A Life Cycle Assessment of the Environmental Impact of Photovoltaic Streetlight Systems

J.G.M. KORTMAN, M.G.H. VAN KAMPEN
IVAM Environmental Research, University of Amsterdam, P.O. Box 18180, 1001 ZB Amsterdam, The Netherlands
L.A. VERHOEF
Netherlands Agency for Energy and the Environment (NOVEM)
P.O. Box 8242, 3503 RE Utrecht, The Netherlands
G. LOOIS
Ecofys research and consultancy, P.O. Box 8408, 3503 RK Utrecht, The Netherlands

ABSTRACT

As a result of ongoing technical improvements and cost reduction, the application of stand alone photo voltaic (PV) streetlight systems has become an economically interesting option for specific situations in the Netherlands, such as remote parking places, intersections, along polder roads and on small islands. This in spite of the fact that the production costs of PV street light systems are still 3 to 4 times higher compared to grid connected systems. In cases where the street lights are situated in long distance from the electrical grid and the conditions for the layout of cables are difficult, PV street lights prove to have a lower combination of investment and exploitation costs (Gooijer, et al, 1996). In those cases a growing number of local governmental organisations chooses photo voltaic (PV) street light systems that offer a cost effective power supply.

In the last few years a lot of experience has been gained with the application of PV street light systems. The market for these systems is estimated to be 10.000 light points in the next 4 years in The Netherlands. Now that the market of PV supplied street lighting is growing the question rises if the integral environmental performance of PV streetlight systems is relatively good. An earlier study (Lindeijer et al, 1993) indicates that especially autonomous PV systems with batteries can be the most critical applications from an environmental point of view (see figure 1).

Batteries are responsible for an important share of the environmental burden of complete autonomous PV systems due to their relatively short life span and their heavy metal content. For this reason the Netherlands Agency for Energy and the Environment (NOVEM) is interested in the overall comparison of the environmental effects of PV powered lighting systems with the effects of conventional grid connected systems. The NOVEM therefore appointed IVAM Environmental Research to conduct a life cycle analysis with two aims:

- to compare the environmental impact of street light systems and;
- to identify the environmental improvement options for the production, use and disposal of street light systems.

In this paper the approach of the study will be presented. Results of the study are presented on the 4th European Conference on Energy-Efficient Lighting itself.

OUTLINE OF THE PROJECT

In the life cycle assessment the environmental effects of both the life cycles of grid connected and PV powered street light systems will betaken into account

PV powered Street light systems are build up from various components such as the solar cell modules, batteries, electrical load- and lighting control appliances, lampposts, fittings and light sources. The environmental interventions of these systems are caused by the extraction of materials, the production of the various components, the assembly and installation of the complete system, the maintenance and the disposal of the whole system after use.

The environmental interventions from the grid connection systems partly differs due to a more simple design of the lamppost, the different energy source in the form of the production of electricity at a power station and the transportation and transformation of electricity by cables to the

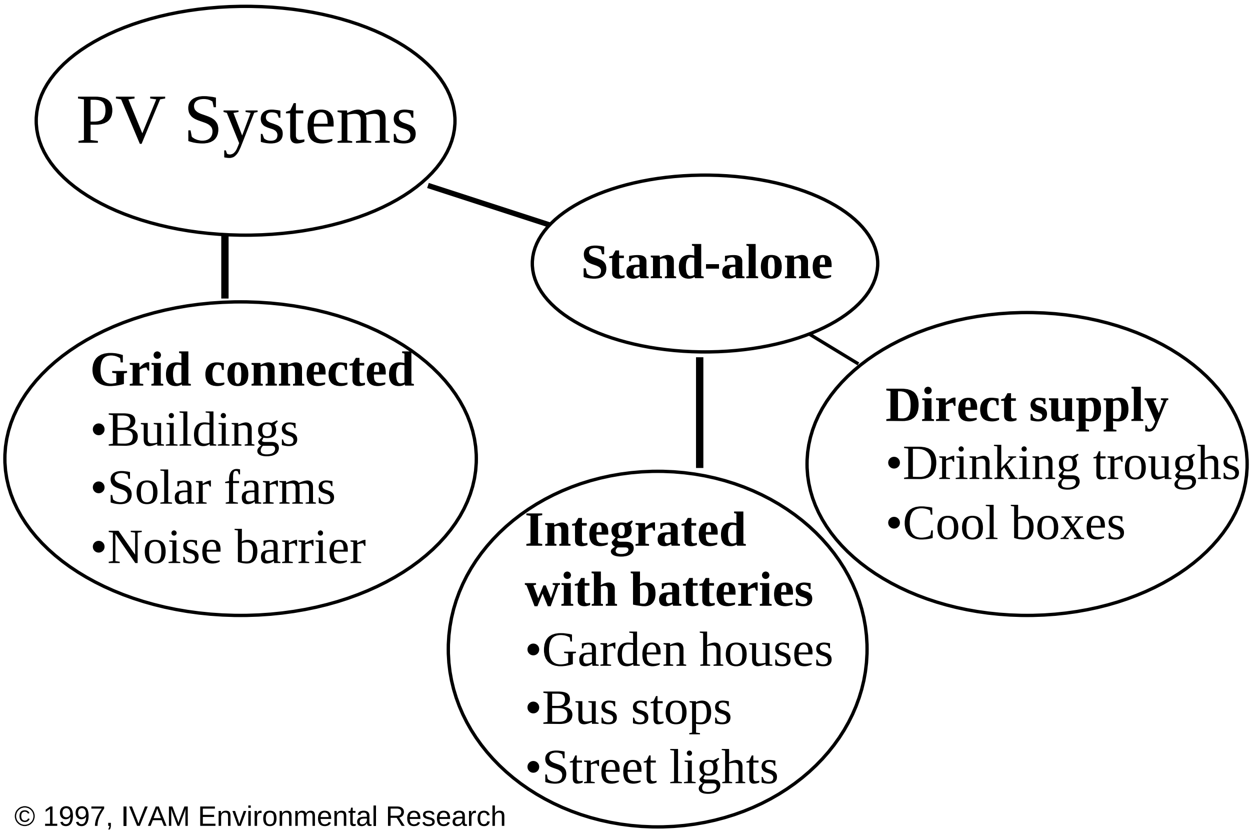

Figure 1. Application of PV systems.

lampposts. For the comparison of the two types of systems one specific intersection is chosen for which the distance to the grid is variable. In order to get a fair comparison a standard set of lighting requirements will be formulated on the basis of international and national product requirements for street light systems, such as NEN EN 40, NPR 993, 994 en 988.

In the next stage of the project Dutch manufactures of streetlight systems will be asked to supply product information that is needed for the comparison.

In the comparison of PV-powered and grid connected street light systems it is expected that the main environmental burdens will be found in different phases of the life cycles. For grid connected systems relatively high environmental effects will probably occur in the phase of the production of electricity at the power station (the consumption of fossil fuels and emissions of CO_2, SO_2 and NO_x) and the layout and the production of the cables. For PV powered street light systems most environmental effects are expected to occur at the production and dispose of batteries and the production of solar cell modules.

THE LCA METHOD

For a quantitative comparison the life cycle assessment method (LCA) is applied. IVAM Environmental Research is involved in the international development of this method within working groups of SETAC. For this project the outlines from the manual "Environmental life cycle assessment of products" (Heijungs, 1992) together with ISO standard 14040.3 are applied. New developments, such as allocation rules for recycling, normalisation factors and weighing methods are integrated in this method. By performing a LCA the environmental burden caused over the entire life cycle of the street light systems is assessed. The LCA method consist of five steps:

Step 1 *Goal definition*

The study has two main aims: the comparison of PV- and grid powered street light systems and the generation of ideas for the environmental improvement of these systems in future development projects. For both types of systems two different products are selected for the comparison.

Step 2 *Inventory*

The inventory is the step of a LCA in which the environmental interventions caused over the product life cycle are gathered. Therefore process trees are made with the most important processes in the life cycle of street light systems: from mining raw materials for the components through production and assembly of the total system, via use and maintenance up to the discarding of the system. On the basis of this process tree the inputs in the form of energy, raw materials and space, and the outputs in the form of emissions and waste are identified. This step will be performed both on the information from producers, information from literature (Alsema, 1996) and LCA databases.

Step 3 *Characterisation*

The inventory generates a long list of inputs (energy and raw materials) and outputs (emissions and waste). The problem is that this information is difficult to interpret and gives no clear information about the contribution of these

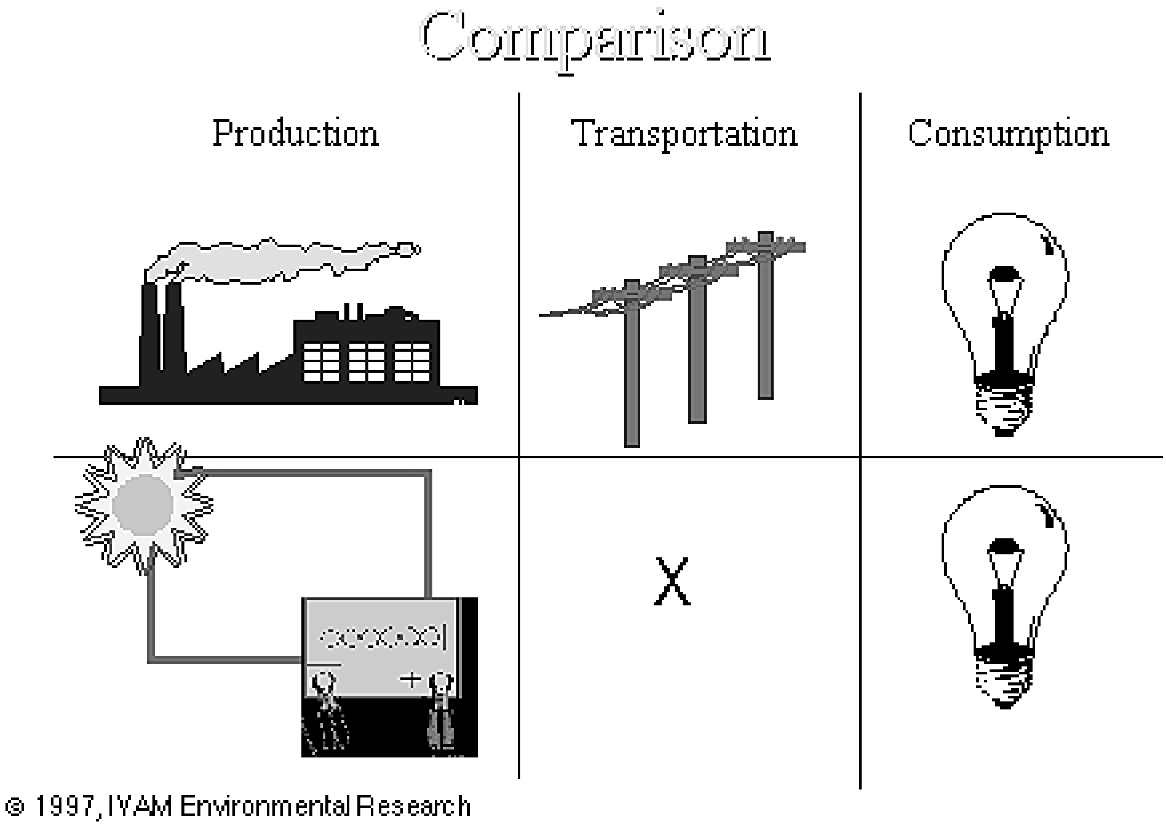

Figure 2. Comparison of life cycles

interventions to various environmental effects. Therefore in the characterisation, all interventions are classified into categories according to the effects they have on the environment. Each substance of the list can contribute to one or more environmental effects. For example, NOx emissions are toxic, and furthermore contribute to acidification and eutrophication. The environmental effects are added up over all the stages of the life cycle and are expressed in terms of the following 11 environmental aspects.

Table 1 Environmental aspects

Depletion	exhaustion of abiotic raw materials
	exhaustion of fossil fuels
Pollution	green house effect
	ozone depletion
	human toxicity
	ecotoxicity
	acidification
	eutrophication
	smog forming
Others:	energy
	waste
	hazardous waste
	space

The contribution of different substances to each environmental aspect is performed with help of characterisation factors from the manual "Environmental life cycle assessment of products (Heijungs, 1992). For instance the characterisation factors for human toxicity for NOx and ammonium are respectively 0.78 and 0.02. The result of the characterisation is presented in an environmental profile of the various street light systems.

Step 4 *Interpretation*

In this step the results of the analysis will be interpreted. Firstly the major impacts of the various systems are identified. In an earlier study (Lindeijer, 1993) it became clear that specific characteristics of the systems in the phase of use, such as the distance to the grid, the capacity of the batteries, the lighting frequency and the life span of various components have a great influence on the outcomes of the study. Therefore some sensitivity analyses will be performed in this step.

The results from the environmental profiles of step 3 are not yet mutually weighed for the various environmental effects and can not be compared with each other. In order to give a more comparable meaning, the effects scores should be normalised and weighed. Due to the experimental phase of the weighing method in which subjective elements are integrated the outcome of step 3 will only be normalised. In the normalisation step all effects scores of a system are related to the annual effect scores in the Netherlands per year.

Step 5 *Generating improvement ideas*

In order to prepare new product development projects a workshop is organised to identify ideas for improvement of the environmental profiles of street light systems. For this workshop various experts from industry and governmental organisations will be invited. With help of criteria checklists (Behrendt, 1996) environmental design strategies will be presented to the audience, such as:

- the production of environmental efficient components, such as solar cell modules, batteries and lampposts;
- the application of more sophisticated load and lighting control appliances;
- efficient settings for the street light lampposts;
- opportunities for recycling of systems components;
- combinations of lampposts with other functions.

EXPECTED RESULTS

At the 4th European Conference on Energy-Efficient lighting the results of the study are presented. They consist of:

- an overview of the environmental interventions in the life cycles of the street light systems;
- the contribution of life stages to the overall environmental impact of the systems;
- the environmental profiles with effect scores of the systems
- sensitivity analyses for important environmental data and basic assumptions of the study;
- a list with improvement ideas for PV and grid powered street light systems;
- recommendations for the environmental analysis of other autonomous PV systems. ●

REFERENCES

Alsema, E.A.; Environmental aspects of solar cell modules, 1996, University Of Utrecht, The Netherlands.

Behrendt et al; Life cycle design: a manual for companies, 1996, IZT, Berlin, Germany.

Gooijer, H de, Loois, G. 1996. ”Zonne energie voor openbare verlichting in Nederland” (Sun power for street light systems in the Netherlands), Ecofys, Advies- en Onderzoek, Utrecht, The Netherlands

Heijungs, R, et al; Environmental life cycle assessment of products, manual and guide, 1992, CML, Leiden, The Netherlands.

Lindeijer, E.W. Brouwer, J.M.; Milieubeoordeling van accu´s voor PV systemen (A life cycle analysis on 4 types of batteries for PV systems), 1993, IVAM Environmental Research, University of Amsterdam, The Netherlands.