Solar Power in the European Context: Conversion Efficiency and the Issue of Carbon

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Abstract

The European Union is committed to increasing the use of renewable energies across Europe. One of the ways this is to be done is through the promotion of solar photovoltaics (PV), a method with significant environmental benefits. However, the high costs of electricity generated through PV have constrained the market reach of this option. This paper takes the form of a policy discussion, analyzing the fundamental issues concerning this type of energy, and its place in the European alternative energy market. Furthermore, a scenario is drafted to estimate how efficient solar panels should ideally be to make electricity produced by them cost-competitive with conventional, grid-tied energy sources. The study considers both a conventional scenario and another, with carbon capture costs incorporated into the final electricity prices. It is observed that in order to be competitive with conventional fossil-based electricity, photovoltaic conversion efficiencies should be around 34%. Incorporating carbon costs would further help promote solar PV, making it more price-attractive compared to emission-intensive electricity generation based on fossil fuels. The final part of the paper sheds light on the new developments on European PV, mainly in regards to the 2008 European Commission Climate Change Package, its implications and reactions from the industry.

SOLAR PHOTOVOLTAIC (PV) IS AN IMPORTANT ENERGY SOURCE AMID RENEWABLES. It uses sunlight to produce a useful electric current, suitable for appliances which are connected to the electricity grid or not, with minimal environmental impact. It is also complementary to other renewable technologies, such as the generation of hydrogen for fuel cells.

In the European Union (EU), three community frameworks call for alternative sources of electricity to be more present in the total European energy infrastructure. The first two are the European Commission (2001) 'European Sustainable Development Strategy' and Directive 2001/77/EC on the promotion of renewable electricity (European parliament 2001). The common pursued objectives are to shift dependence away from fossil sources, improve energy security boosting electricity production in Europe and avoid the environmental costs that are likely to arise in case fossil resources are kept on the forefront of electricity generation.

The third framework was kick-started by the European Commission's 'Renewable Energy Roadmap' (European Commission 2007a: 6). It included the ideals that were pursued by a subsequent piece of European legislation, the European Climate Change Package, put forward by the European Commission (2008a).

The Photovoltaic Technology Platform is another important initiative in the field. It is headed by the European Commission, under the Joint Research Centre. The Platform involves research institutions, governments and private agents in the solar energy

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sector. The objective of the platform is to promote photovoltaics in the long term. It is the largest multi-stakeholder PV project of its kind in the world, and the ultimate goal is to promote the necessary technological advances and policy suggestions to promote solar power in Europe.

But why should PV be promoted? The uptake of PV promotes new technological chains and the creation of skilled employment, all desired externalities on the policy-maker perspective. Additionally, electricity generated by sunlight has the lowest environmental impact among renewables. Those desirable characteristics make solar energy a very attractive option for an envisioned low-carbon society.

The debate about promotion of PV in Europe is currently in the limelight. The 23rd European Photovoltaic Solar Energy Conference (Valencia, September 2007), the Jean Monet Conference on Sustainability (Brussels, October 2007) and the Sustainable Energy Week (Brussels, January-February 2009) are examples of events in which PV was praised as a promising technology to effectively reduce dependence on fossil fuels. The recorded investments in solar energy constitute another proxy that provides insight on the importance given to the topic all over Europe.

There has been a considerable academic debate about PV, both in policy making perspective and at technical level (Nemet 2006; Jager-Waldau 2007; Jaegesberg 2008; Huld *et al.* 2008). As of 2009, the prices of PV electricity seem to be the largest impediment preventing a faster development of this type of generation. Gregory Nemet (2006) identifies points that inflate prices of solar power. His study identifies areas of action, where development is needed to bring down PV electricity prices. One of his conclusions is that learning curves alone have not been enough to bring down PV prices in the past three decades. This reinforces a multi-dimensional strategy to tackle high prices. The most essential areas for action are silicon supply, conversion efficiency and economies of scale.

From an environmental perspective, it would be desirable to see a faster adoption of solar PV in Europe. This leads to the question: would PV generation in Europe rise faster if prices were in a stronger downward trend? Harmon (2000: 7) observed declining prices in PV installations by observing values from 1968 to 1998. He further claims that economies of scale and standardization of panel production provided an important contribution towards the cost reduction of PV.

Given the available information about photovoltaic generation, actions should focus on the main issues known to hinder the decrease in module prices. But would actions targeting only the photovoltaic industry be enough to boost the desirable PV option in the European market? The answer to this question is probably not. The highest advantage of PV only becomes evident when an external factor is incorporated in a cost-benefit analysis. This is done by comparing PV electricity with the costs of carbon emitted in conventional electricity generation; in other words, by considering the environmental impact as costs from cheaper options of electricity. Before going into the scenarios considering carbon emissions it is necessary to examine the European Union's position on solar photovoltaics.

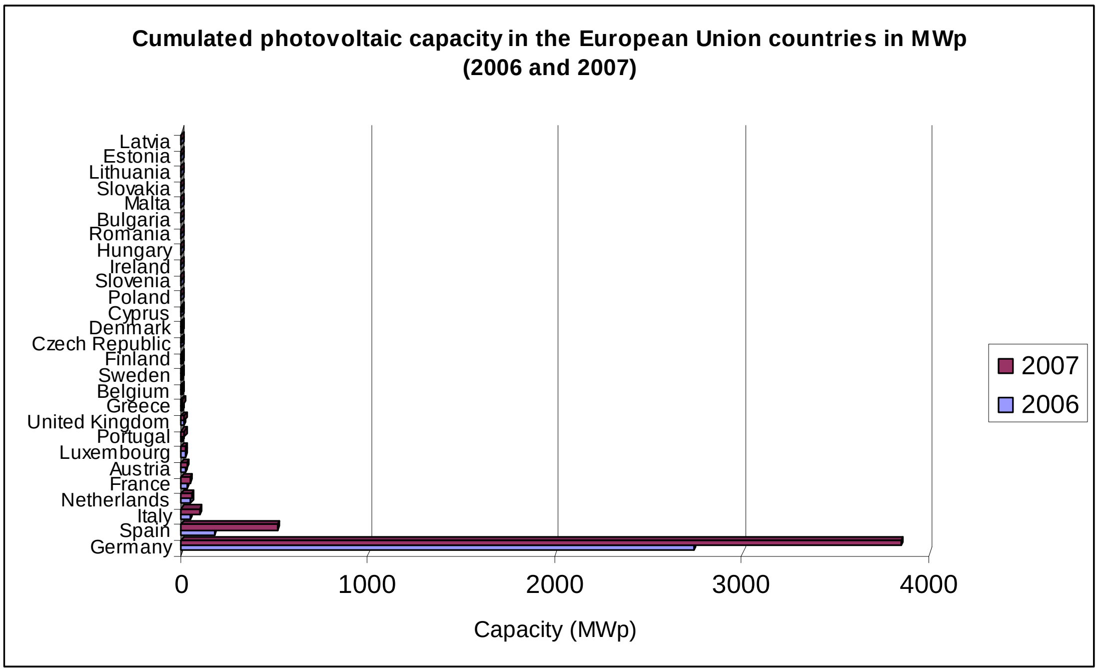
PV in Europe

Europe is the largest producer of photovoltaic cells in the world as of 2008, and the production has been growing at an exponential pace (see EurObserv'ER 2008: 8). The main producer is the German-based Q-Cells AG which delivered 389 MWp of solar cell equivalent in 2007, presenting an annual turnover of € 858 million in the same year.

There is a strong upward trend in energy consumption in the European Union. After 2004 with twelve new member states experiencing acceleration in economic growth, the energy demand stands out as a clear pressure-point for EU policy.[1] If the energy for the future European development is to be based on from fossil sources, the environmental consequences might offset the efforts in other EU countries investing in renewables at a faster pace.

According to the Photovoltaic Energy Barometer from 2008, there is a strong disparity among European member states in regards to their adoption of photovoltaics (see Graph 1).

Graph 1:



Source: Photovoltaic Energy Barometer (Eurobersv'ER 2008) adapted by the author.

The European PV installed capacity, both grid-tied and isolated systems, is in practice determined by the German, Spanish and Italian installations, which together represent 95% of the total capacity. According to the 2008 Energy Barometer, the new member states which joined the European Union after 2004 have all less than 2 MWp of installed capacity in their territories.

Potential hypotheses to explain the low penetration of photovoltaics in the European member states which joined the union after 2004 include: high cost of PV electricity, absence of specific government policies,[2] lower income per capita and inexistence of a native photovoltaic industry. Apparently the approach taken by such countries to build up renewable energy is more focused on biomass and waste-to-energy initiatives (Streimikiene *et al.* 2005).

[1] In 2004 the EU expanded include ten countries from Eastern Europe and the Mediterranean (Cyprus, Czech Republic, Estonia, Latvia, Lithuania, Hungary, Malta, Poland, Slovakia, Slovenia) and a further two states (Bulgaria and Romania) became members in 2007.

[2] An example is the scheme adopted by the German government, promoting a special feed-in tariff to foster photovoltaics. The German Erneuerbare-Energien-Gesetz was a fundamental intrumento in the uptake of PV in Germany. However, there is criticism in regards to the environmental reasons of funding PV via feed-in tariffs. The price of a ton of CO2 spared via PV generation can cost 30 times the average price of a carbon certificate under the European Emission Trading Scheme. Available at: http://www.faz.net/s/RubC5406E1142284FB6BB79CE581A20766E/Doc~E42CAA2FCFBC84BDBAD620C3CD0329144~ATpl~Ecommon~Scontent.html?rss_aktuell, last accessed 9 April 2009.

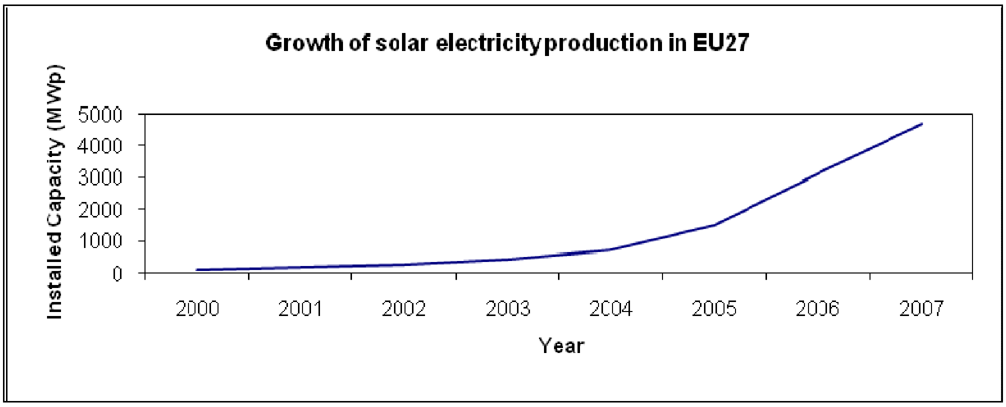
It is difficult to implement feed-in tariffs or other costly subsidy mechanisms for PV in countries with tighter government budgets, such as the case in most Eastern Europe. In this scenario, those countries become crucial targets for support from European Research Grants and Structural Funds.[3] Yet, the alternative to use EU-funds is limited. In order to attract substantial private investments to the solar energy sector in countries where PV presence is small, cross-border economic incentives such as certificate trading and guarantees of origin must be in place. These have the potential to concentrate investments in countries with the best geographical conditions for renewable electricity generation, in the case of PV, countries with the highest solar incidence.

Given that governmental initiatives are inherently limited to the form of direct financial support, it is thus important that the uptake of cleaner alternatives become attractive for private investors to take on, through means of directed policy such as taxation breaks, feed-in tariffs or certificate trading mechanisms. The rational usage of regional advantages such as lower labor costs and solar incidence information play an essential role in regards to the investment decision from private agents into photovoltaics. Launching measures on the wider European level is important to avoid concentration of renewables within the wealthiest European nations which can afford the higher costs. A European approach to renewable energy, in the form of directives that create market reserve for photovoltaics in the EU27 could make the market much more attractive for entrepreneurs. Notwithstanding, creation of market reserves must be accompanied by measures to improve the efficiency of PV technology.

Adding to the European dimension of the problem, leaving the regulation of the sector to individual member countries would be highly undesirable because not all countries have the resources or interest to foster photovoltaics. It is also important to bear in mind that the environmental consequences of unsustainable energy activity, e.g. pollution and Greenhouse Gas Emissions constitute a good example of a cross-border problem affecting all European countries and the world.

Let us look into the recent development of photovoltaics in the European market. Solar electricity is still a marginal contributor to the total electricity production in the European Union. Of the total 386 TWh produced from renewable sources of energy in 2005, only 1,4 TWh (0,36%) originated from solar photovoltaics. As of 2007, the overall contribution still lies under 1%. On the other hand, the growth of solar power has been the most expressive among all renewable sources in Europe, as shown in Graph 2:

Graph 2:



Sources: EUROSTAT Energy Survey (2005) and Photovoltaics Energy Barometer (EurObserv'ER 2008)

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[3] 7th Framework for Research in Renewable Energies, with a budget of EUR 2.4 billion (2007–2013). ESF funds amount to EUR 380 billion in the 7-year programming period. Improvements in national energy efficiency standards and promotion of renewable energy sources are both aims of energy projects supported by the ESF.

The production of PV electricity grew 1272% between 2000 and 2005. Interestingly, the solar panel surface in the EU grew only 73.5% in the same period. Two probable reasons for this difference are that more solar panels were connected to the electric grid in the 5-year period, thus appearing in the statistics, and that new installed solar panels are likely to be more efficient than the old ones, producing more electricity per exposed area.

Comparing the increase in solar power usage with other renewables, the contrast becomes even more evident. Table 1 shows the growth of solar electricity in comparison with the other main sources of renewable electricity, namely: hydroelectric, wood and forestry residues, municipal waste and biogas.

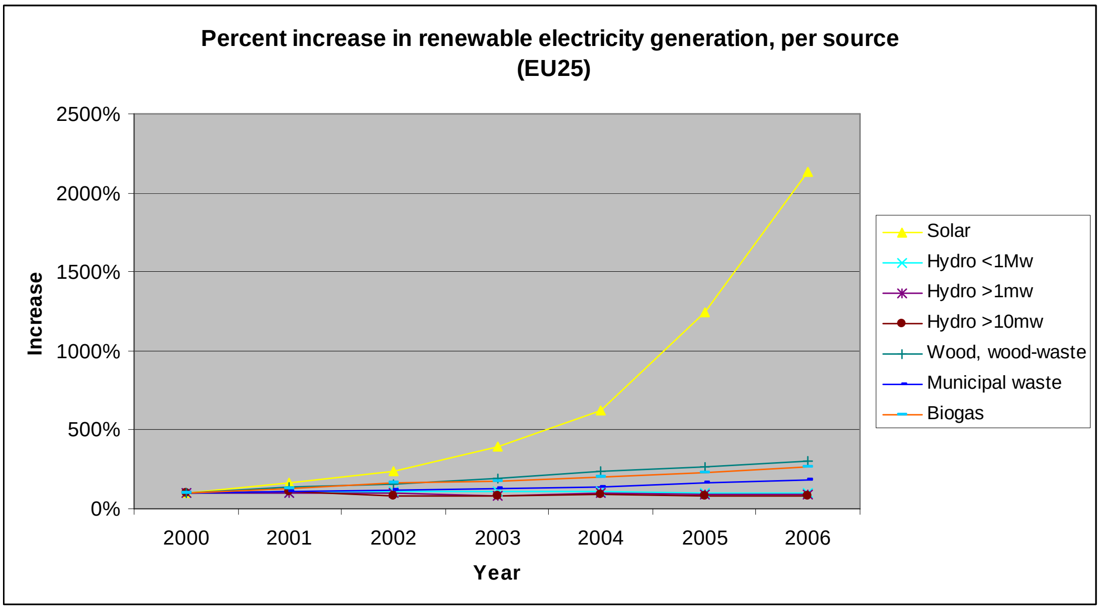
Table 1: *Electricity generated from renewable energy sources (Absolute values, in GWh)*

Data for EU25

Generation (GWh)	Year						
Source	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Solar	117	193	281	462	725	1455	2495
Hydro <1Mw	8735	9027	9282	9356	9386	9075	9112
Hydro >1mw	31719	32089	30516	27284	32380	28822	30024
Hydro >10mw	294441	315644	254033	246838	257279	244513	248615
Wood, wood-waste	15463	20604	24567	29698	37383	41660	46311
Municipal waste	13606	14803	16222	17815	19248	22624	24710
Biogas	5764,4	7367	9292	10101	11607	13442	15380

Source: EUROSTAT, adapted by the author

Graph 3:



Source: EUROSTAT Yearly Energy Statistics 2005 and 2006. Adapted by the author**.**

New data available in separate reports, commissioned by the European Commission´s Directorate-General for Transport and Energy (DG Tren) indicate that the fast-paced growth in photovoltaics continued up to 2008, with no signs of slowing down. For example, in 2006, 1.228 megawatts of new generation capacity were installed in the EU, practically doubling what was added in 2005 (645mw) (European Commission (2008c: 24). Most of the new installed capacity is made of grid-tied systems. Similarly to what has been exposed on Graph 1, geographic concentration remains an issue, as 92% of the installed capacity in the EU27 is located in Germany alone.

Although small in absolute generation – 1.22% of the total electricity from renewables in 2006, excluding hydroelectric - solar PV has had the highest growth rate from all renewable sources of electricity in the EU. In addition to the large percentage increase in electricity generated from PV depicted in Table 1, the new renewable energy assessment commissioned by Directorate-General for Energy and Transport presented an average annual growth between 1997 and 2006 of 56% for photovoltaics, by far the largest of all build up rates among renewables. This strong growth trend signals that significant investments in the field are being constantly undertaken. Given that carbon costs are currently not incorporated into prices, solar electricity still has a large gap to overcome; only then can it effectively compete with cheaper fossil options.

The cost of solar electricity

It is important to understand the particularities of photovoltaics that guide policy-making in the sector. There are a large number of factors influencing the costs of electricity generated through PV. External factors include environmental conditions, such as ambient temperature, sunlight incidence, availability of sunlight-tracking systems, total area exposed to sunlight, etc. Solar panels using the current silicon-based technology have a conversion rate of approximately 17%.[4] This means that, from all sunlight that meets the silicon wafers, 17% is converted into electric output.

For a general picture of the photovoltaic basics, two expressions will be used: (A) and (B).

The basic equation concerning energy conversion efficiency, in this case sunlight-to-electricity, follows:

(A)
$$e = \frac{P_m}{E \times A_c}$$

- Where *e* stands for the conversion efficiency (0-100%),
- P_m stands for peak power generation (watts)
- E represents solar irradiance per area (standard 1000w/m^2)
- A_c for the surface area of the solar cell/panel (m^2).

In this sense, for the standard E in one square meter of PV cell area, the generated output for a 17% efficient PV surface will be 170 watts/hour.

Another equation can be used to exemplify different variables influencing the cost of solar electricity. For this, the author has drafted a hypothetical expression (**B**) to characterize cost-related factors of PV electricity.

(B)
$$c = \frac{(s+m+i)}{e} + \alpha$$

[4] As stated by multiple industry sources. Available at: http://www.qcells.de/cmadmin_1_1315_0.html, http://www.ersol.de/produkte/solarzellen/, last accessed 9 April 2009.

Where:

- ***c*** stands for cost per unit of electricity generated, i.e. eurocents per kilowatt;
- ***s*** for raw silicon input, **m** for manufacture costs and **i** for infrastructure (mounts, stands, wiring, power inverters).
- ***e*** stands for the efficiency (conversion coefficient) of the solar panel and
- α represents the hypothetical costs of carbon dioxide capture and storage.

In the case of PV electricity generation, α tends to be 0, as no CO_2 emissions take place in the post-production phase.[5]

Later in this section, **(B)** will be used as a model to plot a hypothetical cost curve of PV electricity. First, let us further analyse the specific parts of (**B**).

Silicon prices (***s***) float as a commodity. In more detail, the mineral silica has to be processed into polysilicon wafers to be used on solar cell production. Although silica is a relatively cheap mineral, the transformation into polysilicon requires specialized plants, and the world production is virtually concentrated in only 7 companies.[6] This raises the issue of competitiveness (or lack thereof) in the sector. As of 2006-2007, the scarcity of silicon wafers kept prices high, consequently acting as a bottleneck to the growth of the solar PV market.[7]

As mentioned, the supply of PV-grade silicon is restricted. As a result, any pursued initiative to lower overall PV electricity costs should tackle this problem.

Options for dealing with ***s*** are:

a) measures to boost production and/or lower prices of wafers;
b) development of newer-generation PV technologies which are less reliant on silicon, e.g. thin film and polymer cells; and
c) technology improvements that allow higher electricity output from the same (or smaller) silicon inputs. Initiatives aimed at better silicon management, including long term contracts and vertical integration are already being pursued by major manufacturers such as Q-Cells AG.[8]

The shortage *of **s*** makes the polysilicon market very attractive for investments. The trend is that new manufacturers enter the production market, and existing ones are likely to expand their production. However, there was conflicting information from industry sources regarding the movements in silicon prices. Photon consulting pointed that future contracts were pricing the kilogram of polysilicon at USD 50-90 in the first quarter of 2009, forecasting a reduction in prices. However, the same report pointed at the high spot-market prices in early 2009, where silicon is quoted at USD 100-180.

Manufacture costs (***m***) represent labour inputs to produce the solar panels by the industry. PV manufacture is strongly reliant on skilled human capital investments. Consequently, the high capital costs are reflected on the PV panel shelf price. As any other component, labour costs have to be amortized during the solar panel lifetime.

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[5] This point can be disputed, as emissions do take place during the production of solar panels. Although, the electricity generated by the solar panel during its operational life far exceeds the fossil energy inputs required for production. See Corkish, Richard (1997).
[6] Those are: Hemlock, Wacker, REC Silicon, Tokuyama, MEMC Semiconductor, Mitsubishi, and Sumitomo.
[7] Scarcity of silicon as of 2006. Available at: http://tomkonrad.wordpress.com/2006/07/17/the-polysilicon-wafer-industry/, last accessed 9 April 2009.
[8] Reference to Q-Cells long term approach to reduce the dependence on polysilicon. Available at: http://venturebeat.com/2006/09/19/solaria-raises-22m-to-lower-cost-of-solar-cell-manufacturing/, last accessed 9 April 2009.

But are the manufacture costs the bottleneck preventing cost-reduction in solar electricity? Probably not.

European companies have developed great part of the present photovoltaic technology. 40 European producers of high tech machinery and automation systems for solar cell manufacturers are listed in Solarbuzz consultancy.[9] This is advantageous, as the bulk of physical and human capital can be found in the European single market, facilitating production. However, similar to what could be noticed in the section about PV generation in Europe, equipment manufacturers are also concentrated in the same countries which have the largest installed PV capacity, namely Germany, Italy and Spain.[10]

Labour is also a relevant issue in the photovoltaic industry. Skilled technical labour is known to be expensive in any country. In any case, wage levels in the countries concentrating the European PV industry will probably never drop to Asian levels (such as those encountered in consumer PV firms in Shenzhen, China). As a result, European competitiveness with international producers has to be achieved by other, non-labour-intensive ways.

Infrastructure costs (***i***) are those required to effectively set up and connect solar installations to the commercial power grid. Those include mounts, solar trackers, power inverters, wiring and maintenance. Most of this equipment is available in Europe with high efficiency rates. This means that even if foreign producers are to compete with the European PV industry, they are likely to use European-made equipment to optimize efficiency in the installations.

Conversion efficiency (***e***) is the coefficient which goes from zero – in case of no conversion from luminous energy to electric current – to one, when the conversion is total. As mentioned, industrial-grade solar cells achieve about 17% conversion efficiency as of 2007. Ceteris paribus, the higher the conversion coefficient, the lower the final cost will of PV electricity generation will be.

The conversion efficiency mentioned in the expression (A) uses η, which is the real conversion value. For (B) we will use a simplification to give a better dimension on the importance of higher conversion efficiency to the final cost of PV electricity. Let the current industry-standard, 17% efficiency, be attributed the value 1. Twice this conversion efficiency, that is 34%, receives the value 2. For better clarification the correspondent values follow in the table below:

Table 2:

Correspondence table	
Conversion efficiency	Denominator in (A)
17%	0.17
34%	0.34
51%	0.51

Therefore, the cost function (**B**) would be:

[9] A list of PV equipment manufacturers and their geographic distribution. Available at: http://www.solarbuzz.com/solarindex/ProcessEquipmentManufacturers.htm, last accessed 9 April 2009.
[10] According to public figures from the European Photovoltaic Industry Association (EPIA).

For the standard 17% efficiency:

$$c = \frac{(s+m+i)}{0.17} + \alpha \qquad \textbf{(B1)}$$

For a hypothetical 34% conversion efficiency:

$$c = \frac{(s+m+i)}{0.34} + \alpha \qquad \textbf{(B2)}$$

For a rather unfeasible 51% conversion efficiency.

$$c = \frac{(s+m+i)}{0.51} + \alpha \qquad \textbf{(B3)}$$

In other words, *ceteris paribus*, the higher the conversion efficiency, the lower the cost. In ***B2***, two times more PV electricity could be generated by the same $(s+m+i)$ inputs. That represents a 50% price reduction on the output, considering a 34% efficient conversion.

One can argue that conventional grid-tied solar installations are far from achieving a 34% efficiency mark. As a counterargument, new techniques such as quantum dots have the potential of achieving more than 60% efficiency, if the technology materializes.[11]

Model: An estimation of the cost of PV electricity based on (B)

To aid a comparison between real past prices of PV electricity and estimations based on different conversion efficiencies, equation (***B*)** will be used to plot an alternative curve for the price-trend of photovoltaics between the period of may 2008 and March 2009 (*Graph 4*). For clarification, the $(s+m+i)$ component of equation B is further defined, so that *s* represents the past prices for one kilogram of PV-grade polysilicon in the spot market, *m* represents variation in industrial labor costs and *i* the prices of inverter and photovoltaic modules. The relative weights for *s*, *m* and *i* in the equation are 45%, 27.5% and 27.5% respectively.[12] Observed prices of PV electricity represent the average of commercial and industrial prices extracted from the Solarbuzz consultancy statistics.

On Graph 4 (below) the real observed prices for PV electricity between May 2008 and March 2009 are compared to ***B1***, ***B2*** and ***B3*** (hipotetical estimations with 17%, 34% and 51% conversion efficiencies). The model values were adjusted to match the observed prices of May 2008.

The curves illustrate a gap between real observed prices and the 17% efficiency model (***B1***) starting from November 2008 onwards. This coincides with the fall in polysilicon prices at the spot market which happened in the same period. The graph also illustrates the smaller absolute impact of polysilicon price reduction in ***B2*** and ***B3***, when conversion efficiencies are higher.

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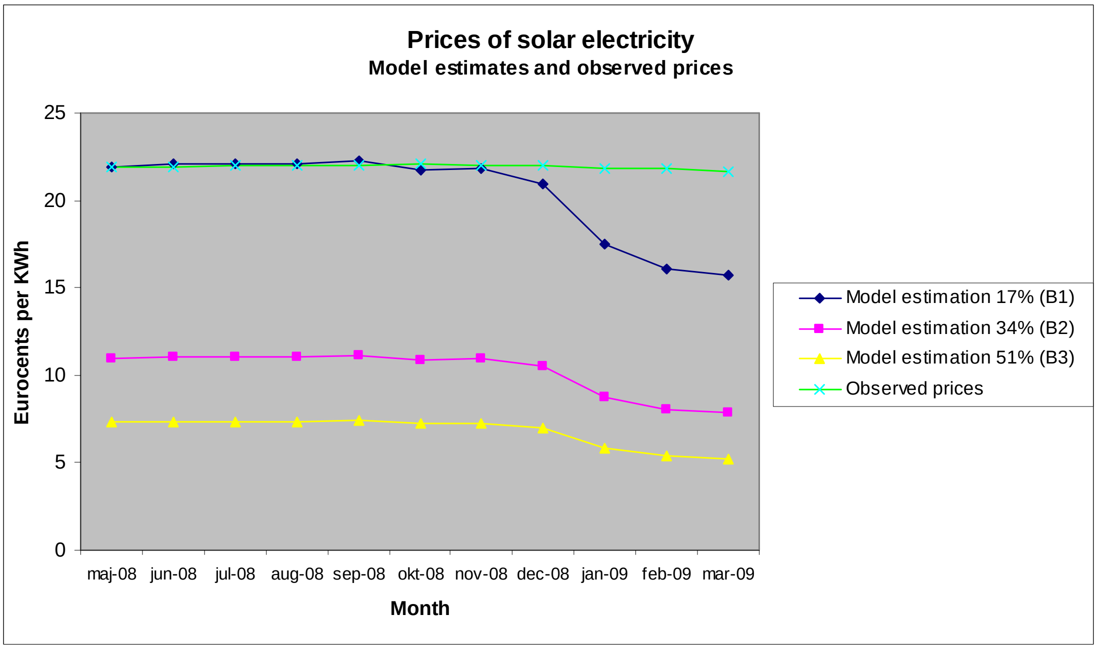
11 Highly Efficient Multiple Exciton Generation in Colloidal PbSe and PbS Quantum Dots - Center for Basic Sciences, National Renewable Energy Laborarory, Golden, Colorado 80401, Department of Chemistry, University of Colorado, Boulder, Colorado 80309, and Naval Research Laboratory, Washington, D.C. 20375. The text is available as a link in the bibliography.
12 Weight of silicon in total cost of photovoltaic modules is around 45%. Quoted from Solarbuzz Industry Facts. Available at: http://www.solarbuzz.com/FastFactsIndustry.htm, last accessed 9 April 2009.

Graph 4:



Sources: EUROSTAT, Solarbuzz, Photon Consulting, DigiTimes. Adapted by the author.

But why are the model results different from the actual historical data? It is known that investments in solar photovoltaics are made with long-term perspectives. This involves panels produced and installed in the past, when silicon was more expensive. It should be also noted that PV investments are tied to governmental support schemes, which tend to stabilize prices for long horizons of time. In this sense, recent reductions in the prices of inputs should take time before affecting the final prices of PV electricity.

Another reason for the perceived disparity is that many companies in the photovoltaic industry have supply contracts directly with silicon producers. Model ***B*** considers silicon prices on the spot market, while the industry often deal in long term supply contracts. The prices in the spot market concerns mainly newcomers in the PV industry who have not yet secured long term contracts, or supplies to cover production peaks. Prices in future contracts can be much different from the spot market. An industry consultancy noticed that the future prices for silicon in the first quarter of 2009 were quoted at USD 30 – 50, mainly driven by expectations of a drop in silicon prices (Economist 2008). In contrast, prices in the spot market for the same period were around USD 100 – 180. The difference between prices in the spot market and future contracts points that the previous expectation of stronger price reductions – what prompted the low prices of past contracts – did not materialize, hinting that polysilicon is not in oversupply as of March 2009.[13]

Even though there are justifications for the inflexibility of prices in PV electricity in the short term, the long term trend points at a possible cost reduction. Competition issues apart, a downward trend in polysilicon prices may stimulate the PV industry to relay their lower costs to their final product, lowering the price of PV in the future.

Real price data will be presented on the next section, in scenarios where carbon costs enter the discussion. In this section we could notice that solar PV has multiple aquiles-

[13] See Photon´s 7th Solar Silicon Conference. Available at: http://guntherportfolio.com/2009/03/photons-7th-solar-silicon-conference/, last accessed 10 April 2009.

heels. High costs of silicon supply, expensive manufacturing processes, and the need for special equipment to regulate and transmit the current generated. Moreover, the low efficiency of sunlight-to-electricity conversion (as of 2007, 17% in average), together with high production costs, make it difficult for solar power to compete with conventional sources of energy. Coal, natural gas and oil, all have lower generation costs per kWh.

Governmental subsidies, such as the German feed-in tariffs and green certificates, should not be seen as a long term solution to boost the presence of solar energy into European markets (European Commission 2008a). The dependence on special support mechanisms could make solar PV into a fragile, non-economical sector. In this sense, there is a strong interest from both EU officials, member state governments and the private sector to strive towards improving the value of PV energy systems. This can be seen in multiple ways: the provisions in the German feed-in tariff system, which gradually reduces support to photovoltaics as to give an incentive for efficiency increases in the sector; European research grants under the Seventh Research Framework Programme (FP7) focusing on PV improvement and the industry itself, constantly looking into ways to improve their products and competitiveness. They must eventually be truly competitive to grow in share as a complement to classic fossil fuels. Still, for a true competitiveness between fossil energy and PV is achieved, the market failure represented by not considering the environmental costs of fossil energy shall be eventually corrected.

The ever-increasing volume of information raising awareness about the real costs bound to fossil-based electricity generation which is intensive on greenhouse gases (GHG) emissions prompts policy makers to re-evaluate the costs of renewable sources of energy. The well-publicized Stern Review (2006) gained notoriety while providing figures for the actual cost of the market failure that is not to consider the economic cost of greenhouse gas emissions. In the scope of this work, the only greenhouse gas analyzed is carbon dioxide. This choice was made due to the availability of information on carbon prices.

The next section of this work will show that when higher conversion efficiencies of solar PV electricity are considered and carbon costs are incorporated to fossil-based electricity, photovoltaics start to pay off.

The issue of carbon: attributing economic value to emissions

The evaluation of the economic attractiveness of photovoltaic electricity is done primarily by comparing it with alternatives. Let us consider oil prices as a benchmark for fossil electricity. Graph 5 illustrates how close the prices of oil-based and photovoltaic electricity got to each other during the peak on oil prices in the middle of 2008.

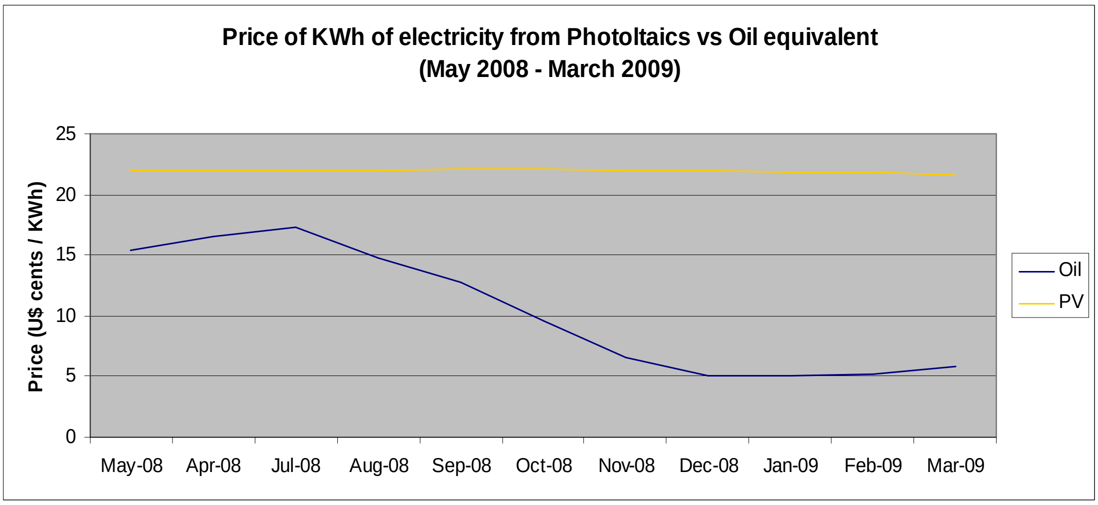
With the reduction of oil prices internationally on the second half of 2008 due to slower economic activity, the price-gap between oil and PV grew significantly. This made PV less attractive, *ceteris paribus*. But is it fair to draw a simple comparison of market prices, given the hidden environmental costs of fossil-based electricity?

So far we have analyzed PV electricity separated from carbon-management implications. Now, let us imagine a scenario where carbon emissions play a role in the cost-determination of energy sources. Carbon emissions are considered as byproducts of electricity generation using coal and natural gas inputs. According to the Stern Report (2006), the current trend in carbon emissions have the potential to reduce global GDP in two-digit figures during the next one hundred years. That said, carbon release into the atmosphere has to be reduced if society wants to avoid the costs of inaction. Initiatives such as the European Emission Trading Scheme (EU ETS) address the problem by imposing market rationale to the carbon issue by attributing quotas, and hence monetary weight to emissions.

The EU ETS system targets the largest carbon emitters, such as heavy industrial plants and coal/natural gas power stations. It works by making available a certain number of carbon quotas on the market, forcing heavy emitters to acquire more quotas if they surpass a certain emission threshold. Relevant for this text is the fact that the EU ETS system changes the cost function of power stations – inflating final energy prices – by making fossil-intensive operations more costly.

Raising prices of carbon quotas trough the EU ETS system would not be enough to curb CO_2 emissions by itself. Economic growth and aggregated price stability need to be observed while calibrating the number of quotas for each period. This is particularly important to avoid macroeconomic problems, i.e. economic de-acceleration and price instability, both potential effects of abrupt increases in energy prices. Carbon quotas must increase in price along with energy efficiency improvements.

Graph 5:



Sources: Solarbuzz, US department of Energy. Considering Barrel of oil equivalent (boe) = 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. Conversion efficiency from oil to electric current of 45%.

A complement to emission trading: Carbon Capture and Storage

The emerging technology of carbon capture and storage (CCS) offers the potential of a de-facto reduction of CO_2 concentrations in the atmosphere. Systems such as the so called *clean coal* power plants can in theory reduce the negative effects of coal usage, with a moderate increase in the kilowatt-per-hour price tag.

From this point on, this article will consider a hypothetical scenario where CCS is used to remediate global warming. The feasibility of such scheme, although technically close to reality, still depends on continued R&D investments and experiments on widespread, large scale operations. The European Commission launched in 2007 a Strategic Energy Technology Plan (SET-Plan) highlighting CCS as an important future technology. On January 2008 the EC issued a Communication on CCS demonstration projects prepared by Directorate-General for Transport and Energy.[14]

[14] European Commission Communication: *Supporting Early Demonstration of Sustainable Power Generation from Fossil Fuels* [COM(2008) 13 final]

In short, CCS is not a fictional concept. The EU has already shown interest towards this technology via the creation of the European CCS Project Network[15] and, if it is proven to work, a new option will be available for policy makers to draw legislation mandating CCS systems for intense-CO_2 -producers, such as power stations and heavy industries. This would inevitably raise the production cost of electricity originated from fossil resources, making them less attractive. In this sense, the competitiveness of PV systems could increase.

CCS is a technology in development aimed at reducing the negative externalities of fossil fuels usage. Through sequestration of carbon from heavy emission sources such as coal power plants and industrial furnaces, carbon capture and storage renders conventional sources of energy less harmful to the environment.

A comparison from market prices of electricity from different sources is the best way to exemplify the scenario where carbon capture and sequestration is carried to prevent environmental costs. Considering those elements, prices of fossil fuels tend to increase, while those of PV electricity do not.

In (**B**), the cost of carbon capture is represented by α . The end-prices for electricity are considered to be: 3.75 Coal, 5.50 for natural gas and 21.46 for solar PV. All values are in US cents per kWh generated and were extracted from the international figures at the US Department of Energy.

For PV electricity, α =0 (in the generation phase). For natural gas and coal, values of α vary according to the cost estimation for the CCS.

The following simulation (Table 3) represents the average cost to generate one kWh of electricity using different forms of energy, namely coal, natural gas and solar PV. Three scenarios are presented, with different cost estimations for carbon capture and storage. Moreover, three conversion efficiency levels for PV panels are considered, representing B1, B2 and B3 mentioned in section two of this work.

As exemplified by Table 3, if the current trends towards the creation of mandatory CCS mechanisms coupled with taxation schemes over carbon emissions materialize, the costs associated to carbon management will significantly lower the attractiveness of fossil fuels as dominant sources of energy.

If CCS costs are considered (UN estimation), and given the current PV efficiency (17%), solar electricity is still 190% more expensive than the best fossil alternative from an environmental perspective, natural gas. Doubling the conversion efficiency, i.e. e=2, the price gap falls drastically, to a 45% price difference. This value can be compared to wind power, the most cost-effective source in renewable electricity. That said, it is important for European and national legislation to push for measures fostering technological development. The objective is to allow the industry to mass-produce solar cells with 34% efficiency, avoiding increased costs. The inputs (*s*+*m*+*i*) play an essential role, raising areas of interest for PV-oriented policies:

- Cost-reductions in polysilicon supply and development of non-silicon-intensive cells;
- Manufacture improvements, such as economies of scale and better technique;
- Infrastructure development: objective and transitional tax reliefs, production of more efficient transformers and inverters.

[15] See: European Commission contract number EU:72962-2009, establishing the European Carbon Dioxide Capture and Storage (CCS) project network coordinated by Det Norske Veritas AS.

Considering efficiency, a successful achievement of e=2 or e=3 cells without large increase in production costs will contribute in a decisive manner to make solar energy price-competitive with fossil-based electricity.

Table 3: Prices of electricity from fossil and solar PV, with and without carbon capture and storage (CCS)

A - Considering: CCS costs: 39.9 U$ per ton (Edinburgh*)			
Source of energy	**Without Carbon Capture**	**CO2 Emissions**	**With Carbon Capture**
	(US cents per kWh)	**(grams per kWh)**	**(US cents per kWh)**
Coal	3,75	920	7,05372
Natural Gas	5,5	452	7,123132
Solar (17% efficiency)	21,46	0	21,46
Solar (34% efficiency)	10,73	0	10,73
Solar (51% efficiency)	7,15	0	7,15
B - Considering: CCS costs: 44 U$ per ton (UN*)			
Source of energy	**Without Carbon Capture**	**CO2 Emissions**	**With Carbon Capture**
	(US cents per kWh)	**(grams per kWh)**	**(US cents per kWh)**
Coal	3.75	920	7.39
Natural Gas	5.50	452	7.28
Solar (17% efficiency)	21.46	0	21.46
Solar (34% efficiency)	10.73	0	10.73
Solar (51% efficiency)	7.15	0	7.15
C - Considering: CCS costs: 103 U$ per ton (UK*)			
Source of energy	**Without Carbon Capture**	**CO2 Emissions**	**With Carbon Capture**
	(US cents per kWh)	**(grams per kWh)**	**(US cents per kWh)**
Coal	3.75	920	12.27
Natural Gas	5.5	452	9.69
Solar (17% efficiency)	21.46	0	21.46
Solar (34% efficiency)	10.73	0	10.73
Solar (51% efficiency)	7.15	0	7.15
Considering:			
1- All scenarios: 90% CCS efficiency.			
2- Conversion efficiency increases without significant price changes in PV Panels.			
3- Emissions during refining/production processes of coal/solar panels <u>not</u> taken into consideration.			

***Sources:** University of Edinburgh: Institute of Geosciences; US Department of Energy; UN / Intergovernmental Panel on Climate Change – IPCC; UK: Parliamentary Office of Science and Technology (Note N. 238. March 2005)

As of March 2009 the European Commission has launched the European CCS network and will be monitoring results of technology demonstration projects for the upcoming years. The EC is not considering yet any option to implement CCS, as it can take decades before the technology becomes market feasible.[16] In the new legislation which will be presented below, carbon capture and storage has been made eligible for support through EU grants for demonstration projects. If the technology proves solid and feasible on large scale plants, it is possible that future legislation will address the issue of carbon storage in energy facilities with a much stronger pricing component than the current EU ETS has. This could, as discussed in this section, make photovoltaics substantially more competitive with conventional fossil energy.

There is one strategic element in the whole discussion. The industry can neither wait for technological breakthroughs nor legislation that mandates the incorporation of carbon costs into electricity prices. Ultra-high oil prices to boost the market reach and penetration of PV also seems to be an undesirable scenario, from the policy maker perspective. The challenge faced by the European photovoltaic industry is how to sell photovoltaics today, in a scenario where PV is not economically competitive with most generation alternatives (Pernick and Wilder 2008: 36).[17]

New developments in Photovoltaics: The European Commission legislation proposal for a climate change package in January 2008

Following the Renewable Energy Roadmap presented in early 2007, the European Commission worked throughout that year on its hard law proposal, a package composed of directives which aimed at curbing the negative effects of climate change. Relevant for this work is the directive on renewable sources of energy proposed on 23 January 2008 and adopted by the European Council and Parliament on 17 December 2008. The measures were suggested in the form of actions targeting the way energy is produced and used in the European Union and abroad. A 20% renewable energy target was introduced as a binding mechanism to drive member states into adopting cleaner sources of energy. The documents were also an attempt to unify elements of the current renewable electricity directive (2001/77/EC) with a broader context of measures aimed at tackling threats that could potentially arise from a mismanaged energy infrastructure in Europe.

The European Commission made important suggestions concerning photovoltaics in its directive proposal that are worth mentioning at this stage. Examples are: intermediate targets to monitor the uptake of renewable until 2020; safeguarding of feed-in tariff systems; priority access to the grid for renewable electricity; mandatory use of renewables in all new or refurbished buildings.[18]

The Climate Change Package aims also at strengthening technologies that could be complementary to photovoltaics in the future, such as the previously mentioned CCS and hydrogen. The new renewable energy directive, which is part of the Commission´s package on climate change, aims at reducing emissions, improving energy efficiency and lowering the dependence on fossil fuels. According to this directive proposal member states would be subject to binding compliance targets by 2020. Photovoltaics, under the category of renewable electricity, received special attention as a new market mechanism suggested by the Commission.

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[16] Study developed by McKinsey points that CCS might be price competitive by 2030. See: Carbon Capture and Storage: Assessing the Economics (September 2008)

[17] According to this recent study, which is similar to the European PV Industry future predictions for solar electricity, cost parity between photovoltaics and fossil energy will be achieved in 2015. The study must be seen with caution, given that the fast-paced increase in oil prices was interrupted after the study was published.

[18] EPIA Press release on the proposal for a Directive on the promotion of the use of energy from renewable energy sources. Date of publication 23 January 2008. Available at: http://www.epia.org/fileadmin/EPIA_docs/documents/PR_080123.pdf, last accessed 9 April 2009 (p. 2).

In order to drive market agents towards investing in the needed clean technologies for the 2020 target, the European Commission proposed together with the legislative package of January 2008 a certificate trading system for renewable energy, also named green certificate trading. The system is a market approach to make the best usage of capital and natural resources. This would allow regions with comparative advantages to produce renewable energy for themselves and others, by issuing tradable certificates for the generation surplus. The idea was initially used in the Unites States, in the form of State-level measures.[19] The European proposal to extend such a system to a much larger, EU-wide scale is unprecedented in the world.

According to the European Commission, a certificate trading system would allow European regions with high solar incidence to become attractive for investment in PV. With binding targets for renewable energy, member states would have to achieve their 2020 targets for usage of renewable energy. If a specific country fails to generate enough renewable energy to fulfill its national target, it would, under the Commission proposal, have the option to acquire green certificates to supplement its deficit, achieving the quota. Certificate prices would fluctuate in a classic supply and demand system, and would de-facto transform green certificates into a tradable commodity.

As mentioned in the first part of this work, more than ninety percent of all photovoltaic capacity is concentrated in Germany. With the exception of southern Spain, which has considerable photovoltaic generation, regions with high mapped solar incidence within the EU (e.g. Greece, southern Italy, southeastern Romania, southern France), are largely neglected when it comes to investment in PV installations.[20]

But why are PV installations not in the areas of highest solar incidence? The answer could involve skilled labor, infrastructure issues, population income and even cultural perception of the value of clean energy systems. But the factor that correlates the best with successful photovoltaic buildup is the existence of support schemes in the form of feed-in tariffs.

By granting a premium to electricity generated on rooftop panels or other fixed installations, feed-in tariffs are the most successful existing instrument to incentivize acquisition of PV systems in Europe. The German system offers a premium to its users, paying a higher price for PV electricity fed into the grid. This opens the perspective of investment security, as users know exactly how long it might take to achieve payoff from the initial investments in photovoltaics.[21] That is the main difference between feed-in tariffs and certificate trading: the latter is a dynamic, market system with fluctuating prices, while feed in tariffs establish the payment schemes in advance.

The problem, however, lies in the fact that feed-in tariffs could be quite expensive to uptake. Not all European countries could afford adopting such a system as Germany did, and this leads to the geographic inconsistence that is seen on the distribution of PV installations in Europe. There is also the uncertainty issue: it is not known how a broad certificate trading scheme would perform to promote photovoltaics in face of other energy alternatives, and that puts the industry in skepticism. Given that many forms of energy are considered to be renewable (i.e. biomass, wind, small hydro), having a system of certificate trading allowing market operators to freely decide upon

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[19] List of renewable energy certificates options available in the US. Available at: http://www.eere.energy.gov/greenpower/markets/certificates.shtml?page=1, last accessed 9 April 2009.

[20] Spain had almost 70 megawatts of on-grid PV generation capacity in early 2007. Available at: http://www.iea-pvps.org/products/download/rep1_16.pdf, last accessed 9April 2009. See also: Solar incidence maps in Europe, Joint Research Centre. Available at: http://re.jrc.ec.europa.eu/pvgis/countries/europe.htm, last accessed 9 April 2009.

[21] Explanation of the feed-in tariffs system by the European Photovoltaic Industry Association. Available at: http://www.epia.org/fileadmin/EPIA_docs/documents/An_Argument_for_Feed-in_Tariffs.pdf, last accessed 9 April 2009.

the source used could jeopardize the competitiveness of the most expensive option, that is, photovoltaics.

Reaction from the industry – EPIA's stance

The European Photovoltaic Industry Association (EPIA) is the entity which represents the industry under a single voice in Brussels. Its main functions are to monitor relevant legislation and lobby towards policy makers (European Commission and Parliament) for legislation which attends the interests of the PV sector in Europe.

In January 2008 EPIA issued a press-release with its view on the Renewable Energy directive proposal, published by the European Commission on the same day. The tone of the reaction was positive in general. According to EPIA, the 20% renewable energy target for 2020 opens many opportunities for the PV sector. It also praises the initiative to launch intermediate targets before 2020, in order to better monitor the growth of the installed capacity. [22] The European Commission's suggestion to mandate new and refurbished buildings to adopt renewables was also seen as a positive development, as it could, in theory, mean that every future building in the EU could utilize photovoltaics. According to the same press-release from EPIA, this would allow for major market growth which is paramount to provide the industry with the economies of scale which are necessary to improve technology, resulting in better performing and cheaper solar cells in the future.

Despite the general positive approach of the EPIA towards the Commission's suggestion, there was also a point of skepticism within its press release. This was connected to the Commission's proposal for the adoption of 'Guarantees of Origin in Europe', a form of energy label which differentiates renewables from other sources of energy. Also on its January 23th 2008 press-release, the EPIA mentioned that the whole concept must be clarified and a blueprint of the system should ideally be presented before the directive enters into force. So far, the directive has been adopted and a clarification has not yet been presented by the European Commission.

At the end of January 2008, the European Commission and private groups organized a large event entitled Sustainable Energy Week in Brussels. During the presentations in this event, the EPIA and its members clearly expressed their reluctance to adopt the idea of a certificate trading system.[23] The reasons for this stance can be found in the EPIA position papers from January 2008; these include the lack of past data to support large-scale adoption in the EU, and the fact that certificate trading is a commodity-like system, where prices fluctuate such as in stock markets, making any investment decision more complex.

As of April 2009, the EPIA is focused on the developments after the adoption of the Renewable Energy Directive by the European Parliament and Council on the 17 December 2008. The impending definition of the role of photovoltaics in the proposed European certificate trading mechanisms offer an entirely new set of challenges and opportunities to the PV industry. This is a fertile ground for future policy discussion.

Conclusion

Amongst the options available, solar PV is a promising alternative for helping Europe achieve a sustainable energy infrastructure. Nonetheless, key issues such as production

[22] EPIA's stance on the European Commission proposal for a Directive on the promotion of the use of energy from renewable sources. Available at:
http://www.epia.org/fileadmin/EPIA_docs/documents/PR_080123.pdf, last accessed 9 April 2009.
[23] Anton Milner, CEO of the German solar cells manufacturer Q-Cells and speaker at the event.

costs conversion efficiency and have to be addressed through better supply management, more research, incentives towards mass production and economies of scale. The photovoltaic technology platform is one attempt to tackle this issue, with results yet to come.

Solar PV is to be promoted not only among large industries and governments, but in a decentralized approach down to the households, turning electricity production into a flexible system. As PV is inherently a decentralized technology, it could also contribute to Europe's security of supply and change the way electricity grids are currently used.

PV electricity is expensive if directly compared to conventional sources such as oil, coal and natural gas. Even though the price difference between fossil and PV electricity varies depending on the levels of oil prices, PV has still a long way to go before price parity is achieved. Besides fostering improvements in production and conversion efficiency of solar cells, it is also fundamental to add the environmental costs of fossils usage to final energy price calculations. This would provide more realistic cost estimations, necessary for a better understanding of benefits associated to renewable energy. As of 2009 there are no concrete plans at the European level to mandate the incorporation of carbon costs into electricity beyond what currently exists in the European Emission Trading Scheme.

The compatibility of measures within all EU member states is important, so as to avoid building disparities among different EU countries. Measures must include incentives to private investors, concession of directed and time-limited tax breaks and European grants. Transitional support schemes such as the successful feed-in tariffs should continue to be encouraged. A better definition of Guarantees of Origin should be presented by the European Commission, so as to clear existing doubts about the issue. The trade of green certificates should also be better studied and designed before the 2008 renewable energy directive proposal enter into force, so that doubts can be clarified. The potential of trading systems is enormous because they could proportionate real market dynamics to photovoltaics. That in turn would make the best usage of regional advantages in the production of renewable electricity, such as solar incidence, knowledge, infrastructure, land availability and labour.

It is important that the European authorities carry a constant monitoring of the PV market, including an investment return benchmark to track cost-efficiency trends. Such analysis is important if carbon management practices are to enter the formula of the future European energy infrastructure. Intermediate targets towards the 2020 proposals would be one step in this direction. A successful practice in the European Union would certainly inspire similar initiatives in third countries, reinforcing the European experience and paving the way for global policy and trading systems of renewable energy.

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