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Environmental impacts from the solar energy technologies

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Abstract

Solar energy systems (photovoltaics, solar thermal, solar power) provide significant environmental benefits in comparison to the conventional energy sources, thus contributing, to the sustainable development of human activities. Sometimes however, their wide scale deployment has to face potential negative environmental implications. These potential problems seem to be a strong barrier for a further dissemination of these systems in some consumers.

To cope with these problems this paper presents an overview of an Environmental Impact Assessment. We assess the potential environmental intrusions in order to ameliorate them with new technological innovations and good practices in the future power systems. The analysis provides the potential burdens to the environment, which include—during the construction, the installation and the demolition phases, as well as especially in the case of the central solar technologies—noise and visual intrusion, greenhouse gas emissions, water and soil pollution, energy consumption, labour accidents, impact on archaeological sites or on sensitive ecosystems, negative and positive socio-economic effects.

Keywords: Solar energy systems; Photovoltaic; Environmental impact assessment

1. Potential environmental impacts of solar energy technologies and mitigation measures

Every energy generation and transmission method affects the environment. As it is obvious conventional generating options can damage air, climate, water, land and wildlife, landscape, as well as raise the levels of harmful radiation. Renewable technologies are substantially safer offering a solution to many environmental and social problems associated with fossil and nuclear fuels (EC, 1995, 1997).

Solar energy technologies (SETs) provide obvious environmental advantages in comparison to the conventional energy sources, thus contributing to the sustainable development of human activities (Table 1). Not counting the depletion of the exhausted natural resources, their main advantage is related to the reduced CO_2 emissions, and, normally, absence of any air emissions or waste products during their operation.

Concerning the environment, the use of SETs has additional positive implications such as:

- reduction of the emissions of the greenhouse gases (mainly CO_2, NO_x) and prevention of toxic gas emissions (SO_2, particulates)
- reclamation of degraded land;
- reduction of the required transmission lines of the electricity grids; and
- improvement of the quality of water resources (Various, 2000).

In regard the socio-economic viewpoint the benefits of the exploitation of SETs comprise:

- increase of the regional/national energy independency;
- provision of significant work opportunities;
- diversification and security of energy supply;
- support of the deregulation of energy markets; and
- acceleration of the rural electrification in developing countries.

This article overviews of the various environmental aspects of the deployment of SETs and illustrate the ways that can be used to successfully address potential burdens to the environment.

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Table 1
Environmental and social indicators of SETs

Indicator	Central solar thermal	Distributed solar thermal	Central photovoltaic power generation	Distributed photovoltaic power generation	Solar thermal electricity
CO_2 emissions savings	1.4 kg/kWh or 840 kg/m^2 a	1.4 kg/kWh or 840 kg/m^2 a	0.6–1.0 kg/kWh	0.6–1.0 kg/kWh	Annually 688 t/MW when compared to a combined cycle plant 1.360 t/MW when combined to a cola fired plant
Production employment (EU wide)	4000 jobs/a	4000 jobs/a	2–3000 jobs/a	2–3000 jobs/a	1 permanent job/MW for operation + 10–15 jobs/MW for 12–18 month construction
Total employment	12,000 jobs/a	12,000 jobs/a	4–5000 jobs/a	4–5000 jobs/a	1000 permanent jobs for 1000 MW

(EC, 2002).

2. Generic issues

Furthermore, unfavourable effects of SETs are usually minor and they can be minimized by appropriate mitigation measures. The potential environmental burdens of SETs are regularly site specific, depending on the size and nature of the project. As it is obvious from Tables 2 and 3, these burdens are usually associated with the loss of amenity (e.g. visual impact or noise—during the installation and the demolition phases) and the impacts can be minimized by (ETSU, 1996; Gekas et al., 2002; Frantzeskaki et al., 2002; Tsoutsos, 2001):

- the appropriate siting of central solar systems, which involves careful evaluation of alternative locations and estimation of expected impact (away from densely populated areas and not in protected areas or areas of significant natural beauty); the residential solar systems can be installed anywhere, especially integrated in the roofs;
- the appropriate operational practices (including rational water use, safety measures, waste disposal practices, use of biodegradable chemicals, etc.);
- the engagement of the public and relevant organizations in the early stages of planning, in order to ensure public acceptance;
- the use of the best available technologies/techniques and the improvement of technology (e.g. use of air as the heat-transfer medium in central tower systems, "advanced" Stirling engines);
- the integration in the building's shell;
- the sensible planning constraints and pre-development assessments (e.g. on water use, habitat loss, estimation of expected CO_2 savings, etc.);
- the training of workers, use of special sunglasses during operation and construction, use of heat-insulating uniforms, familiarization with the system;
- the re-establishment of local flora and fauna, giving the environment enough time to come up to its previously state again; and
- thorough Environmental Impact Assessment Studies for central solar systems.

3. Environmental impacts from solar thermal heating systems

Though the production of solar thermal (ST) systems requires reasonable quantities of materials, insignificant amounts are also consumed during their operation; at that time the only potential environmental pollutant arises from the coolant change, which can be easily controlled by good working practice. The accidental leakage of coolant systems can cause fire and gas releases from vaporized coolant, unfavourably affecting public health and safety. On the contrary, the large-scale deployment of ST technologies will significantly reduce the combustion of conventional fuels and will consequently; reduce the environmental impacts associated with these fuels.

More analytically:

3.1. Land use

For low/medium heat systems it is the characteristics of the chosen system, which define the land use. For instance, in the case of single-dwelling hot water or space heating/cooling, no land will be required since the system will usually be added to the roof of the existing building. Communal low-temperature systems might use some land, though again the collection surfaces might well be added on already existing buildings. The principal additional use of land might be for heat storage.

Table 2
Solar energy technologies' negative impacts

Impacts–burdens	Alleviation technologies/techniques
Solar thermal heating	
Visual impact on buildings' aesthetics	Adoption of standards and regulations for environmentally friendly design; Good installation practices; Improved integration of solar systems in buildings; Avoid siting of solar panels on buildings of historic interest or in conservation areas.
Routine & accidental releases of chemicals	Recycling of the used chemicals; Good practices—appropriate disposal.
Land use	Proper siting and design.
Photovoltaic power generation	
Land use: large areas are required for central systems.	Use in isolated and deserted areas;
Reduction of cultivable land	Avoidance of ecologically and archeologically sensitive areas; Integration in large commercial buildings (facades, roofs); Use as sound isolation in highways or near hospitals.
Visual intrusion—aesthetics	Careful design of systems; Integration in buildings as architectural elements; Use of panels in modern architecture instead of mirrors onto the facade of buildings.
Impact on ecosystems (applicable to large PV schemes).	Avoidance of sensitive ecosystems and areas of natural beauty, archaeological sites.
Use of toxic and flammable materials (during construction of the modules).	Avoidance of release of potentially toxic and hazardous materials with the adoption of existing safety regulations and good practice.
Slight health risks from manufacture, use, & disposal	Good working practices (use of protecting gloves, sunglasses, clothing during construction).
Solar thermal electricity	
Construction activities	Good working practices; Site restoration; Avoidance of sensitive ecosystems and areas of natural beauty.
Visual impact—aesthetics	Proper siting (avoidance of sensitive ecosystems and areas of natural beauty, densely populated areas).
Land use	Proper siting.
Effect on the ecosystem, flora and fauna (especially birds)	Proper siting (avoidance of sensitive ecosystems).
Impact on water resources water use (for cooling of steam plant) and, possibly, water pollution due to thermal discharges or accidental discharges of chemicals used by the system	Appropriate constraints (not the excessive use of existing resources);Improved technology (use of air as heat-transfer medium);Exploitation of the warm water in the nearest industry in the production stream.Good operating practices and compliance with existing safety regulations;Employees should be educated and familiarized with the systems.
Safety issues (occupational hazards)	

(Tsoutsos et al., 1997; Various, 2000).

Table 3
Grade of the potential negative environmental impacts of solar technologies

Environmental problem	Central solar thermal	Distributed solar thermal	Central photovoltaic power generation	Distributed photovoltaic power generation	Solar thermal electricity
Visual impact	+ +	+	+ +	+	+ + +
Routine & accidental releases of chemicals	+	+ +	+ + +	+ + +	+ +
Land use	+ +	+	+ +	+	+ + +
Work safety and hygiene	+ +	+ +	+ +	+ +	+ + +
Effect on the ecosystem	+		+		+ +
Impact on water resources	+ +	+	+	+	+ + +

(EC, 2002 adapted by the authors).

For high temperature systems, the land-use requirements of concentrating collectors providing process heat are more problematical.

Concerning the loss of habitat and changes to the ecosystem due to land use in the case of large-scale systems, provided that predevelopment assessments are carried out and ecologically important sites are avoided, these are unlikely to be significant.

3.2. Routine and accidental discharges of pollutants

During the operation of the ST system coolant liquids may need change every 2–3 years. Such discharges require careful handling. In some cases, the coolant will be water based; but all indirect systems are likely to contain anti-freeze or rust inhibitors, as well as substances leached from the system during use. Heat transfer fluids might therefore contain glycol, nitrates, nitrites, chromates, sulphites, and sulphates. Higher temperature applications would use more complex substances, such as aromatic alcohols, oils, CFCs, etc. The large-scale adoption of SETs might well require control on the disposal of these substances (OECD/IEA, 1998).

Except for the normal use, there may be the risk of accidental water pollution through leaks of heat transfer fluid. In parallel, solar converters can achieve relatively high temperatures if their coolant is lost (up to 200°C). Consequently, at this temperature, there is a fire risk, with the additional problem of out-gassing from panel components (insulant, plastic components, epoxys) and the release of heat transfer fluids in gaseous state or following combustion (e.g. burnt freon).

3.3. Visual impact

Till recently "integration" used to be synonymous with "invisibility". It was actually considered desirable to hide the fact that the solar elements were different than other building elements. This trend, fortunately, changed. Architects have discovered that solar elements can be used to enhance the aesthetic appeal of a building, and their clients have discovered the positive effects of advertising the fact that they are using solar energy. The solar elements are used as architectural elements in attractive and visible ways.

The aesthetic impact of solar panels is evidently a matter of taste, though flat panels usually are designed in such a way as to fit closely to the existing roofline and produce little glare.

Modern ST systems allow for the manufacturing of collectors that can be easily integrated in buildings in an aesthetically pleasant manner.

3.4. Effect on buildings

Theoretically the ST placement in the shell of the buildings could increase fire risk (OECD/IEA, 1998) and water intrusion into the roof. This can be easily avoided, since only four holes per panel on the roof will be integral part of the roof.

3.5. Other burdens

Other burdens applicable to central power systems only (e.g. noise—during the construction period, visual intrusion, etc.) are likely to prove insignificant (provided areas of scenic beauty are avoided), because such schemes are likely to be situated in those areas of low population density. Therefore, all the impacts of suitably located large ST schemes are expected to be small and reversible.

4. Environmental impacts from photovoltaic power generation

Photovoltaics (PV) are seen to be generally of benign environmental impact, generating no noise or chemical pollutants during use. It is one of the most viable renewable energy technologies for use in an urban environment, replacing existing building cladding materials. It is also an attractive option for use in scenic areas and National Parks, where the avoidance of pylons and wires is a major advantage.

4.1. Land use

The impact of land use on natural ecosystems is dependent upon specific factors such as the topography of the landscape, the area of land covered by the PV system, the type of the land, the distance from areas of natural beauty or sensitive ecosystems, and the biodiversity. The impacts and the modification on the landscape are likely to come up during construction stage by construction activities, such as earth movements and by transport movements. Furthermore, an application of a PV system in once-cultivable land is possible to damnify soil productive areas. The "sentimental bind" of the cultivator and his cultivable land is likely to be the reason of several social disagreements and displeasure.

4.2. Routine and accidental discharges of pollutants

During their normal operation PV systems emit no gaseous or liquid pollutants, and no radioactive substances. In the case of CIS and CdTe modules, which include small quantities of toxic substances, there is a potential slight risk that a fire in an array might cause small amounts of these chemicals to be released into the environment (Various, 1996).

In large-scale central plants a release of these hazardous materials might occur as a result of abnormal plant operations and it could pose a small risk to public and occupational health. Thus there must be emergency preparedness and response in case of an accidental fire or exposure to heat. Emissions to soil and groundwater may occur inadequate storage of materials (OECD/IEA, 1998).

4.3. Visual impacts

Visual intrusion is highly dependent on the type of the scheme and the surroundings of the PV systems. It is obvious that, if we apply a PV system near an area of natural beauty, the visual impact would be significantly high. In case of modules integrated into the facade of buildings, there may be positive aesthetic impact on modern buildings in comparison to historic buildings or buildings with cultural value.

- Optimal architectural solutions to minimize potential impact on visual amenity and building aesthetics (i.e. PV integration into buildings and other installations). The use of PV as a cladding material for commercial buildings is showing the architectural possibilities of the technology to both the architectural profession and their clients. Advances in the development of multi-functional PV facades, which perform aesthetic and practical functions such as shading and heat extraction, have provided an important stimulus for architectural expression (Hestnes, 1999).
- Proper siting and design of large PV installations.
- Use of colour to assemble the PV modules in large-scale systems.

Integrated PV electrification schemes, which help to regenerate rural areas and user associations have successfully overcome the problems of managing and maintaining remote schemes by establishing mechanisms for collecting user payments, arranging regular maintenance, obtaining finance and providing advice on energy efficient appliances.

4.4. Depletion of natural resources

The production of current generation PV's is rather energy intensive (especially the poly crystalline and the mono-crystalline modules) and large quantities of bulk materials are needed (thin film modules have less primary energy requirement per W than the a-Si PV modules (a-Si are thin films also!) because of the difference in cell efficiency, so can be an answer to that problem) . Also, small quantities of scarce materials (In/Te/Ga) are required; also limited quantities of the toxic Cd.

In general the Cd emissions attributed to CdTe production amount to 0.001% of Cd used (corresponding to 0.01 g/GWh). Furthermore Cd is produced as a byproduct of Zn production and can either be put to beneficial uses or discharged into the environment (Fthenakis and Zweibel, 2003)

Several aspects have to be studied to minimize environmental impacts related to the production of the PV cells:

- prospects for thinner cell layers;
- the full potential of the concentrator PV technologies;
- prospects for more efficient material utilization;
- safer materials and alternatives; and
- module recycling technology and its efficiency.

4.5. Air pollution

As far as life cycle assessment is concerned, the environmental performance of the system depends heavily on the energy efficiency of the system manufacturing and especially electricity production. The emissions associated with transport of the modules are insignificant in comparison with those associated with manufacture. Transport emissions were still only 0.1–1% of manufacturing related emissions. In the case of poly- and mono-crystalline modules, the estimated emissions are 2.757–3.845 kg CO_2/kWp, 5.049–5.524 kg SO_2/kWp and 4.507–5.273 NO_x/kWp (Raptis et al., 1995; OECD/IEA, 1998).

In urban environment, modern PV systems, which are architecturally integrated into buildings, are able to provide a direct supply of clean electricity that is well matched to the demand of the building, but can also contribute to day-lighting, and the control of shading and ventilation. Also, PV panels can be used instead of mirrors directly into the facade of a building. PV systems also assist to create a supportive environment within which to encourage other means of energy saving by the building promoters, owners and users. PV energy services are particularly obvious where only low levels of power are needed, such as in rural electrification applications, and where the users are able to benefit directly from the very high reliability of having their own PV generator. In the former case, to install a PV generator is frequently cheaper than to extend the mains grid over long distances.

4.6. Noise intrusion

As with all types of construction activity, there will be little noise. Also, there will be some employment benefits during the construction phase and especially for large schemes during the operational phase.

Manufacturers should be encouraged to produce systems that are easily recyclable.

Options for energy demand reduction must always be considered along with the assessment of PV applications.

4.7. Waste management

In the case of stand-alone systems, which are small fraction of the market (Tsoutsos et al., 2003b), the effects on health of chemical substances included in the batteries should also be studied. A life cycle analysis of batteries for stand-alone PV systems indicates that the batteries are responsible for most of the environmental impacts, due to their relatively short life span and their heavy metal content. Furthermore a large amount of energy and raw materials are required for their production. A module-recycling scheme can improve this situation (Fthenakis, 2000).

5. Environmental impacts from solar thermal electricity

The limited deployment of ST electricity to date means that there is little actual experience of the environmental impacts that such a scheme may have.

Similarly to other SETs, ST electricity systems present the basic environmental benefit of the displacement or the avoidance of emissions associated with conventional electricity generation (Tsoutsos et al., 2003a). During their operation, these systems have no emissions. Some emissions do arise from other phases of their life cycle (primarily materials processing and manufacture), but they are lower, compared to those avoided by the systems operation.

5.1. Materials' processing and manufacture

Energy use and gas emissions (CO_2, SO_2, NO_x) in materials' processing and manufacture of ST systems are noticeable. The impacts of these emissions vary according to location, and are fewer than those of conventional fossil fuel technologies (Norton et al., 1998).

5.2. Construction

These projects have the usual environmental impacts associated with any engineering scheme during the construction phase—impact on landscape, effects on local ecosystems and habitats, noise, virtual intrusion, and topical vexation such as noise and temporally pollutant emissions due to increased traffic because of transportation of workers and of material, occupational accidents, temporal blindness (Theodoratos and Karakasidis, 1997), etc.

5.3. Land use

ST electric systems are amongst the most efficient SETs when it comes to land use (they produce annually about 4–5 GWh/ha). To date, most sites used or considered for ST systems are in arid desert areas, which typically have fragile soil and plant communities (OECD/IEA, 1998).

5.4. Ecosystem, flora and fauna

Attention during the planning, construction and operation phases can minimize the effects on vegetation, soil and habitat (OECD/IEA, 1998). Furthermore, the shade offered by the reflectors has a beneficial effect on the microclimate around the scheme and on the vegetation, too. Provided that such schemes are not deployed in ecologically sensitive areas or in areas of natural beauty, it is unlikely that any of the above changes would be considered as significant.

Central concentrator power systems could pose a danger to birds, but operational experience shows that birds avoid any danger areas (possibly by being sensitive to air turbulence) (OECD/IEA, 1998). Flying insects can also be burnt when flying close to the reflector's area. The loss of the insect population is insignificant.

5.5. Visual impact

In addition to the collector systems, the main visual impact would come from the tower of the central receiver systems. However, the atmospheric requirements for these systems point to their deployment in areas of low population densities, so provided that areas of outstanding natural beauty are avoided, visual intrusion is unlikely to be significant.

5.6. Noise

Likewise, noise is insignificant in comparison to any other power option, such as the conventional, the wind power generation, and the gas turbines. The noise from the generating plant of large-scale schemes is unlikely to cause any disturbance to the public. Noise would be generated primarily only during the day; at night, when people are more sensitive to noise, the system is unable to operate.

The Stirling engines of stand-alone parabolic dish systems are a source of noise during operation, but they are unlikely to be any noisier than the stand-by diesel generating sets, which they generally displace. Also, new (technological) advanced Stirling engines are constructed to operate noiselessly.

5.7. Water resources

Parabolic trough and central tower systems using conventional steam plant to generate electricity require the use of cooling water. This could place a significant strain on water resources in arid areas. In addition, there may be some pollution of water resources, through thermal discharges and accidental release of plant chemicals (OECD/IEA, 1998), although the latter can be avoided by good operating practice. Stand-alone parabolic dish systems require no water, other than for periodic cleaning of reflective surfaces and so they have little impact on water resources.

5.8. *Health and safety (occupational hazards)*

The accidental release of heat transfer fluids (water and oil) from parabolic trough and central receiver systems could form a health hazard. The hazard could be substantial in some central tower systems, which use liquid sodium or molten salts as a heat-transfer medium. Indeed a fatal accident has occurred in a system using liquid sodium. These dangers will be avoided by moving to volumetric systems that use air as a heat-transfer medium.

Central tower systems have the potential to concentrate light to intensities that could damage eyesight. Under normal operating conditions this should not pose any danger to operators, but failure of the tracking systems could result in straying beams that might pose an occupational safety risk on site.

5.9. *Social impacts*

There will be some employment benefits during the construction and operational phase.

6. Conclusions and recommendations

SETs present tremendous environmental benefits when compared to the conventional energy sources. In addition to not exhausting natural resources, their main advantage is, in most cases, total absence of almost any air emissions or waste products. In other words, SE can be considered as an almost absolute clean and safe energy source.

Furthermore, the use of SETs can have additional environmental benefits, associated with:

(i) the SE potential to be employed in stand-alone applications (e.g., avoidance of grid connection, with all associated impacts on the ecosystem and the landscape; feasibility of installation and continuous/remote operation of equipment that perform functions related to protection or rehabilitation of environmental media, such as air quality monitoring, lake-water re-aeration, etc.),

(ii) multi-purpose applications of SETs (e.g. combined solar systems for water and space heating).

Finally, the use of SETs has significant socio-economic benefits, such as diversification and security of energy supply, provision of significant job opportunities, support of the restructure of energy markets, reduction of the dependency on fuel imports and acceleration of the electrification of rural communities in remote/isolated areas.

On the other hand, it must be realized that no man-made project can completely avoid some impact to the environment, so neither can SET installations. Potential environmental burdens depend on the size and nature of the project and are often site specific. Most of these burdens are associated with loss of amenity (e.g., visual impact or noise in the case of central systems).

However, adverse effects are generally small and can be minimized by appropriate mitigation measures, including the use of the best available abatement technologies.

Technologies or techniques that can be used to eliminate or minimize potential environmental impacts from SETs may involve, in some cases, the use of air emission or odour control equipment, design tools for optimal design and siting of the installations, best practice guidelines, improved pieces of equipment (such as gearless or lubricant-free motors), or, completely innovative design (e.g., closed-cycle plants, submerged plants, etc.).

It is up to the involved factors (investors, developers, and permitting authorities) to make the appropriate decisions by taking environmental issues into serious consideration. To that end, an Environmental Impact Assessment for central solar systems, which should estimate the magnitude of potential environmental impacts and propose appropriate mitigation measures, can play a significant role to proper project design and to a subsequent project public acceptance.

References

EC, 1995. Externalities of Energy' Externe Project, DGXII, JOULE, Report No EUR 16520 EN.

EC, 1997. Energy for the future: Renewable Sources of Energy. White Paper, European Commission, DG XVII.

EC, 2002. Scientific and technological references. Energy technology indicators, DG RTD, www.cordis.lu/eesd/src/indicators.htm.

ETSU, 1996. The environmental implications of renewables, Interim report for the UK Department of Trade and Industry, DTI, UK.

Frantzeskaki, N., Gekas, V., Tsoutsos, T., 2002. Environmental implications from the use of solar systems. Examples of the potential impact mitigation in a sustainable perspective, 7th National Conference for Solar Energy Sources, Patras, 6–8 November 2002 (in Greek).

Fthenakis, V., 2000. End-of-life management and recycling of PV modules. Energy Policy 28, 1051–1058.

Fthenakis, V., Zweibel, K., 2003. CDTe photovoltaics: real and perceived EHS risks, NCPV Program Review Meeting, www.pv.nnl.gov, March 2003.

Gekas, V., Frantzeskaki, N., Tsoutsos, T., 2002. Environmental impact assessment of solar energy systems. Results form a life cycle analysis. Protection and Restoration of the Environment VI, Skiathos, 1–5 July.

Hestnes, A.G., 1999. Building integration of solar energy systems. Solar Energy 67, 181–187.

Norton, B., Eames, P.S., Lo, N.G., 1998. Full-energy-chain analysis of greenhouse gas emissions for solar thermal electric power generation systems. Renewable Energy 15, 131–136.

OECD/IEA, 1998. Benign energy? The environmental implications of renewable, international energy agency, www. iea.org.

Raptis, F., Sachau, J., Kaspar, F., 1995. Assessment of the external costs of the photovoltaic and wind energy life cycle—national implementation in Germany, report, DG XII, JOULE, ISET, Kassel, Germany.

Theodoratos, P.C., Karakasidis, N.G., 1997. Hygiene—occupational safety and environmental protection. Ion, Athens (in Greek).

Tsoutsos, T., 2001. Marketing solar thermal technologies: strategies in Europe, experience in Greece. Renewable Energy 26 (1), 33–46.

Tsoutsos, T., Edge, M., Papastefanakis, D., 1997. Renewable energy sources and environment, CRES, DG XVII, ALTENER (in Greek).

Tsoutsos, T., Gekas, V., Marketaki, K., 2003a. Technical and economical evaluation of Stirling dish solar thermal power generation. Renewable Energy 28 (6), 873–886.

Tsoutsos, T., Mavrogiannis I., Karapanagiotis, N., Tselepis, S., 2003b. An analysis of the Greek Photovoltaic Market. Renewable and sustainable energy reviews (in press).

Various, 1996. Boyle, G. (Ed.), Renewable energy. Power for a sustainable future. The Open University, Oxford Press, London.

Various, 2000. Karapanagiotis N. (Ed.), Environmental impacts from the use of solar energy technologies. THERMIE.