Evaluation and Impact Assessment of the European Non Nuclear Energy RTD Programme

Development and implementation of a methodology for evaluation and impact assessment of the energy programme of the Fifth and Sixth Framework Programme of the European community for RTD activities

AREA REPORT

AREA 1: Solar Energy

Version 1

Date: 15 May 2009

Specific Tender:
BUDG 06/PO/01/Lot3
Under Framework Contract No.
DG BUDG No BUDG06/PO/01/LOT no. 3
ABAC 101908

EPEC

31st December 2008

Contact name and address for this study:

Dr. Paul Simmonds
Technopolis Ltd.
3 Pavilion Buildings, Brighton BN1 1EE, UK
Email: paul.simmonds@technopolis-group.com
Tel: +44 1273 204320

European Policy Evaluation Consortium (EPEC)
Brussels contact address: 25 rue de la Sablonnière – B-1000 Brussels
Tel: +32 2 275 0100 Fax: +32 2 275 0109
E-mail: contact@epec.info URL: www.epec.info
Content

1. Introduction 6

2. Main challenges and opportunities of the solar energy area 7
   2.1 Scientific challenges and opportunities 7
      2.1.1 Fifth Framework Programme 8
      2.1.2 Sixth Framework Programme 10
      2.1.3 Seventh Framework Programme 12
   2.2 Political/regulatory challenges and opportunities 14
   2.3 The environmental challenges 15
   2.4 The social challenges 15
   2.5 The economic challenges 15

3. EC-funded research activities in the area 17
   3.1 Objectives and rationales 17
      3.1.1 FP5 objectives 17
      3.1.2 FP6 objectives 18
   3.2 Structure and main characteristics of research activities 19
      3.2.2 Participants profile through social network analysis 21
   3.3 Content and evolution of research activities between FP5 and FP6 25

4. Scientific achievements 27
   4.1 Outputs 27
      4.1.1 Scientific and technical challenge: increase efficiencies 28
      4.1.2 Scientific and technical challenge: cost reduction 29
   4.2 Impacts 29
   4.3 Contribution to ERA strengthening and international collaboration 30
      4.3.1 FP5 and FP6 has contributed European Research Area 31
      4.3.2 Collaboration with partners outside Europe is difficult 32

5. Policy impacts 33
   5.1 Assessment of policy impacts 33

6. Economic and social impacts 35
   6.1 Assessment of economic and social impacts 35
   6.2 Development and commercialisation of CIS/CIGS thin film solar cells in Europe 36
   6.3 Crystalline silicon photovoltaics 38
      6.3.1 Development of solar grade silicon feedstock 39
      6.3.2 Development of thin film silicon solar cells 40
   6.4 Photovoltaic in Germany – a case study on factors explaining its rapid take off 41
   6.5 Concentrated Solar Power in the FPs 45
6.6 Diffusion and dissemination of scientific results to economic and social arena 47

7. Environmental impacts 50
   7.1 Energy efficiency 50
   7.2 CO2 emissions 50

8. Summary and conclusion: added value of EC-funded research 52
   8.1 European Added Value 52
   8.2 Scientific impact 53
   8.3 Economic impact 53
   8.4 Policy impact 54
Table of exhibits

Figure 1  Different PV-technologies, their efficiencies, and the goals for 2002 ......................... 9
Figure 2  Annual installed capacity of flat plate and evacuated tube collectors ......................10
Figure 3  The aims in 2002 for the efficiency of pv-cells (%) ................................................. 11
Figure 4  The goals for 2003 and the achievements at 2002 .................................................. 11
Figure 5  Key targets according to the European Strategic Agenda ....................................... 13
Figure 6  Innovation challenges for CSP in 2006 for the different CSP technologies, with the potential cost reduction .................................................. 14
Figure 7  Project profiles in FP5 instruments .......................................................................... 19
Figure 8  Funding profiles in FP5 instruments ....................................................................... 20
Figure 9  Project profiles in FP6 instruments ........................................................................ 20
Figure 10 Funding profiles in FP6 instruments ....................................................................... 20
Figure 11 Distribution of participations by type of participant in FP5 and FP6 ..................... 21
Figure 12 Collaboration between countries in FP5 projects (Solar energy) ......................... 22
Figure 13 Collaboration between countries in FP6 projects (Solar energy) ......................... 23
Figure 14 Participants in FP5 projects ................................................................................ 24
Figure 15 Participants in FP6 projects ................................................................................ 24
Figure 16 Outputs produced as a direct result of the project in solar energy (n=65) .......... 28
Figure 17 Achievement of outcomes and their impact – on the individual ....................... 30
Figure 18 Achievement of outcomes and their impact – on society .................................. 33
Figure 19 Achievement of outcomes and their impact – on the organisation ...................... 35
Figure 20 Federal funding for PV in Germany (1982-2008) .............................................. 42
Figure 21 Renewable electricity in Europe .......................................................................... 50
Figure 22 Renewable electricity in Germany in 1990 and 2007 .......................................... 51
1. Introduction

This document is the area report of the “Evaluation and Impact Assessment of the European Non Nuclear Energy RTD Programme” (hereafter referred to as “the evaluation”). The evaluation includes all projects funded in FP5 (1998-2002) and FP6 (2002-2006) in the area of solar energy. This includes both photovoltaics (pv) and thermal solar energy. The focus of this evaluation is to a large extent on pv, because this includes the majority of the projects.

Within Europe Germany is by far the most important country when it comes to solar energy, both in terms of R&D efforts, industry size and installed capacity of pv-systems. This makes that Germany gets most attention in this evaluation. Also in terms of economic spin-offs from EU funded research Germany is important. The mini-case on thin film CIS/CIGS shows that technology that is developed in different European countries like the Sweden, France, Switzerland and even the US is transferred and commercialised in Germany. Main reason for this is that the German government has invested heavily in pv (and other renewable energy technologies); not only R&D funding, but more importantly it created a market for pv which has boosted demand and hence the development of the pv industry in Germany. On top of that some Germany states like Saxony provide attractive (fiscal) incentives for companies who build a production plant for pv. In section 6.4 more insight will be given in the factors explaining the success of pv in Germany.

In addition to scientific and technical results, the industrial relevance and economic impact of the EU funded research projects in FP5 and FP6 is also stressed in the interviews with companies and research institutes. We have found a number of examples that show a direct economic impact of European funded research. This will be illustrated by 3 mini-cases:

- CIS/CIGS thin film (section 6.2),
- Crystalline silicon, and in particular the production of metallurgical solar grade silicon (section 6.3.1),
- Silicon thin film (section 6.3.2).

With regard to solar thermal a mini-case is presented about concentrated solar power (CSP). CSP is a promising technology to build large solar power plants in sunny area’s. In FP5 and FP6 different projects are funded to develop this concept. In addition 3 large demonstration projects were co-funded in FP5 in Spain. These projects received a lot of attention from the public and policymakers to illustrate the potential of the technology. This case will be presented in section 6.5.

The report is structured around the following sections:

- Main scientific, political, economic, environmental and social challenges
- Overview of the EC funded research activities in the field of solar energy
- Scientific achievements
- Policy impacts
- Economic impacts, including five case studies
- Environmental impacts
- Summary and conclusion and European added value
2. Main challenges and opportunities of the solar energy area

2.1 Scientific challenges and opportunities

Photovoltaic

Before the start of FP5 pv was merely a promising technology. In only 10 years this changed radically and nowadays there is a real market for pv in Europe (especially Germany) and this market is still growing. In this period pv industry developed in Europe (especially Germany), from only a few companies that produced solar cells for niche markets (space applications, etc) to many companies specialised in producing solar cells against the lowest possible production costs. Around 2000 pv started to take-off and nowadays there is a reasonable amount of installed pv and production capacity in Europe (especially Germany) and this amount is still increasing.

The development of the pv-industry was triggered by the development of machinery and process technology for solar cell modules, which was essential to lowering the production costs, because of learning effects and industrial up-scaling. This made it possible to take the step from small-scale manufacturing to an industrialised process with high throughput and lower costs. Another important driver was the Germany feed-in tariff that created a market for pv in Germany and stimulated the demand for pv.

During the FP5-Fp6 period the main technological challenges were to reduce production costs and increase the efficiency of cells and modules. (Multi)crystalline silicon solar cells are dominating and have the largest market share, but other technologies are being developed as well and offer promising alternatives for niche-markets or to reduce production costs. For both crystalline and thin film solar cells the same technological challenges apply:

- Shifting the practical efficiency towards the theoretic maximal efficiency,
- while minimising the cost of the solar cells. This is integrated in one indicator that can be used to compare PV-cells of different technologies: the cost per power (€/Wp). Thus, a more efficient PV module may have higher costs, but still be more favourable for market reasons because of its high power yield.
- Lowering the cost, and increasing the efficiency and lifetime of system components that are used to install the modules, to transport and store the energy etc., also known as the Balance of System (BOS)
- Increasing the lifetime of a PV-module. The lifetime is an important factor in the cost (rate of return) and the convenience of PV for end-users.

In general these main challenges (increase practical efficiency while reducing production costs; indicated by decreasing cost per power (€/Wp)) have remained the same for FP5, FP6, and FP7, but some specific challenges can be mentioned for the different programmes.

Solar thermal

The field of Solar Thermal energy should be split up in two separate domains: the low and medium temperature ST and the high temperature ST.

Low and medium temperature ST are technologies that produce heat with a temperature lower than 220 °C that is used directly or stored and used later. Typically, the system of low and medium temperature ST is rather low tech. Already at the start of FP5 there was a large installed capacity of these low-tech solar heat production units. Low temperature ST is mainly used for domestic hot water use. However, during the period of both FP5 and FP6, the large potential of integration of low and medium temperature ST in other systems than hot water use was investigated: the demand for heating and cooling is 49% of the total energy demand in Europe, most of which is needed at low- to medium temperatures. As a result, technological
challenges related to the integration of heat receiver systems into domestic or industrial systems such as space heating, cooling or air conditioning systems emerged. General challenges for low-temperature ST include:

- Integrating the solar heat receiver systems into other systems for domestic and industrial use, such as heating, cooling, air conditioning, desalination of water, etc. Especially this search process for applications and the development of the applications, requires R&D.
- Increasing the efficiency of the solar heat receivers, while improving the life time and robustness of the system.

High temperatures ST consist of technologies that use heat with temperatures above the 220 °C for electricity production. To achieve high temperatures, lenses and mirrors are used to focus direct sunlight of a large area to a device that produces the heat. While the earth is circling around the sun, these lenses and mirrors need a tracking system to follow the sun. The receiving device needs to capture the heat, which should than be converted to electricity. In order to produce electricity in a continuous process the heat needs to be stored. Alternatively, it can be integrated in conventional thermal plants. This kind of solar power is called concentrated solar power (CSP). Along the chain of subsystems many technological alternatives exist. Many contesting technologies exist for the receivers, heat exchangers, heat to electricity converters and the energy storage systems. Within the broad field of research (as well as in the FP5 & FP6) these technological options are developed and tested. At the start of FP5 no dominant design existed. Nowadays, still no dominant design has emerged, however, a roadmap is been developed in FP6 to compare the technological alternatives.

CSP is used to reach high efficiencies and to reduce the collector size and land use, thus reducing the cost and environmental impact. It can be integrated as a solar boiler into conventional thermal cycles in parallel with fossil-fuelled sources. As a result, they can be provided with a fossil fuel back-up system without the need of a separate back-up power plant. A drawback of CSP is that it is highly depending on the right amount of sunlight. Because of the high cost, the concentrator technologies are only suitable for sunny areas, such as the Mediterranean climate. Therefore this sort of technology is piloted in primarily Greece, France and Spain.

Although CSP is amongst the cheapest renewable energy sources, it needs to shift the efficiency of the subsystems and the system as a whole to the highest level, while minimising the cost of the systems. The challenges are to a large extent related to engineering and demonstration to increase the scale of CSP power plants. The main scientific challenges are related to energy storage as this defines to a large extent the success of CSP.

2.1.1 Fifth Framework Programme

Photovoltaic

At the start of FP5 the most important challenge was to scale up production and to increase both the practical as well as the laboratory efficiency of solar cells. In this challenge, several different emerging technologies were competing, however, further exploration of potential new technologies was also on the agenda. The goals for the different pv-technologies during the FP5-period are given in Figure 1.
Solar thermal

The low temperature ST for hot water preparation in particular had already taken off in this period. Especially in China and Taiwan there was a huge increase in installed collectors, albeit the use of low-key technology. However, ideas for integration into other domestic and industrial systems were investigated. Space heating, cooling, cooking, and industrial use of the low-temperature are thought of, but only received limited attention. Development of these areas would require R&D, especially engineering efforts.

Figure 2 shows the global annual installed capacity of solar thermal power. Not much scientific work was done on the improvement of these low temperature systems. However, ideas for integration into other domestic and industrial systems were investigated. Space heating, cooling, cooking, and industrial use of the low-temperature are thought of, but only received limited attention. Development of these areas would require R&D, especially engineering efforts.

---

1 For the goals of 2002, we based us on the goals for 2000 and 2005 and took the weight average of these values, thus assuming that the goals follow a linear growth: goals often do.
In the domain of high-temperature ST’s, decreasing the cost of STE was the largest challenge. The Cost Reduction Study for Solar Thermal Power Plants, prepared for the World Bank in early 1999 concludes that the potential market of STE could reach an annual installation rate of 2,000 MWe. The White paper of the EC for a community strategy and action plan of 1997 foresaw at least 1 GWe of those systems implemented by the year 2010. This was to be realised by the implementation of 20-30 commercial CSP’s in Southern Europe, of 30-50 MWe each. However, the report identified several technological and scientific barriers to overcome.

Technological challenges in this period were development of large plants against low cost. Therefore, R&D focussed on development of improved components and subsystems. For each sub system several technological alternatives exist and these need testing. To reach the goal of 1GWe in 2010, the receiver plants will need to scale up, while lowering the costs. Large-scale deployment or commercial demonstrations were the main goals. In this period, only small projects have been carried out in Europe. Spain is the epicentre of the implementation activities for central receivers (e.g SOLGAS and Colon).

Furthermore, several demonstration projects showed that the lifetime of CSP was often too short in order to be commercially interesting. More demonstration projects were needed to test what combinations of sub systems lead to high efficiencies, with low cost and long lifetime.

To conclude: at the start of FP5, low temperature ST was already growing fast. For high temperature ST many technological challenges remained. Just as in other renewable energy domains, main drivers where to increase efficiency while lowering cost.

### 2.1.2 Sixth Framework Programme

**Photovoltaic**

At the time of FP6, the most important challenges were to further increase the production of PV-systems, while decreasing the costs of the complete system. Important challenges were to be found in the lifetime of the systems, the efficiency of the cells and lowering of the (industrial) production costs. The goals for the different pv-technologies during the FP6 period are given in Figure 3.

---

Figure 3 The aims in 2002 for the efficiency of pv-cells (%)

<table>
<thead>
<tr>
<th>Semiconductor</th>
<th>Achieved in 2000</th>
<th>Goal 2005</th>
<th>Goal 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>sc-Si</td>
<td>15-17</td>
<td>16-18</td>
<td>&gt;20</td>
</tr>
<tr>
<td>mc-Si</td>
<td>13-15</td>
<td>14-16</td>
<td>&gt;20</td>
</tr>
<tr>
<td>a-Si</td>
<td>10</td>
<td>12</td>
<td>&gt;15</td>
</tr>
<tr>
<td>III-V</td>
<td>24</td>
<td>25</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>


Solar Thermal

For Solar thermal energy sources, by the time of FP6 a broad range of solar collectors is available. Domestic hot water applications are well developed and are undergoing only increment changes. The Campaign for Take-Off (CTO) launched by the European Commission set mid-way targets for 2003. In 2002 these targets were almost met (see Figure 4).

Figure 4 The goals for 2003 and the achievements at 2002

<table>
<thead>
<tr>
<th>Installed capacity M m²</th>
<th>2002 (achieved)</th>
<th>2003 CTO</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.6</td>
<td>15</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: ESTIFF, CTO and White Paper3

However, for other low temperature applications R&D is still needed. The ESTIF4 issued an action plan for ST in Europe5. A first research priority they set was to integrate ST in the existing heat and construction technologies, in order to improve implementation. Integrated systems have a higher consumer convenience and therefore more likely to be implemented successfully. Research issues were the combination of ST with other renewable energies such as biomass, heat pumps, and standardised integration with space heating and cost effective applications for industrial process heat. Industrial process heat can be applied in a range of sectors, for instance for drying processes, evaporation, pasteurisation etc. and therefore has a huge potential. However, to realise this potential the cost of the heat needs to be comparable with current systems6. Most of these issues were challenges on the engineering level. The low and medium temperature options are however not present in the FP6 of DG Research and are therefore not part of the projects evaluated.

Further, new applications needed research as well. The following potentials were identified: 7

- Medium and long-term heat storage. Because solar energy is most available in summer, while the demand is lowest, it would pay off to store heat. Experimental storage facilities are being tested. Further R&D is needed in order to increase the efficiency.

- Solar Cooling. Cooling is needed then, when the sun is shining most. At this time, the first solar assisted cooling systems were on the market. The remaining research priorities were

---

4 European Solar Thermal Industry Federation
further development of small cooling units, system integration with other domestic ST applications and development of cooling units that are capable of using low temperature heat.

- Desalination. Solar thermal collectors can be used for desalination and disinfection of drinking water. Research issues remained on the corrosion resistance of the material used and on the development of specialised collectors. In both areas iterative processes were needed of basic research as well as piloting, in order to gain system know-how.

High temperature ST also continued its developments. In 2003, the total amount of demonstration projects counted up to 2.7 GWe of CSP. Most of these projects aimed to begin commercial operation before 2010. The total planned investment represented 4.5 billion €, including $200m of GEF grants and €15 m of grants for demonstration projects from the FP5. As a result, the forecast made in the White paper of 1997 (1 GWe) would be reached. However, CSP still needed further research to overcome several technological problems. To bring CSP to the energy markets – and thus lower the cost by means of economies of scale – there were several important issues identified: resource assessment, improved performance, cost reduction.8

**Resource assessment** is important for CSP in several domains. First of all it is important to have an accurate assessment of the solar radiation and the fluctuations in it. Furthermore, these radiation levels need to be linked to other resources, such as infrastructure, land use etc. The increase of performance is a continuous research effort. Increased performance of the system will mean that for the same amount of power, less material, land etc. is used and this will therefore decrease the cost. The main parts of the system to improve are the optical, thermal as well as the conversion technology, i.e. the technology to convert heat to electricity. Improving the performance and the operating hours of the system will increase the total energy generated and therefore the revenue per plant. **Cost reductions** can be made in the CSP components; these costs can add up to 50% of the total cost due to the low production scale; scale benefits are to be expected and mass production would reduce these costs.9 Also, operation and maintenance cost could be decreased. Improved component design is needed to reduce mirror breakages that often occur. Improved mirror performance requiring less cleaning is also an R&D challenge.

While the domestic application of low temperature ST is growing vastly in the traditional market, R&D is needed for new applications of ST. Interesting fields are application in industry, in cooling and desalination. CSP is still in its pilot phase. Scientific challenges remain in lowering the costs (operational and production) while increasing the efficiency.

### 2.1.3 Seventh Framework Programme

**Photovoltaic**

At the start of FP7, the most important challenges are again to further increase the production of PV-systems, while decreasing the costs of the complete system. Also, increasing the sustainability of the PV-modules is a challenge.

The Strategic Research Agenda of the European Technology Platform on Photovoltaic summarises the main challenges. This is shown in the table below. For more detail we refer to the SRA10.

---

9 This could for instance be reached when ST is applied in industrial processes as well.
While heating and cooling make up a large part of the energy consumption, there still is a large potential in low and medium temperature ST. In recent years this potential has not been fully exploited; according to several expert opinions more efforts are needed. The European Solar Thermal Technology Platform for instance developed a Strategic Research Agenda which identifies several challenges in order to boost ST:

- The number of solar thermal systems has to be sharply increased
- ST has to be introduced in new market segments like the commercial and industrial sector (R&D and market deployment measures are needed)
- New ST applications, e.g. Solar Assisted Cooling and process heating have to be developed (strong R&D and market deployment measures are needed)

The SRA puts strong emphasis on new fields of application like industrial process heating, water treatment and desalination. These new fields of applications demand both basic as applied research on many parts of the systems. Main issues are raised about the collectors, thermal storage, collector development and improving the systems and integrating the systems, see Figure 6.

In the high temperature CSP field, the challenges remain the same as in the FP6 time frame. At the start of FP7, the goals are relatively the same as at the start of FP6. However, there is an increased call for developing more applications of the low-medium temperature ST, especially by the industry that has developed in Germany and Spain. Research topics remain in thermal storage, collector development and improving the systems and integrating the systems, see Figure 6.

---


12 ESTTP, Strategic Research Agenda for Solar Heating and Cooling”, December 2008
2.2 Political/regulatory challenges and opportunities

During the course of FP5-FP6 the Commissions ambitions towards renewable energy have become more challenging and more explicit. In the FP5 period there were no clear targets with regard to renewable energy. There was a general believe that renewable energy was important. At the end of the FP6 period clear and ambitious targets have been developed, resulting in the overall binding target to have 20% renewable energy by 2020. This target has a big impact on European research in the area of renewable energy and solar energy in particular.

No specific targets have been set for the share of solar energy in the renewable energy mix in Europe and there are no specific policy actions towards the promotion of solar energy at EU level. Solar energy, and pv in particular, is seen as one of the possible technological options that can contribute to a more sustainable energy system in the (near) future. Pv is one of the most expensive form of renewable energy today so for the large scale application of pv in Europe it is imperative to reduce costs. Cost reduction is also the underlying rationale for EU RTD activities in this area, because cost reduction will for a large share come from scientific and technical progress.

The Strategic Research Agenda for photovoltaic solar energy technology (published in 2007) is an important document that lies down these main scientific and technical challenges to achieve the ambition of pv. This SRA is written and validated by the European (research) sector and because of its broad acceptance in the sector also used by European policymakers to define research priorities in FP7 calls. It is clearly the most important document with regard to public research priorities in this field. During the FP5 and Fp6 period such a document did not exist.
For high temperature ST for electricity, a roadmap is developed in the ECOSTAR project of FP6. In this project many of the important players were involved. Several technological alternatives were investigated and compared, based on several demonstration projects. The roadmap shows many of the technological challenges in high detail, and indicates which improvements require which efforts. As a result, more focus in the research has emerged. Nevertheless, the ECOSTAR roadmap does not seem to have the large exposure as the SRA of pv does.

2.3 The environmental challenges
Solar energy can contribute to some of today’s key global environmental challenges, because electricity from solar energy is clean, without emission of hazardous gasses nor CO2 emission.

With regard to the technology itself there a number of environmental challenges:

- Solar systems have “embedded energy”, because production pv modules is rather energy consuming. Currently it takes about 2-4 years to earn back the energy that was needed for the production (energy pay back time). The challenge is to reduce the environmental impact of pv production.

- Inorganic pv uses hazardous materials which provide a potential health treat and also high temperature ST uses fluids which can be hazardous. The environmental challenge is to reduce the use of hazardous materials or replace these materials by non-hazardous materials.

- A large share of the energy use is a demand for heat. A challenge for ST remains to satisfy the heat demand directly with heat from sunlight. This would make conversion of energy carriers redundant.

2.4 The social challenges
The solar resource (the sun) is widely available, meaning that it can be applied almost anywhere in Europe and the world. And because of the modularity of solar energy, it is accepted as a means to serve energy needs in dispersed and isolated communities.

Europe has a leading technology position in the pv sector and has a significant market share of pv capacity installed. The pv industry is high-tech and offers huge potential for Europe in terms of economic growth, (highly skilled) jobs and energy security and diversification. Also in high temperature ST Europe holds a strong position, as well as in niches of low temperature ST. An issue in all these sectors is however the availability of skilled labour in Europe at different levels (research, installation, etc).

2.5 The economic challenges
Obtaining cost savings is the key challenge for both pv and ST and for years the main focus of R&D efforts in Europe and other parts of the world. Both R&D and the creation of a market for pv systems can contribute to this reduction of costs. Furthermore, for low temperature ST there remains the challenge to integrate the solar heat in many other systems, such as cooling, refrigerating, heating and etc.

- R&D. Both for pv and CSP it is believed that cost reduction will result from technical progress, so ongoing investments in R&D are needed. Cost reductions by R&D are described in the SRA’s and roadmaps and a key challenge for the sector.

- Economies of scale. In the case of pv this means scaling up the industrial production process in order to reduce the cost per module produced. And this means that market development and stimulating demand is important to achieve cost reductions. Although electricity generated by pv is showing a continuous reduction in price, it is still no competitive with electricity prices from other sources. In Europe many governments have recognised and have developed various policy schemes aiming to develop a market for pv and have economies of scale. The German “Renewable Energy Sources Act” (EEG) is a successful example that has indeed created a market for pv in Germany and as result production costs of pv have been reduced due to economies of scale. Achieving economies of scale is a key challenge for the sector.
3. EC-funded research activities in the area

With regard to solar energy there are not specific priorities. The main objective is reduction of costs of solar energy, but the EC has not specified more details how to achieve this. Within this broad objective researchers were free to submit proposals and projects are selected bottom-up. In FP7 there more strategic priorities are set with regard to RTD objectives. In the field of pv the SRA provides more specific guidance towards research priorities.

On the other hand, there are no “blind spots” in European research in the field of solar. This means that all important research topics with regard to solar energy are covered. The SRA in the field of pv has clearly contributed to the structuring of research priorities at the European level, but it was published at the end of FP6.

European research is small share (about 20%) of total amount of public research activities in Europe. This means that the Commission can try to influence the remaining 80% research that is funded by the member states into a direction desired by the EC or align with national research projects. The SRA pv is an example of the first and co-funding of the 11 MW solar thermal power plant in Spain is an example of the latter.

European research funding has some unique features, the most important one being stimulating international research collaboration, which is an important objective.

3.1 Objectives and rationales

3.1.1 FP5 objectives

The objectives with regard to renewable energy, and solar energy in particular, were very broad in FP5. As a result there was hardly any strategic steering on which research topics to fund and which ones not. It was a bottom-up competitive process meaning that excellent scientific ideas that fitted within the overall targets got funding. There was not prioritisation of topics within the field of solar energy by the Commission. Since FP5 there was more emphasis on the environmental aspects of energy. There was much focus on renewable energy and minimising the negative effects of the use of fossil fuels. This can in part be explained by a context of decreasing public acceptance of nuclear power and of concern about the environmental impacts of fossil fuels.

The goal of the NNE programme in FP5 was to develop the energy system in such a way that it would contribute to a sustainable energy supply. Setting these goals led to three bundles of activities:

- Cleaner energy systems including renewable like solar,

  "With regard to solar this means the development and demonstration, including for the purposes of decentralised generation, of the main new and renewable energy sources, in particular biomass, fuel-cell, wind and solar technologies. And integration of new and renewable energy sources into energy systems."

- Economic and efficient energy for a competitive Europe,

  "No specific targets for set for solar energy"

- R&D activities of a generic nature.

  "No specific targets set for solar"

The objectives of these key actions were respectively to reduce the environmental impact of energy production and use and to produce a reliable, clean, efficient, safe and economic supply of energy.
3.1.2 FP6 objectives

The policy objective of FP6 is to create sustainable energy systems. Thus, the strategic goals of FP6 include the reduction of energy-related greenhouse gas emissions in accordance with the Kyoto Protocol, the enhancement of European energy security, the increase of energy efficiency and productivity, and the adoption of renewable energy technologies. These strategic aims are meant to increase European industry’s competitiveness and the living standards of European citizens.

In FP6, energy research is mainly funded under the ‘Sustainable Energy Systems’ (SES) subpriority. This SES is built up from two complementary parts: Short to medium-term research (DG Energy and Transport) and medium to large term Research (DG Research).

Within regard to solar energy, more specific targets were set in relation to FP5. Although still rather broad, the objectives of FP6 in the field of solar were more specific and more clear (see section below). So, there was more strategic steering on the funded research activities than during FP5.

3.1.2.1 Short to medium term research

These activities are predominantly demonstration-type actions, with a research component of about 20%. These activities include pre-normative and socio-economic research, energy technology integration, dissemination, technology transfer activities, and technological, market-related and financial issues. These topics are financed by DG TREN and therefore not part of this evaluation.

**Electricity from photovoltaics. Priorities to be addressed are:** Innovative production concepts for high efficiency PV cells/modules to be integrated into larger scale (multi-MW) photovoltaic production facilities in order to lower the Wp cost; and including low cost integrated components or devices for grid connected or stand alone PV generators; Support actions aimed at kick-starting Si-feedstock production by EU industries to secure a reliable and affordable supply for fostering PV cell cost reductions; Transfer to industrial scale of a new generation of PV technologies / products to facilitate the integration of innovative solutions at lower costs; Large area, low cost photovoltaic modules for building integrated PV (BIPV) and autonomous solar electricity generation systems in industrialised and developing countries; Integration of photovoltaic installations in generation schemes to feed local distribution grids, closer to the point of use and development of new devices and systems to manage these installations.

**Heat/cooling from renewable energy sources:** Solar heating and cooling based on a new generation of solar water heating, solar space heating and/or cooling systems, or "combi-systems", which are designed for large scale production with improved performance and reduced costs; Solar industrial process heating or solar desalination systems with improved performance at competitive costs;

In addition research is conducted on the large scale integration of renewable energy like solar energy sources into energy supplies (integration of distributed electricity generation, storage of electricity, optimised schemes for providing heating and cooling from solar in buildings, etc)

Source: http://cordis.europa.eu/sustdev/energy/energy.htm

3.1.2.2 Medium to long term research

Research activities with impact in the medium and longer term focus on research and development, research-related networking activities, training and dissemination activities. This part is more about scientific and technological issues rather than market and financial...
implementation issues. The main targets are to decrease the cost of electricity and fuel to competitive levels through developing highly efficient concepts and bringing about major cost reductions in the entire production chain, as well as improving the reliability, safety, availability and durability of renewable energy systems.

For photovoltaics, the strategically important areas in which research should be concentrated are: innovative concepts and fundamental materials research for the next generation of PV technologies (e.g. organic or hybrid solar cells), thin film PV technology (development of cost-effective PV cells and modules based on new and improved technologies and materials), PV processing and automated manufacturing technologies (to reduce the costs and improve materials usage in the manufacture of PV cells and modules), PV components and systems - balance of systems (research into components and their integration into the overall system) and the research for innovative applications of PV in buildings and the built environment (to develop integrated PV module systems which are configured for ease of mounting on building roofs and facades, hybrid PV/heating systems). The main targets are to: decrease the investment cost for PV systems to 1-2 €/Wp (with a module cost of 0.5-1 €/Wp) by 2015 and to decrease PV electricity cost to below 0.1 €/kWh by 2015.

Concentrated solar thermal (for electricity and heat generation: new concepts for low-cost, efficient and reliable components and systems; for non-electrical processes: high temperature chemical solar reactors for the production of hydrogen and other high-value materials). The main target is to decrease the cost of electricity production with these RES to 0.05 €/kWh by 2020.

Source: http://cordis.europa.eu/sustdev/energy/energy.htm

3.2 Structure and main characteristics of research activities
The area dedicated to solar energy represents 18.8% of DG RTD’s contribution to the energy area (83.8 Mln Euros) in FP5 and 17.5% in FP6 (76.1 Mln Euros). In FP5, 93 projects were funded for 625 participations and 365 distinct participants were detected. In FP6, 20 projects were funded for 261 participations and 147 distinct participants.

Figure 7 present consortium profiles of solar energy projects in FP5 instruments. About 89% of the total number of projects correspond to shared-cost actions in FP5. Regarding the size of consortium profiles, we note a homogeneous distribution of maximum consortiums among FP5 instruments.

Figure 8 highlights that European Commission funding covers 50% of total eligible costs of FP5 shared-cost actions in solar energy and over 85% of total eligible costs of other FP5 instruments. About 96% of total EC funding in the domain of solar energy is granted to FP5 shared-cost actions.
Figure 8  Funding profiles in FP5 instruments

<table>
<thead>
<tr>
<th></th>
<th>Minimum Funding</th>
<th>Average Funding</th>
<th>Maximum Funding</th>
<th>Total EC funding</th>
<th>Total eligible costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared-cost actions</td>
<td>0,02</td>
<td>0,99</td>
<td>2,38</td>
<td>89,27</td>
<td>167,03</td>
</tr>
<tr>
<td>Accompanying measures</td>
<td>0,18</td>
<td>0,41</td>
<td>1,00</td>
<td>2,48</td>
<td>2,92</td>
</tr>
<tr>
<td>Support to networks</td>
<td>0,40</td>
<td>0,40</td>
<td>0,40</td>
<td>0,80</td>
<td>0,82</td>
</tr>
<tr>
<td>Fellowships</td>
<td>0,13</td>
<td>0,14</td>
<td>0,15</td>
<td>0,42</td>
<td>0,42</td>
</tr>
<tr>
<td>Total</td>
<td>92,97</td>
<td>171,19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9 present consortium profiles of solar energy projects in FP6 instruments. It reveals that about 60% of the total number of solar energy projects correspond to Specific Targeted Projects in FP6.

Figure 9  Project profiles in FP6 instruments

<table>
<thead>
<tr>
<th></th>
<th>Minimum Consortium</th>
<th>Average Consortium</th>
<th>Maximum Consortium</th>
<th>Number of projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Projects (IP)</td>
<td>17</td>
<td>21,5</td>
<td>28</td>
<td>4</td>
</tr>
<tr>
<td>Specific targeted research proj. (STREP)</td>
<td>5</td>
<td>10,25</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Coordination actions (CA)</td>
<td>4</td>
<td>13</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 10 discloses that 56% of EC funding in the domain of solar energy is allocated to FP6 IPs and about 39% to FP6 STPs. The table shows that about 58% of total eligible costs of FP6 solar energy projects is covered by EC funding.

Figure 10  Funding profiles in FP6 instruments

<table>
<thead>
<tr>
<th></th>
<th>Minimum Funding</th>
<th>Average Funding</th>
<th>Maximum Funding</th>
<th>Total EC funding</th>
<th>Total eligible costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Projects (IP)</td>
<td>7,00</td>
<td>10,58</td>
<td>16,00</td>
<td>42,34</td>
<td>75,40</td>
</tr>
<tr>
<td>Specific targeted research proj. (STREP)</td>
<td>1,79</td>
<td>2,50</td>
<td>4,19</td>
<td>29,99</td>
<td>52,06</td>
</tr>
<tr>
<td>Coordination actions (CA)</td>
<td>0,22</td>
<td>0,94</td>
<td>1,70</td>
<td>3,77</td>
<td>4,30</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>76,10</td>
<td>131,75</td>
</tr>
</tbody>
</table>
3.2.1.1 Participants profile

Figure 11 presents the distribution of the funded participations by type of participant in FP5 and FP6. The figures lead to the following observations:

- Research centres are the main beneficiaries of EC contribution in FP5 and FP6 projects in the area of solar energy.
- Evolution of this distribution points up a strong increase of number of participations of research centres in solar energy research (40% in FP6 against 31% in FP5) and decrease of industrial participation from 44% in FP5 to 33% in FP6.
- Research centres and industries are the main beneficiaries of EC contribution in FP5 and FP6 projects in the area of solar energy.

![Figure 11: Distribution of participations by type of participant in FP5 and FP6](image)

3.2.2 Participants profile through social network analysis

Figure 12 and Figure 13 illustrate collaboration between countries in FP5 and in FP6 solar energy projects. The main elements to stress are:

- In FP5 solar energy projects, collaboration between countries was organised around 2 main groups:
  - New member states (red triangles) mainly collaborated with each other
  - EU15 Member states mainly collaborated with each other and predominantly with Germany, Spain and with Switzerland (associated country)
- In FP6 solar energy projects, collaboration between countries focused on four countries: Germany, Spain, France and Israel (IL; associated country).

Comparing both figures clearly shows that the number of collaborations between countries has increased significantly; the FP6-network (Figure 13) is denser than the FP5-collaboration.

---

13 Explanation of the network figures: The position of nodes in the graph (centrality/periphery) provides information on the involvement of countries or research entities in the most prominent projects. As an example a participation in an integrated project or a network of excellence will contribute to locate a node in a central position. On the contrary Specific support actions or small specific targeted research projects will contribute to move node away from the centre. The size of nodes reveals the number of direct and indirect connections with other nodes. There is an indirect connection when a node is on the path between two other nodes. The social network analysis locates the nodes regarding the geodesic distance (shortest path) between nodes. Concretely, the bigger the node (country or legal entity) the more likely it is that the node is on the path between others nodes. It is called a power indicator and helps to identify key stakeholders in each area. The proximity between nodes (countries or research entities) indicates collaboration frequency between countries or legal entities. Hence, core groups can be easily distinguished through the graphs.
network (Figure 12). This can be explained because new instruments are introduced in FP6 (i.e. integrated projects and networks of excellence) that stimulated the development of big pan-European networks.

Furthermore Figure 13 shows a rise in the number of international cooperation countries collaborating in solar energy projects; these countries collaborate first and foremost with Germany, France, Spain and Israel and also with each other. It also reveals that some EU countries participating in FP5 solar energy projects are no longer present in FP6, for instance Luxembourg, Ireland, Portugal and Greece.

Three associate countries collaborate significantly with other countries involved in FP5 and FP6 solar energy projects: Switzerland and to a lesser extent Norway both record a drop in the number of collaborations with other countries. On the contrary, Israel experienced an extensive increase in its collaboration with countries involved in FP6 solar energy projects.

Figure 12  Collaboration between countries in FP5 projects (Solar energy)
Figure 13 Collaboration between countries in FP6 projects (Solar energy)

Figure 14 and Figure 15 present participants and participations in FP5 and FP6 solar energy projects. The figures draw the following observations:

- The number of projects, participations and participants considerably declined
- Major participants in FP5 solar energy projects are:
  - the National Centre for Scientific Research (CNRS), France
  - the Fraunhofer research institutes (FhG), Germany
  - the Energy research Centre of the Netherlands (ECN)
- Key participants in FP6 solar energy projects are:
  - the National Centre for Scientific Research (CNRS), France
  - the Fraunhofer research institutes (FhG), Germany
  - the Energy research Centre of the Netherlands (ECN)
  - the Atomic Energy Commission (CEA), France
  - the Centre for research in Energy, Environment and Technology (CIEMAT), Spain
Figure 14 Participants in FP5 projects

Figure 15 Participants in FP6 projects

Analysis of the participations reveals that all main European universities and research institutes in the field of solar energy are involved in European funded research. At the same time new universities and institutes are involved as well. With the emerging of new concepts to produce pv-cells (i.e. deposition technology) and the need for analysis and modelling other areas of expertise are needed. During FP5, but especially during FP6, research groups from
other disciplines like physics or chemistry that have no direct history in semiconductor or PV related research are attracted as well and participate in projects.

### 3.3 Content and evolution of research activities between FP5 and FP6

The solar energy projects have a high level of industrial relevance because the overall aim was (and still is) to reduce costs of solar energy systems which has an obvious interest of the industry. For pv, the long term objective is to reduce the cost of a typical turn-key system from 5 Euro/Wp today to 1 Euro/Wp in 2030 and even 0.5 Euro/Wp in the long term future. For solar thermal this focus on cost reduction has not changed during the course of FP5 and FP6.

**Photovoltaic**

With regard to pv, there was a strong focus in FP5 on transfer of lab results and processes to industrial production. Many relatively small and focused research projects were funded in well-defined areas. Research projects were funded in both thin film (CIS/CIGS and silicon thin film) and crystalline silicon solar cells. Also more advanced topics got funded including organic solar cells and roll to roll manufacturing technologies which is at least 20 years away from market introduction. Research done in the area of crystalline silicon and thin film in FP5 is about 5-7 years from commercial (pilot) application. Topics include:

- Research on new materials or optimal usage of solar material,
- Research on cell and module design and manufacturing (i.e. improve efficiency, increase production yield, etc) for both thin film and crystalline solar cells,
- Systems (i.e. BoS) and pv concentrator technology
- Building integrated pv (pv for built environment)
- Standards and others
- Network development and coordination activities in the frame of the ERA

In FP6 in general bigger projects got funded than in FP5 with a broader research focus than many of the FP5 projects. The overall aim is still improving efficiencies and reduction of cost, mainly by optimizing manufacturing processes. In FP6 the same topics are important as in FP5 and many research trajectories started in FP5 got follow-up in FP6 (and in national programmes in for instance Germany). FP6 projects are closer to market application than FP5 projects, typically between 1-3 years.

A clear difference with FP5 is that in FP6 there is more attention for integration and “an overall system perspective”. Especially the big IPs aim to bring together all relevant partners and knowledge on a certain topic and “wrap up” all the knowledge and expertise developed in the past decade. Four IPs are funded in FP6 and these IPs represent the main research topics in both FP5 and FP6. The IPs are:

- Crystal Clear on crystalline silicon. The project aims to reduce the cost of modules by optimising different parts of the value chain (i.e. feedstock, wafers, cells, modules)
- Athlet on thin film technologies. The project aims to provide the scientific and technological basis for industrial mass production of cost effective and highly efficient large scale thin film solar modules
- Full spectrum on (among others) concentrator technology and high efficiency multi-junction solar cells. The project aims to make use of the full solar spectrum to produce electricity.

---

• Performance on measurement and characterisation. The project aims to develop reliable test procedures and measurement methods for pv modules.

Solar Thermal

While wind, biomass and pv rely on a long base of R&D and public investments (both national and on European level), solar thermal has long been standing on the sideline. Both on national and European level, funding has been unstable for Solar Thermal.

In FP5 many different topics in the field of solar thermal were funded and projects were relatively small. The set up of FP5 was generally broad, funding was not only dedicated to CSP, but also to newer and more basic problems, such as solar cooling, air conditioning etc. Most visible in FP5 were three large demonstration projects in Spain in the field of CSP (PS10, ANDASOL, and SOLAR TRES plants). Each project received a EU contribution of €5m, for the PS10 – this was about 30% of the total investment of these projects. The demonstration projects have resulted in the building of 3 power plants - of which 2 are finished today.

In FP6 larger projects got funded and with regard to CSP there was a focus on subsystems and storage of energy in particular because this is a key issue for CSP. Storage is a factor for sun energy, to cover up for the low energy production at less sunny days in spring and autumn, and for energy at night. There are many ways to store energy, for instance in the form of hydrogen, hot fluids or phase change materials; these alternatives are researched in FP6. Where FP5 launched three large demonstration projects, in FP6 no demonstration projects got funded. Other topics in the field of solar thermal have received less attention in FP6, although there might be high potential that could benefit from European attention16,17.

17 ESTTP, Strategic Research Agenda for Solar Heating and Cooling”, December 2008
4. Scientific achievements

4.1 Outputs

An online survey among project participants was conducted during September and October 2008. In total 65 participants in the theme solar energy responded to this survey, resulting in a response rate of 14%.

In the survey participants were asked for direct results of the research (outputs). These can be scientific research results or technological results, which may enable the creation of new products or processes, create new intellectual property or increasing technological awareness. It is expected that these outputs will lead to results for the direct beneficiaries of the programmes and, hopefully, that these will lead in future to an impact on society at large.

All respondents were provided with a list of 18 potential outputs from their project and asked to indicate for each whether they had been produced by them or other members of their own organisation as a direct result of the project. It is important to highlight that most of the FP6 projects had not yet finished. These respondents were therefore stating the extent to which outputs had been produced so far, rather than the final achievements.

All 65 respondents reported having produced at least one of the outputs listed. The full list of outputs and the proportion of respondents who reported having produced each is shown in Figure 16. The most commonly produced outputs from projects have been ‘conferences, seminars and other events’ (97%) and ‘new or improved tools, methods or techniques’ (94%). The least commonly produced outputs were ‘spin-off companies’ (10%) and ‘licenses sold’ (13%). This ranking for the theme solar energy is the same as for all other fields, though a higher share of respondents in the solar energy theme indicates that results have been produced compared to the overall findings for all themes.

For those respondents reporting a particular output having been produced, they were further asked to estimate the number in each case. Based on these figures, it has been possible to calculate the average number of each output produced by these respondents. Than we calculated the average number produced by any participant, regardless of whether they reported actually producing the output or not (second column of Figure 16). This allows us to ‘gross-up’ to the total number of participants involved in all FP5 and FP6 NNE projects and estimate the total number of outputs produced overall across the programme so far which is shown in the last column of Figure 16.

So, for example, on average solar energy participants produced between 3 and 4 events during a project and therefore an estimated 3,101 events have been produced overall across all solar energy projects. Compared to the other themes solar energy was particularly strong on events, newly qualified people and new jobs. There is no significant change in type and average number of outputs between FP5 and FP6.
Figure 16  Outputs produced as a direct result of the project in solar energy (n=65)

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Share of respondents indicating that output is produced</th>
<th>Average output for all participants</th>
<th>Total maximum estimated outputs for all projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conferences, seminars and other events</td>
<td>97%</td>
<td>3.5</td>
<td>3101</td>
</tr>
<tr>
<td>New or improved tools, methods or techniques</td>
<td>94%</td>
<td>3.0</td>
<td>2658</td>
</tr>
<tr>
<td>Publications in refereed journals or books</td>
<td>90%</td>
<td>3.1</td>
<td>2747</td>
</tr>
<tr>
<td>Newly qualified personnel (e.g. MSc, PhD, etc)</td>
<td>89%</td>
<td>2.4</td>
<td>2126</td>
</tr>
<tr>
<td>Other publications</td>
<td>86%</td>
<td>2.8</td>
<td>2481</td>
</tr>
<tr>
<td>New R&amp;D strategy</td>
<td>77%</td>
<td>2.4</td>
<td>2126</td>
</tr>
<tr>
<td>New or improved processes</td>
<td>75%</td>
<td>1.8</td>
<td>1595</td>
</tr>
<tr>
<td>New or improved demos, prototypes, pilots,..</td>
<td>73%</td>
<td>1.5</td>
<td>1329</td>
</tr>
<tr>
<td>New or improved models and simulations</td>
<td>71%</td>
<td>1.7</td>
<td>1506</td>
</tr>
<tr>
<td>New jobs</td>
<td>69%</td>
<td>1.6</td>
<td>1418</td>
</tr>
<tr>
<td>New or improved products</td>
<td>65%</td>
<td>1.5</td>
<td>1329</td>
</tr>
<tr>
<td>New or improved services</td>
<td>46%</td>
<td>0.8</td>
<td>709</td>
</tr>
<tr>
<td>Patent applications</td>
<td>38%</td>
<td>0.5</td>
<td>443</td>
</tr>
<tr>
<td>Other outputs</td>
<td>33%</td>
<td>0.1</td>
<td>89</td>
</tr>
<tr>
<td>Copyrights</td>
<td>32%</td>
<td>0.9</td>
<td>797</td>
</tr>
<tr>
<td>Software or codes</td>
<td>29%</td>
<td>0.5</td>
<td>443</td>
</tr>
<tr>
<td>New or improved norms or standards</td>
<td>17%</td>
<td>0.3</td>
<td>266</td>
</tr>
<tr>
<td>Licenses sold</td>
<td>13%</td>
<td>0.1</td>
<td>89</td>
</tr>
<tr>
<td>Spin-off companies</td>
<td>10%</td>
<td>0.4</td>
<td>354</td>
</tr>
</tbody>
</table>

Source: Participant survey

The interviews confirm the large amount of (maximum) outputs produced in the EC funded projects. During the interviews we found evidence of all types of outputs listed above. In general the interview partners confirm that the projects are of good scientific quality and that the scientific impact of the projects is high. Especially the FP6 Integrated projects produced many publications in (refereed) journals and conferences. The FP5 projects are smaller and more focused, but show high scientific quality as well.

4.1.1 Scientific and technical challenge: increase efficiencies

Technical and scientific goals are achieved in most projects and the main challenges related to efficiency as formulated in section Error! Reference source not found. have been addressed and achieved. Some projects did not achieve their goals, but even then much knowledge was developed on materials or processes to improve efficiencies and/or to reduce production costs of cells. If a scientific or technical project goal is not achieved, the reasons mentioned by the interview partners are that the goals were too ambitious or that the project was delayed and because of that goals were not (yet) achieved.

For example, in the Athlet project (FP6) one of the goals was to demonstrate 15% efficiency of a poly Si cell on foreign substrates in laboratory environment. The state of the art at the start of the project was 9%, achieved by the Japanese firm Sanyo. During the project good progress was made and much knowledge was generated to improve efficiencies of this type of cell. Until now a lab efficiency of 14.4% is achieved and the project partners are confident that the goal of 15% will be achieved before the project ends in January 2010. For amorphous Si the state-of-the-art was 9%. The aim of the project was to reach 14%, but this goal is too ambitious, according to one of the main research partners interviewed, and will not be achieved. However, this does not mean that the project is a failure, because a lot of knowledge is gained about the different layers (a a-Si cell is made up of about 15 layers) and how to optimize these layers.

Another example comes from the Larcis project. The main goal of the Larcis project was to optimise manufacturing technology for the different layers of CIS thin film solar cells. The project achieved good scientific and technical results, most notably it proofed that 19% cell
efficiency (in lab) can be reached with a novel buffer layer using an inline deposition process. This breakthrough enables industry to improve efficiency of the modules and at the same time reduce production costs. It is expected that this technology will soon find its way to industry as it offers huge potential.

4.1.2 Scientific and technical challenge: cost reduction

For the challenges related to reduction of production costs of solar energy it is much more difficult to determine if European projects have achieved this. Clearly, all EC funded projects are geared to cost reductions, for instance by reducing the amount of silicon used in the production process, or by increasing the effectiveness of heat storage systems. The potential for cost reduction based on lab or small pilot tests is often proofed and clearly stated.

But to determine whether cost reduction has indeed been achieved in practise is difficult to measure. A new (process) technology or cell design, etc developed in an EC funded projects and which has the potential to reduce costs needs to be applied by industry first before cost reductions in pv production becomes visible. But even then it is difficult to quantify these cost savings and the impact of the EC funded project on this, because industry is not willing to give insight into their production costs because this is very sensitive information of competitors. During the interviews with industry we have found some clear evidence that suggest that industry has applied some of the results coming out of EC funded research which has indeed resulted in significant costs savings. It has however not been possible to quantify this because of confidentiality issues.

For example in the Flash project a new approach to rapid thermal processing was developed. This was applied by the industry partner in the production line and resulted in a higher throughput and hence a cost reduction of about 10%. This illustrates that technology developed in EC funded project can indeed have a major impact on the competitiveness of the European pv industry. Other industry partners interviewed for this study claim significant impacts of EC funded projects on their organisation, but are unable to quantify this. In section 6 we will focus more on the economic impact.

In addition, the structure of pv production was analyses thoroughly in the Crystal Clear project (FP6). The consortium gathered anonymous data from the industrial partners about their production efficiencies and costs and was able to build a database which gave insight into the production costs of pv and where opportunities for cost reduction and efficiency improvement are. Some first conclusions are that the data proved to be very reliable and that the production of solar cells has indeed become much more efficient in recent years. This means that the energy (and hence cost) pay-back time has significantly improved. In Mediterranean countries a solar cell has an energetic payback time of 2 years!

Furthermore, in the area of thermal solar energy systems, the PS10 project (FP5) resulted in a 11 MW central receiver system, near Seville in Spain. Recent economic support measures (i.e. a feed-in tariff of 21 €c/kWh) that have been considered in countries like Spain have paved the way for commercial application of concentrating solar thermal. Together with several European partners, Solúcar succeeded in realising this demonstrating receiver. Its construction started on June 2004 and it is into service by 2006. Although not every step in the project went according plan, the consortium succeeded in building the construction and make it operative. The PS10 is success in many aspects. It demonstrated that high temperature ST power plants can work. Furthermore, Solúcar is now developing more ST power plants –such as the PS20. “PS10 might be considered a milestone itself, as a whole, for solar CRS market penetration, since only one demonstration plant would be enough to proof the technology before starting commercialisation, and therefore should be followed by a series of fully commercial and competitive power plants with sizes of 20 -100 MW each”

4.2 Impacts

In the participant survey respondents were asked to assess the impact of the project on themselves as individuals. Figure 17 summarises the responses. Enhanced knowledge stands out, with 89% of respondents sighting their project as having either a medium or large impact in this area, followed by enhanced reputation, enhanced skills and new or enhances university-industry links.

We have found no significant difference in terms of impacts between FP5 and FP6 projects; nor in the survey nor during the interviews.

Figure 17  Achievement of outcomes and their impact – on the individual

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No impact</th>
<th>Small impact</th>
<th>Medium impact</th>
<th>Large impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced reputation or image</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or enhanced university-industry links</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced skills</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or enhanced links to EU contacts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or enhanced access to complementary expertise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or enhanced interdisciplinary research opportunities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced career prospects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or enhanced access to additional funding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or enhanced links to non-EU contacts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Participant survey

It is clear that the FP5 and FP6 projects increased the stock of knowledge, skills and reputation. These are by far the main impacts on the individuals who have been involved in the project. Interestingly, two-third of respondents indicate that their project has a medium to large impact in the area of university-industry links. This highlights that EU projects are really focussed on industry-research collaboration. Many interview partners stressed this point as well and both research and industry partners stressed the importance of working together across Europe.

4.3 Contribution to ERA strengthening and international collaboration

All interview partners stressed the importance of international collaboration between research partners, but also between research and industry partners. National funding programmes are often not designed to engage in international collaboration so the European Commission fills this gap. The possibility to cooperate with foreign (research) partners is by most interview partners seen as the main added value of European funded research.

Some research institutes interviewed for this study have established new contacts with industry partners in other European countries that still last after the project ended. Without European funding these relations would never have been established. For example, the German Fraunhofer ISE has developed a long-term cooperation with UK based BP.
All partners interviewed indicated that European cooperation is necessary because not all knowledge is available on the national level. By collaborating with the best researchers of Europe, the speed of technology development in Europe is increased. Especially for new and emerging concepts for (thin-film) pv, which requires many different technologies and different disciplines, European collaboration provides added value and reduces time-to-market. For example, Germany has a strong knowledge base in the field of solar energy, but even in Germany not all knowledge is available, and German (research) partners are looking to cooperate with research partners from France, Italy, The Netherlands or Sweden as well. The added value of European collaboration is clearly illustrated by the development of CIS/CIGS technology in Europe. Since FP4, a strong European network is build of research institutes and universities from Germany, Sweden, France, and Switzerland who have been working together for almost two decades to develop CIS/CIGS technology and make it ready for industrial application. Since 2006 these efforts have paid off and a number of companies are now commercially producing solar systems based on this technology (see section 6.2 for more details on this technology). All partners interviewed claim that European funded research has played an important role in bringing the partners together and sustaining this network for a long period of time. And because of that technology development is increased and resulted in a shorter time to market. (In 2006 the first company commercially producing pv systems using CIS-technology was located in Europe (Germany)). Also straightforward practical reasons make European cooperation valuable. Especially in the field of CSP, a test facility with a high level of sunlight is needed. For German researchers, the cooperation with Spanish partners is very valuable, because this gives an easy access to test facilities in Spain (such as Seville, Alméria etc.).

In the field of high temperature ST, cooperation with non-EU partners is strong: Israel is one of the larger contributors in these projects. For the Israeli interviewees, the European FP’s make up a substantial part of their research budgets. European FP investments are important for the research institutes, especially during FP6. For the research groups, the FP investment makes up about one third to a half of the research funds of these research groups. Apart from the advantage of receiving funds, the non-EU partners see a guiding effect of the FP’s. Especially in Europe you can see a lot more activities in solar energy in general because of the substantial research budgets. The research budgets attract good researchers and set priorities for the research. The Israeli partners gladly take part in European projects for this reason. The interviewees stress the importance of the networking. The projects allow partners to cooperate and to get to know new potential partners. According to the interviewees this makes the total development in the longer run more cost effective: several bilateral and multilateral projects were set up with European partners, after the finishing of the projects – this would not have been the case without the FP’s.

4.3.1 FP5 and FP6 has contributed European Research Area

In addition to the network effects mentioned in the previous section, the FP6 Integrated Projects (IPs) have a strong effect on the European Research Area as they aim to bring together all relevant European organisations (both research and industry) in a certain field. There are no Networks of Excellence (NoE) in the field of solar energy. There are 4 IPs covering different aspects of pv:
- Crystal Clear (focusing on crystalline silicon pv)
- Full Spectrum (high efficiency solar cells and pv-concentrator)
- Athlet (exchange of knowledge between different thin film concepts to reduce costs)
- Performance (testing and labelling of cells and systems)

For example, at the start of Crystal Clear more than 80% of the relevant research institutes, universities and companies in the field of crystalline silicon pv in the EU were involved. Moreover, the project covers the total value chain from silicon feedstock, to wafer technology, cells, and modules. This approach enabled partners to learn from each other and understand the processes and challenges in different parts of the value chain. This again stimulated
cooperation among the value chain and between organisations from different countries. So, this project is an example of European added value because such a project would not have been possible in for instance the Netherlands because not all parts of the value chain were available in the Netherlands. Despite some administrative issues and delays in the first year of the project, the interview partners were all possible about this approach and stressed the added value of having brought together all expertise in Europe on crystalline silicon pv.

Another example is the Athlet project which aims to bring together knowledge on three different types of thin film pv in order to learn from each other and explore possibilities to reduce cost. The European Commission was strongly stimulating the European thin film community to put efforts together and form a European consortium. However, as all three technologies were very different from each other it turned to be difficult to find a common topic that is relevant for all partners involved in the consortium. As a result cooperation was limited, especially at the start of the project, and hardly any new relations were formed. Later a number of common topics were defined, including research on TCOs and major scientific advances were booked in this field.

4.3.2 Collaboration with partners outside Europe is difficult

According to the interview partners it is important to cooperate with other European countries in order to compete as Europe against the US, Japan and China. In this regard, many interview partners expressed their concern in involving too many non-European partners in the Framework Programme. At the moment European solar cell manufactures are able to compete with Chinese manufactures because they can deliver better quality and performance due to high level of technical competence. If Chinese partners are involved in European projects they get access to European technology and improve their competitive position. This will have a negative effect on the European pv industry. This is illustrated with two examples.

For instance, high-efficiency triple junction solar cells based on GaAs have been developed in Europe (Germany), as a reaction on the advanced position of the US in this field. Ten years ago the US were far ahead of Europe (and the rest) of the world with this specific type of solar cell, which is in first instance developed for space applications because of its high efficiency. The German government, the European Space Agency (ESA), and the European Commission found this a crucial important technology for Europe and have invested significant amounts of money to build a knowledge position in Europe around triple junction GaAs solar cells. This was successful (35% efficiency has been achieved) and Europe is now able to produce high-efficient triple junction GaAs based solar cells for space application and for terrestrial applications as well. Especially for terrestrial applications, in combination with concentrator technology a large new market potential is seen. This example illustrates that Europe is competing with other global regions in terms of technology and that research cooperation with other regions is not straightforward, according to some of the interviewees.

Another example comes from thin film solar cells. Ten years ago Japanese companies had an advanced knowledge position in this field and were far ahead of European companies. Due to investments of national governments (especially Germany) and the European Commission Europe’s knowledge position in this field increased and a number of companies have been founded in Europe that commercially produce thin film solar cells and compete with Japanese firms. Involving Japanese firms or research institutes in European research projects would have been difficult given the competitive position of Japan versus Europe.
5. Policy impacts

5.1 Assessment of policy impacts

In the survey respondents were asked to assess the impact of the project more broadly, on energy and the environment. Figure 18 summarises the responses, with those areas most frequently seeing large level of impact appearing at the top of the figure.

Not unexpectedly, development of renewable energy sources, development of clean energy systems and reduced costs of sustainable energy systems are areas of medium or large impact from the solar energy projects. This is alignment with the technology (produce clean renewable electricity from the sun) and the main challenge for this technology (reduce cost in order to be competitive with electricity from fossil fuels). The development of new environmental legislation/policy was reported as an area with no or small impacts.

Figure 18  Achievement of outcomes and their impact – on society

The research funded in FP5 and FP6 in the area of solar energy is technology-driven, focussing on new materials, cells, modules, systems, etc. This means that the impact on policy is limited or very indirect. During the interviews with project participants we have not found any evidence of direct policy impacts at the regional, national or European level as a result of the funded projects.

Both FP5 and FP6 include a number of projects that aim to develop European networks, roadmaps and coordination activities with in the frame of ERA, both for pv as for CSP. In FP5 six of these projects were funded. In FP6 the project pv ERA-Net is funded aiming to stimulate networking and integration among national and regional RTD programmes in the field of PV. It involves 17 partners (ministries and funding agencies) from 13 countries.
Finally, in FP6 the secretariat of the European Photovoltaic Technology Platform is funded. This platform includes all major players in the field of solar energy in Europe. In FP5 already the project PV-EC-NET provided the basis for this platform.

In 2007 the platform published the Strategic Research Agenda (SRA) for Photovoltaic Solar Energy Technology that lies down the main scientific and technical challenges to achieve the ambition of pv. This SRA is written and approved by the Europe (research) sector and because of its broad acceptance in the sector also used by European policymakers to define research priorities in FP7 calls. It is clearly the most important document with regard to public research priorities in this field and has a high impact of setting priorities of NNE research policy in Europe.

While CSP was always a bit underrepresented on the research agenda, it started to gain visibility in the course of FP5. Several interviewees indicate that the PS10 project has been important to this respect, because of the high visibility and recognisability of the project. Although it is hard to pinpoint exactly what the influence of this kind of demonstration projects was, it is believed that the PS10 tower gave a push to ST on both national as European level. The PS10 does not only have an iconic image, but also was a successful and economic viable demonstration project, due to the feed-in tariffs of the Spanish government.

In FP6 a roadmap for CSP was developed in the ECOSTAR project. The roadmap assesses advantages of several technological alternatives and the improvements that can be made on medium and long term. The ECOSTAR project sets out scientific challenges and also shows which technological alternatives are more likely to have success. The ECOSTAR roadmap is likely to have a bottom-up effect on the field: the roadmap does not have the exposure as the SRA of pv.

Furthermore, within the FP6 a Technology Platform on solar thermal energy was launched: the European Solar Thermal Technology Platform (ESTTP). The ESTTP can help accelerate the development of solar thermal technology so that it can quickly become a significant energy resource, meeting heating and cooling demands in Europe. Main goal of ESTTP is to develop a vision for solar thermal technology in 2030, and to work out a strategic research agenda towards this mission. Lately, a roadmap was developed for ST domain\(^{19}\). According to experts, this domain is somewhat neglected in R&D efforts – especially considering the large potential and easy access to that potential. The SRA has been published in December 2008, and does not yet have policy implications, but it can have an effect on the near term future, as the roadmap is backed by both researchers and industry.

---

\(^{19}\) ESTTP, Strategic Research Agenda for Solar Heating and Cooling, December 2008
6. Economic and social impacts

6.1 Assessment of economic and social impacts

The overall aim of the solar energy RTD programme in FP5 and FP6 is to improve efficiencies and reduce costs of pv systems which is obviously of great interest to the industry. Both the survey and interviews show that this is true indeed and that economic impacts from European funded research are emerging in a number of European countries, most notable Germany.

In the survey conducted for this study respondents were asked to assess the impact of the project on their organisation. Figure 19 summarises the responses, with those areas most frequently seeing large impacts appearing at the top of the figure. Enhanced reputation and image (82%) and enhanced cooperation with partners in EU countries (72%) stand out.

Having the opportunity to conduct research in new areas is medium to large impact for 63% of the respondents. This indicates that participants regard EU funded research as possibility to develop new competences in technology areas that are new for the organisations.

Overall the impact of solar energy projects on participants’ own organisations is impressive, even for commercial outcomes: 60% reports medium to large impacts on competitiveness and an other 40% reports medium to large impacts on productivity and increased employment. And even 10-15% report medium to large impacts on turnover, market share and / or profitability. This indicates that EU funded projects in the area of solar energy are relevant for industry and have some level of economic impact as well.

![Figure 19](attachment:image.png)

Source: Participant survey

The industrial relevance and economic impact of the EU funded research projects in FP5 and FP6 is also stressed in the interviews with companies and research institutes. We have found
a number of examples that show a direct economic impact of European funded research. This will be illustrated by 3 mini-cases:

- CIS/CIGS thin film (section 6.2),
- Crystalline silicon, and in particular the production of metallurgical solar grade silicon (section 6.3.1),
- Silicon thin film (6.3.2).

These cases include three main technology fields for photovoltaics that have received a lot of attention in both FP5 and FP6 and where we have found evidence of technology that is developed in European funded projects is commercialised by industry. Many European projects build upon knowledge developed earlier. For instance, most of the basic principles on thin film processing are developed in universities in the eighties. So for thin film a typical time-to-market is 15-20 years. For the projects started in FP5 (1998) we see commercial spin-offs since 2006. So, time to market of (European) funded research is about 10 years.

One has to keep in mind that funding from the EC was only one source of funding, next to national public funding and private investments. Usually these other funds are bigger than funds from the EC. For instance, the German federal government spends about 40 MEuro per year on R&D in the field of solar energy during the period 1998-2008, compared to approximately 21 Meuro per year that the EC spends on solar energy for Europe as a whole (budget for solar energy was 76 Meuro in FP6 and 92 Meuro in FP5). Nevertheless, all the interview partners have indicated that EC funding has had a positive and important impact on the development and commercialisation of solar energy technology in Europe, despite the relatively small amount of money that comes from the EC compared to other funding sources.

Finally, much of the economic spin-off of European research in the field of solar energy take place in Germany. The mini-case on thin film CIS/CIGS shows that technology developed in Sweden, France and US is transferred to Germany. Main reason for this is that the German government has invested heavily in pv (and other renewable energy technologies); not only R&D funding, but more importantly it created a market for pv which has boosted demand and hence the development of the pv industry in Germany. On top of that some Germany states like Saxony provide attractive (fiscal) incentives for companies who build a production plant for pv. As a result of this Germany is leading in Europe when it comes to R&D and production of solar cells, and installed capacity. In 2008 more than 74,000 people were employed in the German solar energy industry (of which 57,000 in pv20). In section 6.4 more insight will be given in the factors explaining the success of pv in Germany.

With regard to solar thermal a mini-case is presented about concentrated solar power (CSP). CSP is an promising technology to build large solar power plants in sunny area’s. In FP5 and FP6 different projects are funded to develop this concept. In addition 3 large demonstration projects were co-funded in FP5 in Spain. These projects received a lot of attention from the public and policymakers to illustrate the potential of the technology. This case will be presented in section 6.5.

6.2 Development and commercialisation of CIS/CIGS thin film solar cells in Europe

Since the beginning of nineties a number of European research organisations have been working on Copper-Indium-Selenide (CIS) and Copper Indium Gallium Diselenide (CIGS) material for thin film solar cell applications. This includes the University of Uppsala (Sweden), Swiss Federal Institute of Technology (ETH, Switzerland), University of Barcelona (Spain), CNRS (France), Hahn–Meitner Institute Berlin (Germany), University of Stuttgart and ZSW in Germany.

Research in this area has received significant amounts of funding from national governments (i.e. BMBF in Germany has funded many projects in this area, as did STEM, the Energy Agency in Sweden) and the European Commission in the past decade in order to develop and

---

optimize efficient CIS/CIGS thin film solar cells and make the technology ready for large-scale commercial production.

During the FP4 and FP5 period projects focused specific components of the cell i.e. substrate, backcontact, absorber, Cd-free buffer layer (i.e. Transparent Conductive Oxides TCOs), etc. to demonstrate feasibility of the concept in a laboratory scale for small area. In addition much research was performed on process technology and production methods, in particular deposition and evaporation techniques, to produce the thin layers of light absorbing material.

During the FP6 period the focus has been on transferring promising laboratory results to large-scale industrial production. For the commercial production it is important that the different process steps are not too complicated and a lot of effort is needed to streamline and optimize production processes in order to achieve high throughput and quality.

The impact of this continuous research effort in the past 15 years has only recently been visible in terms of economic spin-offs. Wurth Solar was the first company to enter commercial production of CIS modules in 2006 and since then three other companies have opened production facilities for large-scale commercial production of CIS or CIGS thin film solar cells in Europe. All factories are located in Germany because of the attractive market for pv and attractive government schemes in Saxony (solar valley) to set-up a factory there.

Below the development and commercialisation of CIS/CIGS technology is described by highlighting some examples of technology that is successfully transferred from university and research institutes to companies.

• In 1993 the promising results of the research done by Stuttgart University in Germany on CIS solar cell technology were transferred to ZSW. The institute built a laboratory pilot line for 30x30 cm solar modules and demonstrated the production maturity of the CIS technology. In 1999 Wurth Solar was founded and the CIS-technology was transferred from ZSW to Wurth Solar for commercial application. Wurth Solar built a pilot line to test whether commercial CIS production was economically feasible. Meanwhile ZSW continued research in the area of production and module technology and kept a close relation with Wurth Solar. In 2006 Wurth Solar started with the commercial mass production of CIS solar modules at 15 MW/year and it was the first company that produced thin film CIS solar cells in large volume. Since 2007 the plant runs at full capacity (30 MW/year) and produces about 1000 modules per day. The efficiency of the modules is about 12%. Wurth Solar employed in 2008 about 210 people of which 2/3 work in production. ZSW research focus is still dedicated to CIS technology over the entire value chain. A part of the research is short-term oriented and focused on optimising productivity characteristics like material costs, throughput and yield, module construction, long term stability, etc. Long-term research goals are improving cell efficiency (19% was achieved with a test cell), flexible CIS solar cells, roll-to-roll printing techniques and organics solar cells.

• Around the same time, in 1993, the Hahn-Meiter Institute in Berlin was doing research on industrial proven technology to manufacture CIS solar cells. Together with research centers in Oxford, Barcelona and Naples, and the companies Saint Gobain (glass manufacture from France) and Vakuumtechik Dresden a European research project called Sulfurcell was started in 1998 to demonstrate that a small area 15% efficient thin film solar cell was possible and could be produced cost-effective. This resulted in 2001 in the spin-off company Sulfurcell Solartechnik GmbH. Development continued within Sulfurcell, with support from HMI, and in 2003 a pilot line was set-up and expanded in 2006 when commercial production started. In 2007 the production capacity was about 1 MW/year. The company now employs 60 people and is planning to build a second production facility.

• In Sweden the Ångström Solar Center at the University of Uppsala’s has been working on the development of CIGS solar cells since the nineties. In 2001 a spin-off company was set-up named Solibro AB to commercialise the CGIS technology developed at the institute. Solibro has achieved to produce modules at industrial scale with efficiencies exceeding 11.5%. Based on a closely related technology, the Ångström Solar Center has realized efficiencies of up to 16.6% in minimodules and 18.5% in solar cells in laboratory conditions. In 2006 Solibro GmbH has been set-up as a joint venture between Solibro AB and Q-Cells. Q-Cells has a 67.5% shareholding in the new company. Solibro GmbH
currently has a production capacity of 30 MWp per year and 183 employees in Germany (Bitterfeld-Wolfen, Saxony) and Uppsala. The company is expanding its production capacity in Germany and announced in October 2008 that it will build a new manufacturing plant for CIGS modules in Germany with a production capacity of 90 MWp. This will result in 250 new jobs in the region and a 165 million investment in the new factory. First modules from the new factory are expected before the end of 2009.

- Finally, Shell Solar has played a major role in the development of first-generation CIS technology both in Europe and the US. Shell Solar participated in European funded projects via its partner Saint Gobain from France. In 2007 the company AVANCIS was founded which is joint-venture between Shell Solar and Saint Gobain. AVANCIS brings CIS thin-film modules on the market with an efficiency level of 11%. The company builds upon the knowledge developed by Shell Solar and its 3 MW CIS factory in Camarillo California (USA) and Saint-Gobain’s experience in glass processing and production. The company opened its first production plant of 20 MW in Torgau Saxony (Germany) in October 2008 and plans to expand its production capacity at this location to 80 MW. AVANCIS has created 85 new highly qualified jobs in the first wave of development at the Torgau production site and a further 45 will be added in 2009, according to the website. In addition 30 R&D employees are working at the R&D facility in Munich.

To conclude, EC research funding during FP4-FP6 has clearly contributed to the development and commercialisation of CIS/CIGS technology in Europe. At the same time other factors (i.e. RTDI funding from national governments, private investments by Adolf Wurth GmbH, etc) played an important role as well, but EC funding clearly proved to be important.

All the interview partners have indicated that EC funding has had a positive and important impact on the development and commercialisation of CIS technology in Europe, despite the relatively small amount of money that comes from the EC compared to other funding sources (i.e. German BMU has invested in 2007 14.3 MEuro in CIS/CIGS technology aiming to reduce material costs and improve yield).

The main added value of EC funding is the collaboration with European research partners, which is very difficult to achieve with national funding. We have found clear evidence that international collaboration resulted in exchange of knowledge between research groups in different countries. This has resulted in faster development of certain aspects of the CIS/CIGS thin film solar cell, most notably the work on alternative buffer layers to replace the traditional Cd-based layers and the development of techniques to deposit this layer in a large-scale manufacturing environment. By combining knowledge on this particular topic from some of the leading institutes in Germany, France and Sweden significant process is made on this topic, resulting in reduction of development time and application by industry.

Due to continuous project funding from the EC over the period FP4-FP6 a strong network pan-European network in the field of CIS/CIGS technology was developed and continued for 15 years. All interview partners see this as an important effect of EC-funding that has paid off in the last few years when CIS/CIGS technology entered commercial production.

6.3 Crystalline silicon photovoltaics

Crystalline silicon solar cells have 80% market share and have been a main topic in European and national (in particular Germany) R&D funding for many years. In FP6 the largest project in terms of funding was on crystalline silicon (Crystal Clear). In FP7 however, it seems that this topic is not likely to receive funding anymore while many scientific and technical challenges still exist.

As the overall aim is to reduce costs of pv modules there is an strong incentive to reduce the amount of silicon used and hence reduce costs. There are basically two options to achieve this goal; wafer-based and thin film silicon (this will be elaborated in see section 6.3.2).

With regard to wafer-based silicon solar cells there are different ways to reduce the amount of silicon used, by:

- improving the ingot crystallisation process,
• reducing the loss of material during the sawing process,
• reducing the thickness of the wafer, and
• alternative methods of wafer formation like EFG (edge-defined film-fed growth) and RGS (ribbon-growth-on-substrate)

All these options have been explored in many (small) FP5 and two (large) FP6 projects and have been successful to some extent to reduce costs. Especially with regard to improving the ingot crystallisation process to produce solar grade silicon significant scientific and technical process was made which has found its way into commercial application. This will be elaborated in more detail in the sections below.

6.3.1 Development of solar grade silicon feedstock

With regard to the development of solar grade silicon feedstock interesting progress has been during the FP5-FP6 period, which has found its way into an industrial pilot plant in Trondheim Norway operated by a newly established company Fesil Sunergy AS.

In FP5 two projects were funded (Solsilc and Spurt) focusing on the development of alternative processes to produce solar grade silicon. These projects were motivated by the fact that the pv industry uses in fact by-products from the semiconductor industry. Although this silicon feedstock has a very high level of purity, it is actually too pure for solar cell applications and too expensive. And because the processes to produce this very pure silicon are very energy-intensive, there is a clear interest from the pv industry to produce solar grade silicon (sog-Si) at low costs that meets the requirements of the pv industry.

Within the projects Solsilc and Spurt a number of European organisations (i.e. SinTeF (Norway), ScanArc (Sweden), ECN (Netherlands), and Sunergy (Netherlands) cooperated to develop the so-called “solsilc” process (a metallurgical process to produce solar grade silicon) and test the feasibility of this technology to produce solar grade silicon at industrial scale. The results of these projects were very successful and proved that solar grade silicon could be produced using a metallurgical process. A major advantage of the solsilc production process is that about 70% less energy is used than a standard chemical production process to produce the same amount of sog-Si.

Stimulated by Sunergy (an strategic investor in renewable energy) the consortium remained active after the projects ended and in 2004 the consortium started a search for a possible partner who could contribute to the further development and finally industrialisation of the Solsilc production process. This resulted in an informal co-operation with FESIL, a Norwegian ferroalloy company that had produced and refined silicon already for many years. Together with FESIL the Solsilc-process was further developed and in 2006 a formal agreement was signed between the consortium and FESIL and a new company was established named Fesil-Sunergy.

Currently Fesil-Sunergy is building a pilot plant in Trondheim with a capacity of 100 tons upgraded metallurgical silicon (UMG-Si) a year. The production is expected to start by the end of 2009, but due to the current economic crisis and drop in demand and prices for silicon this is not certain. This (pilot) plant which uses the solsilc-process is unique in the world as all silicon feedstock used today by the pv industry comes is produced by using traditional chemical processes which are very energy intensive and costly.

The next step that is foreseen is a scaling up of this pilot plant to a production capacity of 1250 ton per year. In addition there are plans for a full-scale plant with a production capacity of 7,000-10,000 tons that should be in operation in 2010.

Building upon the FP5 projects, in FP6 the Foxy project was funded to further develop and optimize refining, purification and crystallisation processes for metallurgical solar grade silicon feedstock. In addition, the project also explored the possibilities to recycle silicon and to use n-type silicon as raw material for solar grade silicon feedstock. This latter was follow-up from previous research projects in FP5 that explored the possibilities to use n-type silicon as cheap substrate for EFG-ribbon wafers and thin films (i.e. PF5 projects Mophet, Nessi).
Also in the large integrated FP6 project on crystalline silicon pv (CrystalClear) knowledge acquired in the projects mentioned above was used to define strategies to reduce overall costs of solar module production. An important outcome of the CrystalClear project was that it provided clear evidence that 50% energy efficiency gain of the total pv systems is to be gained at the ingot production process. Clearly, the solsilc-process will contribute to achieving this objective and improve the energy-efficiency of pv systems and reduce costs at the same time.

6.3.2 Development of thin film silicon solar cells

Thin film silicon cells are another major topic that received a lot of attention in both FP5 and FP6. It is another technological pathway to reduce the amount of silicon used because it does not use wafers. In fact, a thin layer of high-quality silicon layer is deposited onto a cheap substrate such as low-grade metallurgical silicon, glass or other ceramic material. Main advantage is that less silicon is used and no sawing is needed which reduces material costs. Disadvantage are the relative low efficiencies compared to wafer-based solar cells.

An interesting example in this field is the development of the micromorph solar cell, which is a combination of amorphous and microcrystalline silicon deposited on a glass substrate. This technology was first developed by FZ Julich in Germany and other partners in the FP5 project DOIT. This project established the basic technology and showed that it could work in a (pilot) production as well. Together with other partners like Applied Materials (equipment manufacturer) the technology was developed further and an industrial manufacturing system was developed for thin film silicon solar cells.

The research results from the FP5 DOIT project and other FP5 projects on thin film silicon were followed-up by the FP6 project Athlet. This is an integrated project on different types of thin film technologies including CIS/CIGS thin film solar cells and amorphous-, micro- and polycrystalline silicon thin film solar cells. It included all the main research and industrial partners in this field, but because of that, the project lacked focus and there was no real cooperation between the partners. Main reason for this is that every industrial partner works of a different type of thin film technology and even within the same technology there are different challenges, manufacturing processes, etc. This means that there was not a real common set of research topics or knowledge needs and hence no real motivation to cooperate with each other. On top of that the industrial partners were each others direct competitors. After a number of workshops a common topic of interest was found around the transparent conductive oxide (TCO) layers. All thin film solar cells consist of up to 15 different layers that need to be deposited upon each other. Japanese producers (Sharp) had already proven that up to 50% of the efficiency of the cell is determined by the quality of the TCO layer making it an interesting topic for further research. So, much of the research effort in this project was focussed around the TCO.

Using the knowledge obtained in different FP5 projects which also included research on the TCO, in the Athlet project significant progress was made to develop a stable TCO layer that could also be deposited using industrial processes. The interview partners indicate that R&D on the TCO layers was boosted by cooperation in European FP5 projects and in particular in the FP6 Athlet project, because knowledge and experiences was bundled. For instance, FZ Julich developed a very stable TCO layer based on zinc-oxide for micromorph solar cells which is applied by HMI institute in Berlin to develop deposition process to produce stable high temperature layer for polycrystalline solar cells. This has also triggered the CIS/CIGS community to look into this technology as an alternative TCO.

To conclude, due to the research efforts in FP5 and FP6 a stable TCO layer is developed (at least of lab and pilot scale). In addition the process technology to deposit this layer in industrial processes is developed and ready for transfer to industry. To push the results of this research to industrial production the German BMU funded in 2007 a 4,5 MEuro R&D project to learn more about the zinc oxide TCOs. The consortium consists of leading (German) modules manufactures who have also been involved in European research (i.e. including Schott Solar, FZ Julich, HMI Berlin, Applied Materials, Santor (Q-Cells)).

Some of the interview partner from research organisations suggest that (some of) the results of these European projects can be applied by industry within 1-2 year. Some say that industry just has to implement this new TCO in order to improve efficiencies and increase. They have
no choice. If industry decides to implement certain process steps and gives it high priority is
can go even faster. Important factor is that additional testing on reliability, etc needs to be
done, before it can be applied in industrial processes because of the 20 year warranty of solar
modules. Some interview partners from industry claim that they use already some of the
aspects of the research on TCO into their industrial processes. They cannot quantify this.

The industrial potential of the silicon thin film technology is further stressed by the fact that in
2005 Q-Cells, via Santor (formerly Brilliant 234) acquired from FZ Julich the technology on
micromorph solar cells, including the (pilot) line developed by FZ Julich and AM to produce
these thin film silicon solar cells. According to the website the first pilot line with a production
capacity of 8 MWp started test production in the middle of 2007 and the first modules have
been manufactured with a module efficiency of 7,5%. A further expansion of the pilot line to
24 MWp production capacity is due to be completed in 2009.

Schott Solar has been involved in developing thin film silicon from the start of FP5 in various
projects (DOIT, Subaro, Lactis) and is since two years commercially producing micro- and
amorphous crystalline silicon thin film solar cells. Schott Solar has a 3 MW pilot plant in
Munchen and a micro crystalline silicon thin film plant in Jena with an annual production of
33 MW, including some 200 jobs.

6.4 Photovoltaic in Germany – a case study on factors explaining its rapid take off

The success of photovoltaic power in Germany cannot only be explained by analyzing the
impact of R&D (and funding). Although many academic studies have found evidence
explaining that higher investments in R&D, lead to higher innovative performance and
economic growth of firms or countries, other academic theories explain that R&D only is no
guarantee for innovation and economic growth.

A recent theoretic framework that investigates innovation in a wider context of factors that
influence successful development of technologies is the functions approach for technological
innovation systems21. This framework can be used to analyze innovation systems of renewable
energy technologies and consists of the following seven dimensions:

- entrepreneurial activity,
- knowledge development,
- knowledge diffusion,
- guidance of the search,
- market formation,
- resources mobilization, and
- lobby activities / creation of legitimacy.

The idea is that each of these functions serves as both a pre-condition and an accelerator of
innovation processes. The more of these functions are performing well, the higher the speed of
the innovation process and successful commercialisation of the innovative technology.

For photovoltaic in Germany such a functions analysis is conducted by Van der Klauw22 which
has resulted in several success factors explaining the success of photovoltaics in Germany and
the contribution of R&D and European R&D funding to this. This analysis is based on expert
interviews together with additional literature and data research.

Entrepreneurial activity

21 Hekkert et al. 2006 Functions of innovation systems: A new approach for analysing technological
change. Technological Forecasting & Social Change.
22 Klauw, M, van der. 2009. The dynamics of the functions of innovation systems of renewable energy
The first entrepreneurs had started already in the early days in the 1970s to produce solar panels, however their products had low efficiencies and were too expensive to compete with the existing technology of electricity production. Only since the end of the 1990s, when technology was substantially improved, production costs were lower and federal subsidies were introduced, a real photovoltaic power industry emerged. A large network of component producers, equipment and machinery producers, assemblers and installation firms began to emerge in the 1990s.

Entrepreneurship, according to our experts from the interviews, typically serves as a precondition for a successful industry, but it only emerges after the main barriers for profitable exploitation of the technology are taken away. The importance of entrepreneurial activity for the success of PV in Germany is considered as low by the experts.

Knowledge development

The expert interviews and literature study show that for some decades the German federal government has invested in R&D in photovoltaics. After the first oil crisis, Germany realized that their dependency on fossil fuels could harm them and that they should invest in alternative energy sources. The federal funds to PV research have increased annually in the period 1974-1981 and stabilized on a relative high funding amount since 1982. Since 1982 the German federal government has invested an average of 31 million euros per year in PV R&D.

Figure 20 Federal funding for PV in Germany (1982-2008)

![Federal funding for PV in Germany](source: BMU 2008)

Via the European Framework Programmes German (and other sources) research organisations and industry receive R&D funding as well, but this relatively small compared to national resources. In the period 1998-2006 the EC spent approximately 21 Meuro per year on solar energy for Europe as a whole\(^{23}\) and German organisations secure approximately one-third of this budget (or 7 Meuro per year).

The experts interviewed agree that this continuous funding in Germany has resulted in a very strong and high tech knowledge base on photovoltaics. Moreover the spread in funds between basic and applied research has guaranteed both long-term knowledge development and application of knowledge for applications in industry and improvement of existing products and processing methods. The value of knowledge development to the success of the German PV sector is thus high. The continuity of this knowledge development was an important driver for technological innovation on the short and long term.

---

\(^{23}\) Budget for solar energy was 76 Meuro in FP6 and 92 Meuro in FP5
Knowledge diffusion

In order to profit from knowledge development in universities and research institutes, it is crucial that this knowledge is spread to industrial players, so that they can translate this knowledge into innovative products and economic growth. In the German PV industry this was done in two ways. The first is knowledge transfer between various industry sectors and research disciplines. Germany is an industry nation and has an historic tradition in (industrial) research. The large pool of knowledge on various disciplines appeared to be very valuable for the production of PV modules. Especially the cross fertilization between various sectors, such as machinery, glass, semiconductors, coatings and flat panels made that the PV industry could flourish in Germany and profit from the high tech knowledge that was already available in industry and research institutes. The second way of knowledge transfer was between (applied) research institutes and firms. An example is the foundation of Wurth Solar in order to commercialise the technology developed within the applied research institute ZSW and the university of Stuttgart. The examples in the previous sections illustrate that the R&D and production departments of firms cooperate with research institutes for the optimization of their processes.

Knowledge diffusion was an important success factor for PV, but not considered as a key success factor according to the interviewed experts. It serves more as an accelerating factor than as a crucial requirement for success. It is therefore valued of medium importance.

Guidance of the search

There are two main public triggers that have guided PV development in Germany. The first is societal and political awareness and enthusiasm for renewable energy sources. According to the interviewed experts, the German society is favorable to renewable energy, because of a wider ecological awareness both at the level of the individual and at the political level. This brings us to the second driver for PV in Germany: Herrmann Scheer from the social democratic party (SDP). He is the most important politician for the development of PV. His efforts began in the 1980s and still he is politically active for the stakes of solar energy. It is his main effort that the 1,000 roofs program (since 1989) and the 100,000 roofs program (since 1999) were established and have become successful triggers for innovation in the PV industry. Hereby he created general support for PV, which made the step to the successful Erneuerbare Energien Gesetz (EEG) of 2004 also successful. Scheer symbolizes the political willingness to develop a long term policy that makes it attractive to invest in renewable technologies and at the same time creates an new high tech industry in Europe. So, guidance of the search is therefore considered as a very important success factor.

Market formation

All experts interviewed agree that market formation, together with knowledge development, is a very important success factor. Without an attractive policy that stimulates demand for PV modules, the industry would never have taken off. Market formation activities started already in 1989 in Germany with the 1,000 roofs program: a three-year federal budget that covered 70% of the investment costs in PV modules for consumers. This program served as a trigger for demonstration projects of PV technology and created the first entrepreneurs who entered the commercial PV market. When this program ended however, the demand for modules decreased and almost all firms in the industry stopped their activities or went bankrupt.

In 1999 the PV industry got a new boost thanks to the 100,000 roofs program. Knowledge on the (cost-effective) production of PV cells and modules had increased in the mean time due to significant investments in R&D (see section 0) and modules with a higher efficiency and lower costs entered the market. The 100,000 roofs program offered attractive loans to customers of PV modules instead of subsidies. Initially it were mainly Japanese firms (i.e. Sharp) who profited from this increased demand for PV in Germany, but the program triggered the second take-off of the German PV industry. Only a few years later a full German PV industry was developed from (almost) scratch, but building upon the knowledge and expertise developed since the eighties.

The 100,000 roofs program was succeeded by the Erneuerbare Energien Gesetz (EEG) from 2004, in which no longer attractive loans were offered, but attractive feed-in tariffs were
determined. These tariffs varied for PV between 40 to 55 eurocents per kWh delivered to the electricity grid (guaranteed for 20 years). Every year the government support will decrease, stimulating the industry to reduce production cost (i.e. economies of scale). This policy measure appealed even more to the general public, resulting in an even faster growth of installed capacity and thus economic growth of the industry.

As a result the German industry gradually took over the global market for PV that was dominated by the Japanese until 2005. Since 2000 the German PV industry doubled every year in terms of turn-over, employment and PV capacity produced. In 2008 about 57,000 people were employed in the German PV industry and German PV manufactures generated a turn-over of 5,200 MEuro\(^2\). So, the value of market formation policy to the success of PV in Germany is thus valued high.

Resources mobilization

Resources mobilization had place in two ways: on the one hand the federal and European budgets for knowledge production in research institutes and industrial R&D departments since the 1970s and on the other hand the financial resources for the 1,000 (investment subsidies) and the 100,000 roofs (favorable loans) programs. Since both knowledge development and market formation are considered very important triggers for industry growth, the necessary resources that financed these measures are also considered of a high value to the success of the industry.

Lobby activities and creation of legitimacy

The experts interviewed have agreed that no lobby activities have lead to the immediate success of the industry. There were no strong lobby groups or industrial associations in place for PV and their influence have been very little. As one expert says it: “the industry has not pushed policy, but policy has pushed the industry”. Creation of legitimacy has not had a major impact as well. The main legitimacy creating events were the oil crises of 1973 and 1979, which created awareness of the German dependency on fossil fuels and started the investments in knowledge production on alternative energy sources. However, since the 1970s no creation of legitimacy was visible anymore in Germany. In other European countries, according to one experts, the European Photovoltaic Energy Association (EPIA) has performed successful efforts in establishing policy for the development of PV, for example in Spain. The German industry has however taken of without these successful lobby activities. The value of lobby activities to the success of the industry is thus considered low.

Conclusion

For a renewable technology to be successful it is important that all of the factors described above are in place and support technology development. Clearly Germany has done better than many other European countries in fulfilling these factors. The results of the analysis show that the most important activities that lead to the development of a successful PV industry in Germany are:

- Continuous investment in knowledge (R&D), both basic and applied science
- Public and political awareness and enthusiasm for the importance of renewable energy for society, and PV in particular
- Policy instruments that effectively stimulate demand for PV when electricity prices are not yet competitive with non-renewable energy sources

The example of PV in Germany shows that R&D and hence European and national funding of R&D plays an important role, but it is definitely not the only factor explaining the rapid growth of PV in Germany. This also holds for EC funding; it is an important factor but the impact on the success of PV in Germany is limited. Despite the relatively small EC budgets

---

and the fact that EC funding is not continuous over longer periods of time, the interview partners indicate that EC funding has had a positive and important impact on the development, because it provided the possibility to develop international R&D collaborations resulting in exchange of knowledge and faster time-to-market.

According to the interview partners the EEG-scheme is clearly the key factor explaining the success of PV (and other renewable energy technologies) in Germany. This has triggered demand for PV and stimulated industry to invest in bigger and more efficient factories, bringing down the cost of PV (economies of scale), etc. As all relevant knowledge and technological experiences was in place in Germany this resulted in a rapid take-off of the Germany PV industry since 2000.

6.5 Concentrated Solar Power in the FPs

While wind, biomass and pv rely on a long base of R&D and public investments (both national and on European level), CSP has long been standing on the sideline. Both on national and European level, funding has been unstable for CSP. However, under the FP5 & FP6, large investments were made in CSP technologies. The FPs supported four types of projects: demonstrations projects, R&D projects for subsystems, R&D projects for hybrid systems and R&D projects aimed at “solar chemistry” (i.e. chemical processes such as production of hydrogen, fueled with solar power). Below we will elaborate on the DG Research projects PS10 (demonstration and prototyping) and the R&D project for subsystems DISTOR and accordingly we will draw conclusions based on these projects and other CSP projects.

PS10

In the CSP domain, three demonstration projects were launched, the PS10, ANDASOL, and SOLAR TRES projects. Each project received a EU contribution of €5m, for the PS10 – this was about 15% of the total investment made. The demonstration projects have resulted in the building of 3 power plants - of which 2 are finished today. The projects demonstrate 3 different technologies (i.e. steam power tower, parabolic trough and molten salts power tower), which are implemented by a small group of companies and research institutes.

The PS10 is the project that finished first – it is a successful demonstration. The objectives, which are met, are:

- Construction of a 10MWe solar tower plant;
- with an investment in the order of 3€/We.
- Scaling up of the production of heliostats to about 80,000 m² for 140€/m².
- Validating the steam storage system.

One objective is still pending results: the electricity production per year – the PS10 should produce 20GWh/year.

However, the PS10 can be seen as a ‘scientific’ and commercial success. From an engineering perspective, a large amount of know-how was created during the building of PS10, which is now used in other projects. Solúcar, is now following up the PS10 by the PS20 project. In this PS20 the know-how that is developed during the construction of the PS10 is used. Furthermore, the PS10 project is used as information source for roadmaps, such as the ECOSTAR roadmap. Also, the practical knowledge that is retrieved in the project is now used (by for instance DLR in Germany) in theoretical design.

Other scientific results were obtained by prototyping and ‘learning by doing’. Along the way, knowledge was obtained by testing and prototyping. This accumulation of knowledge led to small changes in the project according to the newly created insights It was for instance planned at the start to use a new technology to receive the sun light (a volumetric receiver), however, the prototype would not work after repeated efforts. Therefore, this receiver technology was abandoned because of integration problems with the steam cycle on which the storage and conversion unit is based. As a result the ambitions of the plant were reset and another (more conventional) technology was used.
Several reasons of the success of PS10 are more generally applicable for CSP. First of all, the combination of national expertise (in this case Germany and Spain in particular) boosted the competences. Germany has a long base of knowledge, on all parts of the CSP systems. In particular the DLR is a research institute that is present in nearly all CSP projects, because of its broad base of knowledge on ST. Germany also has the most developed industry in this domain, consisting many SMEs but also larger companies, working on all parts of the system. Especially since the end of the nineties, the Spanish solar industry was also growing rapidly: during the FP5, the demonstration projects were (increasingly) commercially attractive due to Spanish legislation. In 2002, the Spanish government introduced a feed-in tariff of €0,12/kWh. The feed-in tariff of 2002 was not high enough to cover the risks and initial investments of the power plants. Therefore, the Spanish government increased the feed-in tariff in 2004, for the plants that could first reach 200 MW to €0,18/kWh, guaranteed for 25 years, with annual correction for the market price of energy. This set of instruments removed investor’s concerns. Banks and industrial suppliers launched a race of the major Spanish market players to be among the first that reach 200 MW.

Furthermore, the Spanish government invested largely in solar energy research, for instance in Ciémat, a prominent research institute.

**DISTOR**

Where FP5 launched three large demonstration projects, in FP6 the focus on CSP is put on subsystems. An important issue for CSP is the storage of energy. Storage is crucial to realise electricity production at night and on less sunny days, particularly in spring and autumn. There are many ways to store energy, for instance in the form of hydrogen, hot fluids or phase change materials (PCM). The DISTOR project aimed at storing energy with PCM. The goal of the project was to develop a storage medium based on the micro encapsulation of PCM in a matrix of graphite. After the development phase the developed alternatives should be demonstrated and selected. The DISTOR project met its objectives:

- A preferred PCM material was selected
- The graphite tube was successfully scaled up to application in a 100 kW design and proved to be successful for further scaling up
- The cost for a full-scale direct steam generating storage is about 0.01-0.02 €/kWhth.

The DISTOR project is seen as success for several reasons. From a scientific perspective, the DISTOR project resulted in many publications with interest of the scientific community, because of the analysis of several storage techniques in practice. The project demonstrated which concepts of phase change materials are working, it found the most appropriate technique and design. Now, the project gets scientific follow-up. One of the problems of the eventual system is the high cost of the building. One of the project partners (Candeias, Fr) is now digging into this problem and is currently developing cheaper systems. Furthermore, the same company is developing other ideas based on the project, which cannot be mentioned due to confidentiality reasons.

From an economic and innovation perspective, the project also gets follow up. Although no actual patents stem directly from DISTOR (yet), the DISTOR project has economic follow up. Companies such as SGL now use the developed and tested materials and design. This German company uses the carbon matrix as a storage medium. Also, Aben Goa uses parts of the storage systems in its work. DLR is investigating the possibilities to use parts of the DISTOR project in the PS10 demonstrator plant. Furthermore, the FPs have a structuring effect on the innovation system. The DISTOR project for instance attracted Candeias, a French company that used to focus on nuclear energy; now it also aims at the field of energy storage for renewable energy sources. The R&D budgets provided by the EC make it possible for European companies to open up new niche markets, which were not yet exploited. As mentioned earlier, Candeais is still working on the ideas that were initiated in the DISTOR project.

*The added value of CSP projects in the FPs*
Concluding, the investments in the CSP projects have had a large impact on the CSP technologies in the EU. The interviewees are positive about the impact of the FP5 and FP6. The added value of the FPs are the continuity because of the extra R&D resources, the visibility of the demonstration projects and the appealing image as well as the seeding of industry in Europe:

- The CSP projects gave continuity to the CSP research. National budgets are often changing over time, due to political choices. In Germany there were large cutbacks in the investments in CSP on the national level. Several interviewees indicate that at that time the FPs have played an important role in the maintenance of the knowledge capacity. Also in other countries (even outside the EU) the FPs have a compensating effect on the national budgets. Typically, when the national budgets are high, EU funding accounts for about 20% of the public funding of the research groups working on CSP. When there are meagre national budgets, the percentage rises to about 50% of the public funding.

- Particularly the demonstrating projects gave a boost the visibility of CSP. Nowadays CSP is seen as a potentially economic technology with high efficiencies (in power plants efficiencies are reached of over 30%). The interviewees find that the demonstration projects launched in FP5 have had a positive effect on the image of CSP. In particular the PS10 project, in which an 11 MW power plant is built, had a large visibility in the world.

- The projects helped the start up of industries. The investment of €5m by the FP's in the demonstration projects attracted industry to work on CSP. Once the industries were interested, the FPs had a structuring pull at national level. The demonstration projects were one of the drivers for a lobby on national level for reinforced stimulation, such as the feed-in tariff. After a couple of years, the feed-in tariff in Spain has been set at such a level that the commercial plants are at an economic break-even point. Also in the other projects, industry is triggered to develop solar energy markets, as the initial investments in R&D are lowered by the EU contribution. Also the other projects attracted. In the end the demonstration projects delivered a large part of know-how that is used in many development projects today.

- The individual projects give a structuring effect. Not only do the FP projects establish a base for networking, tying several actors on a supranational level. Also because of this network, the individual projects are connected – e.g. there are plans to use the accumulated knowledge in the DISTOR project in the PS10 demonstration plant.

6.6 Diffusion and dissemination of scientific results to economic and social arena

Research in the field of pv and CSP has high industrial relevance because most projects are geared towards cost reduction (either reducing the use of materials or reducing costs of manufacturing). If industry partners are involved in a project dissemination of the research results in to industrial environment is very likely. The cases presented above illustrate that this has indeed happened. But also if no industrial partners are involved in the project, or industrial partners have no immediate interest, it is likely that the results of the research are disseminated at a later stage via the research institutes of university that has conducted the research. For instance the biggest solar cell manufacturer of Europe, Q-Cells, has acquired technology from different research organisations in Europe, and is developing it further to make it ready for commercial production - Solúcar further uses the know-how developed in the ST demonstration projects to expand its solar power plants.

With a few exceptions, the research partners typically conduct the actual research in EC funded projects. Industry is often involved, but when it comes to conducting the R&D the role of the industrial partners is limited. This has also to do with the fact the industry is very young and only existing since the beginning of the 21st century. There are few companies with a long track record in solar energy that have sufficient R&D capabilities themselves and in addition there are few high-tech start-ups who are actively involved in (European) R&D. The majority of the companies active in the industry (especially the big solar cell manufactures) exist for
only a few years\textsuperscript{25} and are focused on optimizing their own production process. This type of companies has outsourced their R&D to the major research institutes in the field like Fraunhofer, DLR and ECN.

In EC funded projects collaboration between research and industry involves a small group of organisations (3-4) working actively together. This is especially the case in the bigger projects in FP6 – in the large projects a strict distribution of labour makes that cooperation only takes place between a limited amount of partners. For instance, in many projects the industry partner is a component supplier (i.e. supplier of the wafer) or a module manufacturer and has little knowledge or R&D-capabilities on cell design. This is typically the expertise area of research institutes like ECN, IMEC or Fraunhofer. So, the research institutes or university works on a new type of cell design or technique and the role of the industry partner is to test if this can effectively be produced at industrial scale with sufficient quality and throughput levels (proof of concept in industrial production machinery). It often happens that samples of cell designs are sent around Europe and each partner applies his specific knowledge or process technology.

Although in CSP the division of labour between industry and research institutes is not that strict – CSP involves less fundamental research – comparable patterns of division of labour are identified. The industry focuses on certain subsystems, e.g. software or components for the solar tracking devices, that are not really interesting for the research institutes.

For the research institutes cooperation with industry is important, because the institutes often have only small pilot production lines for testing. In order to test the feasibility of a new design or technique it is necessary to test it at large scale industrial (pilot) manufacturing processes. The large amount of information retrieved in the demonstration projects of CSP for instance, led to new insights about the technological alternatives. In the DISTOR project several alternative energy storage systems were tested. It became apparent that some storage systems were practically not feasible, or had large practical obstacles that were not identified in the laboratory phase. As a result these technological options are yet abandoned.

Another typical role for industry partners is to “assess” or “monitor” research projects from an industrial perspective. For a new idea to be applicable in an industrial environment it is important that the process technology involved is not too complex and that the materials used are not too expensive. Otherwise it does not make sense to try to implement it in an industrial environment as the aim is to reduce costs of pv modules.

Industrial cooperation is more easy to establish and much more effective if no direct competitors are involved in a project. The FP6 Larcis project included a number of industrial companies (i.e. Wurth Solar, Saint-Gobain, Solibro AB), but at the start of the project only one company was producing CIS solar cells (Wurth Solar). However, during the project the pv industrial landscape changed significantly and due to joint ventures and acquisitions the industrial partners in the project became direct competitors to Wurth and started producing CIS solar cells as well (Saint-Gobain and Shell Solar set-up the company AVANCIS and Solibro AB and Q-Cells set up Solibro GmbH). This was not an optimal situation to work together and share knowledge, also because at the start of the project no consortium agreement was made. One interview partner pointed out that some industrial partners were not actively involved and some did not provide any input themselves into the project. The reason for this was that they did not have any knowledge yet and were mainly involved in the project to learn from other (industrial) partners about production techniques, processes, and machinery. One of the industrial partners with a more advanced knowledge position in this particular area had the feeling that they provided a lot of knowledge and experiences without getting anything back. As a result collaboration and exchange of knowledge in this project was limited and occurred at a bilateral level only.

On the other hand we have found evidence that it provides added value if companies from different parts in the value chain are involved. In the Crystal Clear project the whole value chain from silicon feedstock producers, to wafer manufactures, solar cell manufactures, modules assembly is involved in the project. This provided added value because companies

\footnotesize{\textsuperscript{25} According to their own website Q-Cells is now the largest solar cell manufacturer in the world employing 1700 people by the end of 2007, but was only founded in 1999 employing only 17 people at that time)
and institutes could learn from each other, exchange knowledge and use it to optimize their own activities.
7. Environmental impacts

7.1 Energy efficiency

The increasing market for pv systems in Europe (especially Germany) and ongoing technical innovations (co-funded by the EC as described in the chapters above) increase energy efficiencies of solar cells and at the same time reduces costs. This makes that the rate of return for customers improves. At the same time the energy-payback time improves as well. Recent research on the life cycle of solar cells within the FP6 Crystal Clear project proves that the energy payback time of solar cells is reduced significantly of the years. One of the interview partners who is involved in this projects states that in Mediterranean countries a solar cell has an energetic payback time of only 2 years!

7.2 CO2 emissions

The share of solar energy (pv) in total renewable energy generation in Europe is limited, but shows impressive growth rates in recent years (mainly because of Germany and Spain). In Europe 4,2 TWh of electricity is generated from photovoltaics in 2007. In 2006 this was only 2,5 TWh. This is about 0,8% of all renewable electricity generated in the EU.

Figure 21    Renewable electricity in Europe

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomasse</td>
<td>17,0</td>
<td>27,9</td>
<td>39,7</td>
<td>41,1</td>
<td>47,2</td>
<td>56,2</td>
<td>68,8</td>
<td>80,1</td>
<td>89,9</td>
<td>89,9</td>
</tr>
<tr>
<td>Wasserkraft</td>
<td>260,3</td>
<td>297,8</td>
<td>321,5</td>
<td>339,7</td>
<td>380,8</td>
<td>377,4</td>
<td>303,6</td>
<td>282,4</td>
<td>285,8</td>
<td>312,1</td>
</tr>
<tr>
<td>Windenergie</td>
<td>0,8</td>
<td>7,3</td>
<td>22,2</td>
<td>27,0</td>
<td>36,6</td>
<td>44,2</td>
<td>56,9</td>
<td>70,5</td>
<td>81,9</td>
<td>104,4</td>
</tr>
<tr>
<td>Geothermie</td>
<td>3,2</td>
<td>4,0</td>
<td>4,8</td>
<td>4,6</td>
<td>4,8</td>
<td>5,4</td>
<td>5,5</td>
<td>5,4</td>
<td>5,8</td>
<td>5,8</td>
</tr>
<tr>
<td>Photovoltaik</td>
<td>0,0</td>
<td>0,0</td>
<td>0,1</td>
<td>0,2</td>
<td>0,3</td>
<td>0,5</td>
<td>0,7</td>
<td>1,5</td>
<td>2,5</td>
<td>4,2</td>
</tr>
<tr>
<td><strong>Summe</strong></td>
<td>281,3</td>
<td>337,1</td>
<td>388,3</td>
<td>412,6</td>
<td>368,7</td>
<td>383,7</td>
<td>437,5</td>
<td>439,8</td>
<td>465,7</td>
<td>516,3</td>
</tr>
</tbody>
</table>

Source: BMU. 2008

The majority of the European PV systems are installed in Germany. Due to the EEG feed-in scheme in Germany the demand for renewable energy, and pv in particular, is increased and compared to 1990 tripled. In 2007 1,1 GWp of pv systems was installed in Germany, cumulating to 3,8 GWp installed pv capacity in Germany in that year. Since 1999 the amount of installed pv capacity in Germany is doubled every year. In 2007 3,1 TWh of electricity is generated from PV. This represents 11,2% of all renewable electric energy generated in Germany and 0,5% of all energy generated in Germany.
According to the BMU 27 PJ of primary energy is saved in 2007 in Germany because of pv and in total about 2 million tonnes of CO2 is not emitted in 2007 in Germany. As Germany is responsible for about 75% of all electricity generated from pv in Europe this means that in Europe a total of 36PJ of primary energy is saved and 2.6 tonnes of CO2 is not emitted\textsuperscript{26}.

\textsuperscript{26} Figures adapted from: BMU. Erneuerbare Energien In Zahlen - Nationale und internationale Entwicklung. Stand December 2008
8. Summary and conclusion: added value of EC-funded research

During the FP5-FP6 period solar energy and photovoltaics in particular has taken off in Europe. Both the amount of installed pv capacity and the number of industrial companies producing solar cells have increased rapidly since 2000, especially in Germany. Before the FP5 period the European solar industry hardly existed and was merely a niche-market (i.e. space application) R&D was mainly conducted in research institutes aiming to make (production) technology ready for large scale and cost-efficient commercial application. The key scientific challenge was (and still is) to reduce (production) costs and/or increase energy efficiencies.

Since 2000, R&D efforts in the past 10 years paid off and the first commercial solar cell factories where founded. Since than new companies were founded every year and the production capacity for solar cells increased every year as well. R&D in the FP6 period was still focused on reducing costs and/or increasing efficiencies, but it was more oriented towards industrial application by focusing on optimising the solar cell production process.

Nowadays the pv industry has developed into a real industry sector in Europe. In Germany alone more than 74,000 people are employed in the solar industry in 2008. The large majority of Europe's solar cell companies are housed in Germany.

In the FP5-FP6 period solar thermal energy has become of interest as well. The installed capacity of low temperature ST increased rapidly in the world, but mainly due to developments in Asia. In addition to low and medium solar thermal energy, many European (and national projects, especially in Spain and Germany) were focused on concentrated solar power (CSP). It seems an attractive technology to produce electricity from heat and various demonstration projects (co-funded by the EC) in the past 10 years have shown that it can work in practise. Challenges are to reduce costs and/or increase efficiencies of the various (combinations) of subsystems needed for CSP and increase the scale of the power plants.

8.1 European Added Value

European funded research accounts small share (about 20%) of total amount of public research activities in Europe in the field of solar energy. In countries like Germany and the Netherlands, who have significant budgets for R&D in the field of solar energy, the share of EU funded research is even lower. For example, in Germany the federal government spends about 40 Meuro per year on R&D in the field of solar energy during the period 1998-2008, compared to approximately 21 Meuro per year that the EC spends on solar energy for Europe as a whole (budget for solar energy was 76 Meuro in FP6 and 92 Meuro in FP5).

Nevertheless we have found clear evidence that EU funded research does have added value especially by providing a vehicle for cross-boarder cooperation. Two-third of respondents of the survey indicate that their project has a medium to large impact in the area of university-industry links. This highlights that EU projects are really focussed on industry-research collaboration. Many interview partners stressed this point as well and both research and industry partners stressed the importance of working together across Europe:

- All interview partners stressed the importance of international collaboration between research partners, but also between research and industry partners. National funding programmes are often not designed to engage in international collaboration so the European Commission fills this gap. The possibility to cooperate with foreign (research) partners is by most interview partners seen as the main added value of European funded research.

- For new and emerging concepts for solar cells (i.e. thin-film) many different technologies and expertises are needed and this may not always be available on the national level. By collaborating with the best researchers of Europe technology development in Europe is fastened and reduces the time to market.
The added value of European collaboration is clearly illustrated by the development of CIS/CIGS technology in Europe. Since FP4 a strong European network is build of research institutes and universities from Germany, Sweden, France, and Switzerland who have been working together for almost two decades to develop CIS/CIGS technology and make it ready for industrial application. Since 2006 these efforts have paid off and a number of companies are now commercially producing solar systems based on this technology. All partners interviewed claim that European funded research has played an important role in bringing the partners together and sustaining this network for a long period of time.

Sometimes straightforward practical reasons make European cooperation valuable. Especially in the field of CSP, a test facility with a high level of sunlight is needed. For German researchers, the cooperation with Spanish partners is very valuable, because this gives an easy access to test facilities in Spain (such as Seville, Almería etc.).

The Integrated Project (IP) Crystal Clear involved more than 80% of the relevant research institutes, universities and companies in the field of crystalline silicon pv in the EU. Moreover, the project covers the total value chain from silicon feedstock, to wafer technology, cells, and modules. This approach enabled partners to learn from each other and understand the processes and challenges in different parts of the value chain. This again stimulated cooperation among the value chain and between organisations from different countries. This project is an example of European added value because such a project would not have been possible in for instance the Netherlands because not all parts of the value chain were available in the Netherlands. Despite some administrative issues and delays in the first year of the project, the interview partners were all possible about this approach and stressed the added value of having brought together all expertise in Europe on crystalline silicon pv.

8.2 Scientific impact

As we have not conducted a citation impact analysis or peer review it is hard to judge the scientific excellence of the funded projects in FP5 and FP6. What we do know is that all research organisation in Europe that play a role in the field of solar energy research are involved in EU funded research, including the leading institutes in this field who play a prominent role in FP5 and FP6. Moreover, all interview partners claim that they are satisfied with the scientific results of the projects.

From the survey and the interviews it is clear that the FP5 and FP6 projects increased the stock of knowledge, skills and reputation of the organisations involved. This is by far the main impact on the individuals who have been involved in the project.

8.3 Economic impact

The overall aim of the solar energy RTD programme in FP5 and FP6 is to improve efficiencies and reduce costs of pv systems which is obviously of great interest to the industry. Both the survey and interviews show that this is true indeed and that economic impacts from European funded research are emerging in a number of European countries, most notable Germany.

The survey shows an impressive economic impact of EU funded research: 60% reports medium to large impacts on competitiveness and an other 40% reports medium to large impacts on productivity and increased employment. And even 10-15% report medium to large impacts on turnover, market share and/or profitability. The industrial relevance and economic impact of the EU funded research projects in FP5 and FP6 is also stressed in the interviews with companies and research institutes. We have found a number of examples that show a direct economic impact of European funded research:

- A number of EU funded projects in FP4, FP5 and FP6 has clearly contributed to the development and commercialisation of CIS/CIGS technology in Europe by companies like Wurth Solar, Sulfarcell, Solibro (QCells) and Avancis. The main added value of EC funding is the collaboration with European research partners, which is very difficult to
achieve with national funding. We have found clear evidence that international collaboration resulted in exchange of knowledge between research groups in different countries. This has resulted in faster development of certain aspects of the CIS/CIGS thin film solar cell, most notably the work on alternative buffer layers to replace the traditional Cd-based layers and the development of techniques to deposit this layer in a large-scale manufacturing environment. Due to continuous project funding from the EC over the period FP4-FP6 a strong network pan-European network in the field of CIS/CIGS technology is developed and continued for 15 years. This is seen by all interview partners as an important effect of EC-funding and which has paid off in the last few years when CIS/CIGS technology entered commercial production.

- Based upon research conducted in FP5 (Solsilc and Spurt) and FP6 (Foxy and to some extent CrystalClear) the “solsilc” process was developed to produce solar grade silicon. Based on this the company Fesil-Sunergy is building a pilot plant in Trondheim with a capacity of 100 tons upgraded metallurgical silicon (UMG-Si) a year. The production is expected to start by the end of 2009, but due to the current economic crisis and drop in demand and prices for silicon this is not certain. This (pilot) plant which uses the solsilc-process is unique in the world as all silicon feedstock used today by the pv industry comes is produced by using traditional chemical process which is very energy intensive and costly.

- Due to the research efforts in FP5 (DOIT) and FP6 (Athlet) a stable transparent conductive oxide (TCO) layers is developed (at least of lab and pilot scale) for thin film solar cells. As the quality of the TCO has a major effect on the efficiency of the solar cell this is very important breakthrough and is very likely to be applied by industry within the next few years. The interview partners indicate that R&D on the TCO layers was boosted by cooperation in European FP5 projects and in particular in the FP6 Athlet project, because knowledge and experiences of different partners was bundled. To push the results of this research to industrial production the German BMU funded in 2007 a 4,5 MEuro R&D project to learn more about the zinc oxide TCOs. The consortium consists of leading (German) modules manufactures who have also been involved in European research as well.

8.4 Policy impact
The research funded in FP5 and FP6 in the area of solar energy is technology-driven, focussing on new materials, cells, modules, systems, etc. This means that the impact on policy is limited or very indirect. During the interviews with project participants we have not found any evidence of direct policy impacts at the regional, national or European level as a result of the funded projects.

The main policy impact is to be found in the area of coordination activities. With regard to photovoltaics, the European Photovoltaic Technology Platform and the Strategic Research Agenda (SRA) for Photovoltaic Solar Energy Technology published in 2007 provided the largest impact on European policies in the field. The SRA lies down the main scientific and technical challenges to achieve the ambition of pv and as it is written and approved by the Europe pv (research) sector.

While CSP was always a bit underrepresented on the research agenda, it started to gain visibility in the course of FP5. Several interviewees indicate that the demonstration projects in Spain have been important to this respect, because of the high visibility and recognisability of the project. In FP6 a roadmap for CSP was developed in the ECOSTAR project. The roadmap assesses advantages of several technological alternatives and the improvements that can be made on medium and long term. The ECOSTAR project sets out scientific challenges and also shows which technological alternatives are more likely to have success.