Wuppertal Institute
for Climate, Environment
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Photovoltaics and the RoHS Directive

Position Paper

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Over the last years, different photovoltaic (PV) technologies became commercially available, while several others are under development. PV technologies require diverse materials to generate electricity from sun light, including in some cases toxic materials. To date, photovoltaics are not covered by the *European Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment* (RoHS directive), but there is an ongoing discussion about whether or not the RoHS directive should be extended to cover photovoltaics.

Against this background, the Wuppertal Institute for Climate, Environment and Energy has conducted an independent, scientific and open-ended as regards its outcome position paper on the issue of a possible extension of the RoHS directive to photovoltaics.*

1. Renewable energies and photovoltaics

The European Council endorsed at its Meeting in Brussels on 8/9 March 2007 a binding target of a 20% share of renewable energies in the overall EU energy consumption by 2020. Out of the 24 GW of new power capacity constructed in the EU in 2008, 19% (4,700 MW) were photovoltaics (PV) (Kautto and Jäger-Waldau 2009). This is more than the target of cumulative installed PV system capacities that the European Union had set for itself to reach in 2006 (3,000 GW). In 2008 the overall installed capacity of solar photovoltaic electricity was estimated at 9,100 MW.

A variety of technologies fall under the broadly used term “photovoltaics”. From a material use perspective, two large groups of such technologies can be discerned: silicon-based and non-silicon based PV. The former group comprises both crystalline and amorphous (thin film) PV systems. The latter group is mainly composed of cadmium-telluride (CdTe) and copper-indium-(gallium)-selenium (CI(G)S) cells, both thin film technologies. Since 2006 the production of thin film PV systems has experienced a growth rate higher than that of the PV sector as a whole (Jäger-Waldau 2009).

In particular, manufacturers of CdTe PV have rapidly scaled up their production capacities. The comparatively low costs of thin film PV systems –especially CdTe PV systems– are often mentioned as a reason for the rapid growth of PV. However, the relatively low price of CdTe modules is partly compensated by higher installation costs because of lower efficiency of these thin modules compared to traditional Si-PV.

The criticality of certain materials used in these technologies can be assessed considering their scarcity and toxicity (for humans as well as for the environment). In that respect indium, gallium and cadmium as “rare metals”, and selenium and tellurium as “rare earths”, are

* Support by the Non-Toxic Solar Alliance is appreciated.

considered scarce resources. Reserves are limited (e.g. reserves of tellurium reach a mere 22 000 t, USGS 2009) and production capacities are constrained because all these elements are primarily mined as by-products of other basic metals (copper, zinc, tin). Corresponding production capacities present therefore a very low elasticity and shortages can occur in case of rising demand exceeding the production volume allowed by the production of the basic metals, which is mainly determined by non-energy markets.

PV systems can also contain lead used in solders. Cadmium (in CdTe[†] PV) and lead are two toxic to highly toxic substances whose usage is severely restricted, especially in electrical and electronic equipment. Photovoltaics, however, have escaped regulation thus far.

2. Photovoltaics and the RoHS directive

The European Directive –referred to as the RoHS directive in the following– on the restriction of the use of certain hazardous substances in electrical and electronic equipment[‡] (EEE) forbids that, from 1 July 2006, new electrical and electronic equipment put on the market contains cadmium and lead –inter alia. However, a restricted number of EEE types benefit from exemptions. PV technologies, in particular, are so far excluded from the scope of the RoHS directive. If it were to change, the immediate consequences would be that PV systems containing cadmium (CdTe) and lead solders could no longer be imported or manufactured in the European Union.

There are three possible options concerning the future treatment of PV technology under the RoHS directive: i) after a clearly defined phase-out period, the same restriction on the use of hazardous substances applies to PV technology as to other EEE; ii) PV technology is permanently excluded from the scope of the RoHS; iii) PV producers are allowed to benefit from "grace periods" that are periodically (e.g. every four years) examined and possibly renewed. Of these options, only the first two should be seriously considered. The third option would only perpetuate the uncertainty that prevails today about the future of specific PV technologies (CdTe PV) and the use of lead in solders. In a sector that requires long term commitments both on the production and consumption sides, this would send the wrong signal to investors.

When considering the actual terms of the RoHS directive, and of the underlying precautionary principle, the regulation of all PV technologies is the only option of the remaining two that actually makes sense. Strong principles command the RoHS directive, as well as all EU

[†] CdTe itself is not as hazardous as cadmium, but as a cadmium compound it is still considered a hazardous substance.

[‡] DIRECTIVE 2002/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

directives[§]. They prescribe the following order of priority in occupational health and environmental protection issues: (a) the substitution of hazardous material should be the top priority; (b) if substitution is not possible, collective protection measures should be put in place (e.g. operating below atmospheric pressure in production); (c) ultimately, measures of individual protection apply (e.g. use of personal protection equipment).

The arguments of the proponents of the CdTe PV systems who, of course, advocate a permanent exclusion of this technology from the RoHS directive may well be valid but they disregard the raison d'être of the RoHS directive. Before going into details, it is worth reminding these arguments here (Jäger-Waldau, 2009).

(1) First, proponents of the CdTe PV systems cite studies that have found that CdTe used in PV is in an environmental stable form that, under normal use conditions and in case of foreseeable accidents, does not leak into the environment. (2) Second, they note that LCA studies have concluded that air emissions of cadmium from the whole life-cycle of CdTe PV (including mining, smelting and purification) and the potential accidental emissions occurring during residential fires are both orders of magnitude lower than cadmium emitted into air routinely from coal and oil power plants that PV displaces. (3) Third, they use the argument that every PV technology has some environmental, health, and safety (EHS) issues, but that the commercial viability of any of the current PV technologies should not be restricted because of these issues. (4) Fourth, proponents of CdTe technology rely on studies that showed that current production of CdTe PV modules have shorter energy pay back times and lower life cycle CO_2 emissions than other PV systems, e.g. crystalline silicon (c-Si) or CIGS. They argue that a low production cost technology like CdTe PV could accelerate PV inroads in the energy market and that a significant market penetration of any technology would help the whole PV industry by improving the installation infrastructure and reducing the installation cost of solar electricity. (5) Fifth and finally, CdTe advocates echo the announcement made by leading CdTe PV producers that they offer to take back end-of-life modules and recycle them.

Even though the arguments in favour of CdTe PV reminded in the previous section are by and large correct, they cannot invalidate the proposal that all PV technologies ought to be regulated under the RoHS directive, neither can these arguments prove that CdTe PV systems need to be excluded from the RoHS directive. The directive saw the day in order to enable reducing the content of hazardous substances (incl. cadmium and lead) in waste, and limiting the presence of such substances in products and in production processes. Exemptions from the directive requirements are only permitted if substitution is not possible from the scientific and technical point of view or if the negative environmental or health impacts caused by substitution are likely to outweigh the human and environmental benefits of the substitution.

This alone clearly imposes that cadmium (in CdTe) should be allowed in PV systems if, and only if, all alternative PV technologies –that do not use any of the substances banned by the

[§] Such as the COUNCIL DIRECTIVE 98/24/EC of 7 April 1998 on the protection of the health and safety of workers from the risks related to chemical agents at work (fourteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) directive– can not replace CdTe PV systems in a way that is satisfactory for human health and the environment. Therefore, the indication that CdTe in PV is in a stable form under normal use conditions and in case of foreseeable accidents (see (1) above) is not as such an argument in favour of CdTe PV systems, as long as substitutive technologies exist, which is the case (silicon-based PV). As long as CdTe PV systems are allowed, there will be cadmium used in production processes, present in consumer products, and eventually in waste streams, all things that the directive is designed to help avoid (despite (3) above).

Furthermore, independent testing has shown that CdTe modules exhibit a high maximum leaching potential of both cadmium and tellurium (NGI 2009a, NGI 2009b). It means that away from normal use conditions and benign accidents, leaching of cadmium can occur. Tests have shown that when the CdTe film is exposed to water (for example the protective glass layers are damaged) CdTe dissolves, thus increasing the risk of leaching into the environment.

While it is true that CdTe PV displacing conventional coal and oil power generation prevents large amounts of cadmium from being emitted into the air (see (2) above), the same stands for other PV technologies that do not rely on CdTe, such as Si-based PV. Recent LCAs (e.g. Fthenakis et al. 2008) show that the differences in the indirect emissions of cadmium between different PV technologies (based on the amount of energy needed for the production of the PV system) are very small in comparison to the emissions from conventional energy technologies that PV could displace. Therefore, the life cycle performance regarding cadmium emissions of different PV technologies are not that far apart as to justify an exemption of CdTe PV from the RoHS directive.

To restrict the use of hazardous substances in EEE and to allow for strategies that stimulate research into substitutes, are both stated aims of the RoHS directive. The exclusion of photovoltaics from the RoHS directive may have contributed to the fact that CdTe PV systems benefited from lower production costs compared to other cadmium-free alternative technologies (see (4) above) to fuel their strong recent growth. Because cadmium is a waste-product of zinc, production does not slow down even if demand drops. Consequently, sufficient amounts of cadmium are available and affordable for the PV industry today, in part because it was widely banned from electronic products by the RoHS directive and from other applications like pigment in plastics or glass because of environmental and health concerns (USGS 2010). Therefore, part of the cadmium that could no longer be used in EEE, plastics and glass is now to be found in the production of solar electricity from photovoltaics.

There are, however, several PV technology alternatives, all with their particular strengths and weaknesses, and which all are continuously improved, requiring intensive targeted R&D activities. Further delaying permanent ban on cadmium-based PV technologies will send the wrong signal to producers and investors and deprive other technological options from the conditions needed to ramp up production capacities and decrease production costs. Moreover, on the consumption side, the stock of cadmium-containing PV will grow, aggravating the issue of hazardous waste disposal at the end of their lifetime.

There is to date virtually no experience in the management of end-of-life CdTe PV systems, or of other PV technologies. PV systems installed today are expected to last for 25+ years. By the time they will need to be disposed of, the company that produced the modules may no longer exist. The last owner of the installation may very well be different from the first buyer, ignorant of any take-back system put in place, or reluctant to bare the costs for dismantling its end-of-life PV system. To prevent hazardous substances from ending up in waste streams which nobody can assure that they will be properly managed, the preferred option should always be to refrain from using such substances in the first place.

Furthermore, for the recycling of cadmium and lead contained in photovoltaics to be economic 25 years from now, demand will be needed for these metals at that time. However, bans on cadmium and lead are clearly expected to reach ever further. Even if photovoltaics were to be the last application where cadmium and lead are allowed, it will probably have moved away from the CdTe technology by that time –e.g. organic PV may have taken over. In the end, the problem will be that of toxic waste disposal –not recycling.

The extension of the RoHS directive to PV systems will not only influence which semiconductors can be used, it will also restrict the use of lead in solders in such systems. The same reasoning as for cadmium apply. Furthermore, the development of lead-free solders for other electronic products and components has been demonstrated and is now established. There is no principle argument why it should not work with PV.

3. Effects of an extension of the RoHS directive to photovoltaics

3.1. Effects abroad and on international trade

The RoHS directive has a strong influence outside of the European Union. When the EU decides to restrict the use of certain materials in electronic and electrical equipment, this will lead to a worldwide phase-out on these materials in EEE, especially in products exported to the EU. PV are exported from and imported to the EU. The RoHS directive has value of example and has a massive influence on production world-wide.

Furthermore, coverage of PV by the RoHS directive will not only impose a ban on hazardous substances in semiconductors for PV but also on lead solders. Both aspects are important for the production, the use, and –especially– the end-of-life of PV in developing countries. Even though it might be that some PV producers have a recycling system, cadmium and lead will be widely banned when PV produced today reach the end of their lifetime (in 25 to 30 years). Then, there will be no need for recycling CdTe and lead, but for a safe waste treatment.

The experience of electronic wastes shows clearly that recycling concepts developed in industrial countries are not sufficient in a global context. A certain amount of electronic waste will be handled in developing countries under inappropriate conditions, far away from any kind of safe working conditions. This is highly relevant because especially cheap PV can be an option for less developed countries and regions. It can make a basic electrification possible, induce development in rural regions, and, to a certain degree, reduce rural depopulation. However, considering typical circumstances in such areas, it seems unrealistic to expect collection and recycling schemes for used PV to be as reliable as in Europe. Therefore, strict European directives forcing the substitution of hazardous substances not only influence Europe but can also ensure additional protection to other regions.

3.2. Effects on competitiveness and employment

Growing and reliable solar markets around the world and especially in Europe have provided PV manufacturers the opportunity to scale and reduce costs (Gillette 2010). On that basis, producers of CdTe PV deployed a smart and aggressive expansion of production capacities (incl. easily duplicable, automated large scale production centres located in countries where costs of labour are low). This management, rather than a better technology per se, explains the competitive price point of CdTe technology against silicon-based alternatives (Beyer et al. 2009). Therefore, a ban on cadmium and lead would not hinder the photovoltaic industry to continue improving its competitiveness.

The market share of thin film PV technologies has almost tripled globally in the past five years (from 5.9% in 2004 to 16.7% in 2009). The exponential growth of CdTe PV was instrumental in this trend. In 2009, CdTe photovoltaics accounted for 9% of the global PV market, for only 1.1% in 2004. Both alternative thin film technologies (amorphous Si and CIGS) also captured new market shares, although at a much slower rate. The drastic increase in the number of CdTe PV installed in the past years means a quick growth of the stock of cadmium in EEE across the world. This is a concern for the coming 25 to 30 years, but even more for the years after, when those modules reach the end of their lifetime.

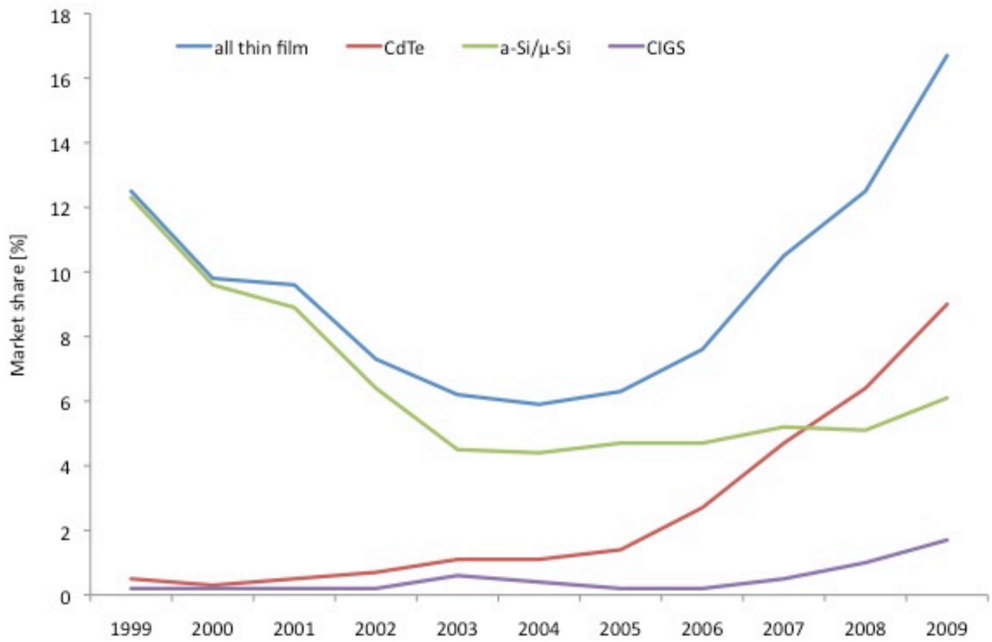

Figure 1: Global market shares of the different thin film PV technologies. CdTe, a-Si/μ-Si, and CIGS stand for cadmium-telluride, amorphous / microcrystalline silicon, and copper-indium-gallium-selenium, respectively. Data source: Photon (4-2008), Photon international (3-2009, 4-2009)

The cost per installed kWp was nearly halved during the last 4 years. With sustained public incentives, the installed cost of photovoltaics is on a pathway toward grid parity. High irradiance solar projects will reach it first. A ban on CdTe photovoltaics will not prevent this from happening, even though it may delay it.

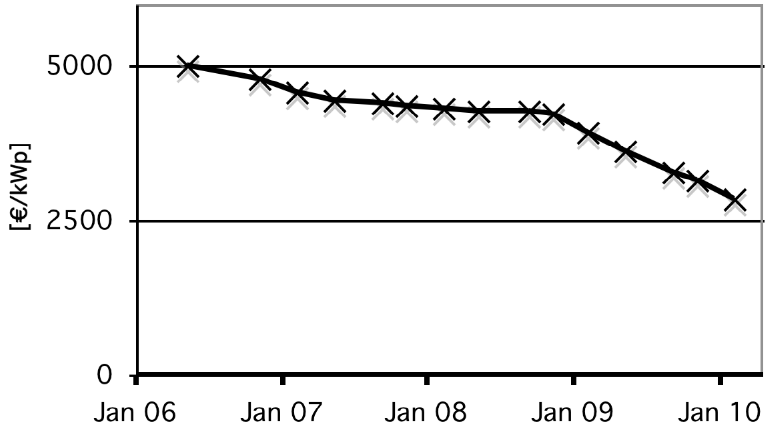

Figure 2: Cost of PV per installed kWp. Data source: BSW (2010)

For 2009 the employment figures in photovoltaics for the European Union were estimated in the range of 85,000 to 90,000 (Jäger-Waldau 2009). Of this number, less than 1% correspond to people employed in CdTe module production in Europe (Beyer et al. 2009). About two thirds of the employees in the photovoltaic sector in Europe work in the installation of solar modules. These jobs are bound to demand in Europe, which is not technology related but depends on public incentives. Hence, an extension of the RoHS directive will have only negligible effects on European labour market.

3.3. Effects on environmental and climate targets

Analyses over the complete life-cycle of photovoltaics have shown that emissions of greenhouse gases, air pollutants (SOx, NOx), and heavy metals are insignificant in comparison to the emissions that they replace when introduced in average European and U.S. grids (Fthenakis et al. 2008). This is true regardless of the PV technology selected.

Among PV technology options, thin-films require lower material and energy inputs in the production process. Consequently, CdTe PV induce substantially less emissions (GHG, SOx, NOx, heavy metals) life-cycle wide per KWh produced than non thin-film silicon-based PV (Fthenakis et al. 2008). However, it is not clear how CdTe PV performs in those terms compared to thin-film silicon-based technologies. In any case, the gap must be smaller than with non thin-film alternatives.

Photovoltaics will continue to play an important role in the rise of renewable energies and in climate change mitigation. Therefore, supply of PV systems needs to be able to meet demand even if the scope of the RoHS directive is extended. The global market for photovoltaics shows today an oversupply that is larger than the share of CdTe technology in that market (Beyer et al. 2009). Current competitors of CdTe technology have the capacity to buffer in the coming years any drop in supply due to a ban on cadmium. Future new entrants with technologies in R&D today will also increase the offer in the coming decade.

Expected levels of demand will be met with or without CdTe PV. In general, PV technology will also continue to improve towards lower per kWh impact than the existing options (Raugei and Frankl 2009). Climate targets that for a part rely on the development of photovoltaics will not be adversely affected by the extension of the RoHS. Overall sustainable development goals will be positively affected.

4. Conclusions

The conclusion of this position paper is that no matter how low potential environmental and health impacts may be under normal operating conditions of CdTe PV, it is not a valid argument against the extension of the RoHS directive to photovoltaics. Cadmium and lead in market products should be substituted when substitutes exist, which is the case for photovoltaics. It is the essence of the RoHS directive. Recycling is not a realistic option because it is only a question of time until cadmium modules and lead solders are widely banned and it is quite open which kind of photovoltaics we will use in 25 or 30 years. Cadmium and lead should not spread in EEE, but need to be disposed of safely.

CdTe solar cell technology is only one of many PV technologies. A ban on CdTe PV will not end the development of photovoltaics. The main goal of the application of PV is the reduction of greenhouse gas emissions from electricity production as an important part of sustainable development. But today's discussion on climate change inadequately limits the focus. The best way towards environmental protection and sustainable development is not limited to the cheapest possible PV.

Producers of CdTe PV and users of lead-solders have preferred collective and individual protection mechanisms to substitution. This is against the widely accepted order of priority for protection measures. It is inherently safer to prevent the use of a hazardous material, which reflects the rationale of the RoHS directive. If a hazardous material is used, even if there is an established recycling concept, there is still a risk of losses during the use phase and recycling processes, and in countries receiving EU exports the establishment of a functioning PV recycling may take still some decades. The extension of the RoHS will ensure that existing cadmium-free solar cells and lead-free solders alternatives are used and further developed in photovoltaics.

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