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A COMPARISON OF DESIGN FEATURES OF 80 PV-POWERED PRODUCTS

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ABSTRACT: In this paper 80 commercially available PV products have been analysed. The data set comprises 46 low power PV products in the range of 0 to 17 Wp and 34 PV products with a power of 17 Wp up to 27 kWp.
The goal of our study is to investigate and evaluate features of PV products that are available on the market now and to present features that are important for manufacturers, industrial designers and users. Finally this survey is meant to identify topics relevant for research on products with integrated PV systems. In our study we analysed (1) the energy technologies applied in this set of products, (2) financial aspects and (3) several human factors. The data have been collected with a questionnaire by about 100 master students. Various features of these PV products were analysed and compared such as PV technology of the products, battery type and capacity, operational voltage, costs and number of simultaneous users. Because of the limited number of PV products analysed we cannot have a spherical picture of PV products' design features. However through this study, valuable information about several features of products has been collected.
Keywords: Batteries, design, photovoltaic, PV market, PV system

1 INTRODUCTION

In recent years, many companies have launched PV products. PV products are products with integrated or added PV systems(cells, electronics, storage like batteries). In figure 1 scheme of four PV systems are shown; 1) autonomous PV system with battery, 2) chargeable system with battery, 3) autonomous PV system without battery and 4) autonomous hybrid system with battery. The need for alternative sources of energy seems to result in a trend. Evidence of this trend is the variety of PV products that anyone can find on the internet. On one hand, more companies have started developing products with integrated photovoltaic(PIPV products) as environmentally-friendlier products (Durlinger, Reinders, Toxopeus, 2010-2011) while on the other hand these products are more commercialized than they were in the past, as media promote alternative sources of energy and eco-friendlier products, like PV products.

This paper is the first framework in my PhD project at TU Delft on PV products.

Type of PV products analysed in this survey are: solar vehicles(cars, boats, aircrafts), lighting, kitchen appliances, entertainment appliances, watches, calculators, chargers and toys. The categories that come out form the analysis of these products are: 1) indoor/outdoor PIPV, 2)low/high power products, 3) autonomous/chargeable, 4) with/without batteries. PV cell technologies used by products are: a-Si cells, m-Si, x-Si, organic PV cells and GaAs cells. Furthermore, battery technology and capacity have been analysed. Battery technologies used are: lead acid batteries, Li-ion, Li-poly and NiMH.

Several researchers analysed products integrated photovoltaic (PIPV) and offer designers new opportunities and techniques to work with. (Mueller et al. 2009), (Reinders et al. 2008), (Geelen et al. 2008), (Randall, 2005) and (Reich, 2010).

After studying the above literature, we realized that there is no paper in which the features of PV products available on the market yet are analysed extensively. With our survey, researchers, designers and manufacturers can find out what the features of PIPV products are and which combination of features is more efficient, useful and/or energy saving.

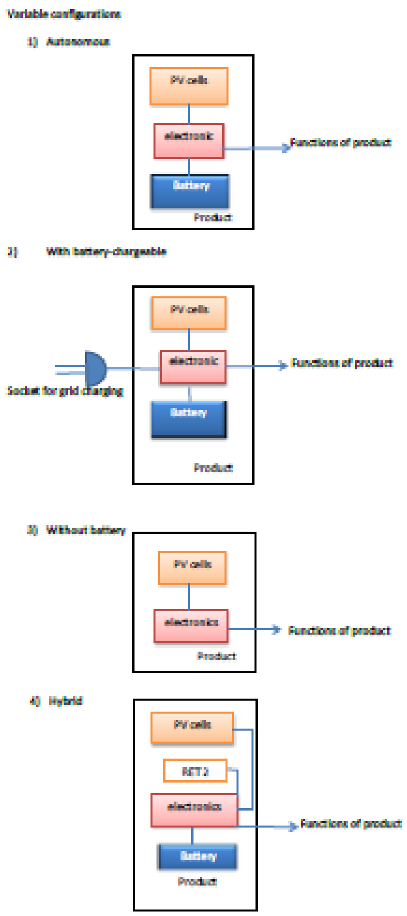

Figure 1: Configurations of PV products 1) autonomous PV system with batteries, 2)chargeable-with battery, 3) autonomous without battery and 4)autonomous hybrid-

with battery PV system.

2 PV PRODUCT CATEGORIES EVALUATED

In this section the PV product categories evaluated are presented and information about some product categories are given. Methods and data are also explained.

2.1 Method and data

To be able to learn from existing experiences and to support future designs of PV products we have evaluated the features of existing PV products for indoor/outdoor use. The study is divided into two sets: Set 1 consists of low power PV products in the power range from 0 to 17Wp and Set 2 consists of high power PV products in the range of 17Wp to 27KWp. Sets of products are divided in this way, because of a gap in PV power of the products between 17 and 28Wp. Data have been collected with a questionnaire by master students that participated in the course Smart Energy Products at TU Delft in the year 2010 and 2011.

The share of PV products analysed, is only determined by author's selection of products, not by the real availability of these products on the market, because this kind of information was difficult to be found via internet. A picture of a PV product from internet was given to each student and information about the design features of the product were asked to be found. In table I the questionnaire that students asked to fill for each PV product is shown.

The questionnaire consists of three sets of questions(general, energy features and user specifications). First concerned questions like product name, year of production, nationality and name of manufacturer, functions of the product and dimensions. The second set was about the energy system in product. In this set questions concerned irradiance conditions, connection of the product to the grid, battery technology and capacity, operational voltage of energy system, PV technology and power. The third set concerned the user with questions about the number of simultaneous users, duration and location of use and cost of product.

Table I: Questionnaire of PV products' design features.

Student name
Student number
Product
Product name
Product category(f.i. consumer product, vehicle etc)
Year of production
Manufacturer
Nationality of manufacturer
Product function 1(f.i. lighting, sound, transportation)
Product function 2
Product function 3
Product dimensions length(m)
Product dimensions width(m)
Product dimensions height(m)
Product weight(kg) (if available)
Energy system in product
Grid connected (yes/no)
Irradiance conditions(indoor, outdoor)
Battery technology(NIMH, NiCd, lead acid, Li-ion, Li-poly, other)
Battery capacity
Operational voltage of energy system (V) (if available)
PV technology(a-Si, x-Si, GaAs, organic, other)
PV area(m2)
PV power(Wp)
Other power electronics(f.i. engine, flywheel, etc)
Power of other electronics(W) (if available)
Estimated energy production(Wh/day)
Efficiency factor of the device (%)
User specifications
Number of simultaneous users
Average duration of use(h)
Location of use(describe)
Estimated energy consumption(Wh/day)
Cost
Retail price(Euro) (if available)
Estimated price(Euro)

2.2 Low power PV products (0 to 17Wp)

Low power PV products (set 1) that were analysed are: chargers, lightning, toys, kitchen/household appliances, entertainment devices (laptops, mobile phones, radio, speakers, etc.) and watches/ calculators.

The most apparent applications of PV in commercially available consumer products in our daily lives during the past 30 years are solar-powered calculators and solar watches.

Figure 2: Casio scientific solar calculator[13], Casio chronograph solar watch[14].

Solar chargers employ solar energy to supply electricity to devices or to charge batteries. Usually they are generally portable. Portable solar chargers are used to charge cell phones and other small electronic devices on the go. Chargers on the market today use various types of solar cells, ranging from thin film panels with 10% efficiency to monocrystalline panels which offer efficiencies up to 19%. Some examples of popular solar chargers include: Small portable models designed to charge a range of different mobile phones, cell phones, iPods or other portable audio equipment (typical power range < 5Watt). Also popular are hybrid chargers, typically used for mobile phones, often combined with a secondary means of charging, such as a kinetic charging system (example: K3 Charger-Solar and Wind Power to Go). Another type of chargers are the solar bags. Solar bags introduce a new generation of bi-functional mobile battery charger by converting everyday natural light to create a renewable power source for our gadgets.

Figure 3: iPhone charger- photon synthese project 'electree', by Vivien Muller[15], outdoor practical photovoltaic solar bag[16].

A solar lamp is a portable light fixture composed of an LED lamp, an integrated photovoltaic solar panel, and a rechargeable battery. Outdoor lamps are used for lawn and garden decorations. Indoor solar lamps are also used for general illumination. Solar lamps recharge during the day. At dusk, they turn on (usually automatically, although some of them include a switch for on, off and automatic) and remain illuminated overnight, depending on how much sunlight they receive during the day. Discharging time is generally 8 to 10 hours.

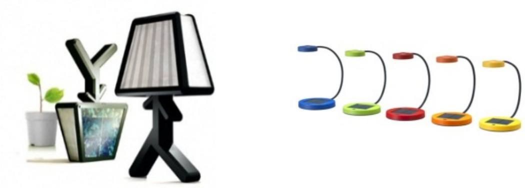

Figure 4: Spark lamp[17], IKEA SUNNAN lamp[18].

2.3 High power PV products (17Wp to 27kWp)

High power PV products (set 2) that were analysed are: solar cars, solar boats, aircrafts, outdoor lighting and solar powered fridges.

Solar vehicles are not sold as practical day-to-day transportation devices at present, but are primarily demonstration vehicles and engineering exercises for universitties or companies. However, indirectly solar-charged vehicles are widespread and some types are commercially available.

The best example of sustainable transport is solar boats. The photovoltaic (PV) panels on the canopy of the boat produce electricity which is stored in batteries that power an electric motor.

There is also military interest in unmanned aerial vehicles (UAVs). Solar power would enable these to stay aloft for months, becoming a much cheaper means of doing some tasks done today by satellites.

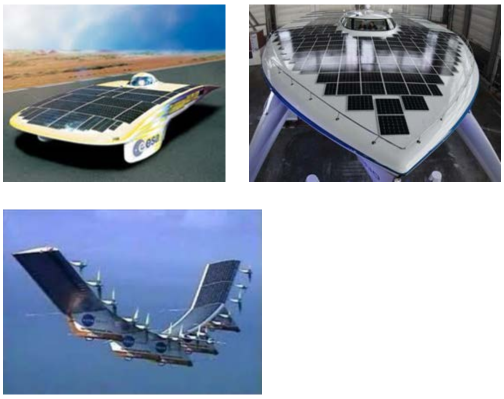

Figure 5: Solar-powered car “Nuna”, built by Dutch for the World Solar Challenge race across Australia in 2001. Nuna uses gallium-arsenide solar panels[19], Planet Solar Catamaran[20], Helios solar aircraft UAV[21].

3 RESULTS FROM QUESTIONNAIRE

In this section we will show our results collected from the questionnaire.

In figure 6 the share of PV products that were analysed is shown.

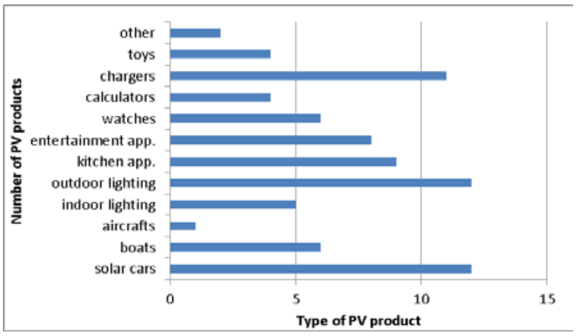

Figure 6: Type of products analysed.

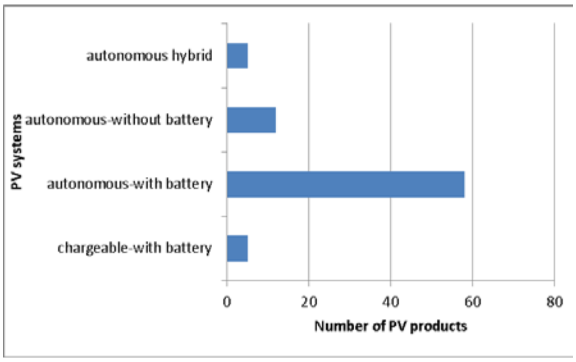

Figure 7: Number of PV products of the PV systems showed in figure 1.

In figure 7 the number of the PV products of each PV system is shown. 58 PV products out of 80 (72,5%)have an autonomous PV system with batteries, while 12 PV products(15%) have an autonomous system without batteries.

44 low power PV products(96%) use batteries for energy storage and don’t have a plug. However, a small percentage of about 4% (2 PV products) are chargeable including battery. PV products that are connected to the grid are several lamps for indoor lighting.

13 low power PV products(28%) are exclusively for indoor use, while 17 PV products(37%) can be used both indoors and outdoors and 16 (35%)for outdoor use only. 31 high power PV products (91%)in set 2 are not grid connected. Only 3 high power PV products(9%), that provide garden lighting, use the grid for charging. Furthermore all high power PV products are used outdoors.

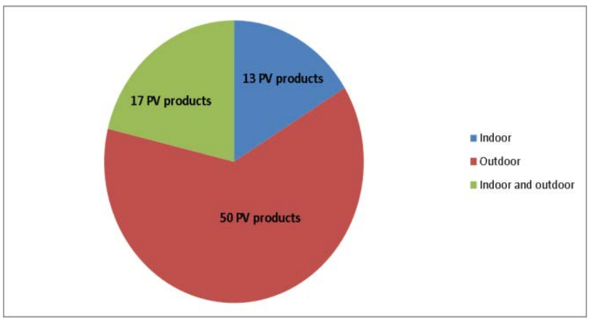

Figure 8: Irradiance conditions of PV products analysed.

3.1 PV technology

14 low power PV products (30%)use thin film solar cells(a-Si), while 11 (24%)use crystalline silicon cells. For 13 PV products(28%) no information was found about the PV technology that is used. It is also interesting that 2 PV products (4%)of this set use organic PV cells(PV toys). This is a good prospect for the future.

8 high power PV products (24%)use m-Si solar cells or a-Si with the same percentage(24%).

Thin film is the technology for photovoltaic cells that is most used for PV products because it is low cost and easily produced in many different shapes.

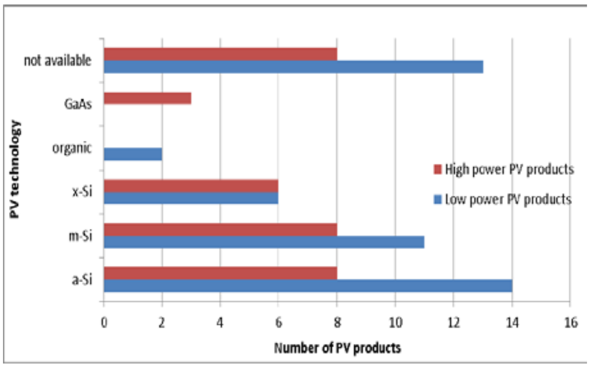

Figure 9: PV technology of PV products analysed.

In figure 10 we notice that the majority of low power PV products analysed (28%), offer power in the range of 0-0,5 Wp. The reason for this is that most products analysed were calculators, watches, toys or low power lights. However there are also 3 appliances with higher power in the range of 10-17Wp. These devices are laptops, lights and chargers.

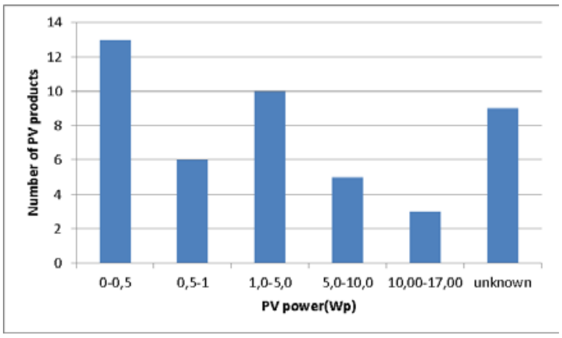

Figure 10: PV power of low power PV products analysed.

In figure 11 it is clear that 10 PV products(29%) have power in the range of 1000 to 27000 Wp. This is reasonable, while most PV products are solar cars and boats with high power.

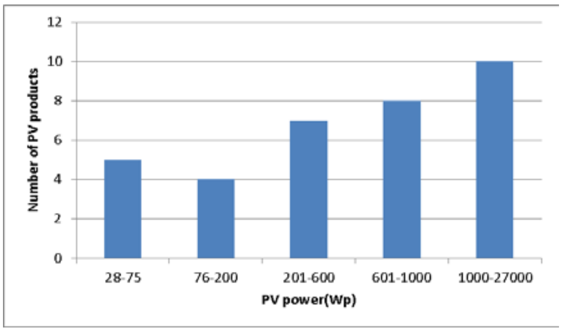

Figure 11: PV power of high power PV products analysed.

3.2 Battery technology

22 low power PV products(48%) use Li-ion batteries, while 6 (13%)use NiMH and only 2 (4%)PV products use NiCd batteries. It is really interesting that 11 PV products(24%) don't use any batteries. Furthermore, 11 PV products(24%) have battery capacity between 1-3Ah, while 9 PV products (19%)have battery capacity between 0,01-1Ah.

Li-ion batteries are the most common type, because they are available in a wide variety of shapes and sizes efficiently fitting the devices they power. Furthermore, they include components, which are environmentally safe as there is no free lithium metal.

8 high power PV products(24%) use lead acid batteries and 8 products use Li-poly, which are the most common battery type that is used for this kind of products. Furthermore, 18 high power PV products(53%) use batteries with capacity between 1 to 100Ah.

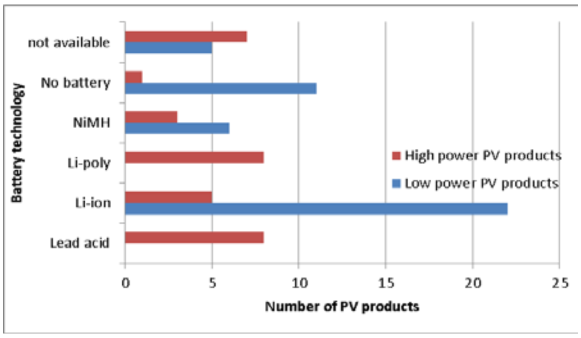

Figure 12: Battery technology of PV products analysed.

In Figure 13 the battery capacity-operational voltage graph of low power PV products is shown. Two points were been cut form the graph for better presentation of the results. The points that left out are one PV product without batteries and operational voltage to 20Ah and one PV product with unknown battery capacity to 20Ah.

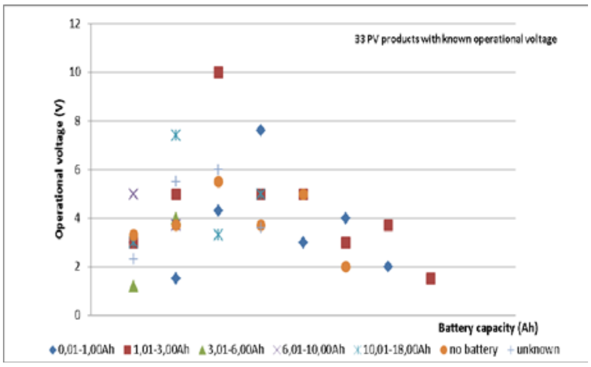

Figure 13: Battery capacity-operational voltage of low power PV products.

In figure 14 we notice that most products of set 2 have battery capacity between 1-500Ah and operational voltage between 25-200V, which is high compared to figure 13 for PV products of set 1, which have battery capacity between 0,01-3Ah and operational voltage 1-6V.

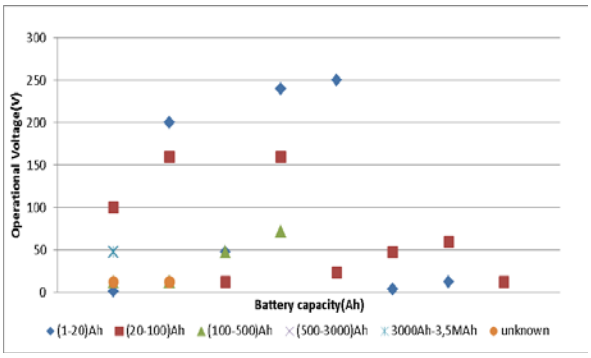

Figure 14: Battery capacity-operational voltage of high power PV products.

Costs depend on the materials, technology, design, usefulness of the device and also the demand for the specific device on the market.

Most low power PV products (20 out of 46 PV products) are sold for 10 to 100 euro. However, there are products with higher price, like the Bonsai solar charger which costs 250 euro.

On the other hand high power PV products have higher cost than low power PV products. 13 PV products have production costs from 1000 to 10000 euro, which are mainly solar vehicles.

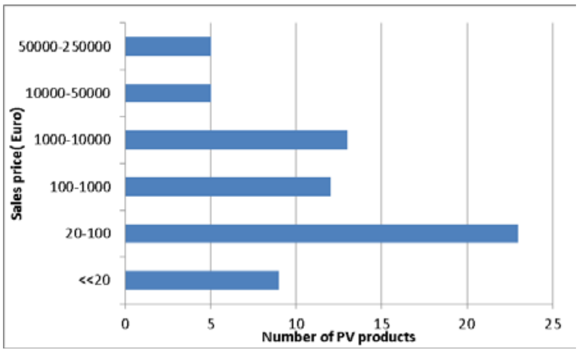

Figure 15: Sales price of PV products analysed.

It is also interesting to see the number of simultaneous users that could use each PV product. 32 out of 46 low power PV products can supply electricity to 1 user at a time, while there are also products that can supply electricity to many people at the same time, such as lights or entertainment appliances (e.g. speakers). On the other hand high power PV products like solar boats used by multiple users, while solar cars or aircrafts usually used by 1 user. However many solar cars and aircrafts have no passenger and they can only be used as models for scientific research.

In figure 16 the nationality of manufacturer is shown. 27 out of 80 PV products analyzed, are manufactured in USA. UK, Japan and China follow with a big difference from USA.

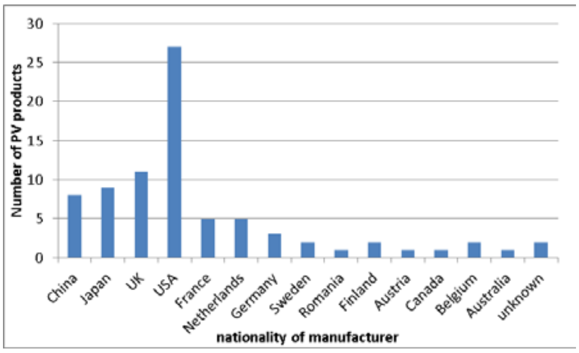

Figure 16: Nationality of manufacturer of PV products analysed.

4 CONCLUSIONS

In this paper, we collected and compared a number of PV products both for outdoor and indoor use, that are available on the market. Most of these products are mainly for outdoor use. However, it is interesting that from this survey we found out that there is also a quite high percentage of PV products that are used indoor (16%)or both indoor and outdoor(21%). Also interesting is the fact that there are devices, even in low percentages(2,5%), that use organic PV cells (PV toys), and a high percentage of devices (15%)that use no batteries. This lead us to further investigate indoor PIPV. However in this study PV products are collected arbitrarily from internet and also information founded from students through internet. The validity of the results depends on students findings and on the correctness of the information that internet and companies offer. Unfortunately we cannot conclude to a final result about the design features of PIPV products, because of the limited number of PV products that were analysed. If one wants to have a clear view of PV products' design features, a wider range of product categories should be analysed. However through this study, valuable information about several features of products is collected.

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