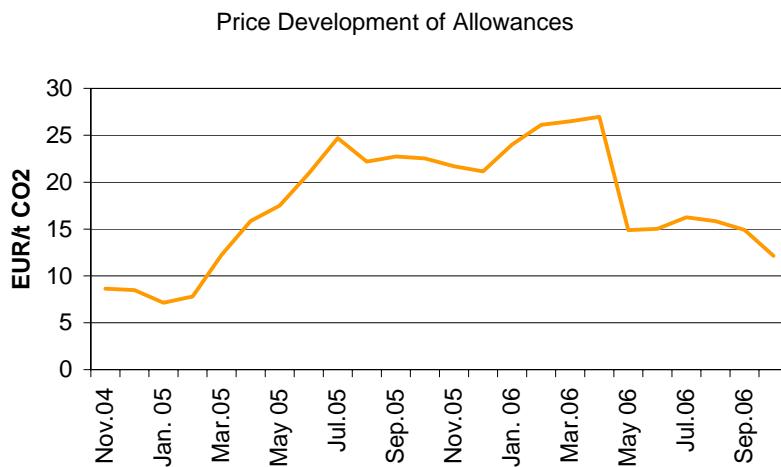
The European *Emission Trading Scheme (ETS)* – a cap and trade system – is a cornerstone of the European Climate Change Programme and is helping to achieve the Kyoto targets of the EU at least cost. Additionally, the ETS aims to result in an internalisation of external costs for green house gas emissions caused by the use of fossil fuels. As the ETS captures the energy sector, the implementation of the Kyoto Protocol leads to a change in electricity prices.

The ETS is based on Directive 2003/87/EC. This directive established a scheme for greenhouse gas emission allowance trading in order to promote cost-effective and efficient emission reductions. Within the scope of the directive are CO<sub>2</sub> emissions from energy activities, production and processing of ferrous metals, mineral industry and other industrial activities (i.e. pulp and paper) exceeding certain threshold levels referring to output or production (Directive 2003/87/EC 2003). The directive requires Member States to develop

National Allocations Plans (NAPs), stating the total quantity of emission allowances which are allocated to the covered installations. The first trading period lasts from 2005 to 2007, followed by five year trading periods.

In this context, a utility also has to pay the CO<sub>2</sub> certificate prices for emissions caused by generating electricity from fossil fuels. This represents an additional monetary burden from the utilities point of view which can be reduced by generating PV electricity.

PV offers environmental benefits for society (see section 4) and cost saving for utilities. This section attempts to show the contribution of PV in the reduction of CO<sub>2</sub> certificate costs from the utilities perspective.



**Figure 26. Price development of CO<sub>2</sub> Allowances**  
Source: EEX (<http://www.eex.de>)

*"CO<sub>2</sub> prices are determined by factors like economic growth, weather, abatement options and market sentiments".* (Sijm et al., 2005) The weather factor on which PV also directly depends has a major impact on emissions of the covered installations. A cold winter increases demand for heating (e.g. by electricity or fossil fuels, **whereas a warm summer increases power demand for air-conditioning**). Winter 2005 showed a clear increase in energy consumption and therefore a rise in emissions. It is widely acknowledged that this is an important factor influencing the CO<sub>2</sub> price rise in early 2005. (Sijm et al., 2005)

As market prices of allocated allowances represent opportunity costs, the introduction of an emission trading scheme affects marginal electricity generation costs. Taking into account the potential CO<sub>2</sub> emissions reductions factors for PV (see section 4.1) and given certificate price levels we can determine monetary savings for the utilities for each alternatively generated kWh PV electricity. This is done for all reported European countries.

The utilities had to pay approx. 18 EUR on average (from 2005 to October 2006) for each tonne of emitted CO<sub>2</sub>. Taking into account this average value for all reported EU countries and PV's CO<sub>2</sub> reduction potential at country level (see Table 6 ).

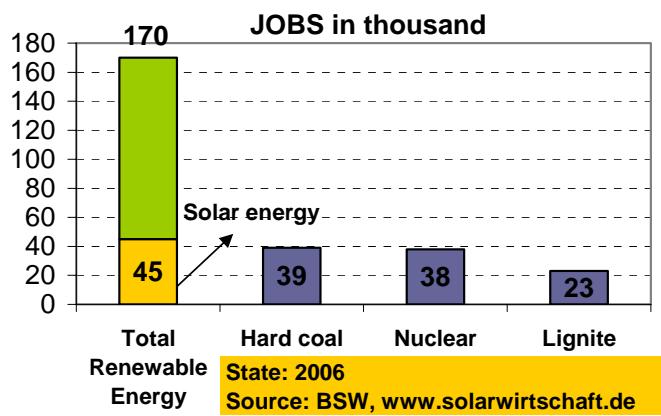
Table 12 summarises the derived values, i.e. the certificate cost saving, expressed in specific terms of EUR-Cent/kWh. As can be seen, in the Netherlands a utility can reduce its cost burden by about 0,62 EUR-Cent for each kWh generated PV electricity, whilst in the United Kingdom (GB) the highest value of 1,86 EUR-Cent/kWh occurs.

**Table 12. Contribution of PV electricity in CO<sub>2</sub> certificate price saving for utility**

Reducing Cost of CO <sub>2</sub> Certificate by PV generation (EUR-Cent/kWh)							
AT	DE	DK	ES	FR	GB	NL	SE
1,59	1,85	1,58	1,64	1,60	1,86	0,62	0,66

## 6 INDUSTRY DEVELOPMENT AND EMPLOYMENT VALUES

New job opportunities are one of the most important societal benefits for decision makers which are considered for new energy policies (Watt, 2001). In comparison to conventional energy technologies renewable energy technologies create more jobs as indicated in Figure 27. The figure is an overview of energy related jobs by fuel source in Germany for 2006. The solar energy market, for both PV and solar thermal resulted in 45 thousand jobs – a higher figure than any conventional fuel option.



**Figure 27. Created jobs from renewable energy vs. conventional energy technology in Germany in 2006**

The PV world market is growing continuously. In 2005 it grew more than 45% to 1 759 MW. Germany was the largest single market with 603 MW in 2005, followed by Spain with 20,2 MW (Jäger -Waldau, 2006).

According to the German Association of Solar Energy (BSW) about 3 500 PV companies exist in Germany, 50 of them are manufacturing cells, modules and other components. The market turnover in 2005 rose to a value of 3 billion EUR from which 70% remained in Germany. It is expected that this business volume will rise by 2020 to an amount of 15,2 billion EUR. At present around 25% of manufactured PV products are exported. Direct and indirect jobs in the PV sector are estimated at about 30 000 in 2005.

The second largest PV market in Europe is Spain which made big progress with regard to local PV industry development during the past few years. From January 1999 to October 2005 the cumulative investment of the PV sector (including both manufacturers and installers) reached 290 MEUR (IEA-PVPS, AR 2005). According to the Spanish PV industry association (ASIF, 2005) there were 155 PV companies in operation by 2005. Among them 6 are module manufacturers, 12 produce components and other 12 are installers, whilst the rest refers to distributors and other companies.

While other European countries do not have such successful PV markets they do have successful companies like Photowatt in France or Fronius in Austria which concentrate on exporting their products. For illustration Photowatt in France, a cell and module manufacturer, reached a production capacity of 33 MW with an export share of approximately 95% and an annual turnover of 90 MEUR in 2005. The number of employees is estimated at 600 for the

same year. The other mentioned company, Fronius International, located in Austria, is the second largest inverter manufacturer in Europe (IEA-PVPS, AR 2005). In 2005 the company manufactured 60 000 inverters which corresponds to about 175 MW PV capacity and created approximately 90 jobs. 99% of produced inverters were exported with an estimated export value of 47 MEUR.

**Table 13. Employment based on national sources for AT, DE, ES**

Country	Category <sup>20</sup>			Source	Reported year	Annual installed capacity in the reported year (kW)	Cum. installed capacity in the reported year (kW)					
	Direct	Indirect	Total									
AT	Employment effect - primary (direct & indirect)	287	165	452	(Haas et al., 2006)	2004	4 227	21 060				
	Employment effect secondary			257								
				709								
DE	Handcraft	18 000		Total (approx.)	(BSW, Feb. 2006)	2005	600 000	1 400 000				
	Wholesale	3 000										
	Industry	9 000		30 000								
ES		Direct	Indirect	Total	(ASIF, 2005)	Stand -Oct., 2005	57 363	57 400				
	Manufacturing	1 895	947	2 842								
	Installation	1 200	600	1 800								
	Others	1 100	550	1 650								
				6 292								

Table 13 shows the derived data on employment for Austria, Germany and Spain. As this table also implies the categorisation of employment differs between countries. The most consistent categorisation can be found in IEA-PVPS' national country reports but the indicator job/MW differs country by country. Table 14 depicts a summary of derived employment according to data as published in the country reports. EPIA (The European Photovoltaic Industry Association) and Greenpeace estimate 20 created job for each MW of production facilities. It can be expected that this amount will decrease to 10 between 2010 and 2020. Additionally, they also estimate about 30 jobs per MW for the process of installation, retailing and providing other local services, which will drop to 26 jobs / MW between 2010 and 2020 (EPIA/Greenpeace, 2004).

<sup>20</sup> Direct employments results mainly from maintenance, installation, and manufacture of the PV systems. Indirect jobs arise from stimulating other industries affected by the new PV systems (Ban-Weiss, 2004).

**Table 14. Data on employment from IEA-PVPS National Survey Reports**

<b>Country</b>	<b>Research and development. (not including companies)</b>	<b>Manufact. of PV system components (incl. companies R&amp;D)</b>	<b>All other, including employees within electricity utilities, installation companies etc.</b>	<b>Total</b>	<b>Reported year Source: IEA-PVPS Task 1 National Survey Reports (NSR)</b>	<b>Annual installed capacity in the reported year (kW)</b>	<b>Cum. installed capacity in the reported year (kW)</b>
<b>AT</b>	40	720	40	<b>800</b>	2005	2 961	24 021
<b>CA</b>	50	650	380	<b>1080</b>	2006	3 738	20 484
<b>CH</b>	150	300	500	<b>950</b>	2006	2 650	29 700
<b>DE<sup>1</sup></b>	-	35 000	-	<b>35 000</b>	2006	953 000	2 863 000
<b>DK</b>	15	150	20	<b>185</b>	2006	250	2 900
<b>FR<sup>2</sup></b>	-	-	-	-	2005	7 020	33 043
<b>GB</b>	52	522	320	<b>894</b>	2006	3265	14 042
<b>JP</b>	500	6 200	11 000	<b>17 700</b>	2006	286 591	1 708 499
<b>NL</b>	28	92	112	<b>232</b>	2006	1 521	52 705
<b>SE</b>	33	350	22	<b>405</b>	2006	603	4 840
<b>US</b>	350	5 200	2 800	<b>8 350</b>	2006	145 000	624 000

<sup>1</sup> The data in the IEA PVPS National Survey Report was incomplete<sup>2</sup> No labour places data available.

## 7 CUSTOMERS INDIVIDUAL BENEFITS

Building integrated PV systems offer decisive individual values for different customers groups which will be discussed in the following.

As mentioned in section 1.2 PV customers can be classified as follows.

- Residential customers
- Commercial Customers
- Architects and building developers

### 7.1 Residential and Commercial Customers Benefits

These two groups of customers are interested in the same added values of PV systems but they give different weight to them according to their preferences. The environmental benefits, as described in section 4, make PV systems attractive for customers in order to show their contribution in environmental protection and sustainable awareness. *"There is a growing interest in "green" products such as organic food, organic fibers, as well as green buildings"* (Reijenga T.H., 2002). Many commercial PV customers especially are using this visible clean image in order to demonstrate their environmental credentials as mentioned in Watt (2001).

López-Polo et al. (2005) conducted a qualitative survey of value analysis in different countries and for different stakeholders. According to their results residential and commercial PV owners seem to be the stakeholder group for which the added values of PV systems play the most important role. In this study it is observed that the value of PV energy for users and PV system owners now and in the future goes beyond the monetary value of the electricity generation. This confirms the importance of designing deployment programs which consider the individuals voluntary willingness to pay (WTP) (López-Polo et al., 2005)

Customers like non-intrusive features like noiseless, modularity, relatively maintenance free characteristic which make PV systems an attractive technology to provide individuals energy independence and supply security.

#### 7.1.1 Energy Independence

The issue of energy independence by using decentralized energy sources is getting more important in industrialized countries. Before now people in developed countries (except the US) were not used to power outages. However power outages are already a problem in the US and the importance of this topic is increasing in Europe as well. In addition price fluctuations for fossil fuels are causing considerable economic and social disruption (Perez et al., 1999).

According to the estimation of a US study by LBNL (L. Lawton, et al., 2003) a 1 hour outage during a summer afternoon costs the average customer approximately 3 USD for a residential customer, 1 200 USD for a small commercial and industrial customer, and 8 200 USD for a large commercial and industry customer. The major outages (like on August 14, 2003 on the East Coast of US) are very disruptive and the annual cost of these interruptions burden the US economy with tens of billion dollars per year (Hoff et al., 2004). The value of PV for general energy independence and in emergency situations is increased when storage is included (Watt, 2001).

How storage can be profitably combined with customer owned distributed PV systems is examined in Hoff et al., (2004). According to this study PV customers (residential and commercial) can obtain critical load generation in case of outages.

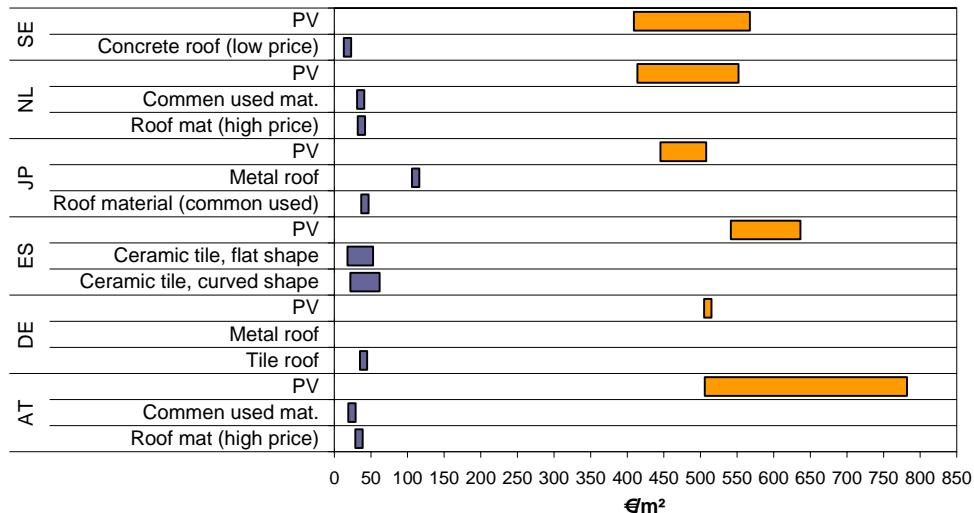
These results also indicate values for utilities. Utilities may be able to dispatch customer owned batteries for short durations of time in order to manage loads in the event of system emergencies. *"The PV system alone benefits the customer via energy savings and demand savings (commercial customers) and also brings value to a utility's T&D system. The addition of storage or load control can bring extra value to commercial customers if driven to reduce local demand. The same storage/control can bring additional value to a utility if driven to maximize T&D capacity and prevent emergencies. Finally, storage benefits the customer by providing outage recovery insurance and benefits the utility by preventing potential outages"* (Hoff et al., 2004).

### 7.1.2 Material Saving

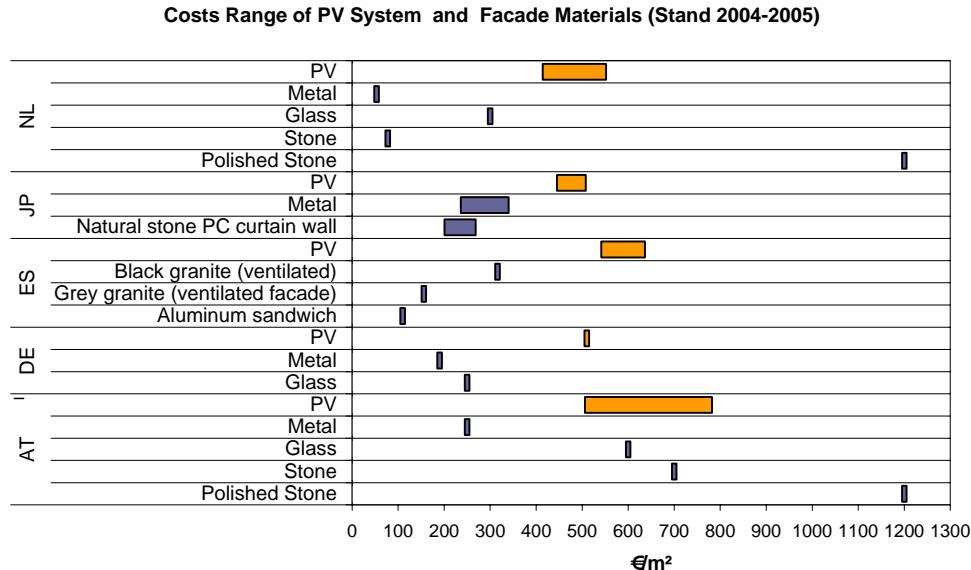
Building integrated PV systems have the potential to avoid some material costs which would be used instead of PV. Obviously, the cost saving depends on the material which would alternatively be used.

In the following, material saving is illustrated against the cost of PV which represents a monetary benefit for consumers. Figure 28 and Figure 29 show a cost comparison of PV in EUR/m<sup>2</sup> against some roof and façade elements based on country-specific data as provided by EU PV Up Scale and some Task 10 partners. The typically used building materials also differ country by country. Thereby, bars marked in yellow show the cost range of PV systems without installation share on turnkey prices. The reduction of installation prices is based on partner's estimations of the share of installation cost on turnkey prices. The estimated share of installations costs on turnkey prices are in Austria and Germany approximately 8%, in France 10%, in GB 24% and for Japan approx. 11%. According to ASIF (2005) the share of installations costs on turnkey prices in Spain for a 5 kW<sub>p</sub> PV grid connected system is 7%. Please note that indicated cost data on building materials does not include cost referring to installation.

**Cost Range of PV System and Roof Materials (Stand 2004-2005)**



**Figure 28. Cost range of PV systems and some roof material**



**Figure 29. Cost range of PV systems and some facade materials**

Sources: AT (Ertexsolar, 2005); DE: (Baukosten, 2002); ES: (COAATG, 2006);  
JP: (NEDO, 2004); NL: (Bouwkosten, 2006); SE: (WS, 2006)

Material replacement using PV for facade cladding is especially relevant for commercial customers who would alternatively use luxury cladding materials. PV installation cost is very reasonable compared with decorative materials for facades (see Figure 29 ) such as marble or polished stone.

An interesting architectural example is the CIS tower (a multi storey building of the Cooperative Insurance Society) in Manchester, England. The building facade is covered with a 391 kW<sub>p</sub> PV systems with an area of 4 000 m<sup>2</sup>. The main decisive factor in choosing PV was interestingly the low additional cost in comparison to other façades elements like bronze or marble. (Photon, 10/2006).

## 7.2 Architects and Building Developers Benefits

Architects and building developers are a special customer group who play a transmitter role and influence decisions regarding use of building integrated PV systems (Haas, 2002). Architects connect the customer (investor), module manufacturers, installers and building developers with each other. The decision of architects to use PV systems as a part of a building roof or facade from the beginning of building design offers reasonable and economic values (Bendel, 2003).

Architects and building developers are interested in green image and using PV systems for their prestige and possibilities for innovative design features. They take into account the multi functional building construction features of PV as well as the contribution of PV systems in improving the thermal performance of buildings. These design features provide the PV customers (investors) a comfortable and sustainable building. Sound proofing is another important factor which can be provided using PV systems. Some of these benefits are explained shortly – mainly based on Watt (2001).

### 7.2.1 Design features

*„PV offers a new and attractive building material which can be used to create new building designs which fit into an increasingly important architectural aim of demonstrating environmental sustainability“ (Watt, 2001).*

The architectural possibilities of using PV as a building part are documented in Reijenga T.H., (2002) and in Watt (2001).

Various multifunctional design features such as shading or daylighting can be realised by applying PV systems with different colours, shapes and transparency features. For instance water and sun protection can be provided using transparent PV modules.

*“The various types of cell material, types of modules, the framed or non-framed laminates, the colours of the cells and the colours of back sheets and frames, all provide a wide range of possible surfaces” (Reijenga T.H., 2002)*

Although almost every form, shape and dimension is possible with tailor-made modules, it must be kept in mind that the standard modules are less expensive than these design types (Reijenga T.H., 2002).

### 7.2.2 Weather protection

As shown in Figure 30 façade integrated PV systems protect the building from weather effects like rain, wind and deterioration while roof systems protect the roof materials. According to Bendel (2003) diverse tests with foil encapsulated crystalline systems have shown that PV façade modules can bear high wind speeds (up to 233 km/h) without damage. An 18 year simulated weather test has shown that no deterioration appeared on the PV modules.

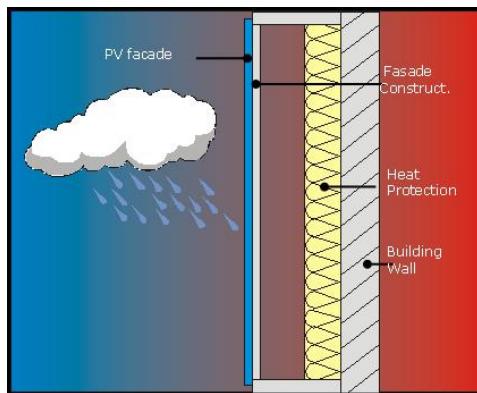


Figure 30. Weather protection

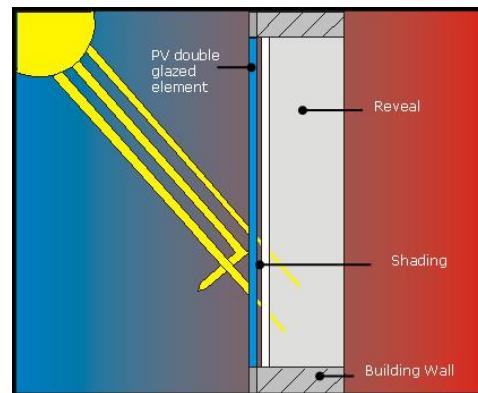


Figure 31. Shading

Source: (hwp & ISET, 2006)

An example can be given from Japan where many houses are re-roofed within 20 years (Konno, 1999) or roof materials are re-painted in 10 years (NEDO, 2004). Hence, If PV modules cover the roof; such maintenance would not be required.

### 7.2.3 Roofing

Roof integrated transparent and semi transparent PV modules can be designed as part of a building skylight (Watt, 2001). PV roofing systems can offer some additional functions like

water tightness, drainage and insulation. The most common roofing systems are roof tiles or slates, shingles and standing seam roofing. (Wolter, 2003).

#### **7.2.4 Shading**

PV systems are logical for combining shading a building in summer and producing electricity at the same time (Reijenga T.H., 2002).

As Figure 31 systems are logical for combining shading a building in summer and producing electricity at the same time (Reijenga T.H., 2002).

As Figure 31 indicates PV systems can offer shading functions (hwp & ISET, 2006) "*Shading elements are typically secured to the outside of the building envelope to limit the amount of daylight and heat entering through a window*" (Watt, 2001). PV shade screens reduce solar heating in the summer and reduce the need for extra ventilation (Wolter, 2003). Shading devices can be retrofit onto existing buildings or can be integrated into new buildings.

Many examples of PV shading can be seen worldwide. Two buildings at ECN (Netherlands energy research foundation), a retrofit and a new building are good examples for using PV systems with multifunctional features. *The aim of the project is to construct energy efficient and sustainable buildings and demonstrate the use of renewables in the built environment*" (Reijenga, 2002). The old ECN building before the retrofit had many technical and thermal problems like overheating in mid summer, inefficient lighting systems, high rate ventilation system with low efficiency and comfort and badly distributed heat. In order to prevent overheating the south façade was equipped with sunshades with PV systems integrated in the shading system. The shading system diffuses the daylight (Reijenga, 2002). A detailed description of the final design and engineering stage of this project can also be found in Kaan (1998).

A building at Wirtschaftshof, Linz used PV louvers in front of glass facades and windows for several tasks (EC, 2003). According to the annual report of project coordinator ZSW this building has been equipped with a self-adjusting PV sun protection system which combines the functions of temporary shading, day lighting, passive use of thermal energy and PV. The passive drive is self regulated and energy supplied by the sun and thus completely autonomous. (ZSW, 2001)

#### **7.2.5 Thermal Energy Conversion**

*Infrared radiation is largely transmitted by PV cells and contributes to heating the module and whatever is behind it (Watt, 2001).* In order to use this transmitted heat hybrid Photovoltaic/Thermal Collectors (PV/T) have been developed. PV cells can be combined with solar water heating or solar air heating collectors. A conventional flat plate solar heat collector with integrated PV cells on the absorber or PV panels in a ventilated solar wall preheating of ventilation air are examples of hybrid PV/T systems (Sørensen et al., 2000).

#### **7.2.6 Soundproofing**

PV building elements have features which can absorb sound. Soundproofing a building can be obtained using PV for facade, roof or window elements (hwp & ISET, 2006). *"The use of PV for sound proofing in buildings and highway barriers has been widely exploited in Europe, where dense urban development makes this a premium value"* (Watt, 2001).

In Japan, in addition to other PV implementations, the Defence Facilities Administration Agency (DFAA) will continue its 1,4 billion JPY (10 MEUR) project on soundproofing measures for houses around airbases using PV systems. (Jäger Waldau, 2006)

## 8 CONCLUSIONS

**Why PV?** – Although PV currently appears an expensive option for producing electricity compared to other energy sources many countries support this novel technology because of its' promising future potential and the additional benefits besides generating electricity associated with PV. These benefits are already effective at present and have been, firstly, identified and, secondly, quantified (especially for the demand side) in order to affect decision making in urban planning.

This value analysis of Urban Scale PV aims to answer the questions discussed below.

**Why should policy makers and governments set financial incentives and market development strategies for BIPV systems?**

Because PV systems have a wide range of important added values which increase the societal welfare towards sustainability, namely:

- Using a worldwide abundant and indigenous available fuel source- the sun!
- Contribution to supply security through avoiding the use of (imported) fossil fuels and reducing fuel price risks respectively
- Reducing greenhouse gas emissions and air pollutants and accordingly avoiding external costs which alternatively have to be borne by the whole society, and
- PV offers the chance to develop a new industry; creating export possibilities and jobs.

**Why should utilities invest in PV systems or PV electricity and/or support their customers using PV?**

Because PV

- contributes to peak shaving which means PV electricity is available especially in the summer months when demand is rising
- electricity is available especially in the summer when electricity prices are high in the spot market.
- reduces the environmental cost burden like CO<sub>2</sub> certificate costs as applied within the European Union
- creates a green image and offers new business opportunities.

**Why should residential and commercial customers be willing to pay voluntarily more for this technology?**

Because:

- PV systems are noiseless, relatively maintenance free, reliable and easy to install to the building.
- They can demonstrate their environmental awareness by using this visible environmental technology as a part of their building
- They can save building material costs through PV systems while they generate the whole or a part of their electricity needs
- They can provide individual energy independence

**Why might architects and building developers consider PV systems in their building and urban planning?**

Because PV systems

- are an innovative design feature of a building and
- offer multifunctional design features like weather protection, shading or sound proofing besides electricity generation
- contribute to improving the thermal performance of a building e.g. by preventing overheating or increasing daylight.
- have a wide range of colours, shapes and offer transparency possibilities
- increase their prestige

Finally, it is important to emphasise that BIPV systems can play an essential role in sustainable urban planning since they are easily and visually attractive integrated in building surfaces. In this respect architecturally well designed BIPV systems are an important driver to increase market deployment.

Environmental benefits, industry development, job creation and avoidance of (imported) fossil fuels give justification for the strong incentives which are needed to achieve an enhanced market deployment as well as the dissemination of urban planning of PV. Avoiding dependence on imported fossil fuels is also an important issue with regard to achieving sustainable development in urban planning.

The environment is a decisive factor for customers. Rapidly increasing customer awareness of greenhouse issues means that the customers also need information on the amount of greenhouse gas emissions reduced, especially policy makers and governments demand such information to justify setting strong incentives, regulations or targets. As a consequence customers can afford PV which has at present, besides all discussed values, one striking deficit: the high capital cost.

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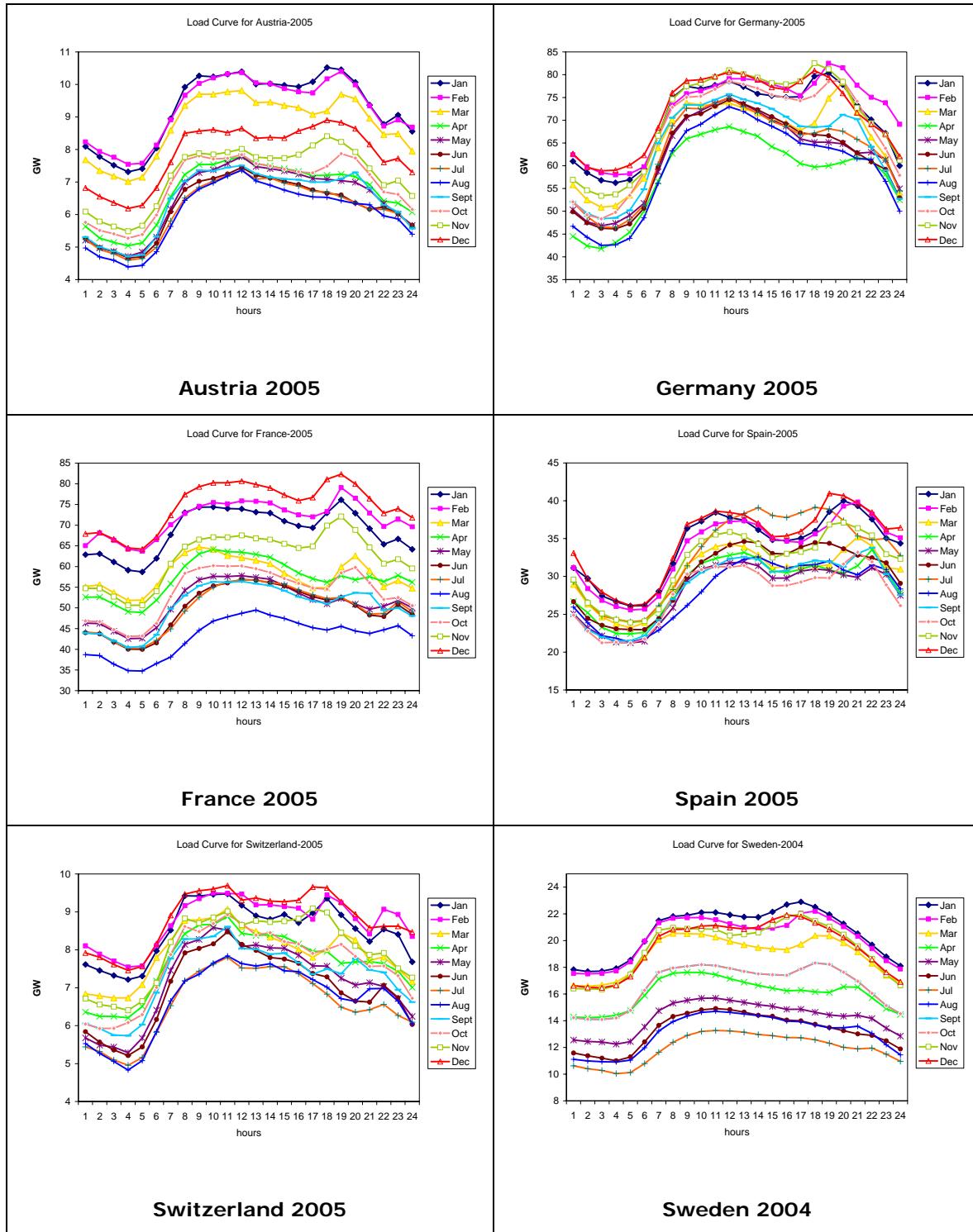
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## APPENDIX A – LOAD CURVES



Source: [www.ucte.org](http://www.ucte.org)

Based on hourly load values for every first Wednesday of a specific month on country level.

