# TOWARDS AN OPTIMIZED DESIGN METHOD FOR PV-POWERED CONSUMER AND PROFESSIONAL APPLICATIONS – THE SYN-ENERGY PROJECT

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ABSTRACT: Within the SYN-Energy project the aim is to improve the design of solar-powered products by improving scientific understanding on basic issues that affect the performance of solar power supplies and by assessing environmental and user issues in an early stage of product design. In the paper we show how an informed product selection can be made based on analyses of energy balance, potential environmental benefits, market potential and user preferences.
Also it is shown that it is not straightforward that solar-powered devices have positive environmental effect. In general only devices where primary batteries are replaced by solar-charged secondary batteries and which have a good design can give an environmental benefit.

Keywords: Solar-powered consumer products, Product design, Environmental effect

## 1. INTRODUCTION

The use of solar cells to supply (part of) the electrical power for electrical appliances can have a number of advantages, such as:

- prolonged or completely grid-free operation for mobile products,
- reduction of battery consumption (and battery waste!);
- enhanced public awareness of solar technology as an energy option.

Also it is often claimed that solar-powered products will result in electricity savings and thus on fossil energy consumption. (But we will show that this is not always the case.)

However, all these benefits can only be realized to their full extent if the product is well designed with regard to the power supply system, the integration of the solar receiver into the product and the overall user interaction. In the past not all PV-powered products really had a well-considered design resulting in sometimes poor performance, short product lifetime or an unappealing appearance. Therefore it is interesting to take a new look at the design methods for such products.

A good design should combine among others a high reliability of the power supply, a user-friendly interface, an appealing look and feel and – last but not least – a low environmental impact. One problem in this respect may be that not all relevant information for a proper design is available, for example solar cell performances under indoor light conditions.

In the SYN-Energy project the aim is to integrate scientific knowledge on PV cell technology and system design, industrial design methods and user-appliance interactions into an improved design method for PV-powered consumer devices. Furthermore the project team aims to:

- increase the basic scientific knowledge of solar cell performance under low-light conditions;
- improve procedures for correct sizing of the PV power and storage subsystems;
- understand the a priory conditions for a product design that results in reduced environmental impacts ((Life Cycle Assessment study);
- involve prospective users in the product identification and product design process;
- stimulate sustainable user behaviour, based on the so-called “script approach”;
- develop a few prototypes of new products and test these among users.

Although our focus is primarily on consumer products, professional applications for stand-alone operation can also be considered.

The SYN-Energy project brings together three groups from the universities of Utrecht, Delft and Twente that have specific expertise in the fields outlined above. Also there is input from industrial and commercial partners interested in solar-powered devices.

Two forms of “synergy” are aimed for in the project: in the first place the “beta-gamma interaction” that results from the collaboration of natural scientists on the one hand and social scientists on the other hand. In the second place it is expected that a good design will achieve a synergy between the storage device and the solar cell and thus result in improved overall performance.

In this paper we will present some first results of the project with regard to product searching and selection, energy balance evaluation and environmental assessment, and the intended activities for investigation of user issues.

In a separate paper at this conference [1] results from measurements on weak light performance of solar cells and their spectral resonse are presented.

## 2 TOWARDS A NEW DESIGN METHOD

One fundamental aspect of our research is to develop and test a *design methodology* that involves prospective users in the design process. In the design methodology we follow a number of consecutive steps in which users and user aspects are explicitly addressed. These steps are:

1. Generation of product ideas
2. Assessing product ideas
3. Selecting a product to be actually developed
4. Detailed design of a prototype
5. Making a prototype
6. Testing the prototype
7. Final design
8. Making the final product

Ideally, one should involve representatives of prospective users in all of these steps. However, given the budget restrictions of the project we followed a pragmatic approach in the first three steps by employing the so-called "I-methodology", in which we as designers considered ourselves as users. In this process we posed ourselves questions for each product like:

- What is the advantage to the user of using a PV energy supply over another energy supply?
- Do the users have a problem with an existing product that PV could help solve?
- Could the device be designed in such a way that it stimulates the user towards more energy awareness, possibly also in connection with other products used?

In later stages, especially in steps 4 and 6, other potential users (besides ourselves) will be involved in order to survey user preferences for a specific target product and to test prototypes (cf. section 4 below).

Next we will explain how the product searching and selection process was conducted in practice.

## 3 SELECTION OF VIABLE SOLAR PRODUCTS

### 3.1 General approach

The project team started with the process of selecting a solar product which would be interesting to test the design method, along the lines described above, and subsequently to develop the selected idea into a prototype.

To begin with we prepared a "long-list" of candidate products which might be suitable for solar power supply. This was done by looking at specific areas of human activities and categories of products. Subsequently the resulting 70 candidate products from the long-list were roughly evaluated with respect to:

- Energy balance (i.e. is a significant solar fraction feasible?);
- environmental impacts;
- added value for user (of the "solar power" aspect);
- market potential.

This evaluation resulted in a "short"-list of 21 candidate products, with a good score on most of the criteria mentioned above (Table I). From this short-list eventually one product was selected to be developed into a prototype, while developing and testing our design method.

We will discuss the method and results for the energy balance and environmental evaluations in some more detail now.

### 3.2 Energy balance

An evaluation of the potential solar fraction in the overall energy supply was evaluated on the basis of:

- energy consumption of the device, both for peak and stand-by operation and for different use patterns (modest/heavy use)
- available area for solar cells;
- irradiation for summer, winter and intermediate season (outdoors only)

**Table I**: Shortlist of potential solar-powered products

| |
|---|
| mobile phone |
| notebook personal computer |
| Personal Digital Assistant (PDA) |
| peripheral electronics (i.e. mouse, keyboard) |
| iPod (hard-disk mp3-player) |
| mp3-player (solid state) |
| digital photo camera |
| digital video camera |
| portable DVD-player |
| GameBoy (mobile gaming devices) |
| mobile GPS |
| satellite phone |
| LED-torch |
| bicycle lamp |
| body scale + body fat meter |
| insect exterminator high voltage |
| fire alarm and home security |
| heartbeat monitor |
| blood glucose monitor |
| Cooling box |
| PV chargers (incl. PV-clothing) |

It proved difficult to find data for the energy consumption of devices, in many cases we had to estimate this on the basis of the battery consumption indicated by the manufacturer. Also the consumption is of course very much dependent on the use pattern. For some devices the heavy user was estimated to require up to 30 times more energy than the average.

Available solar energy was derived from the available cell area for each device (in its present design) and the outdoor irradiation. Of course many portable devices will be used indoors as well, but the problem is that indoor irradiation levels can vary by 2-3 orders of magnitude depending on outdoor light levels and distance from a window. Therefore the solar fraction achievable under outdoor conditions was used as a first screening to determine whether solar power supply for a device was feasible at all.

As an example, Table II shows the result of this approach for four products.

**Table II**: Solar fraction for four products at low and high demand (mWh/day). A value larger than 1 implies a surplus of solar energy.

| | | | Solar fraction | |
|---|---|---|---|---|
| device | demand | mWh/d | summer | winter |
| mobile | E lo | 500 | >1 | 0.55 |
| phone | E hi | 1300 | 0.9 | 0.2 |
| PDA | E lo | 500 | >1 | >1 |
| | E hi | 1500 | 1 | 0.3 |
| laptop | E lo | 4000 | >1 | 0.6 |
| | E hi | 8000 | >1 | 0.3 |
| iPod | E lo | 300 | >1 | 0.9 |
| | E hi | 700 | >1 | 0.4 |

Not surprisingly, we observed that the uncertainty in energy consumption data combined with the possible variations in use intensity and irradiation resulted in large variations in the expected solar fraction. Still the evaluation proved useful to identify at least those applications were solar power would have no chance of success at all.

### 3.3 Environmental assessment

Similarly as with the energy balance we made a first-order assessment of the environmental cost/benefits of solar power supply for the various devices. In the first place we will show a simple energy pay-back evaluation which indicates whether an energy saving potential exists. As energy-related impacts are often a major factor in the environmental profile of product this is already a good indicator of the results from a full LCA. If we want to achieve an environmental benefit the energy pay-back time should be well below the product's expected lifetime, which for most consumer products is 3-5 years (for professional products this may be longer).

For our analysis we start with the following observations:

1) The energy input for producing an (encapsulated) solar cell is in the order of 17 (thin film) – 36 (mono-Si) $MJ_{prim}$ per Wp[1]. This results in an **energy pay-back time (EPBT) of 1.5-2.5 years** for the solar cells without BOS, in a **grid-connected system** under **1700 kWh/m2/yr irradiation [2,6].**
2) The irradiation received by the solar cells on a (portable) device will always be considerably lower than that received by a fixed solar panel standing outside, this incident **irradiation** can easily be a **factor of 10 lower.**
3) Three major options can be discerned for the energy supply which is displaced by the solar energy:
    a) primary (=non-rechargeable) batteries
    b) secondary (=rechargeable) batteries;
    c) AC-grid.
4) The energy input for producing AA-type primary batteries is 0.15–0.21 $MJ_{prim}$ per Wh capacity, this is almost 200 times higher than the energy storage capacity of the battery [3].

Other assumptions are that a secondary battery has a 70% cycle efficiency, chargers/power supplies have an AC-to-DC conversion efficiency of 70% and a zero-load loss of 1 W [5] and for each battery recharging session we assume 4 hours of zero load (or trickle charge) operation.

With these assumptions we obtain the energy pack-back times shown in figure 1 for the case that the solar cell(s) replace primary or secondary batteries as a power source.

We can see that only replacement of primary batteries gives an EPBT below 3 years, even under these rather optimistic irradiation assumptions (170 kWh/$m^2$/yr). If the irradiation is lower (20 kWh/$m^2$/yr), e.g because the product is used indoors for some of the time, then EPBT values of 6 to 100 years are found.

In the case of direct grid-supply (i.e. not via a secondary battery) the situation is a bit more complex. If we assume that the zero–load losses will occur for 24 h/day, then their relative effect depends on the total (DC-) power consumption by the device under consideration.

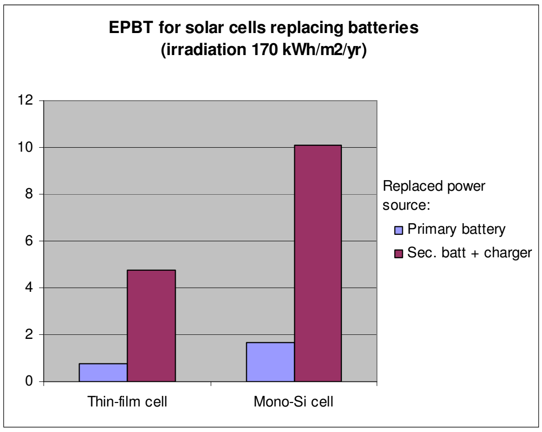

**Figure 1**: The Energy Pay-Back Time (in years) of solar cells as replacement for either primary batteries or grid-charged secondary batteries.

For the power supply itself we may assume the same specifications as for the battery charger (70% conversion efficiency, 1Wh/h zero-load loss).

Figure 2 shows the EPBT for replacement of direct grid-supply by a thin-film solar cell in relation to the device consumption and the irradiation.

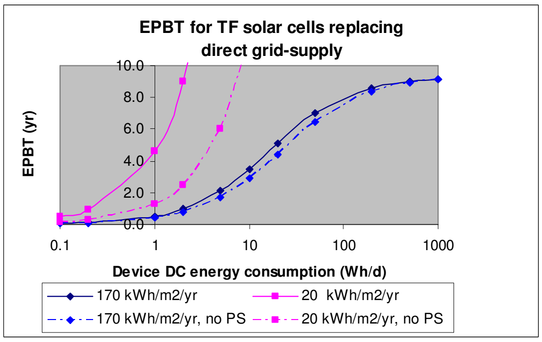

**Figure 2**: The Energy Pay-Back Time (in years) of solar cells as replacement for direct grid-supply, in relation to the energy consumption of the device and the received irradiation. Also the effect of avoiding the production of a power supply is shown ("no PS").

We can conclude from this figure that only for devices with relatively low energy consumption and/or a high irradiation an acceptable EPBT below 3-5 year is achieved. If the solar-powered device no longer needs an additional power supply (for battery charging), this could give an extra energy savings of roughly 10 $MJ_{prim}$, and thus tip the balance in favour of solar-powered devices (see fig.2). For the case of replacing grid-charged secondary batteries the effect of omitting a charger would be roughly similar, i.e. especially beneficial for low-power devices.

Apart from energy savings we should of course also consider other potential environmental benefits to be gained from solar powering of products. But we should remember that a solar-powered device will in most cases need a rechargeable battery too. So the only foreseeable benefits would be the reduction of *primary* battery waste and the avoided material consumption for batteries and – possibly – grid chargers or power supplies.

Summarizing we can conclude that there may be environmental benefits from solar-powering certain

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[1] 1 MJ of primary energy ($MJ_{prim}$) is equivalent to about 0.1 kWh of electrical energy, assuming an average electricity generating efficiency of 0.35.

devices, but in view of the relatively low irradiation and the short life-times of typical consumer products, these benefits are not easy to achieve if the considered devices now employ grid-charged secondary batteries or direct grid-supply. Only replacement of primary batteries has a good chance of realizing environmental benefits.

This shows once more that a good product selection *and* a good design is a prerequisite for obtaining a product that potentially has environmental benefits.

### 3.4 Final product selection

From the short-list we finally selected one single product for further development. Based on a mix of scientific results, rough estimates and pragmatic considerations we came to conclusion that the *cordless computer mouse* would be a good pilot-product.

Among the advantages of this product are that good functioning examples are not on the market yet, that it has a rather low energy consumption and finally that existing cordless mice use primary batteries so there can be an environmental benefit. A design challenge for the solar mouse, on the other hand, is that it has relatively little space for integration of solar cells and that it is only used indoors.

## 4 ASSESSING USER ISSUES

After completion of the product selection process we will start to involve actual users in the research. In the product design phase we will involve users in two ways, notably:

1. By carrying out 15-20 so-called contextual interviews, i.e. interviewing users in a situation in which they are actually working with a computer mouse. By both observing and interviewing them we obtained valuable information on relevant design aspects to make a PV mouse attractive to various users.
2. After we have made a design on paper of the PV mouse, using the information obtained from the interviews, we will organise an interactive session with designers as well as users to go through details of the design to ensure that it will satisfy user requirements. This will be the next step in the project.

## 5 ASSESSING MARKET ASPECTS

In our design process, we also assess the market aspects of the device we intend to prototype. In this assessment, we will evaluate the market in a dynamic fashion, looking at the product proper as well as the PV concept we use.

Of course, the impact of the device would be largest if it could find a mass market. This, however, does not imply that a product that seems to be interesting for a market niche only would not be interesting. In market dynamics, a common process for new mass products is that they initially only attract a group of so-called ‘lead users’, then the ‘followers’ and only after a while the mass market. In our project we try to asses how such a step-like process might develop in connection with the product we develop.

Concerning the possible wider impact of the PV concept we will assess its so-called ‘innovation cascade potential’. A very common pattern in innovation processes is that usually successful innovations do not just happen ‘all at once’ but that they result from a sequence of innovations that follow each other, borrowing bits and pieces from a range of initially separate innovations – the ‘innovation cascade’. In our project we will seek to design the PV-products such that they might stimulate users as well as designers to consider using the PV concept in other devices with comparable problematic or attractive aspects. If, for instance, the user experiences that a PV mouse is attractive compared to a battery powered mouse a demand will surface for other devices using the PV concept which could thus fuel an innovation cascade.

## 6 CONCLUSIONS

Within the SYN-Energy project we aim to improve the design of solar-powered products by improving scientific understanding on basic issues that affect the performance of solar power supplies and by assessing environmental and user issues in an early stage of product design. In this paper we have shown how we came to an informed product selection. Contextual interviews with users rendered valuable information to take into consideration in the detailed design.

Also it was shown that it is not straightforward that solar-powered devices have positive environmental effect. In general only devices where primary batteries are replaced by a solar-charged secondary battery and which have a good design can give an environmental benefit.

## 7 ACKNOWLEDGEMENTS

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