

# **The effect of the EU RoHS directive on the European photovoltaic industry**

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## Executive Summary

The RoHS directive of the EU restricts the use of hazardous materials like cadmium in manufacturing of electronic and electrical equipment. This study assesses whether the application of this directive to the photovoltaic industry – where in particular one technology is based on cadmium telluride (CdTe) semiconductors – will have a strong negative impact on the development of the photovoltaic industry and the EU's ability to meet its ambitious climate change objectives.

The analysis reveals that banning the use of cadmium in photovoltaic technology will not have a negative impact on growth and competitiveness of the industry. The main arguments are:

- A ban on cadmium will have no adverse effects on the industry's ability to meet expected levels of demand, because of:
  - the existence of large overcapacities in the short run, and
  - the availability of alternative technologies and strong competition for technology leadership.
- A ban on cadmium will not harm overall competitiveness of the industry, because:
  - strong competitive pressure within the industry as well as from other renewable and non-renewable energy sources pushes manufacturers to constantly improve the cost structure, quality and sustainability of their respective technology,
  - the strong market position of the cadmium-based CdTe technology is largely due to superior management and business models of an individual company, rather than because of specific properties of that technology. It can therefore be expected that manufacturers of other photovoltaic technologies are capable and willing to repeat this successful business path.
- A ban on cadmium will have only a negligible impact on employment levels in the European photovoltaic industry, because:
  - the largest proportion of jobs in the photovoltaic industry are in activities such as installation and maintenance of solar systems, which depend on final demand rather than on the performance of a specific technology,
  - only 883 workers or 0.7% of total employees in the photovoltaic industry are employed by suppliers or producers of CdTe thin film modules.

Given these results, a permanent exemption of photovoltaic modules from the RoHS directive would not be justified. Moreover, given that the current public support aims at developing competitive technologies for long-term usage, also a long prolongation of the current exemption is not justified since future growth of CdTe producers would come at the expense of other, clean technologies.

In the light of this analysis, the overall conclusion is that given the objective to precautionary restrict the use of hazardous materials in electronic and electrical equipment, any permanent or temporary exemption for photovoltaic modules can not be justified based on disproportionately negative socio-economic impacts.

## 1. Introduction

Secure energy supply is crucial for sustaining future economic growth and development. At the same time, sustainable economic development increasingly requires the reduction of global carbon emissions in order to avoid severe climate change. To address both accounts, the European Union (EU) has committed itself to reduce its total carbon emissions until 2020 by 20% of the level of 1990. To still secure future energy supplies, the share of renewable, emission-free energy sources in total energy consumption is to be increased within the same period from currently about 10% to at least 20%.<sup>2</sup>

Up to now, costs of renewable energies are significantly higher and maximum capacities of existing plants are substantially lower than those of conventional energy sources. Hence, the prospects to meet the EU's 2020-objectives will depend on its ability to strengthen the competitiveness of renewable energies and to build up greater capacity volumes. Since all available renewable energy technologies still show large potential for improvements, these objectives can best be achieved by developing and supporting a mix of different renewable energies.

Solar photovoltaic is an integral part of European strategies to promote renewable energies. Since 1998, installed photovoltaic capacities have been growing at an annual average of about 30% worldwide and even above 50% in the EU.<sup>3</sup> In line with the overall strategy of supporting renewable energies, the strong development of the solar photovoltaic industry in Europe is supported by generous public subsidies. In particular, several member states such as Germany, Spain, France, Greece or Italy have implemented – or are planning to implement – a system of feed-in tariffs which guarantees technology-specific prices for feeding electricity into the power grid. This support has not only promoted the growth of the photovoltaic industry in the EU, but also turned the EU into the largest market for solar energy with a share of about 80% in global demand (EPIA 2009).

Irrespectively of those strong recent achievements, the prospects for future development of the industry are currently discussed in relationship with the forthcoming amendment to the

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<sup>2</sup> Two further objectives of the EU's "Renewable Energy and Climate Change Package" are a 20% increase in energy efficiency and a 10% biofuel component in transportation (see [http://ec.europa.eu/environment/climat/climate\\_action.htm](http://ec.europa.eu/environment/climat/climate_action.htm)).

<sup>3</sup> EPIA (2009) reports that global installed capacities have been growing from 948 MW in 1998 to 14730 MW in 2008. Capacities in the EU-27 have increased from 108 to 9405 MW during the same period.

EU Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment 2002/95/EC (RoHS). The Directive, which entered into the force on July 1, 2006, restricts the use of six hazardous materials in the production of electronic equipment. The use of cadmium – one of the six hazardous materials – in photovoltaic modules is effectively not covered by the directive so far. However, if this will change as a result of the current discussion, the main consequence will be an exclusion of the rapidly developing cadmium telluride (CdTe) photovoltaic technology from the European market. In this context, the European Parliament has already proposed to allow the use of cadmium in solar photovoltaic modules until at least 2018. With the recent rise of CdTe technology in mind, this proposal is based on expected negative socio-economic impacts, one of the conditions under which an exemption from the RoHS directive can be granted. In particular, advocates of this suggestion might argue that the effective execution of CdTe technology will cause a strong decline in supply capacities, a loss in competitiveness as well as severe losses of jobs in the photovoltaic industry.

In this report, the economic consequences of a ban on cadmium in photovoltaic modules will be analyzed. The discussion will start with a brief description of the photovoltaic industry (section 2.1), followed by a detailed impact assessment (2.2). In particular, it will be argued that a ban on cadmium in photovoltaic technologies will have no detrimental impact on the development of supply capacities (section 2.2.1), competitiveness (section 2.2.2) and employment of the European photovoltaic industry (section 2.2.3). Moreover, it is argued that once it has been decided to eventually ban cadmium from photovoltaic modules, the phase out period should not be excessively extended as this will lead to a waste of public support (section 2.2.4) and give rise to increasing environmental concerns (section 2.2.5). Finally, it will be argued that adjustment costs for affected manufacturers appear to be manageable (section 2.2.6).

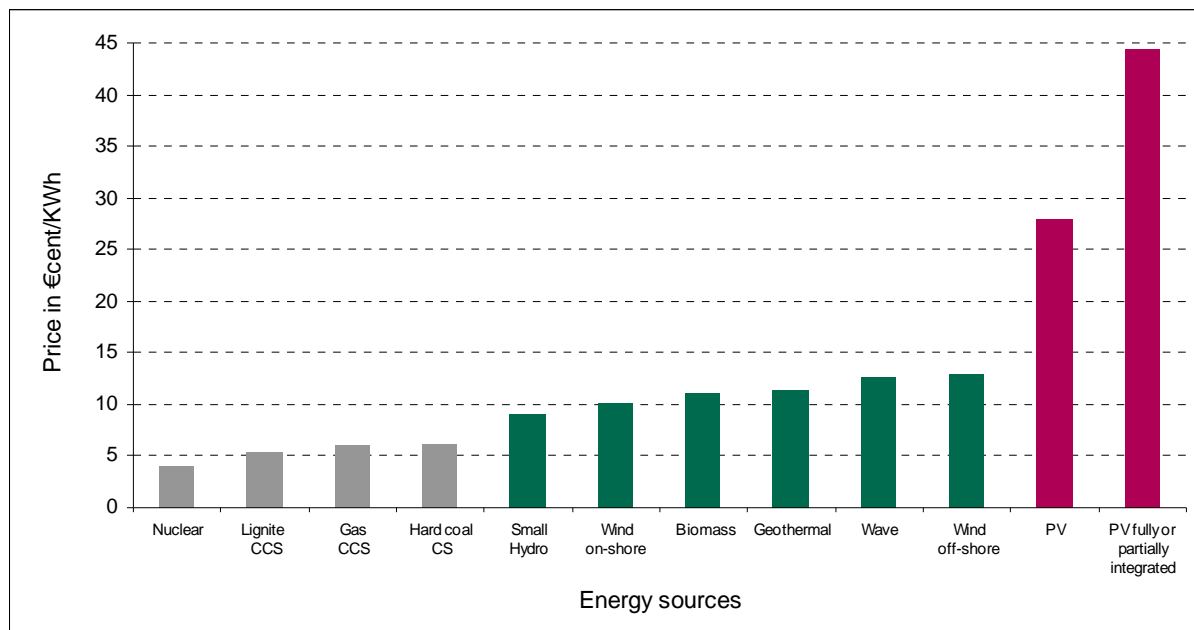
## 2. Analysis

### 2.1 The photovoltaic Industry

Despite its impressive growth rates, solar energy is expected to contribute only 0.6% to the total electricity and 2.8% to renewable electricity consumption in the European Union by 2010 (EREC 2008). The still low importance of solar energy to European energy supply is

mainly due to the high costs of photovoltaic technologies, which clearly exceed those of conventional as well as other renewable energy technologies (Figure 1). Hence, the future of this still very nascent industry depends on the manufacturers' ability to significantly cut the costs of production and installation of solar photovoltaic devices.

**Figure 1. Price of energy by sources (in €cent/KWh)**



Sources: 1) R. Schenkel, Nuclear Power: A key part of Europe's energy mix today and in the future, European Commission, Joint Research Centre, Presentation at AAAS Annual Meeting, Chicago, 12 - 16 February 2009; 2) D. Fouquet (ed.), Prices for Renewable Energies in Europe: Report 2009, European Renewable Energies Federation.

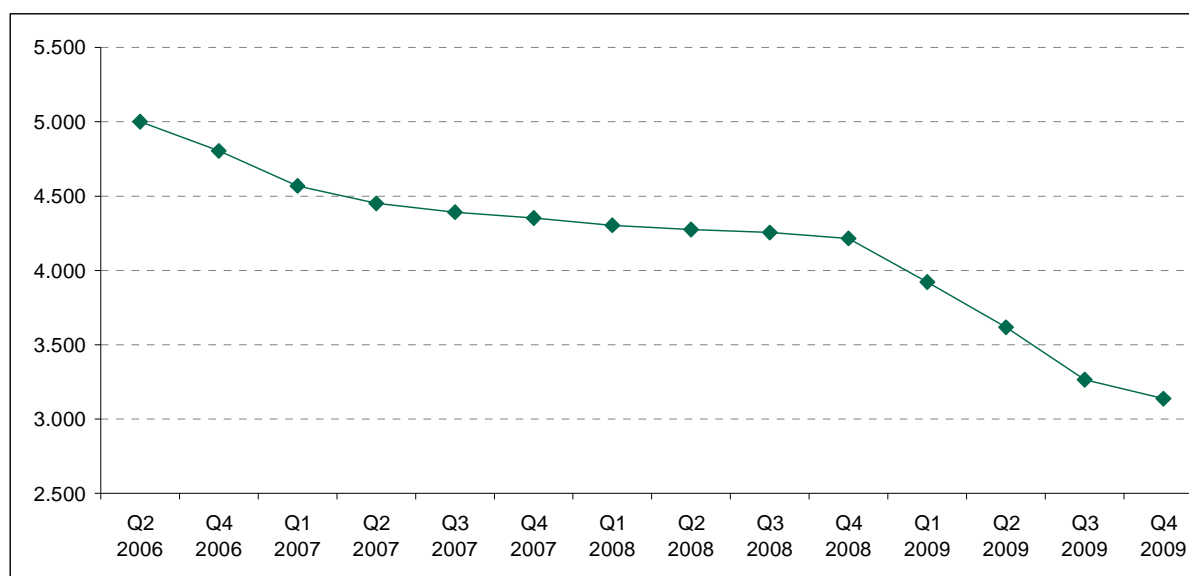
During the past three years, average total costs of manufacturing and installation of photovoltaic systems have already declined by about 40% (Figure 2). This decline is primarily driven by two developments:

- The rapid expansion of production volumes with average annual growth rates of 30-50% over the past ten years has enabled manufacturers to improve their knowledge about production and management processes (*learning effect*). Moreover, higher production volumes also reduce per unit costs (*economies of scale*) since fixed costs for research and development (R&D) or for building production plants can be allocated to a larger number of photovoltaic module.
- Continuous technological improvements which lead to cost efficiency of photovoltaic modules take place in the photovoltaic industry. This is reflected by two generations of

currently available technologies and the expected market entry of a third generation within the next decade. Thus far, in particular the market entry of second generation thin film photovoltaic devices has had a strong impact on cost reductions.

Since production volumes are expected to continue to expand in the future, it can be expected that manufacturing costs will continue to decline. Moreover, also the recent expansion of silicon production capacities and the corresponding reduction of silicon prices has caused total costs to decline, in particular after Q4-2008. In the future, this will allow for further cost reductions as well.

**Figure 2. Average price of installed photovoltaic systems in Germany (in €/KWp)**



Source: Independent, representative survey of 100 installation companies by EUPD-Research for Germany Association of Solar Industry. Further information: [www.solarwirtschaft.de/preisindex](http://www.solarwirtschaft.de/preisindex)

As noted above, the photovoltaic industry has not only expanded capacities and production volumes, but also continuously introduced new generations of solar photovoltaic devices. While the first generation – silicon crystalline solar cells – is still in the growth stage of its product life cycle, a new generation – thin film solar modules – has already entered the market. As shown in Table 1, the characteristics of photovoltaic devices vary between the two generations as well as across different technologies within each generation. In fact, each type of photovoltaic technology has its strengths and weaknesses. While devices of the first generation are more efficient in converting solar energy into electricity, they are also more expensive to produce than those of the second generation. Within the second generation, CdTe modules are the cheapest to produce, but have lower potential efficiency limits than CIGS/CIS photovoltaic modules. Amorphous silicon solar modules currently have the

highest production costs and are less efficient than other thin film technologies. However, in contrast to CdTe or CIGS/CIS, this technology does not rely on the use of scarce materials.

**Table 1. Current photovoltaic technologies (1<sup>st</sup> and 2<sup>nd</sup> generation)**

	1 <sup>st</sup> Generation: Crystalline Wafer Based		2 <sup>st</sup> Generation: Thin Film		
	Monocrystalline Silicon	Polycrystalline Silicon	Amorphous Silicon (a-Si)	Cadmium Telluride (CdTe)	CIS / CIGS <sup>4</sup>
Actual module efficiency <sup>a, d</sup>	15-19%	13-15%	5-8%	8-11%	7-11%
Confirmed module efficiency <sup>b</sup>	23%	16%	10%	11%	14%
Module costs (\$/Wp) Q1 2009 <sup>c</sup>	2.6		1.6	1.0	1.5
Scarcity <sup>d, f</sup>	Not limited by natural resources but by wafer production capacity		Not limited due to low silicon use (1-2% of the amount for crystalline cells).	Limited Tellurium supply	Limited Indium supply
Market share 2009 <sup>e</sup>	76.2%		9.3%	13.2%	1.3%
Expected market share 2010 <sup>e</sup>	74.8%		10.3%	13.0%	2.0%

Source: a) Lenardic (2008), First Solar (2009c), Sunpower (2009); b) Green et al. (2009); c) O'Rourke (2009); d) Beucker and Fichter (2007); e) O'Rourke et al. (2009); f) Morgen et al. (2006).

Since the development of each technology faces specific problems, manufacturers invest substantial resources in R&D in order to improve the competitiveness of their technologies. Producers of silicon crystalline solar cells are searching for opportunities to cut production costs, while manufacturers of thin films seek to increase the efficiency of their devices. Manufacturers are also constantly searching for solutions to mitigate limitations that the scarcity of crucial input materials impose. For example, the future development of the CdTe thin film technology is limited by scarce global reserves of tellurium, just as the scarcity of indium poses a problem for CIGS/CIS. Likewise, silicon used in crystalline silicon solar cells

<sup>4</sup> CIS: Copper indium diselenide and CIGS: Copper indium gallium selenide.

as well as in amorphous silicon thin film modules is not a scarce material, but requires expensive production capacities.

Overall, the current photovoltaic market boosts several alternative technologies which are in fierce competition for technological leadership. Since they all are successful in reducing manufacturing costs, enhancing efficiency levels or improving the availability of input materials, respectively, none of the technologies listed in Table 1 can be considered as universally superior. Moreover, the eminent market entry of a new generation of photovoltaic devices during the next decade, which is expected to be even more cost efficient than any of the currently available technologies, further complicates the evaluation and prediction of specific technology trends in this emerging industry.

## 2.2 Impact assessment

With the structure of the photovoltaic industry in mind, this section will discuss the expected consequences of a ban on cadmium in photovoltaic technologies, mainly focussing on the impact on production capacities, competitiveness and employment. The main assumption underlying this discussion is that a ban on cadmium in photovoltaic technology in the EU – the largest market for photovoltaic modules – will essentially lead to the exclusion of the CdTe technology which relies on cadmium. For all other technologies we assume that cadmium – to the extent that it is used at all – can be substituted by other substances without imposing strong technical or financial problems.<sup>5</sup>

### 2.2.1 Supply capacities

*The exclusion of the CdTe thin film technology from the EU market will have no adverse effect on the industry's ability to meet expected levels of demand.*

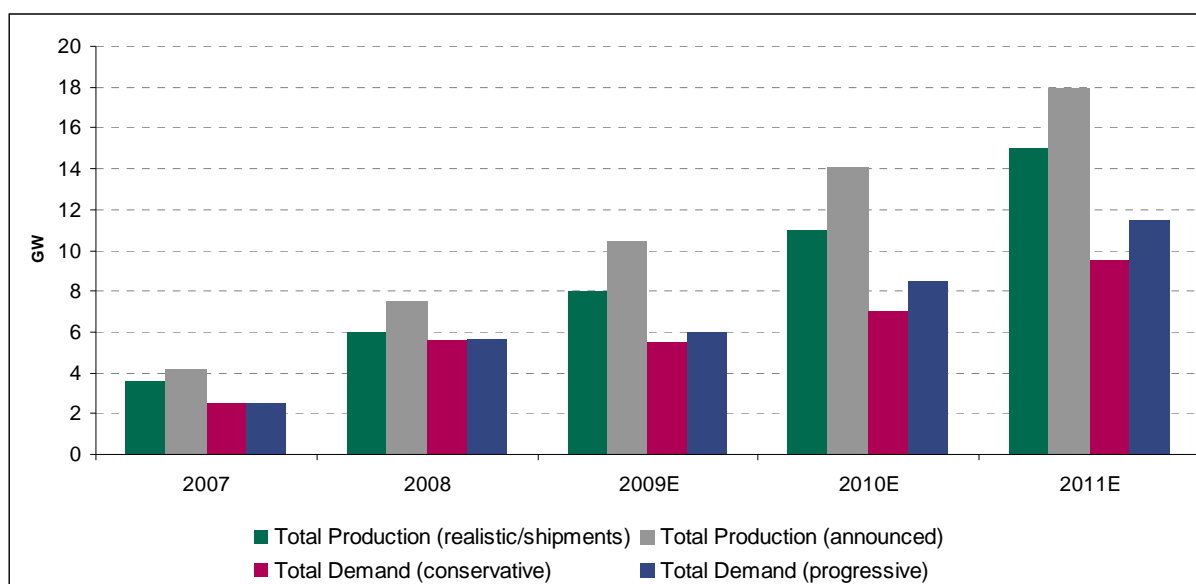
A major concern for banning cadmium in solar photovoltaic technologies is that the subsequent exclusion of the CdTe technology will lead to a substantial reduction of supply capacities which in turn will endanger the EU's ability to meet its 2020 objectives. Currently, CdTe manufacturers account for an estimated share of 13% of total solar photovoltaic supply capacities and are expected to maintain this position also during 2010 (O'Rourke 2009).

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<sup>5</sup> For example, some manufacturers of CIGS/CIS use cadmium as a buffer layer. However, the presence of other, cadmium-free manufacturers demonstrates that substitutes are available without that the overall competitiveness of the technology deteriorates.

Hence, a ban on cadmium will indeed lead to a significant short-term reduction of total supply capacities. However, since global photovoltaic markets are characterized by large capacity oversupplies, this does not necessarily imply that the industry will lose its ability to meet expected levels of demand. Indeed, the volume of the oversupply capacities clearly exceeds the total production capacity of CdTe manufacturers. For example, the estimates shown in Figure 3 suggest that current supply capacities exceed both, realistic and progressive levels of demand by 25% to 31% in 2009, 23% to 36% in 2010 and 23% to 37% in 2011. Hence, even under optimistic short-term developments – that is assuming that Japan introduces a new sustainable and attractive photovoltaic policy, that market developments in Europe will not experience significant drawbacks and that the US gets project financing on track – substantial overcapacities in photovoltaic markets will remain (PV Industry Handbook, 2009). Deutsche Bank forecasts that capacity oversupply will continue characterizing the industry until 2014 (O’Rourke et al., 2009).

**Figure 3. Capacity oversupply in the global photovoltaic market**



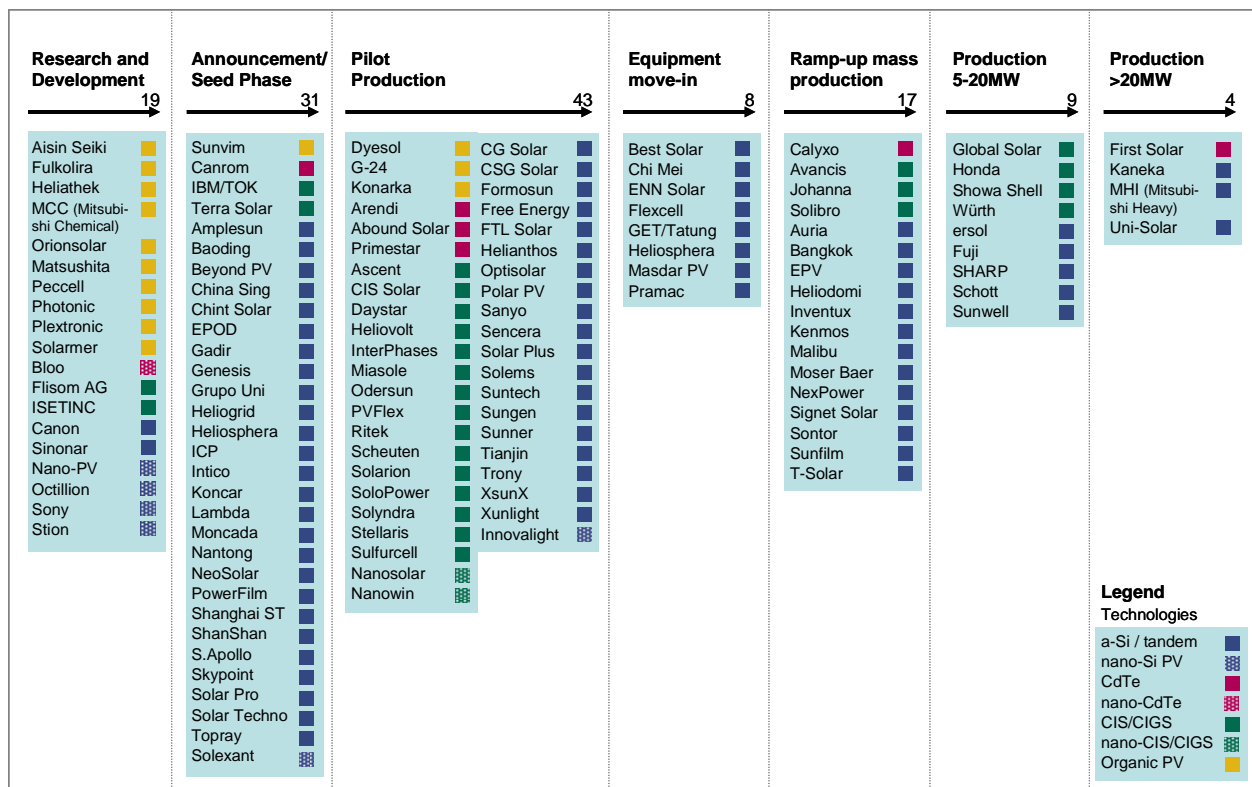
Source: PV Industry Handbook (2009)

In the medium and long term (i.e. in 2014 and beyond) the industry is fully capable to close the capacity gap that a ban on CdTe technology will cause. As argued above, different photovoltaic technologies are in fierce competition for technological leadership without that a single one appears to be superior.<sup>6</sup> Moreover, each technology is produced by several companies worldwide (Figure 4), each of which aims at increasing its market share. In

<sup>6</sup> For details see Table 1 and the analysis in section 2.

addition, an even larger number of firms currently still focuses on R&D, indicating that market entry of more competitors and of new technologies can be expected within the next decade. With this in mind and considering further that manufacturing plants can be built and ramped up to full capacity quickly (estimated at 1.5-2 years) and operated profitably<sup>7</sup> it can be expected that a drop in supply capacities, caused by a ban on CdTe technology, will not have a significant impact on overall supply capacities in the industry over the medium and long term.

Figure 4. Status of Thin Film Manufacturers in 2009



Source: EUPD Research 2009

In summary, this section argues that due to the existing and expected overhang of supply capacities in the short run, as well as because of the availability of several alternative technologies and the strong competition for market and technology leadership across a rather large number of firms, it can safely be expected that the exclusion of the CdTe

<sup>7</sup> For example, 5-year average ROE exceeds 15% for First Solar, Solar World and Motech (<http://finapps.forbes.com/finapps/jsp/finance/compinfo/CIAtAGlance.jsp?tkr=FSLR>; <http://www.reuters.com/finance/stocks/financialHighlights?rpc=66&symbol=SWVG.DE>, [http://www.capital.com.tw/support/CFEContent/ContentAtt/%7B71940955-9C95-4ECB-9E0D-A990B3183E00%7D/6244TT\\_Motech\\_Buy\\_Capital\\_20091110.pdf](http://www.capital.com.tw/support/CFEContent/ContentAtt/%7B71940955-9C95-4ECB-9E0D-A990B3183E00%7D/6244TT_Motech_Buy_Capital_20091110.pdf)).

technology will have no economically detrimental impact on supply capacities of the industry, neither in the short nor in the medium or long terms.

### 2.2.2 Competitiveness

*The photovoltaic industry will continue improving its competitiveness, independently of whether the use of cadmium will be banned.*

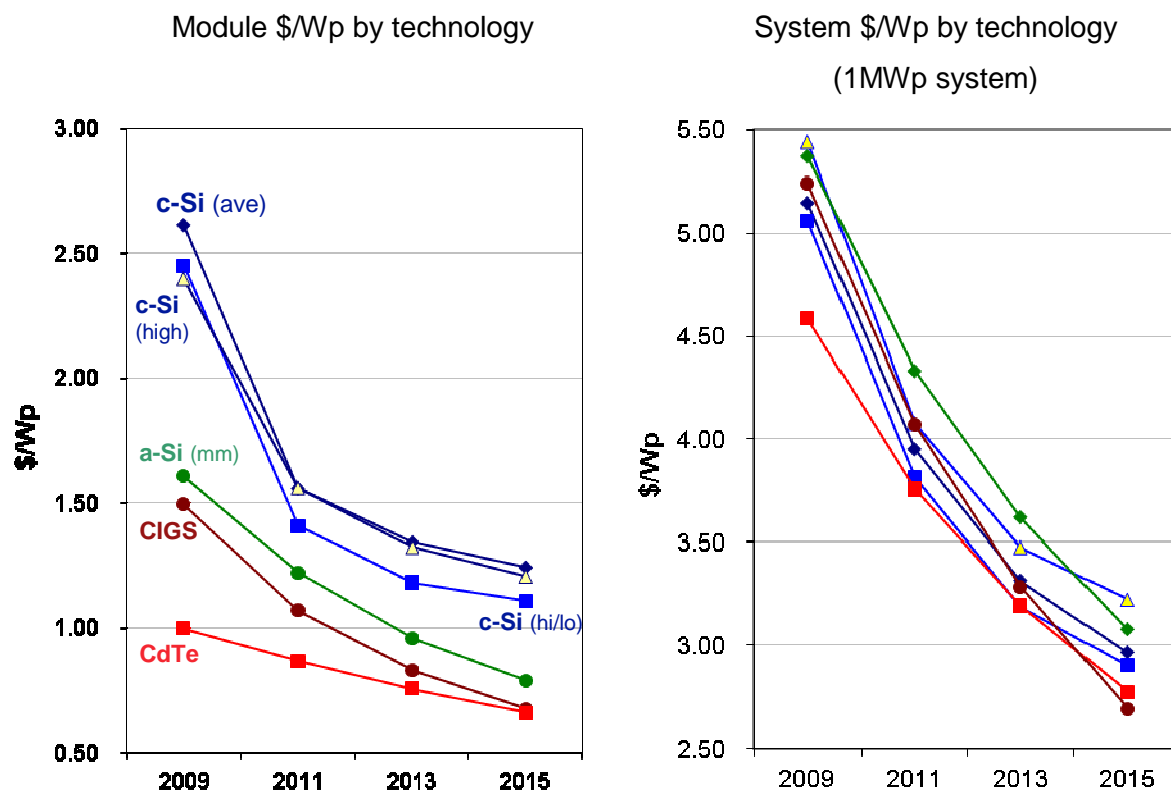
Strong price competition within the photovoltaic industry as well as with other renewable and non-renewable sources of energy forces photovoltaic manufacturers to reduce their production costs, independently of their specific technology. In fact, given that solar photovoltaic is by far the most expensive source of energy (see Figure 1), the survival of individual companies and technologies crucially depends on their ability to lower production and installation costs of their respective devices. In addition, the foreseen reduction of political support to the industry over time, mainly in the form of gradually declining feed-in tariffs,<sup>8</sup> creates future momentum for cost reductions.

Over the past three years, the industry has managed to reduce average total costs of manufacturing and installation by about 40% (see Figure 2). As explained above, these strong reductions have been achieved in all current technologies and where mainly driven by *learning effects* and *economies of scale*. In the near future, this tendency is expected to continue. Expected cost developments for leading technologies until 2015 are given in Figure 5. Although the costs for all technologies are expected to decline, there are clear differences. Based on the costs per module (left figure), thin film technologies – in particular CdTe – have a large cost advantage over conventional silicon modules. However, since thin film modules are less efficient, this advantage diminishes once costs are compared for fully installed systems (right figure). Nevertheless, CdTe still remains one of the most competitive thin film photovoltaic technologies.

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<sup>8</sup> For example, feed-in tariff for large solar plants (>1MW) in Germany are set to drop from more than 30 €cent/KWh in 2009 to about 12 €cent/KWh in 2020(EEG 2008).

Figure 5. Cost comparisons for different photovoltaic technologies<sup>9</sup>



Source: O'Rourke, S. (2009)

In fact, the strong competitiveness of the CdTe technology is almost exclusively due to the achievements of a single firm, First Solar, which accounts for more than 90% of global CdTe production capacities. As the most successful thin film manufacturer First Solar has been taking wise management decisions to speed up the company's success. Key factors for the company's success are:

- **Automated, large scale production:** As a result of continuous optimization efforts, manufacturing takes less than two and a half hours – about a tenth the time it takes for silicon equivalents (First Solar 2009e, Stevenson 2008).
- **The ability to duplicate manufacturing plants easily:** First Solar has standardized production lines of 53MW which it can replicate easily. This enables First Solar to rapidly build up enormous supply capacities. For example, First Solar increased its nameplate

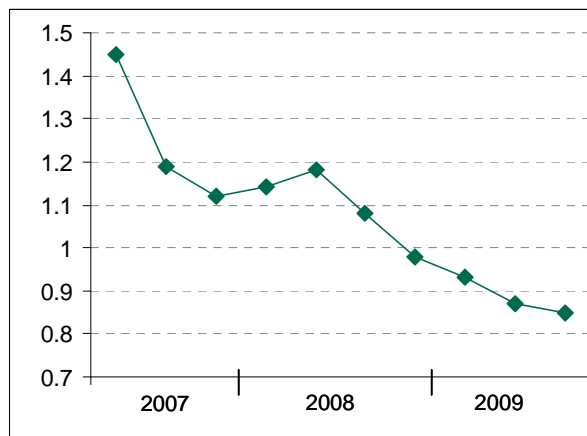
<sup>9</sup> Module costs compare the manufacturing costs of a technology. System prices compare the costs of fully installed system. Unlike module costs, system costs include the costs of installation, which consist of the costs of hardware necessary to install the system, the inverter, other costs like warranties, labour costs and the installers as well as the manufacturer's gross margin. c-Si (ave): average; c-Si (high CE): high efficiency; c-Si (hi/lo): higher than average efficiency and lower costs

capacities in Malaysia from 308MW to 1219MW just in two year period from 2007 until 2009 (Hyden 2009).

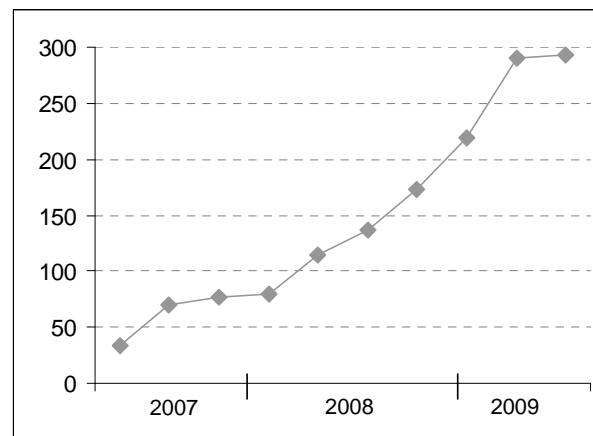
In addition to these key factors, First Solar has improved the competitiveness of its photovoltaic modules by assembling them in large capacity plants which are mainly located in countries like Malaysia. where costs of labor are low Consequently, the reduction in manufacturing costs of the company over the past three years has gone along with a strong increase in its production volumes (Figure 6).

**Figure 6: Module cost per Watt (in US\$) compared to MW produced per quarter**

Total Cost per Watt (\$/Watt)



MV Produced per Quarter



Source: Data for 2007 is from First Solar (2008a), data for 2008 and 2009 is from First Solar (2009b) and First Solar (2009c).

Overall, it appears that the strong competitiveness of the CdTe technology is mainly driven by superior business models and excellent managerial skills of the market leader, First Solar. This implies that the strong competitiveness of the CdTe technology is management- rather than technology-specific.<sup>10</sup> The exclusion of CdTe technology from the EU market will not eliminate these superior management concepts and its key success factors can still be used to improve competitiveness of other technologies.

The discussion in this section has shown that strong competitive pressure has pushed the industry to constantly eliminate drawbacks and improve competitiveness of their respective technologies. In the near future this development is expected to continue without that a

<sup>10</sup> In fact, no other CdTe manufacturer has so far managed to achieve a similar level of competitiveness. For example, Calyxo (Q-Cells) runs a 25MW production line in test mode in 2009 and announced 85MW for 2010 (Q-cells 2009). Moreover, Calyxo's cells offer lower efficiency rates than First Solar's cells (Fabtech 2008). Another German CdTe producer, Antec Solar, became bankrupt in January 2008.

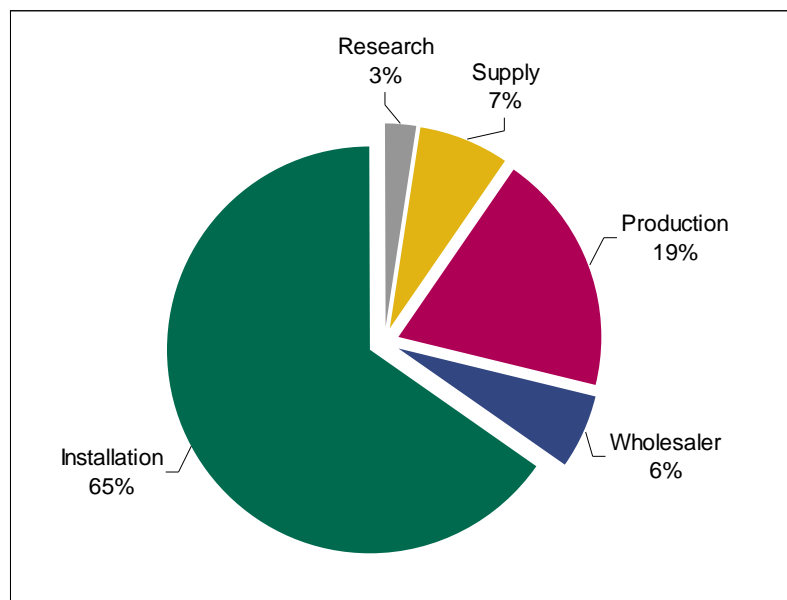
single technology will emerge as clearly superior. Finally, a closer look at the success factors of the leading CdTe manufacturer reveals that its strongly competitive position is due to superior management, not technology. It can hence be concluded that the competitiveness of photovoltaic producers will continue to improve after CdTe technology is banned from the European market.

### 2.2.3 Employment

*A ban of cadmium from the use in photovoltaic technology will have only negligible effects on European labor market*

In line with increasing production volumes, the photovoltaic industry has also become an important employer. Along the global value chain, the installation of modules accounts for by far the largest employment share, followed by production, supply, wholesale and research (Figure 7).

**Figure 7: Distribution of global employment in the value chain of the photovoltaic industry in 2007**



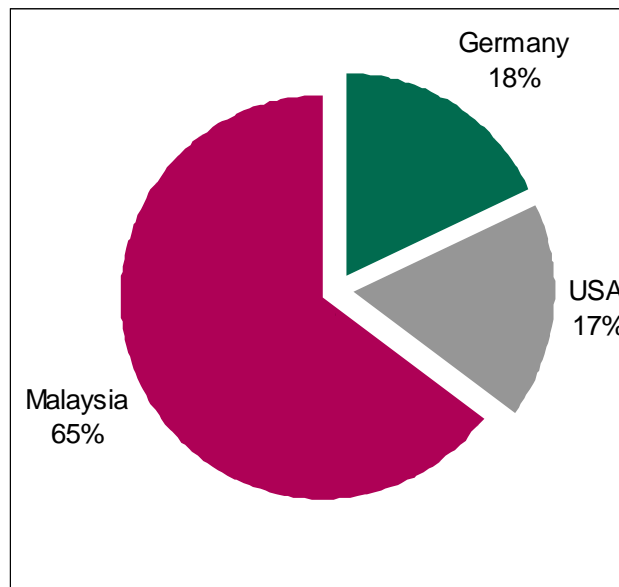
Source: DIW econ based on data from Greenpeace and EPIA (2008).

With respect to the industry's impact on employment levels in Europe, it is also important to consider the regional distribution of those different tasks. In particular, input supply and production can be flexibly located to benefit from specific advantages of different regions

such as low-cost labor in Asia. Photovoltaic manufacturers are expected to increasingly shift production capacities to Asia. On the contrary, the labor intensive installation of solar modules is locally bound to the demand in Europe and will thus be especially high in countries which subsidize photovoltaic energy production. Research is a knowledge-intensive business and will rather settle where the knowledge is best and where public as well as private funding is available, which is mainly Europe, the USA and Japan.

For the CdTe value chain a similar pattern can be expected because 65% of the production capacity worldwide is located in Malaysia while only 18% is based in Europe (Figure 8). In fact, the strong focus on production capacities in a country like Malaysia with relatively low costs of labor is an important driver of the current price competitiveness of the CdTe technology.

**Figure 8. Worldwide CdTe capacity by country in 2009**



Source: DIW econ based on data from First Solar (Hyden 2009), Calyxo (Q-Cells 2009) and Abound Solar (Jaffe 2009). The observed total worldwide nameplate capacity by First Solar, Calyxo and Abound Solar is 1309 MW in 2009.

As the worldwide distribution of CdTe production capacities already indicates, the impact of prohibiting the use of the CdTe-technology will have only minor employment effects in Europe. To our knowledge, five companies are currently operating in production, research and input supply for CdTe modules in Europe: First Solar, Calyxo (Q-Cells), CTF Solar (Roth & Rau), Arendi and 5nPlus. The exclusion of CdTe technology will mainly affect employees of those firms. In contrast, orders for installation services are determined by overall market demand for photovoltaic modules rather than by the supply of an individual technology and

will thus not be affected by the exclusion of a particular technology. It can therefore be expected that workers occupied with installation of CdTe modules can switch to other photovoltaic devices with only minor adjustment costs.

In 2008, the five companies, which produced CdTe modules or supplied the required input, employed only 883 people (Table 2). This makes up about 0.7% of the 130,000 employees (PV employment 2009) who are directly employed in European photovoltaic industry. Hence, the employment effects from terminating CdTe technology will be negligible.

**Table 2: Number of persons employed in CdTe module production in Europe in 2008**

Company	Task in the CdTe value chain	Country	Persons employed in 2008
5n Plus	Supplier	Germany	47
First Solar	Production	Germany	634 <sup>11</sup>
First Solar GmbH	Trading	Germany	44
Calyxo (Q-Cells)	Production/ Research	Germany	116
CTF Solar (Roth & Rau)	Production/ Research	Germany	12
Arendi	Production/ Research	Italy	30
<b>Total in Europe</b>			<b>883</b>

Source: DIW econ based on Oder-Neiße-Journal (2009), Unternehmensregister (2009a), Unternehmensregister (2009c), Unternehmensregister (2009b), Photon Magazin (2008).

#### 2.2.4 Timing

*Since a ban on cadmium and thus on the CdTe technology will not have a detrimental impact on available capacities, industry competitiveness and employment, a permanent exemption from the RoHS directive would not be justified. A temporary prolongation of current exemption for eight years is economically not justified because it will lead to a waste of current subsidies (through feed-in tariffs) for the photovoltaic industry.*

Supporting an infant industry like solar photovoltaic through guaranteeing privileged feed-in tariffs for all generated electricity – as it is, for example, the case in Germany, the world's

<sup>11</sup> Including 29 contract employees and 7 trainees.

largest market for solar photovoltaic modules – serves two goals. The first goal is to build up carbon-free electricity generation capacity in the light of global warming and the 2020 goals of the EU. More importantly, feed-in tariffs aim at stimulating and supporting the development of competitive renewable energy technologies which in the long run are capable to replace conventional technologies. Since all current photovoltaic technologies are not competitive with conventional electricity-generating technologies, feed-in tariffs are typically set at relatively high levels in order to encourage investments into the photovoltaic industry. In order to strengthen the incentives to cut costs, feed-in tariffs decline over time.

Due to their current cost advantage, leading CdTe manufacturers benefit strongly from feed-in tariffs which allow them to further increase production volumes at fairly high levels of profitability.<sup>12</sup> But since the objective of feed-in tariffs is to support the development of competitive technologies for long-term usage, allocating funds to a technology which will be restricted in the future implies a waste of public funds. This argument is further strengthened by considering that despite generous present support, the development of the photovoltaic market is restricted by several factors. Most importantly, market size is limited by demand. In addition, several crucial input factors such as talented personnel for R&D and business development or additional public support to industry development (e.g. for investments in new photovoltaic plants) are not infinitely available. Hence, further expansion and development of the CdTe technology comes at the expense of other technologies which will be less capable at managing large scale production capacities once CdTe is no longer available in the European market. To the extent that public support to the industry aims at developing a competitive industry for long-term usage, feed-in tariffs paid to CdTe producers would be wasted.

### 2.2.5 Recycling

*The need to recycle CdTe photovoltaic modules at the end of their usage period imposes environmental risks which cannot be neglected.*

The lifetime of CdTe photovoltaic modules is about 25 years.<sup>13</sup> Since most of the currently used CdTe thin film modules were produced less than five years ago, recycling of these

<sup>12</sup> For example, First Solar, the leading CdTe manufacturer, reported a return on equity of 25.7% for 2009. (Forbes, 2009)

<sup>13</sup> [http://www.firstsolar.com/en/product\\_design.php](http://www.firstsolar.com/en/product_design.php)

potentially hazardous devices is currently a mainly theoretical issue and arises only in case of manufacturing defects or damages during installation. Yet, in less than 20 years an extensive and continuous recycling effort will be needed as the installed CdTe PV modules will be approaching the end of their lifetime.

CdTe modules are mostly sold in Europe (First Solar 2009a). Therefore, Europe will face the greatest need to recycle hazardous CdTe modules. Until 2009, the estimated amount of cadmium in already installed CdTe modules is about 99.6 tons in Germany and additional 23.3 tons of cadmium in the rest of Europe, mainly Spain.<sup>14</sup> If CdTe thin film manufacturers are granted a 4-year phase out extension in 2010, the stocks of hazardous cadmium in EU will increase by additional 228.9 metric tons until 2014. In case the extension will be extended until 2018, Europe might face a total of 736 metric tons of this hazardous substance in solar photovoltaic devices to take care of.<sup>15</sup>

Some CdTe producers have voluntarily implemented recycling programs. Consumers can alert the companies if they have modules which have to be recycled. Typically, these end-of-life collection and recycling liabilities cover packaging, transportation and recycling costs while owners bear the costs of proper dismantling the modules. However, even if these recycling schemes will work properly, severe risks remain. For example, it's uncertain whether in particular the owners of small systems on private rooftops will be

- willing to cover the costs of dismantling the modules at the end of product lifetime,
- aware of the potential danger that improper disposal of their module contains, and

<sup>14</sup> The estimation of the amount of cadmium installed on European rooftops is based on several assumptions. A typical CdTe module contains about 5.04g of Cd (Zweibel. and Fthenakis 2009),. The average rated power of modules increased from 64 watts in 2005 to 73 watts in 2008 (First Solar 2007, 2008b, 2009a) while total production increased between 2006 and 2009 from 60 MW to 1094 MW (First Solar 2008a, 2009b, 2009c). Germany accounted for 95% of the net sales in 2006 (First Solar Annual Reports 2006-2008). Q4 2009 production is assumed to be the same as production in Q3 2009. In 2008 net sales in Germany were still high (about 74%) while sales in Europe accounted for 94% of all sales. For the year 2009 the same regional distribution of modules sales is assumed. Since there is no data available on the sales of Abound Solar and Calyxo, their production is omitted for 2009, which results in a conservative estimate.

<sup>15</sup> These forecasts are based on the following assumptions: According to the European Renewable Energy Council (2008) the EU expects about 18 GWp installed capacity by 2010 which is expected to grow with a compound annual growth rate of 23.6% to 150 GWp by 2020. EPIA (2009) estimates that market shares of Thin-Film technologies will grow from 22% by 2010 to 25% by 2013. For the later years a market of 25% is assumed. The CdTe modules are expected to account for 50% of the market share for thin-film technologies (for 2010, O'Rourke et al. (2009) estimate the CdTe market share in all thin-film technologies at 52%). Furthermore the average rated power per module is assumed to increase by 3% per year. Overall, this estimate is even conservative because it implies an average capacity increase of CdTe modules by 661 MW per year until 2014, which is less than half of the total current CdTe production (O'Rourke et al. 2009).

- aware of existence and functioning of the recycling scheme by the end of the module life cycle.

In fact, these risks are even stronger when considering that ownership and responsibilities are likely to change over a long period of 25 years.

In addition, further risks to the functioning of proper recycling schemes might arise from insolvency of relevant parties. For example, the bankruptcy of Antec Solar, a German CdTe manufacturer, in 2008 left 450 tons of modules with no appropriate recycling provisions in place (Ristau 2009).

Finally, if the ban of cadmium is accompanied by a generous extension period, the incentives to properly operate recycling schemes will diminish once the end of that period approaches, as CdTe manufacturers increasingly lack the incentive to demonstrate the sustainability of their production.

#### 2.2.6 Future perspective of affected manufacturers

*The discussion in this section will suggest that acceptable adjustment costs for CdTe manufacturers can be realized through a sufficient phase out period.*

The ban of cadmium in photovoltaic cells under the RoHS directive will affect manufacturers that use the CdTe technology as well as other thin film producer that use cadmium sulfide (CdS) as a buffer layer. However, all those manufacturers are clearly aware of the risk that their technology imposes on environment and health and that the use of hazardous substances bears the risk of special regulation (Sinha et al 2007). In the EU the exclusion of cadmium from solar devices has already been discussed in 2003 when the RoHS directive was issued (Ökopol und Institut für Energetik und Umwelt 2004). It can therefore be expected that affected manufacturers and suppliers have strategies in place of how to adjust their production process in case of a change in legislation.

For example, manufacturers of CIS or CIGS thin film cells who use CdS as a buffer layer can substitute it with a cadmium-free buffer layer without adverse effects on efficiency (Powalla et al. 2003, Zalesski et al. 2007). In practice, companies like Showa Shell demonstrate that cadmium-free CIS cells can be successfully produced at current production capacities of 80 MW and strong future perspectives as a planned increase of 900MW by 2011 indicates (Showa Shell 2009).

Manufacturers of CdTe cells will have to switch to other production technologies. However, because capital investments in CdTe manufacturing plants are under reasonable assumptions paid off already in about two years of production,<sup>16</sup> a phase out period of 4 years can allow manufacturers to write off their investments in affected production capacities while giving ample time for switching to other technologies.

### 3. Conclusions

Although some of the currently available photovoltaic modules contain cadmium, they have so far not been subject to the RoHS directive of the EU which restricts the use of hazardous materials like cadmium in manufacturing of electronic and electrical equipment. The directive is currently recasted. Effectively, the application of the RoHS directive to solar photovoltaic modules will exclude CdTe modules, a new and quickly growing technology. So far, the European Parliament has proposed to exempt photovoltaic modules until at least 2018. It is suspected that this suggestion aims at avoiding negative socio-economic impacts, given the crucial role of renewable energies such as photovoltaic in helping the EU to meet its ambitious objectives with respect to combating climate change. This would be particularly justified if exclusion of the CdTe technology will cause a strong decline in supply capacities, a loss in competitiveness as well as severe losses of jobs in the photovoltaic industry.

This report discussed the economic consequences of a ban on cadmium in photovoltaic modules with particular focus on exclusion of the CdTe technology. It is argued that despite its cost competitiveness and strong recent growth, the CdTe technology is one out of several alternatives which all face particular strengths and weaknesses and which all are continuously improved, driven by intensive R&D activities. Hence, it is concluded that a superior technology has not yet emerged. Moreover, the analysis reveals that the strong performance of CdTe – which is mainly determined by achievements of a single firm – is essentially due to superior management rather than technology. Finally, the industry produces with large overcapacities which clearly exceed the potential capacities of CdTe producers in the short and medium run. With this in mind, the report argues that a ban on

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<sup>16</sup> The costs for a production line of First Solar, the leading CdTe manufacturer, is estimated at 45.6 million USD, based on the company's announcements for current investments in Malaysia (First Solar 2009d). Total net income was about 27million USD per line between 4<sup>th</sup> Quarter, 2008 and 4<sup>th</sup> Quarter, 2009 (First Solar 2009c). Assuming a production phase of seven quarters and weighted average costs of capital of 12-14%, the payback period is four years after start of construction and two years after start of production.

cadmium in photovoltaic technologies will have no detrimental impact on the development of supply capacities, competitiveness and employment of the European photovoltaic industry. Moreover, the analysis shows that given the decision to include photovoltaic under the RoHS, the phase out period should be not be excessively extended as this will lead to a waste of public support and gives rise to increasing environmental concerns while adjustment costs for affected manufacturers appear to be manageable.

In the light of this analysis, the overall conclusion is that given the objective to precautionary restrict the use of hazardous materials in electronic and electrical equipment, any permanent or temporary exemption for photovoltaic modules cannot be justified based on disproportionately negative socio-economic impacts.

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