Social Impacts of Photovoltaic Technology: A Preliminary Desk-Based Research

Abstract:

Photovoltaic (PV) technology has distinct environmental advantages for generating electricity over conventional technologies. PV technology does not produce any noise, toxic-gas emissions, or greenhouse gases. It is a zero-emissions process.

However, from a sustainable approach, social impacts should also be analyzed in order to better understand the whole impact of this technology. After explaining the main components of a photovoltaic structure (solar panel and inverter) the article presents the potential social impacts related with photovoltaic technology as the outcome of a preliminary desk-based research that is part of a social impact assessment of the technology.

Photovoltaic technology is close related with the electronic industry where we can find severe social impacts throughout the supply chain from raw material extraction to disposal. In the PV case, the manufacture of solar cells involves several toxic, flammable and explosive chemicals. Many of those components supposes a health hazard to workers involved in manufacturing of solar cells who must be protected from exposure to materials used even if they are relatively inert like silicon. Also, solar farm locations must be carefully selected to reduce competition with agriculture and soil erosion. Finally, because solar PV semiconductor manufacturing processes have roots in the electronics industry, many of the chemicals found in e-waste are also found in solar PV, including lead, brominated flame retardants, cadmium, and chromium. The disposal of electronic products is becoming and escalating environmental and health problem in countries in West Africa, Asia and Latin America.

Key:

Photovoltaic, Social Impact, Life Cycle Assessment

Authors:

Santiago Cáceres Gómez, Francisco Javier Gómez González, Cristina Durlan, Guillermo Aleixandre Mendizábal. Technology Social Impact Assessment Research Group. Universidad de Valladolid (Spain)

Introduction

Photovoltaic (PV) technology has distinct environmental advantages for generating electricity over conventional technologies: PV material requirement are extremely low (V. M. Fthenakis and Moskowitz 2000); PV technology does not produce any noise, toxic-gas emissions, or greenhouse gases (Vasilis M. Fthenakis 2003) so PV contributes to climate change mitigation; photovoltaic operation phase is a zero-emissions process, does not require water and has low maintenance requirements; PV can be used off-grid to supply energy to isolated devices, houses or business, characteristic that is widely used in development projects; solar contribute to the security of energy supply in every country; each module lasts around 25 years; systems can be recycled at the end of their life; thousands of jobs can be created (Greenpeace and European Photovoltaic Industry Association 2011).

The International Energy Agency details the high growth of grid-connected and off-grid PV power (Table 1) but, although most of the authors accept that the current high costs will fall substantially, energy policymakers still prefer to leave its evolution mainly in the hands of the market (Jackson and Oliver 2000).

Year	Off-grid		Grid-connected		Total	
	Cumulative (MW)	Increase (%)	Cumulative (MW)	Increase (%)	Cumulative (MW)	Increase (%)
2005	485	8	3758	55	4243	48
2006	535	10	5347	42	5882	39
2007	663	24	7684	44	8347	42
2008	741	12	13752	79	14493	74
2009	883	19	19875	45	20758	43
2010	980	11	33973	71	34953	68

Table 1: Cumulative installed PV power and annual percentage increase (IEA International Energy Agency 2011)

Nevertheless, from a sustainable point of view, social impacts should also be analyzed in order to better understand the overall impact of this technology. After explaining the main components of a photovoltaic structure, the article presents some potential negative social impacts related with the solar module and the inverter of a photovoltaic system as the outcome of a preliminary desk-based research that is part of a social impact assessment of the technology.

Methodology

The phases considered for the social impact assessment of a project that involves the use of photovoltaic cells includes the following steps: scoping, formulation of alternatives, profiling, projection, assessment, evaluation, mitigation, monitoring, ex-post evaluation or audit (Barrow 2001).

This paper does not consider any particular project. The outcome of the desk-research represents information to be used in the first steps of the methodology of whatever social impact assessment of projects that use photovoltaic cells. So, it will be useful to determine affected stakeholders of the planned action from a complete life cycle approach (scoping), possible alternatives to be considered about what materials and devices should be used (formulation of alternatives) and possible impacts to consider (profiling).

Sheikh and Kocaoglu (2011) carried out a literature review of solar photovoltaic technologies assessment using five perspectives: social, technological, economic, environmental and political (STEEP). The technical and economic perspectives were the most frequent ones (these are typical in an engineering project), whereas social and political were the least considered ones. Few papers reflect the social and political perspective and only at a conceptual level. The authors recommend the inclusion of the five perspectives along with a hierarchical decision model in the analysis of the photovoltaic technologies.

After making a literature review (ISI Web of Knowledge, Internet, NGOs and administration reports), three main sources were used to discuss the potential negative impacts of the PV technology:

Fthenakis (Vasilis M. Fthenakis 2003; V. M. Fthenakis and Moskowitz 2000), one of the most cited author in the literature about photovoltaic cells hazards and safety issues; Silicon Valley Toxics Coalition (2009), a NGO working on health and environmental issues of high-tech industry with an emphasis in PV technology and EPRI and California Energy Commission (2003).

It is important to underline the fact that PV technology is still not mature enough for many of the technologies being implemented (mainly thin-film). Research and development is on stage to increase the efficiency of the cells. It means that the components used to manufacture PV cells will change in the near to middle future and the recount of hazardous materials will change accordingly. On the other hand, hazardous components phase out or substitution is something social impact assessment looks for, an easier task to realize during the first stages of the particular technology system development.

Solar Photovoltaic Technology

There are four primary applications for photovoltaic systems: *off-grid domestic,* that provide electricity to household and villages that are not connected to the utility electricity network; *off-grid non-domestic,* that provide electricity for applications such as telecommunications, water pumping, vaccine refrigeration, etc.; *grid-connected distributed,* that provide power to a customer or to the grid; and *grid-connected centralized,* that works like centralized power station (IEA International Energy Agency 2011).

Although there are different configurations derived from the type of connection (off-grid, grid-connected) , a solar photovoltaic system generally consists of (Thornycroft and Markvart 2003): solar cell panels, inverter, DC isolator, AC switched disconnector, batteries (off-grid), wires and the mechanical structure to support the different devices of the system. The devices considered in the desk-research are the solar cell panels and the inverter.

There are three generations of *solar cell panels*: the first generation is the basic crystalline silicon (c-Si); the second generation corresponds to thin-film technologies that include amorphous silicon (a-Si), Cadmium Telluride (CdTe), Copper Indium Selenide (CIS) and Copper Indium Gallium Selenide (CIGS); and the third generation includes concentrator photovoltaic, organic and other technologies not yet enough commercialized (Greenpeace and European Photovoltaic Industry Association 2011). Finally, Gallium Arsenide (GaAs) and Multijuntions Cells are used mainly in communications and military satellite applications. In this desk-research, only the first and second generations are analyzed.

The inverter converts DC electric energy produced by the PV system to AC electric energy that is compatible with the electric distribution network and devices connected to it. There are inverters for different power needs. They range in power from hundreds watts to kilowatts or even thousands of kilowatts for large scale solar power plants. Inverters, among other components, incorporate: printed circuit boards, resistor, transistors, capacitors, integrated circuits (ICs), transformer, and the container. Severe social impacts of electronic equipment have been found throughout the supply chain of the electronic industry from raw material extraction to disposal (Pellow and Park 2002; Hightower et al. 2006). The disposal of electronic products is becoming and escalating environmental and health problem in countries in West Africa, Asia and Latin America (Silicon Valley Toxics Coalition 2009).

Impacts

The main concerns about occupational and health risks from a life cycle perspective of a PV system are related with the emission of toxic or risky substances used to manufacture PV cells. The potential risk can occur during the manufacturing process, from the leaching of substances or from the combustion of modules. The list of chemicals in the final PV cell is different from the chemicals used to manufacture them, as solvents and acids for cleaning the semiconductors parts or gases for depositing the thin-film layers are not present in the final product (EPRI and California Energy Commission 2003).

Among the most dangerous substances related with PV systems from a life cycle approach, we can find (not all the substances are present in all the PV technologies):

- Silica (SiO_2). The mining of metallurgical grade silica can produce silica dust that has been associated with silicosis, a severe lung disease.
- Cadmium (Cd). Known carcinogenic. Extremely toxic (EPA and OHSA). Potential to cause kidney, liver, bone, and blood damage from ingestion. Lung cancer from inhalation. Workers may be exposed to cadmium compounds during manufacturing. It is restricted by RoHS directive.
- Silane (SiH_4). Most significant hazard. It is extremely explosive. Dangerous for workers and communities. The semiconductor industry reports several silane incidents every year, although some companies use an alternative that in turn could be used in the PV industry.
- Chlorosilane ($HSiCl_3$). Very toxic and highly flammable.
- Silicon Tetrachloride ($SiCl_4$) (waste). Extremely toxic substance. Causes skin burns, and is a respiratory, skin and eye irritant.
- Hydrogen selenide (H_2Se). Highly toxic and dangerous at concentrations as low as 1 part per million in the air. Will present occupational health and safety issues.
- Sulfur hexafluoride (SF_6). Extremely potent greenhouse gas. Accidental or fugitive emissions will greatly undermine reductions gained by using solar power.
- Selenium dioxide (SeO_2). Potential formation at high temperatures. It is a tissue poison like arsenic. The recovery of selenium is very high but not 100 percent.
- Sodium hydroxide (NaOH), hydrochloric acid (HCL), sulfuric acid (H_2SO_4), nitric acid (HNO_3), hydrogen fluoride (HF), phosphine (PH_3) or arsine (AsH_3), Isopropyl alcohol (C_3H_8O). These components require special handling and disposal procedures because of possible chemical burns and risks from inhalation of fumes.
- Kerf (waste silicon dust from sawing c-Si wafers). May generate silicon particulate matter that will pose inhalation problems for production workers and those who clean and maintain equipment.
- Lead (Pb). Highly toxic to the central nervous system, endocrine system, cardiovascular system, and kidneys.

- Brominated flame retardants (BFRs), Polybrominated biphenyls (PBBs) and Polybrominated dephenylethers (PBDEs). Hexavalent chromium (Cr(VI)). They are considered carcinogenic.

The hazard to health depends on: toxicological properties of materials, some of which are toxic, carcinogenic or flammable; intensity or concentration; frequency and duration of human exposures or doses; and the existence of a complete pathway from the compound to the receptor. These, also, depends on the availability and efficiency of safety and pollution control systems (V. M. Fthenakis and Moskowitz 2000). It is also important to note that not-known interactions paths between components (for instance while operation of the PV system) exist and not all the interactions have been tested in the laboratory. Many of the occupational and health problems can be resolved if proper actions are taken, but in some places like developing countries it is not the case (Cha 2008). From a life cycle approach, the impacts can occur in the following cases:

<u>Manufacturing</u> An accidental release (low probability) may present risks to workers and communities in the nearby as a number of gases (silane, phosphine, arsine, hydrogen sulfide…) are involved. The toxicity and explosive nature of these gases can cause both physical (explosions) and biological (inhalation) damages (EPRI and California Energy Commission 2003). Also, exposures to low levels of toxic materials over long periods of time could affect both workers and the general public.

<u>Use/Operation</u> Although the risk is low, potential human damage could occur from the leaching of materials from broken PV modules with heavy metals with cadmium or selenium being of special concern. Accidental fires could release fumes into the atmosphere and the nearby community is the main concern. The risk is higher in commercial buildings than in residential buildings (EPRI and California Energy Commission 2003).

<u>Decommissioning</u> Disposal of large quantities of modules to a single landfill presents potential risks for humans, communities and the environment as the leaching of chemicals can contaminate local ground and surface water. Fthenakis (2003) indicates that the main concern during this life cycle phase will be associated with the presence of Cadmium (Cd) in CdTe and CdS solar films cells and Pb in x-Si panels if they contain Pb-based solder. Nevertheless, he specifies that proper disposal will result in a tiny fraction (0.5%) remaining in the ash, which should be disposed properly in controlled landfills. The long life of PV cells and the fact that it is a young industry make data from landfills not yet available. Many of the chemicals found in electronic waste (e-waste) are also found in solar PV, including lead, brominated flame retardants, cadmium, and chromium. The disposal of PV systems in developing countries, as is the case with e-waste, should be prevented.

A different type of impacts comes from the land uses of large PV installations. PV farm locations must be carefully selected to reduce competition with agriculture and soil erosion; visual impacts affecting visitor experience; or creation of isolated public land parcels.

Conclusions

The manufacture of PV modules uses some hazardous materials which can present health and safety hazards, if adequate precautions are not taken. Hazardous materials could adversely affect occupational and public health during accidents or improper handling and treatment in all the lifecycle stages because of the absence of an appropriate technology, especially in the case of some developing countries as some modules could end there as is the case with other electronic devices.

References

Barrow, C. J. 2001. *Social Impact Assessment: An Introduction*. A Hodder Arnold Publication.

Cha, A. E. 2008. "Solar Energy Firms Leave Waste Behind in China." *The Washington Post*, March 9, sec. Business. http://www.washingtonpost.com/wp-dyn/content/article/2008/03/08/AR2008030802595.html.

EPRI, and California Energy Commission. 2003. "Potential Health and Environmental Impacts Associated with the Manufacture and Use of Photovoltaic Cells."

Fthenakis, V. M. and Moskowitz, P. D. 2000. "Photovoltaics: environmental, health and safety issues and perspectives." *Progress in Photovoltaics: Research and Applications* 8 (1) (January): 27–38.

Fthenakis, V M. 2003. "Overview of Potential Hazards." In *Practical Handbook of Photovoltaics: Fundamentals and Applications*, ed. Markvart. T and Castañer. L, 998. 1st ed. Oxford, UK: Elsevier Science.

Greenpeace, and European Photovoltaic Industry Association. 2011. "Solar Generation 6. Solar Photovoltaic Electricity Empowering The World." http://www.greenpeace.org/international/Global/international/publications/climate/2011/Final%20SolarGeneration%20VI%20full%20report%20lr.pdf.

Hightower, J., Smith, T., Sonnenfeld, D.A. and Pellow D.N. 2006. *Challenging the Chip: Labor Rights and Environmental Justice in the Global Electronics Industry*. Temple University Press.

IEA International Energy Agency. 2011. "Trends in Photovoltaic Applications. Survey report of selected IEA countries between 1992 and 2010."

Jackson, T. and Oliver. M. 2000. "The viability of solar photovoltaics." *Energy Policy* 28 (14) (November): 983–988.

Pellow, D.N. and Park L. 2002. *The Silicon Valley of Dreams: Environmental Injustice, Immigrant Workers, and the High-Tech Global Economy*. NYU Press.

Sheikh, N. and Kocaoglu. D. F., 2011. "A comprehensive assessment of solar photovoltaic technologies: Literature review." In *Technology Management in the Energy Smart World (PICMET), 2011 Proceedings of PICMET '11:*, 1–11. IEEE.

Silicon Valley Toxics Coalition. 2009. "Toward a Just and Sustainable Solar Energy Industry." http://svtc.org/wp-content/uploads/Silicon_Valley_Toxics_Coalition_-_Toward_a_Just_and_Sust.pdf.

Thornycroft, J. and Markvart. T, 2003. "Grid Connection of PV Generators: Technical and Regulatory Issues." In *Practical Handbook of Photovoltaics: Fundamentals and Applications*, ed. Markvart. T and Castañer. L, 998. 1st ed. Oxford, UK: Elsevier Science.