ENVIRONMENTAL EVALUATION OF PV ON BUILDINGS: MARKET STIMULUS OR MARKET BARRIER?

Erik Alsema, David Anink
W/E Consultants Sustainable Building
Mariaplaats 21E, NL-3511 LK Utrecht, The Netherlands, E: alsema@w-e.nl

ABSTRACT: In this paper the environmental and energy performance of PV systems as part of a building is investigated, following the assessment methods in the latest Dutch building code. It is shown that the use of two separate assessments of materials environmental performance next to energy performance can form a stumbling block for PV acceptance by building designers. This is illustrated in a case study for a house with a 3 kWp PV system in 3 solar technology variants: crystalline silicon, cadmium telluride and a-Si foil. An improved assessment is presented which shows the integral environmental impacts of materials and energy over the building life cycle. With this integrated method the environmental benefits of PV on a building are clearly shown. Furthermore we discuss the need for good quality LCA data on state-of the-art PV components in order to provide building designers with the right tools and data for optimal building design, including PV systems.
Keywords: Building integration, Environmental effect, PV market

1 INTRODUCTION

PV systems are a key component for the design of net-zero energy houses. At the same time there is sometimes reluctance among architects and other system designers in the Netherlands to include PV panels in the building design, because of the perceived negative impacts on the environmental performance of the building. This negative impact is observed when buildings with PV installations are evaluated in compliance with the new Dutch Building Code, which demands an assessment of environmental impacts of building materials, next to the well-known energy performance assessment.

In this paper we will review the problems and opportunities from a fair and balanced assessment of building performance with regard to energy, CO2 and other environmental themes. Actions needed by designers, installers, and PV industry are addressed, aiming for a market stimulus for PV installations instead of the market barrier which the Building Code threatens to become now.

2 EVALUATION OF BUILDING PERFORMANCE

2.1 Energy Performance of Building

The present legislation in the Netherlands requires two sets of calculations to be submitted in order to obtain a building permit for a new building. Firstly an Energy Performance calculation has to be submitted which evaluates the overall operational energy consumption of the building. This obligation is in line with European Energy Performance of Buildings Directive (EPBD).

In this calculation an energy balance is prepared for the total building, based on the energy loss factors of the building envelope, the heating, ventilation and air conditioning (HVAC) installations and the possible on-site energy production units (e.g. PV system).The net yearly energy demand of the building under standard conditions is derived from this energy balance, and after normalization against a reference value for the building type, expressed as a dimensionless Energy Performance Coefficient (EPC). This calculation method is called “Energy Prestatie Gebouwen” (EPG; Energy Performance of Building). Only energy demand from building installations (incl. lighting) is included in the EPG method, so household appliances have no influence on the result. For residential buildings a maximum EPC-value of 0.6 is presently required, but in the coming years lower EPC-values will be required, down to EPC=0 (i.e. net zero energy) by 2020.

Installation of a PV system on the building will have a beneficial effect on the EPC-value and it will not be easy to build net-zero energy houses without a PV array on the roof.

2.2 Material Performance of Building

A relatively new requirement in the Dutch Building Code is the environmental assessment of the materials used in the building. For this calculation of the “Milieu Prestatie Gebouwen” (MPG) a special set of tools has been developed especially for the building sector:

1) A standardized calculation method [1], along with standardized assumptions (e.g. on life time), to evaluate the **life-cycle environmental impacts of the materials** used in the construction, maintenance and decommissioning phases of the building (including resource mining and building materials production)
2) A National Environmental Database which comprises LCA data for a wide variety of building materials and building products. The intention is that all suppliers of building products submit validated LCA data for inclusion in this database. Where no producer-specific data are available, also more generic data sets are included, either supplied by industry sector organizations or derived from the ecoinvent LCA database [2].
3) A collection of harmonized calculation tools that may be used by building designers to evaluate the MPG score of their building design. One example of such a building performance tool is the GPR Building software developed by W/E Consultants [3].

A couple of remarks about the MPG method:

1) The MPG method is based on a certain variant of the widely used CML method for environmental impact assessment. However, in order to facilitate easy interpretation of calculation results the different impact scores are aggregated into one single impact score (MPG score). This weighing method is based on impact mitigation costs for the discerned environmental impact categories (e.g cost of wind turbines to mitigate climate change impact). The set

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of weighing factors can be found in [1].

2) Although calculation of the MPG score is obligatory for all new residential and office buildings, no specific limit value has been established yet in the legislation. This may change next year.
3) The operational energy consumption of the building is exempted from the MPG assessment. The reason is that this operational energy demand is already covered by the EPG calculation method and limit value, while the MPG is aimed at reducing the environmental impact of the materials in the building.

2.3 Conflicting results for PV systems in MPG and EPG

Clearly the installation of a PV system on a building will have implications for both the EPG and MPG scores. The energy produced by the PV system reduces the t energy demand of the building and thus improves the EPG score. On the other hand adding PV panels to the building will require extra materials and thus cause extra environmental impacts from the PV components production. This results in a higher (less good) MPG score. The presentation of two different indicators gives rise to confusion among building designers and it even raises doubts about the environmental benefits of PV installations. This confusion is surely not beneficial for the market acceptance of solar PV as part of net-zero energy building concepts.

We will exemplify the described effects for a specific case study and point the way forward to an integrated environmental impact indicator which combines energy and material impacts and thus resolves the issue of conflicting indicators.

3 CASE STUDY – HOUSE WITH 3 KWP PV

We consider a semi-detached house with a usable floor area of 150 m^2. The house fairly well insulated (R_c=5 W/ K.m^2 , U_{window}=1.6 K.m^2/W) and it is heated with a hybrid installation comprising an electrical heat pump and a gas boiler for peak loads. In this configuration it conforms to the EPC=0.6 obligation and it has a total yearly energy consumption of 7440 kWh/yr (=50 kWh/m^2/yr), excluding household appliances. The energy-related CO2-emission from the building is 2600 kg/yr, if no PV is installed.

We consider 4 variants of this house in our analysis of environmental impacts:

- no PV
- with 3 kWp crystalline silicon panels
- with 3 kWp CdTe panels
- with 3 kWp a-Si solar cell foil

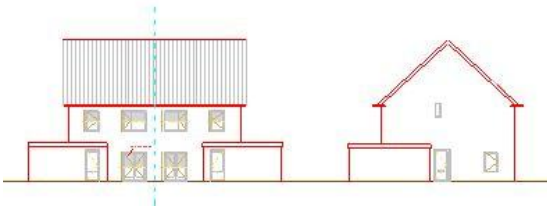

Figure 1: Semi-detached house (i.e. 2 houses under one roof) as case study for effects of PV installation.

4. BUILDING PERFORMANCE RESULTS

4.1. EPG and EPG indicators

Figure 2 below shows the results of the EPG and MPG calculation for the building in the case study. We can observe that the energy performance score (EPG) improves (decreases) after installation of PV panels, while the materials impact score (MPG) deteriorates (increases).

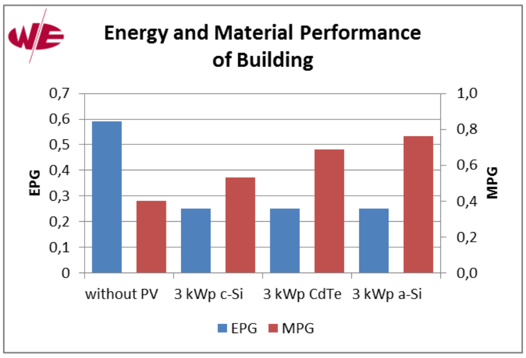

Figure 2: Materials impact score (MPG) and Energy Performance Score (EPG) of a house with different PV installations. N.B. EPG and MPG scores have different units.

Clearly this is a confusing result for building designers: is it good or bad to include PV in the building design?

We can also remark that there are clear differences in the MPG scores of the three solar technologies and the questions arises to what extent these MPG scores offer a good representation of the present-day solar technologies. We will come back to that question in section 5.

4.2 Life–cycle CO_2 emissions

A more holistic view on the building performance can already be obtained by considering the life-cycle $CO_{2,eq}$-emissions for the 4 variants of the building. For this we consider the GHG emissions from the MPG calculation method and combine this with the CO_2-emissions from operational energy consumption according to the EPG method. The result is shown in figure 3 below, with separate contributions from the materials (i.e. embodied CO_2) and from the operational energy consumption.

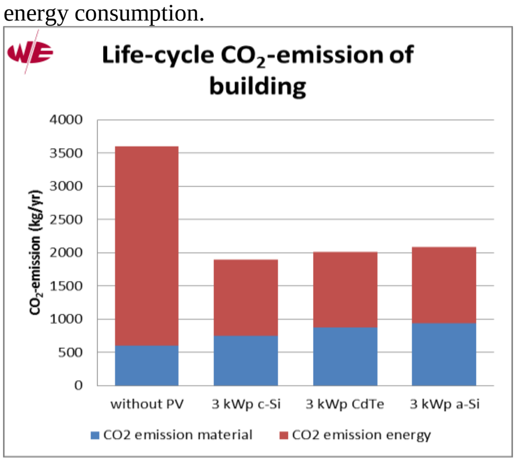

Figure 3: Life cycle $CO_{2,eq}$ emissions from building with different PV installations.

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This consideration of the building's CO_2-balance already shows very clearly that PV more or less halves the CO_2 emissions on a life-cycle basis. For a completely holistic view we should of course consider also other environmental impacts, next to greenhouse gas emissions.

4.2 Integrated Environmental Performance (IPG).

For an Integrated Performance score (IPG) of the environmental impacts of the building we have developed an assessment method which combines results from the existing EPG and MPG methods. For each energy carrier (i.e. electricity, gas) an MPG impact factor is determined which represents the aggregated environmental impact per unit energy. In this way we can determine what we call the EPG*, the (weighted) environmental impact related to the EPG energy consumption. Of course there are questions of system boundaries to be addressed before such an evaluation can be made [4].

In this way we can evaluate both materials impacts and energy impacts, according to one methodology based on the principle of life-cycle assessment. Figure 4 below gives the result of our case study on the basis of the IPG method.

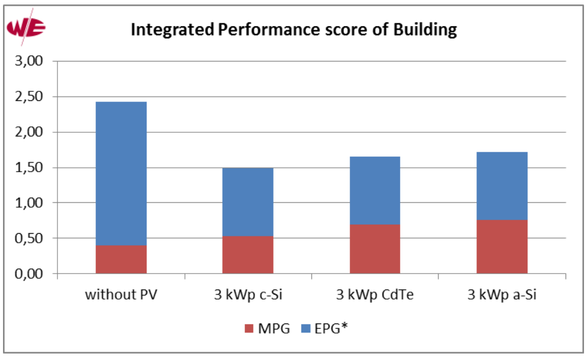

Figure 4: Integrated score of life-cycle environmental impacts combing the MPG material score and a weighted energy consumption indicator (EPG*).

Again we observe a marked improvement of the building performance score after installation of a PV system.

In the R&D project TKI KIEM [4] the development of an integrated assessment methodology for buildings is addressed, and the new indicator will be added to building performance software GPR Building so that it can be used by building designers, product suppliers and building owners to investigate the benefits of solar PV in relation to other building improvement options.

5. SOLAR TECHNOLOGIES IN THE NATIONAL ENVIRONMENTAL DATABASE

For a good comparison of different building options it is necessary that the LCA data in the National Environmental Database (NMD) of building products contains good quality LCA data on all relevant products. Presently Dutch building product suppliers and industry associations are working hard to make available validated LCA data about their products for inclusion in the NMD.

So far, the data on PV systems in the NMD were largely derived from the ecoinvent 2.2 database, and represents the technology status around 2005-2008.

Three types of PV technologies are thus available, as used in this study:

- a mix of multi- and monocrystalline silicon PV panels (60/40 market mix) with a module efficiency of 13,5%;
- Cadmium telluride modules (10% efficiency; frameless) based on data from one producer;
- Amorphous silicon on stainless steel foil (6.5% efficiency), also based on data from one producer.

For the Balance–of-System only one type of roof integration, inverter and cabling layout was considered, again based on standard technology available around 2005. Module and BOS life time was set at 25 years, except the inverter were life time is assumed to be 15 years. It should be remarked that for standard building materials, like glass, steel, aluminium, copper as well as for energy supply the product data from the Dutch NMD were used. This may explain some of the differences with solar technology LCA assessments based fully on ecoinvent or other data sets.

Already in figure 2 we could observe the added impact from the PV system on the materials performance score MPG. Also we saw the differences in the MPG score between the three solar technologies. To analyse these differences a bit further we show in figure 5 the characterized (but unweighted) impacts in the 11 environmental impact categories discerned by the national assessment method. Relative impacts are shown for the total building in 4 PV variants.

We can for example see the relatively high impacts of the building with CdTe panels on resource depletion (due to telluride scarcity) as well as differences between solar technologies with respect to climate change. Next to obvious differences in module materials between c_Si, CdTe and a-Si foil, of course also the differences in module efficiency may explain part of the impact variation. Furthermore remember that overall building life time is set at 75 years, so that impacts from the building structure are depreciated over a three times longer period than is the case for PV system components.

After weighting has been applied to obtain a single aggregated materials impact score (MPG) it appears that only climate change and human toxicity impacts have a discernible contribution to the overall score for all technologies. This seems to be more an aspect of the choosen weighting method than of the LCA data.

Figure 6 finally shows the contribution of different components of the PV system variants to the aggregated impact score for materials (MPG). The build-up of the PV system may appear a bit crude but this is also because it is primarily a building materials database, so not all separate layers and components of a solar module have been included as individual records in the database.

Although CO_2 emissions seem in line with results from other analyses it would be good to improve the quality of the LCA data for solar panels and other PV components, and to extend the product range to more module types and roof support systems.

Producers and the industry association should work together to improve the data quality of their products so that a fair outcome for PV-related products is guaranteed.

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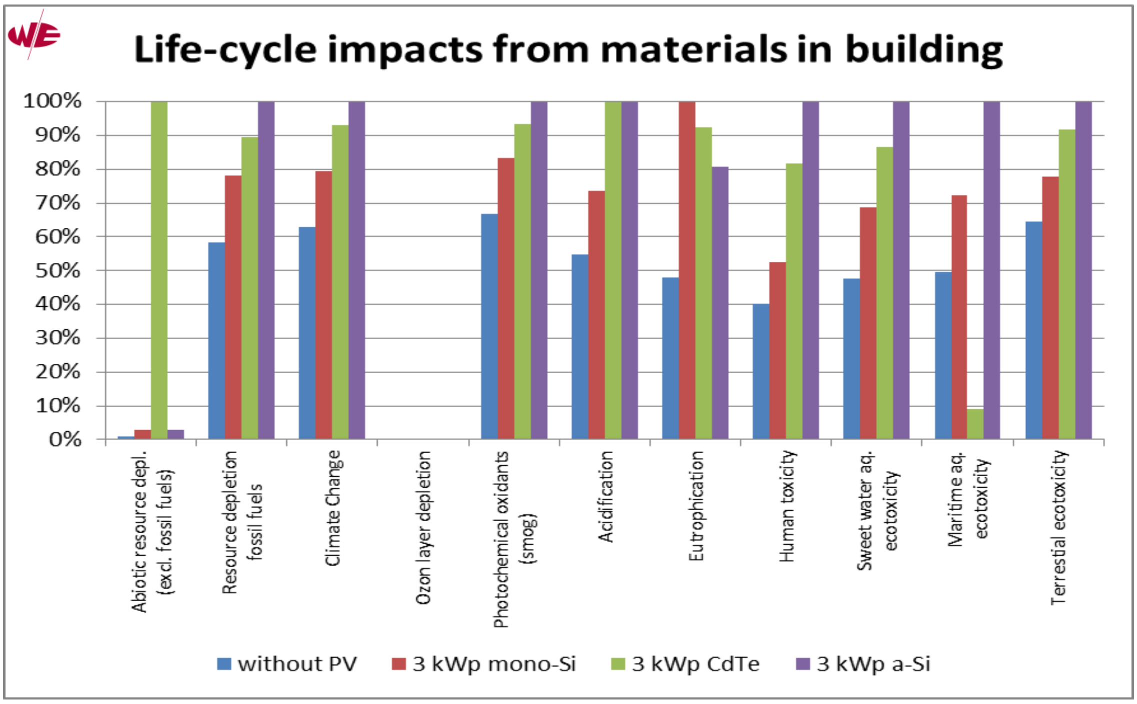

Figure 5: Characterized life cycle impacts from semidetached house with 3 kWp PV system, employing different PV technologies.

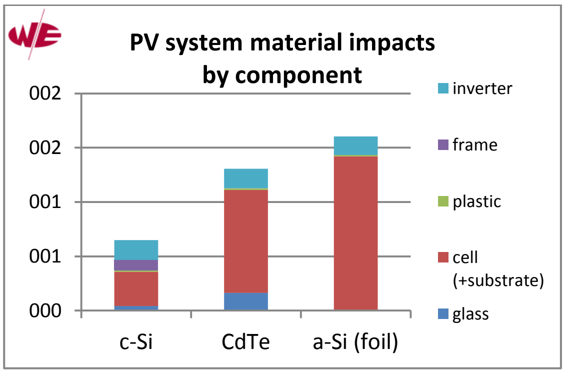

Figure 6: Contribution of PV system components to aggregated impact scores. Note that for a-Si foil the stainless steel foil has been included in the cell material.

5. CONCLUSIONS

We arrive at the following conclusions:

- Building performance assessments which consider energy performance and material environmental impacts separately can put add-on energy-saving installations like PV systems, at a serious and unfair disadvantage;
- A better alternative is to apply an integrated assessment method for energy performance and material performance together. Such methods will help to achieve optimal building designs.
- Additional representative data for different solar technologies are needed in the National Environmental Database.

6. REFERENCES

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[2] See www.ecoinvent.org
[3] See www.gprgebouw.nl
[4] See R&D project TKI KIEM at www.tki-kiem.nl

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