TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Wirtschaftswissenschaften

DRESDNER BEITRÄGE ZUR LEHRE DER BETRIEBLICHEN UMWELTÖKONOMIE

Nr. 61/2013

Günther, E. / Bergmann, A. / Scheel, R. (Hrsg.)

Parameters and Drivers for a Successful and Sustainable Performance of Photovoltaic Manufacturers

Laux, J. / Seiler, R. / Vorreyer, V. / Grundmann, D. / Kießling, H. / Pirl, P. / Rühs, S. / Schulze, C.

Herausgeber:

Lehrstuhl für
Betriebswirtschaftslehre
Betriebliche Umweltökonomie

ISSN 1611-9185

Prof. Dr. Edeltraud Günther
Dipl.-Wirtsch.-Ing. Anne Bergmann
Dipl.-Vw. Ramona Scheel
Julia Laux
Romy Seiler
Vanessa Vorreyer
David Grundmann
Hansgeorg Kießling
Patrik Pirl
Stefan Rühs
Christopher Schulze

Technische Universität Dresden
Fakultät Wirtschaftswissenschaften
Lehrstuhl für Betriebswirtschaftslehre,
insbes. Betriebliche Umweltökonomie
01062 Dresden

Telefon: (0351) 463-3 4313
Telefax: (0351) 463-3 7764

E-Mail: bu@mailbox.tu-dresden.de
www.tu-dresden.de/wwbwlbu

Als wissenschaftliches elektronisches Dokument veröffentlicht auf dem Dokumenten- und Publikationsserver Qucosa der Sächsischen Landesbibliothek – Staats- und Universitätsbibliothek Dresden (SLUB) unter:

http://nbn-resolving.de/urn:nbn:de:bsz:14-qucosa-135950

Projektarbeit eingereicht: 2013
Veröffentlicht: 2013

Foreword

Due to the emergence of shortages concerning natural resources and the globalization of production, sustainability has become vital in business decisions. Meanwhile, sustainability management has become an independent field of research in business science and in the decision processes of companies. The research and teaching of the Chair of Environmental Management and Accounting of the Technische Universität Dresden focus on the economic and environmental efficiency (e^3) in organizations. Strategies for practical use are developed based on scientific concepts. In recent years the importance of the natural environment in the economic sciences has been increasing continuously:

The research program of the Chair of Environmental Management and Accounting at the Technische Universität Dresden is reflected in the composition of the teachings. In this way the knowledge gained from the theoretical and practical research flows directly into each of the lectures. The current scientific series "Dresdner Beiträge zur Lehre der Betrieblichen Umweltökonomie" aims to support this integration process. Contents of the scientific series are predominantly theses selected from the Chair of Environmental Management and Accounting through which the reader may gain an insight into the key activities of the chair as well as a clear understanding of the work content.

The scientific series was composed by Dr. Susann Silbermann and the coordination of the present series was carried out by Kristin Stechemesser.

The present student report "Parameters and drivers for a successful and sustainable performance of photovoltaic manufacturers" was developed within a project seminar in cooperation with a solar module producer. Four perspectives were the starting point for the evaluation: the macro-environment, economic, ecological, and social aspects. Within a PESTEL analysis the political, economic, social, technological, ecological, and legal framework conditions were analyzed over the whole life cycle, consisting of the following stages: processing of raw materials, cell production, panel production, utilization period, and recycling. Concerning the macro-environment the political environment is the most decisive for business decisions, followed by the technological and the economic environment. For the economic evaluation a Life Cycle Costing integrating external costs could identify the highest impact during the cell production, followed by the processing of the raw materials. The highest environmental impact was attributed to both phases equally, whereas the social impact is highest during the processing of the raw materials.

We would like to thank Dr. Holger Hoppe for his support for the student project and hope that the results can be used by companies and industry specific working groups in the photovoltaic industry.

Edeltraud Günther

The scientific foundation of the work is based upon the results of the seminar paper by Julia Laux, Romy Seiler, Vanessa Vorreyer, David Grundmann, Hansgeorg Kießling, Patrik Pirl, Stefan Rühs and Christopher Schulze which was written at the TU Dresden, Chair of Environmental Management and Accounting. Professor/Lecturer: Prof. Dr. Edeltraud Günther / Supervisor: Dipl.-Wirtsch.-Ing. Anne Bergmann and Dipl.-Vw. Ramona Scheel. The authors are solely responsible for the content of this scientific work.

List of contents

List of tables

List of figures

List of abbreviations

ADF	Abiotic Depletion Factor
AP	Acidification Potential
ca.	circa
CML	Centrum voor Milieukunde
CO_2	Carbon dioxide
e.g.	exempli gratia
ECT	Ecological Classification Factor for Terrestrial Ecosystems
EUR	Euro
GRI	Global Reporting Initiative
GWP	Global Warming Potential
HC	Human Toxicological Classification Factor
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventories
LCIA	Life cycle impact assessment
m^2	Square meter
MG	Metallurgical Grade
NGO	Non-governmental organization
NO_2	Nitrogen dioxide
NP	Nutrification Potential
NPO	Non-profit organization
PESTEL	Political, Economic, Social, Technological, Environmental and Legislative Analyses
PM_{10}	Particulate matter
POCP	Photochemical Ozone Creation Potential
PV	Photovoltaic
SA	Social Accountability
SE	SocietasEuropaea
SO_2	Sulfur dioxide
TV	Television
UN	United Nations
USA	United States of America

1 Introduction

In 2050 renewable energy in Germany is supposed to provide 80 percent of the gross electricity consumption, with wind and photovoltaic energy as the main components.[1] Increasing environmental awareness of the public and the knowledge of limited fossil energy resources has led to a significant increase for renewable energy demand in recent years.[2] In addition, consumers demand more background information on product processes, material origin, and sustainable business practices.

The widespread interest of the public, business partners, and politicians has caused companies to include sustainability concepts into the corporate strategy. Sustainable development combines economic, environmental, and social goals of sustainability and has, therefore, an interdisciplinary character.[3] This paper takes up all three dimensions of sustainability and applies them to the solar industry and its stages of life from raw material extraction to the production of solar modules. Due to the lack of reliable data for the utilization period and the recycling process, the economic and ecologic analysis was limited to a cradle-to-gate basis.

In addition to the analysis of the sustainability areas, the macro environment and the stakeholders of the solar industry are also considered in this work. In Chapter 2 the macro environment of the solar industry is presented and the importance of individual factors and stakeholders is analyzed. Chapter 3 centers on the aspects of social aspects. In Chapters 4 and 5 an environmental and an economic assessment is conducted. The report is completed by comprehensive results which summarize the investigated aspects of sustainability.

2 Macro-environment and Stakeholder

The aim of this study is to examine the effects of the economic, ecological, social, political, and technological environments in conjunction with stakeholders of the solar industry. Thus, opportunities and risks shall be found in the solar environment which could affect the company's strategy.

For the analysis of the macro-environment we distinguish between five segments: the political (P), economic (E), social (S), technological (T) and environmental (E) segments. The analyses of the aforementioned segments are also summarized as PESTEL analysis, whereas the legal (L) segment is included into the elaborations of the political (P) segment. Furthermore, the influences of the solar industry stakeholders are included, because changes or trends in the global environment of a company become noticeable by the changing behavior of stakeholders. Moreover, the stakeholders can actively influence the general conditions of a company.[4] In the analysis of the environment, one can distinguish between two approaches: the inside-out and outside-in approach.[5] While the inside-out approach is based on company specific details, the outside-in approach regards the entire solar industry. This analysis builds on the second approach, as an industry analysis is being carried out.[6] As a basis for the

---

1 See UBA (2010), p. 48.
2 See AULICH, H. A. (2007), p. 39.
3 See WISSENSCHAFTLICHE DIENSTE DES DEUTSCHEN BUNDESTAGES (2004), p. 2.
4 See MÜLLER-STEWENS, G.; LECHNER, C. (2011), p. 189.
5 See FAHEY, L.; NARAYANAN, V.K. (1986), p. 46-49.
6 See FAHEY, L.; NARAYANAN, V.K. (1986), p. 36-57.

analysis, a systematic literature review is performed. The relevant literature is analyzed with a content analysis according to FRÜH (2007)[7] and important influential factors are identified. The basic structure of the influential factors is adopted from LOMBRISER/ ABPLANALP (2005) and WELGE/ AL-LAHAM (2005) and is adapted iteratively in the progress of the study[8]. A factor is identified as an influential factor if the factor is either outside of the company, i.e. is not influenced by the company, and thus can cause a change in strategy, relates to the solar energy industry or at least the topic of renewable energies, and is subject to trends and changes. Analyzed sources are characterized to environmental segments, indicators, trends, future outlook, and stakeholders and the quality of the information was weighted single (by mentioning), double (by mentioning and description and/or justification) or triple (by mentioning and verification or application in empirical studies).

The political factors are the most important and were weighted 18 times single, 74 double, and 13 triple. This results in a weighted sum of 205, which corresponds to a share of 26.1 % of all weighted sums (784). The political factors were followed by the technological (21.0 %) and economic factors (19.6 %). Ecological (17.3 %) and social conditions (15.8 %) were not as important as the other categories, but also not categorized as unimportant.

The three most significant impact factors are climatic conditions with a weighted sum of 70 and thus a share of 8.9 % of all weighted sums (784), incentive systems by the government (8.3 %), and the political attitude (8.0 %). All important and relevant factors are presented in Figure 1, where the factors weighted higher than four percent (written in bold type) are considered as important factors and the factors between four and two and a half percent are considered as relevant factors. Factors which are weighted under two and a half percent are identified as not so important and were not presented in Figure 1. These factors are: city structure and urbanization, economic development, limitation of other energy sources, land use, energy costs/ market price, and average income.

7 See FRÜH, W. (2007), p. 102.

8 See LOMBRISER, R.; ABPLANALP, P.A. (2005); WELGE, M.K.; AL-LAHAM, A. (2005), p. 293.

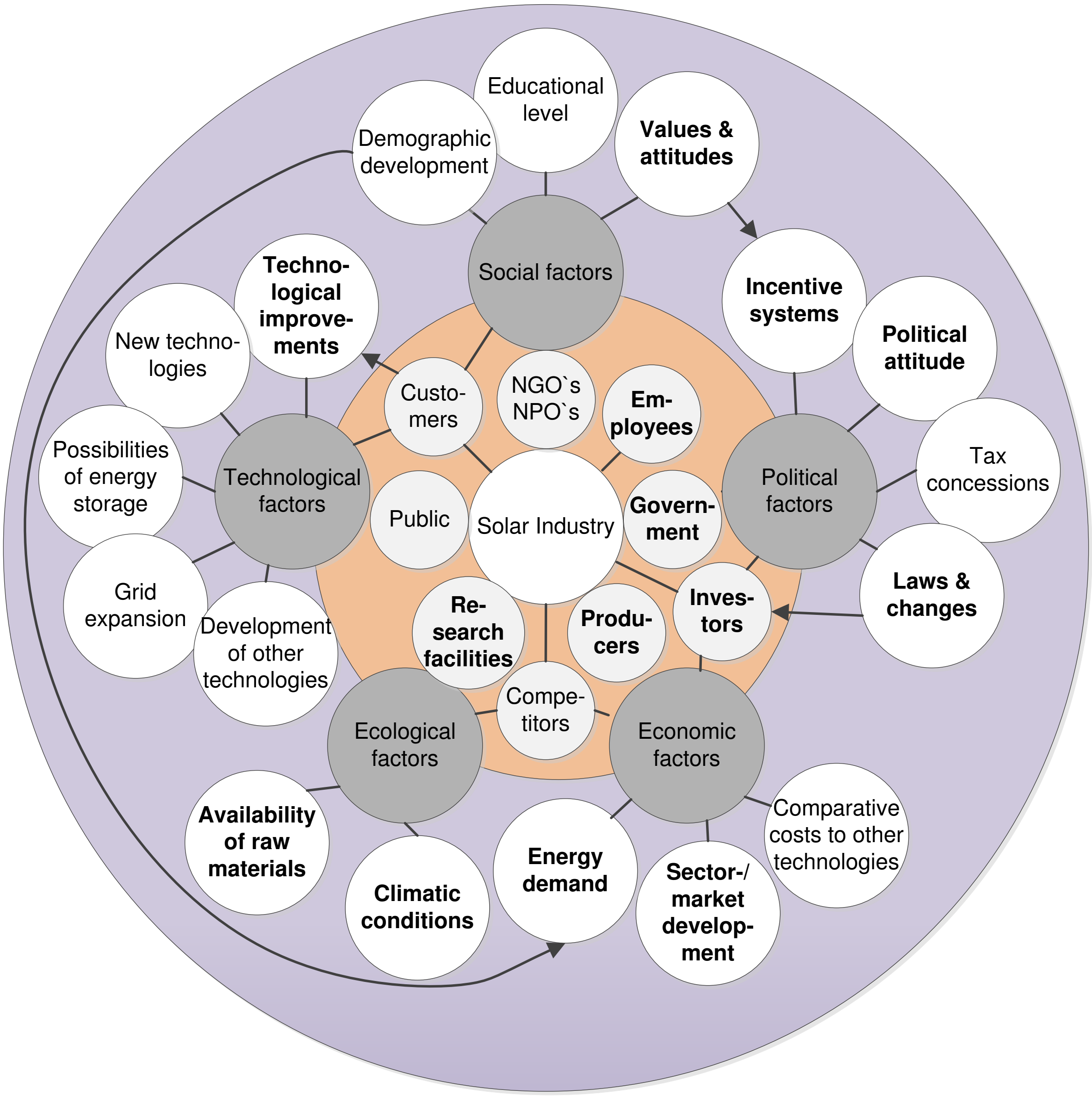


Figure 1: Macro-environment and stakeholders

(Compiled by the authors)

The qualitative analysis displays the following chances and risks, which can have a significant influence on the strategy of a solar company. The increasing demographic and economic development leads to increased energy consumption. Associated with an increased environmental awareness of consumers and the public, it leads to an increased demand for renewable energy. The public exerts more pressure on the political decision makers to create an attractive legal framework, thus allowing solar energy to better compete with conventional energy sources like oil and coal[9]. As a result of the quantitative and qualitative analysis the political conditions are assessed as very important, as markets could only develop with the help of subsidies and incentives from the government. The creation of financial incentives from the government attracts not only consumers and producers, but also investors and generally stimulates the PV industry as a whole[10]. The uncertainty to predict the public

[9] See CARVALHO, D. et al. (2011), p. 5466; HARRIS, J. (2011), pp. 50 et seq.

[10] See MAUTZ, R.; BYZIO, A.; ROSENBAUM, W. (2008), p. 94.

policies and amendments is perceived as a risk, since stable conditions are necessary to attract and retain investors on a long-term basis[11]. Investors have also great expectations for developments of new technologies and strong interest to invest in technologies which will lead to further developmental leaps[12]. Technological improvements and innovations are seen as a necessary prerequisite for future developments of the solar industry. A significant opportunity for the solar industry can be seen in the expected long-term grid parity, where network expansion and the development of energy storage systems play a crucial role[13]. Technological improvements are key factors in the competition with South-East Asia[14]. This risk can be well observed in the current development in the European solar market, as falling module prices represent a technological advance, but also intensify the competitive pressure at the same time.

The values and morals of the population represent the most important factor in the social segment. With increasing environmental awareness of consumers, sales opportunities emerge for the solar industry. The acceptance of large plants, however, is seen as a potential risk factor[15]. In general, the solar industry has the highest acceptance by the public compared to other energy generation plants[16]. On the one hand, education as a further part of the social framework is seen as an opportunity for the solar industry in order to achieve improvements in technology and train professional workers[17]. On the other hand, the lack of knowledge may pose a risk, because insufficient work force skills (e.g. errors during installation, maintenance, or inspection activities of solar modules) can create barriers in the development and use of solar energy.[18]

3 Social Aspects

For analyzing the photovoltaic industry with regard to the individual social sustainability performance of market participants, a systematic literature review is conducted. The goal is to analyze the relevant sources and to determine the most relevant stakeholders as well as social indicators on the one hand and to assess the influence of the four most relevant guidelines ISO 26000, UN Global Compact, Global Reporting Initiative and SA 8000 on the other hand. These guidelines were selected because they are the most relevant and most often used.

Up to now there has been little research done related to the social sustainability of the production process of solar modules. For the analysis of the social sustainability of the photovoltaic industry we adapted stakeholders and social aspects of other industries. The guidelines of the International Standard ISO 26000, the principles of the UN Global Compact, as well as the standards of sustainability reporting of the non-profit organization Global Reporting Initiative (GRI) and the International Standard SA 8000 assisted in defining suitable parameters.

11 See HALEY, U.C.V.; SCHULER, D. A. (2011), p. 19.
12 See CHILLINGWORTH, M. (2007), p. 2.
13 See DAIM, T.; HARELL, G.; HOGABOAM, L. (2012), p. 226 ff., DELUCCHI, M.A.; JACOBSON, M.Z. (2011), p. 1171.
14 See DÖGL, C.; HOLTBRÜGGE, D.; SCHUSTER, T. (2012), p. 196.
15 See. MAUTZ, R.; BYZIO, A.; ROSENBAUM, W. (2008), pp. 106 ff.
16 See. BOSCH, S.; PEYKE, G. (2011), p. 113.
17 See SANDÈN, B.E. 2005, p. 140.
18 See MARGOLIS, R.; ZUBOY, J. (2006), p. 6.

Table 1 presents the Social-Sustainability-Matrix which shows the results of the analysis. The table head shows the life cycle of a solar module with extraction and refining of raw materials, outsourced production, in-house production, operation, and recycling. Moreover, for each step the respective stakeholder groups are shown. The assignment of the identified stakeholders of the systematic literature review with their personal requirements to the corresponding life cycle steps is performed by the author. The first column shows the social aspects which are marked grey if they are particularly relevant for the stakeholders in the respective life cycle step. The marking takes place within linking of the interests of the stakeholders with the respective life cycle step. The table just shows the higher-ranking aspects which are based upon the main topics of the DIN ISO 26000[19]. All identified social aspects of the systematic literature review are allocated to the main topics. All subordinated aspects are described after the following table.

Table 1: Social-Sustainability-Matrix

Life Cycle Step	Raw Material Extraction/Refinery	Outsourced Production	In-House Production								Operation			Recycling	
Stakeholder / **Social Aspects**	*Contractors*	*Outsourced Producers*	*Staff*	*Management*	*Shareholders*	*Investors*	*Trade Unions*	*Society*	*International Community*	*Future Generations*	*Consumers*	*Society*	*Consumer Groups*	*Society*	*Future Generation*
Human Rights															
Health and Security at Work															
Workers' Rights															
Working Practices															
Fair Operational and Business Practices															
Influence of the Society															
Consumer Concerns															

(Compiled by the authors)

The interests of the *contractors* of the life cycle step raw material extraction / refinery as well as the *outsourced producers* and the interests of the stakeholders *staff* and *trade unions* of the in-house production apply primarily to the main social aspect of **human rights** with the following subordinated aspects: avoidance of complicity; abolishment of grievance; discrimination; groups in need to protection; civil and political rights; economic, social and cultural rights; basic principles and rights at work; and rights of the aboriginal people.

Furthermore, the subordinated aspects prevention of accidents and risks of the main social aspect **healthy and security at work** are also especially relevant for these stakeholder groups.

Moreover, the corresponding main aspect of **rights of the staff** follows with the following subordinated aspects: payment; hours of work; nondiscrimination; minorities / adolescents;

[19] See DIN ISO 26000:2010.

forced and child labor; rights of negotiations of collective and freedom of association; as well as the main topic of **practices of work** with working conditions and social protection; social dialogue; and human development and training at the workplace.

Within the in-house production the most relevant interests of the *management*, the *shareholder*, the *investors* and the *international community* correspond to the social aspect of **fair operating and business practices** with the subordinated aspects such as: anticorruption; political involvement; fair competition and trade; corporate responsibility along the life cycle; and respect of ownership.

The subordinated social aspects of the main topic **influence of the society,** such as involvement and development of the society; taxes; education and culture; establishment of workplaces; professional qualification; development of technology and access; establishment of wealth; earnings; healthy; investment of the welfare; and equity investment relate in particular to the stakeholders of the *society* and the *future generations* inside of the in-house production as well as within the operation and the recycling.

The subordinated social aspects of the **consumer concerns,** including safe products; fair practices of advertising, of sales and of contracts; protection of healthy and security of the consumer; sustainable consumption; customer service; complaint management; arbitrations; protection and privacy of consumer data; completeness and quality of product information; protection of basic services; and consumer knowledge and sensitization refer to the stakeholders of the *consumers* and the *consumer associations* within the operation.

4 Environmental assessment

For the investigation of the ecological sustainability, a life cycle assessment (LCA) is executed in which the CML method is used. It is an impact oriented, quantitative method for life cycle impact assessment (LCIA) that covers various material and energy flows within the in- and the output sides of a process.[20] The CML Method is adapted to the procedure through the concept of life cycle assessment (DIN EN ISO 14040:2006) and is structured in four consecutive steps:[21] goal definition, life cycle inventory analysis, life cycle impact assessment, and interpretation. The basis of the investigation is a polycrystalline photovoltaic module with the steps of processing of raw materials, cell production, and panel production. The DIN EN ISO 14040:2006 permits the variation of the system boundary.[22] Due to the lack of data the system boundary is set as cradle-to-gate departing from the originally cradle-to-grave-view of a life cycle assessment (LCA). A photovoltaic module with the dimensions of 1652 mm by 990 mm serves as functional unit. With the help of the study "Life Cycle Inventories of Photovoltaics"[23], the input (materials, energy, and water) and output (emissions air, emissions water and waste) flows are identified and converted to the dimensions of the functional unit. All of the identified material flows get classified in different impact categories. The following impact categories are identified on the basis of the input and output flows of the life cycle inventory analysis: *Abiotic Depletion Factor* (ADF), *Global Warming*

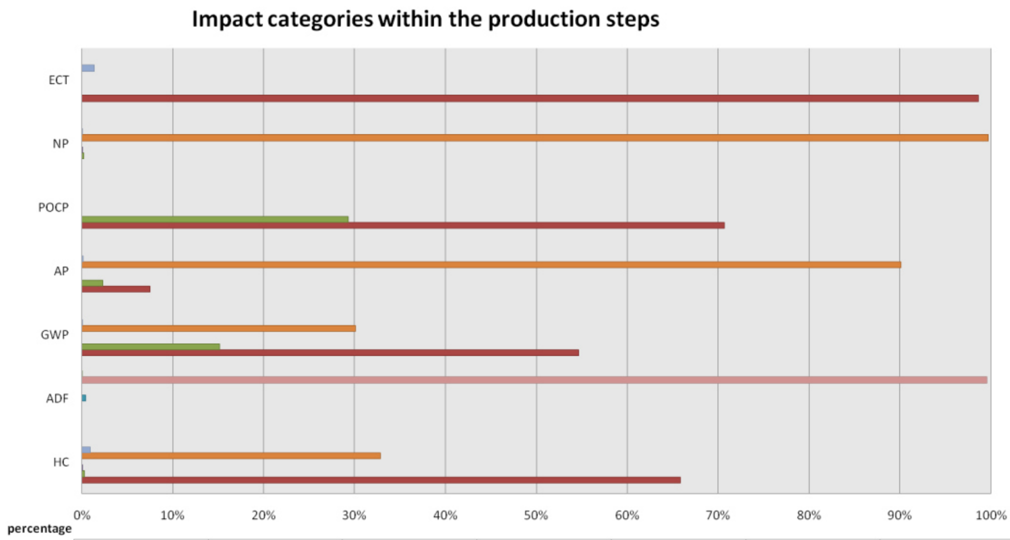
[20] See ADENSAM, H. et al (2000), p. 37-39.
[21] See ADENSAM, H. et al (2000), p. 37-38.
[22] See DIN EN ISO 14040:2006, p. 36.
[23] See JUNGBLUTH, N. et al (2012), p. 76.

Potential (GWP), *Human Toxicological Classification Factor* (HC), *Ecological Classification Factor for Terrestrial Ecosystems* (ECT), *Photochemical Ozone Creation Potential* (POCP), *Acidification Potential* (AP), and *Nutrification Potential* (NP). The various input and output flows of each impact category are applied against the appropriate impact factors according to the CMLIA table from the University of Leiden. Afterwards the different impact categories are added up with the intention to embody the amount of each production stage.

After displaying the compounds they could be allocated to single impact categories producing different extents of ecological effects. The largest extent of an environmental impact category can be identified within the Global Warming Potential (GWP) making a share of ca. 58 % in total. This amount arose through the emission of different compounds affecting the global warming and by the weighting according to the MET-method, which provides different weighting factors for the single categories. As shown in Figure2 the process of gaining metallurgical grade (MG) silicon is the main driver because of the emission of carbon dioxide during the combustion of silica sand and combustible material like charcoal or hard coal coke. Other noteworthy steps are the production of the wafer and the extraction of silicon carbide.

During the etching of the wafer surface, nitrogen oxides are emitted into the air. While extracting silicon carbide, carbon dioxide is emitted as a result of the combustion of silica sand with combustible fuels.

As impact categories with the proximate high influence on the environmental performance of solar module fabrication, the Abiotic Depletion Factor (ADF) and the Human Toxicological Classification Factor (HC) with approximately 9 % each can be identified. The treatment of the cells with metallization paste causes the high scale, especially through the usage of silver. A high extent of the HC is caused by the extraction of MG-silicon. The main driver within that process is the emission of hydrogen fluorides during the combustion. Another amount results within the wafer production through the emission of nitrogen oxides into the air while etching the surface. The categories for Acidification Potential (AP) and for Nutrification Potential (NP) are identified as less influential. The main influence of the wafer production is AP, due to its **90 % share of the emissions.** Again, emitted nitrogen oxides during the etching of the wafer surface are accountable. The same circumstances result in the impact of the NP, where the wafer production amounts to more than 99 %.



	HC	ADF	GWP	AP	POCP	NP	ECT
Module production		0,0136919%					
Treatment with metallization paste		99,5777144%					
Solar cell production	0,9524369%	0,0000003%	0,0038460%	0,1190115%		0,0115894%	1,3662113%
Wafer production	32,8724483%		30,1327362%	90,0804577%		99,7446440%	0,0000000%
Inverter		0,4085933%					
Purified silicon	0,0000846%					0,0049332%	0,0000000%
Silicon carbide production	0,2971435%		15,1819840%	2,2816978%	29,3041214%	0,2388334%	
MG-silicon production	65,8778867%		54,6814338%	7,5188330%	70,6958786%		98,6337887%
Silica sand		0,0000000%					

Figure 2: Extent of the environmental impact categories within the different production steps of solar module production *(Compiled by the authors)*

For the impact categories of Photochemical Ozone Creation Potential (POCP) and Ecological Classification Factor for Terrestrial Ecosystems (ECT) the ratio assessed is near zero. The POCP is formed for 70 % by the MG-silicon production and for 30 % by the silicon carbide-production. As drivers, the emission of carbon monoxide (MG-silicon production, silicon carbide production) and sulfur dioxide (silicon carbide production) are identified. Emissions of antimony and hydrogen fluorides during the combustion processes of MG-silicon production are reasons for the degree of the ECT.

The impacts of the single process stages on the categories can be seen in Figure 2.

In summary, the Global Warming Potential could be identified as the most influential category within the production of polycrystalline PV panels. But also the Abiotic Depletion and Human Toxicological Classification Factor were detected as important aspects. Corresponding processes are mainly found within pre-production stages.

5 Economic Assessment

The following elaborations assess material and energy costs across the entire production chain in relation to the production of 1 m² of polycrystalline solar module. The goal is to identify production processes and materials that account for large portions of internal and external costs.

The analytical framework for evaluating the internal and external costs of the PV manufacturing process comprises all relevant production steps from the sand extraction throughout the module production. Input and output flows are mainly determined by life cycle inventories (LCI) from the ecoinvent project v.2.2+ of JUNGBLUTH et al. (2012). Two of nine life cycle inventories have been specially created by surveying Saxon companies. The analysis refers to the functional unit of 1 m² solar module, consistent with the selected functional unit of the ecoinvent project.

The LCIs are evaluated by pricing the amount of each input material with its current market price according to the production location. For inputs where no world market prices could be determined, two potential suppliers were selected and the current prices were averaged to ensure a realistic price.

The external costs were mainly adopted from the work of KREWITT and SCHLOMANN (2006) and the UMWELTBUNDESAMT (2007). Considered pollutant categories are air emissions (CO_2, SO_2, NO_x), particulate matter (PM_{10}), and the external costs of energy supply. Analogue to the material costs, external costs are averaged if two or more prices for the same substance could be determined. The calculated external costs for European countries could not simply be adapted for the Asian market. Therefore a country-specific conversion which takes specific parameters from the Asian regions into account was executed. To gain proper results, the same life cycle inventories which were used to determine the internal costs were used.

The considered production chain is divided into two geographical production areas. While the posterior part of the production process and the recycling of the modules are attributed to Europe, all anterior production processes are allocated to China. The reason for this is that the largest share of production capacities for solar cell production is located in Asia, particularly in China. As the largest growing potentials for cell production facilities are anticipated in China, it is assumed that solar cells are produced in China.

Considered production processes to determine the overall material and energy costs are: quartz sand extraction, raw- and high-purity silicon production, wafer manufacturing, silicon carbide production, solar glass production, metallization paste, and solar cell and module production. The functional unit is 1 m² polycrystalline solar module. The costs of raw materials are calculated by multiplying current market prices of the input factors and their amounts needed to produce the determined amount of solar module area.

In Figure 3 the five steps for the approach to the determination of economic cost will be illustrated.

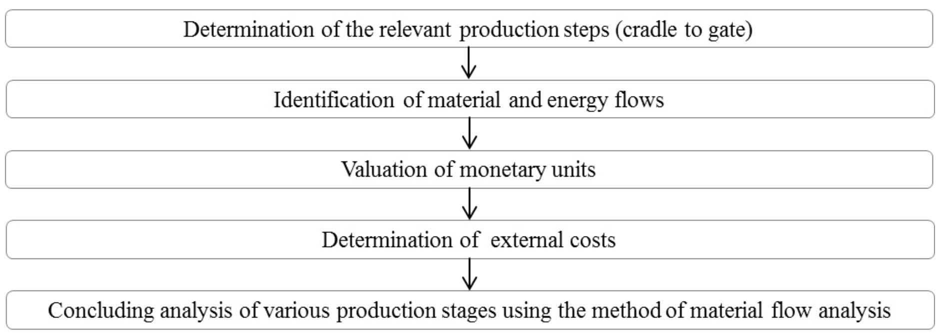
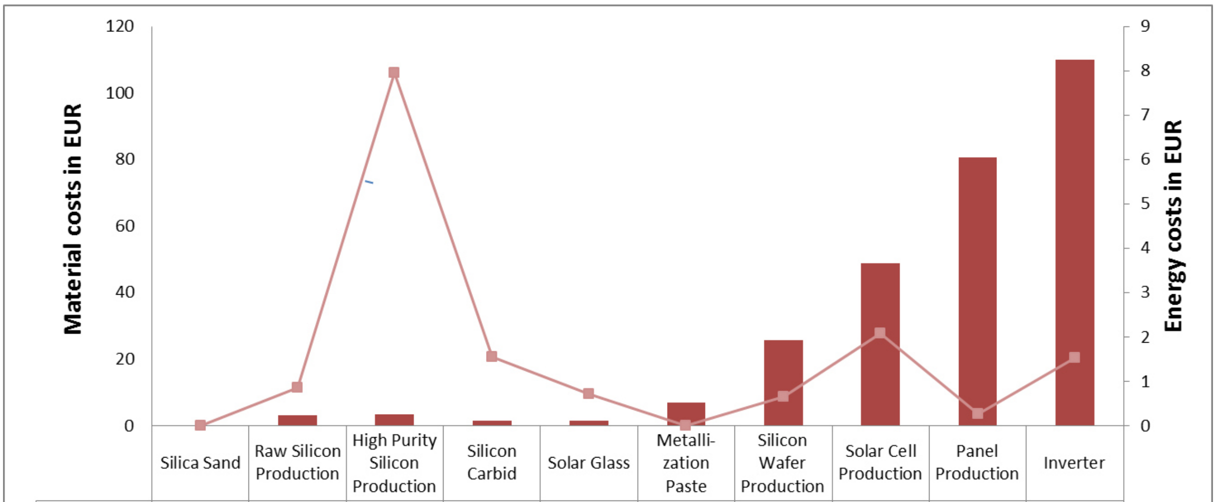


Figure 3: Approach for determination of economic cost

(Compiled by the authors)

The obtained data from the analysis shows that the largest share of material costs can be allocated to the cell- and panel production processes, whereas silicon production accounts for the largest share of energy costs (see Figure 4). 90 % of the material costs along the polycrystalline solar module production chain are connected to the steps of the wafer, cell, module, and inverter production. It bears mentioning that energy costs have hardly any effect on the total cost. Generally energy in the form of electricity is required for the production of solar cells and the inverter. The lowest energy inputs are needed for the metallization paste production and the panel fabrication. In comparison to the material costs, the energy costs are negligible. The steps of raw material extraction for the wafer production are immensely energy intensive and thus have particularly high energy costs. Then again, the lowest shares of material costs occur in the silicon purification and solar glass production. As seen in Figure 4, the most energy intensive process is the high-purity silicon production and should therefore be in the focus of the economic assessment of energy consumption.



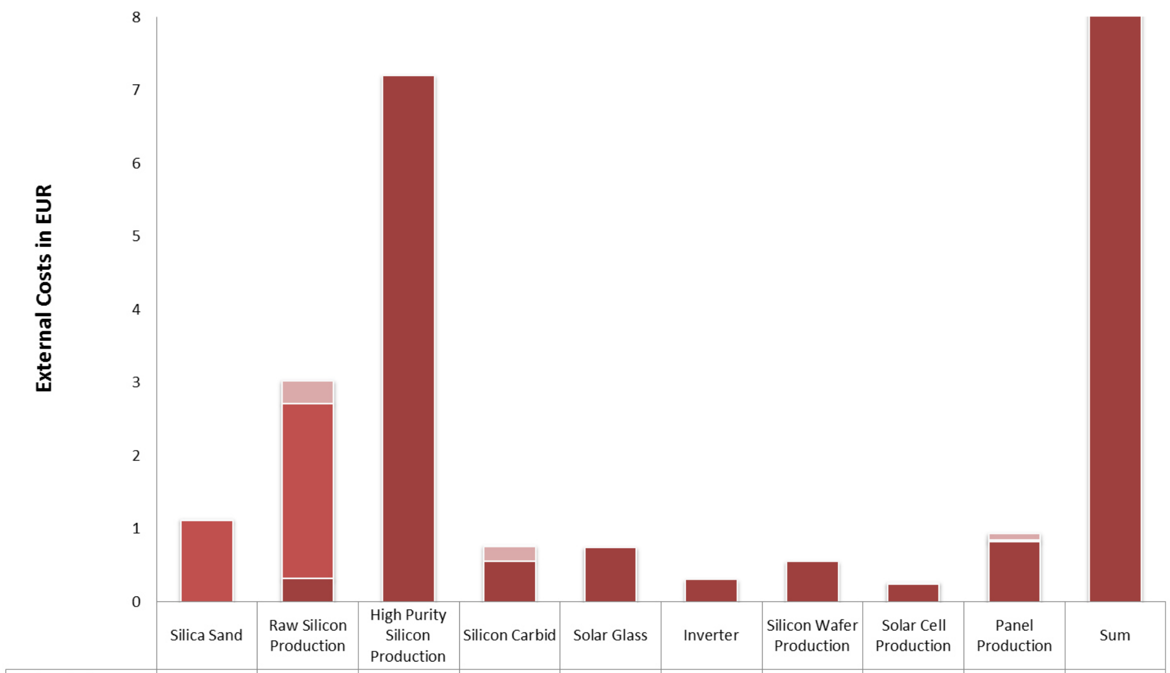
	Silica Sand	Raw Silicon Production	High Purity Silicon Production	Silicon Carbid	Solar Glass	Metalli-zation Paste	Silicon Wafer Production	Solar Cell Production	Panel Production	Inverter
Material	0	3.03	3.38	1.47	1.64	6.95	25.83	48.68	80.58	110.06
Energy	0.002	0.85	7.95	1.55	0.71	0.0005	0.65	2.08	0.27	1.54

Figure 4: Material and energy costs along the value chain for the production of 1 m² polycrystalline solar module surface (Compiled by the authors)

In addition to the internal costs, the external costs are also determined. Due to potential future environmental regulations, the consideration of external costs in internal controlling and planning of companies will be an important factor. Figure 5 shows the external costs of the production process of 1 m² solar panel.

The analysis shows that a total of 15.22 EUR of external costs per m² solar module occurs. Especially the production and processing of silicon products is responsible for a 75 % share of the economic costs. A scenario analysis revealed that a complete shift in production from China to Germany would result in a cost increase to 20 EUR per m² module.

It was determined that the overall energy input along all production stages dominates the external costs. The enormous energy input in high-purity silicon production accounts for the largest external cost block. Although electricity is one of the main input materials in the sand extraction, only low external costs are produced. The main components are costs for health damage caused by the release of fine quartz sand dust in the glassification and extraction. A similar observation can be made in the raw silicon production, where external costs are primarily caused by the release of silica sand dust. Significant external costs due to air emissions occur mainly in cell manufacturing, silicon carbide making, and the raw silicon production. The largest causers for external costs are the energy inputs followed by particulate matter emission and air emissions.



	Silica Sand	Raw Silicon Production	High Purity Silicon Production	Silicon Carbid	Solar Glass	Inverter	Silicon Wafer Production	Solar Cell Production	Panel Production	Sum
Air Emissions	0	0.31	0	0.21	0	0	0	0	0.09	0.61
Particulate Matter	1.12	2.40	0	0	0	0	0	0.02	0.02	3.56
Energy	0	0.32	7.21	0.56	0.75	0.31	0.56	0.25	0.83	10.79

Figure 5: External costs for the production of 1 m² of polycrystalline PV solar module surface (Compiled by the authors)

A summary of the internal material and energy costs, as well as the external costs, are shown in Figure 6.

The respective cost types are represented on the abscissa and the ordinate. Based on the obtained results of the material- and cost analysis, a classification according to DYCKHOFF's (1994) good-bad-neutral classification principle was performed.

Quadrant I is the sector in which the internal production costs and damage costs are the highest. An allocation in this sector is to be avoided from an economic and ecological point of view and it is therefore regarded as bad. In quadrant II, processes are located where the external costs are very high and the internal costs are low. From the perspective of producers these should be evaluated neutral as long as the damage costs are not internalized. Quadrant IV is quite similar, the costs however are interchanged. From an ecological perspective an allocation to this sector is advantageous, due to the low external costs and the high internal costs.

In quadrant III, production processes are located that cause low internal and high external costs. These can be declared good or neutral according to the subjective assessment. Considering all individual production steps, it becomes clear high-purity silicon production is seen as the greatest bad from an ecological and economic standpoint. This is caused by the high energy requirement, which causes high internal and external costs. For the cell production the use of chemicals and high commodity prices play an important role. Furthermore, the processes for silica sand and raw silicon production are regarded as ecologically bad.

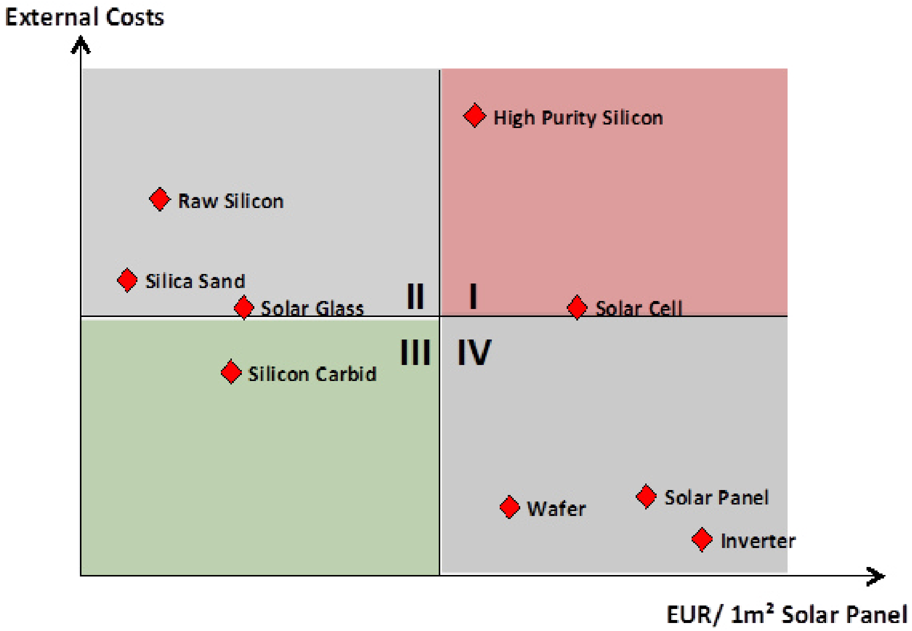


Figure 6: PV- Performance

(Compiled by the authors)

6 Comprehensive results

The evaluation of the production process of a solar module was carried out on the basis of four evaluation aspects: the macro-environment, the social aspects, the ecological profile, as well as the economic profile. This was conducted in an ABC Analysis to emphasize the importance of the impact factors on sustainability. The results are shown in Figure 7 and can be interpreted in the following way: An “A” represents a wide influence on the branch and is displayed through a large bar in the chart. “B” has a middle influence and “C” represents a minor influence displayed through a small bar. If there is no bar at a life cycle stage, it was not considered in the investigation.

The life cycle is divided into the steps *processing of raw materials*, *cell production*, *panel production*, *utilization period,* and *recycling*. The last two stages could not be regarded within the economic and environmental evaluation because of the non-availability of data.

It is conspicuous that social and environmental impacts have a wide influence on sustainability in the *processing of raw materials* as well as the economic and environmental impacts on the *cell production*. The identical environmental evaluation of the manufacturing steps *processing of raw materials* and *cell production* result from different high influences of several impact categories (especially GWP and ADF). The economic impacts of *processing of raw materials* have a middle influence and a minor influence on the *panel production*. In addition, the social impacts have a middle influence on the *cell production* and a minor influence on the *panel production*, the *utilization period,* and the *recycling* process. The impact of the macro-environment and the stakeholder are depicted in Figure 7, too. The bold printed stakeholder and parts of the macro-environment are exposed as being important. The others were identified as less important.

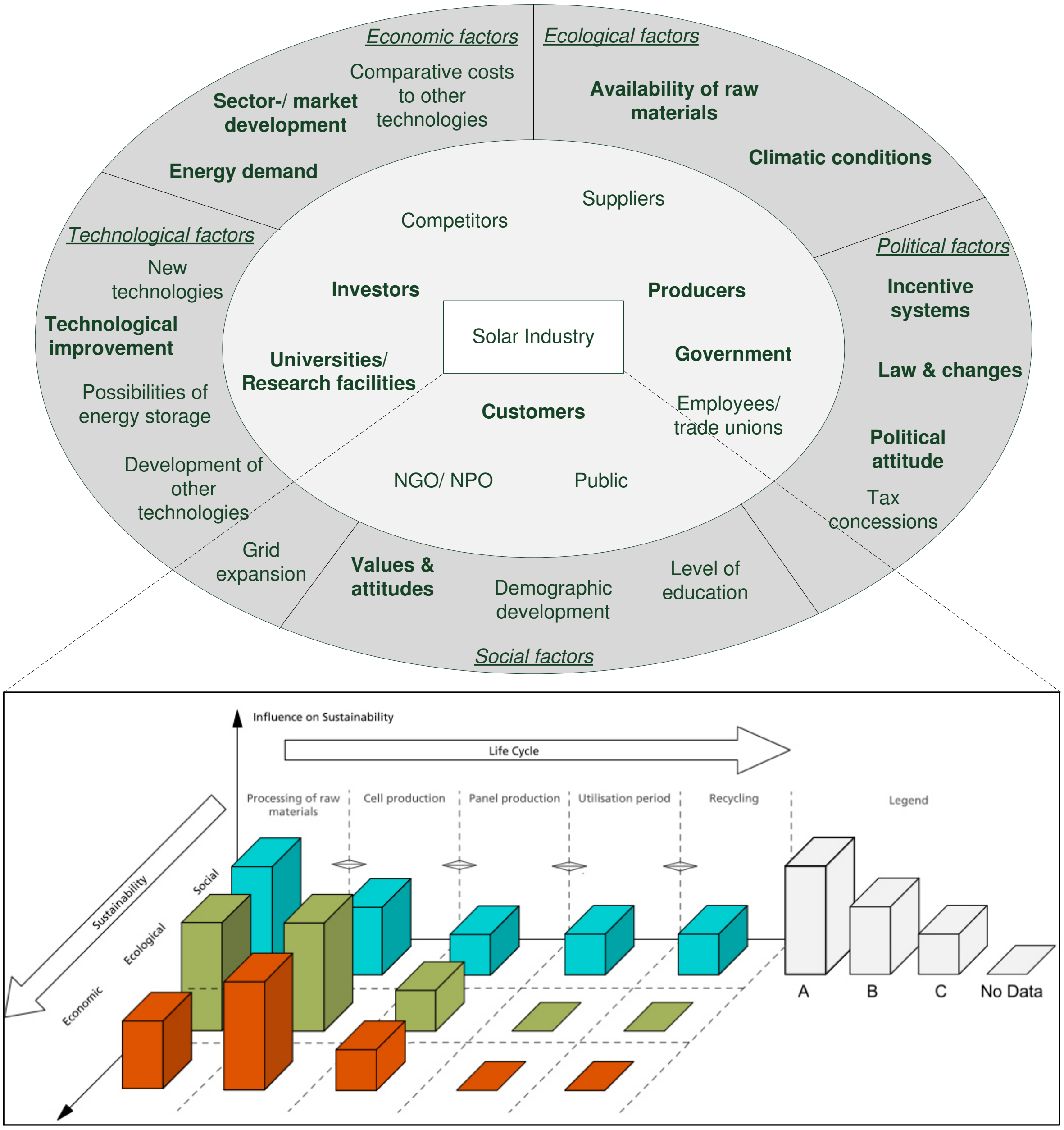


Figure 7: Comprehensive Results

Source: adapted by the authors from GÜENTHER, E.; SCHEIBE, L. (2005)

References

ADENSAM,H.; GANGLBERGER, E.; GUPFINGER, H.; WENISCH, A. (2000): „Wie viel Umwelt braucht ein Produkt?“; Studie zur Nutzbarkeit von Ökobilanzen für Prozess- und Produktvergleiche; Analyse von Methoden, Problemen und Forschungsbedarf. Wien, Oktober 2000; Pg.37-40.

AULICH, H. A. (2007): Von der Manufaktur zu Giga-Watt-Anlagen – die Solarenergie auf dem Weg zur Großindustrie. In: Produktionstechnologien für die Solarenergie. Jahrestagung des Forschung Verbundes Sonnenenergie in Kooperation mit dem Bundesverband Solarwirtschaft e.V. (BSW-Solar), 2007, Heft Themen 2007, Pg. 36-45.

BOSCH, S.; PEYKE, G. (2011): Gegenwind für die Erneuerbaren–Räumliche Neuorientierung der Wind-, Solar-und Bioenergie vor dem Hintergrund einer verringerten Akzeptanz sowie zunehmender Flächennutzungskonflikte im ländlichen Raum. In: Raumforschung und Raumordnung, 2011, Pg. 1-14.

CARVALHO, D.; WEMANS, J.; LIMA, J. u. a. (2011): Photovoltaic energy mini-generation: Future perspectives for Portugal. In: Energy Policy, 39. Jg., 2011, Heft 9, Pg. 5465-5473.

CHILLINGWORTH, M. (2007): Go green, or go under…. In: Information World Review, 2007, Heft 235, Pg. 8-9.

DAIM, T.; HARELL, G.; HOGABOAM, L. (2012): Forecasting renewable energy production in the US. In: Foresight, 14. Jg., 2012, Heft 3, Pg. 225-241.

DIN EN ISO 14040 (2006): Umweltmanagement – Ökobilanz – Grundsätze und Rahmenbedingungen (ISO 14040:2006); Deutsche und Englische Fassung EN ISO 14040:2006.

DIN ISO 26000 (2010): Leitfaden zur gesellschaftlichen Verantwortung (ISO 26000:2010).

DÖRGL, C; HOLTBRÜGGE, D.; SCHUSTER, T. (2012): Competitive advantage of German renewable energy firms in India and China: An empirical study based on Porter's diamond. In: International Journal of Emerging Markets, 7. Jg., 2012, Heft 2, Pg. 191-214.

DYCKHOFF, H. (1994): Betriebliche Produktion. Theoretische Grundlagen einer umweltorientierten Produktionswirtschaft. Berlin u. Heidelberg.

FAHEY, L., NARAYANAN, V.K. (1986): Macroenvironmental Analysis for Strategic Management, 2. Auflage, St. Paul 1986.

FRÜH, W. (2007): Inhaltsanalyse, 6. Auflage, Konstanz 2007.

GUENTHER, E.; SCHEIBE, L. (2005): The hurdles analysis as an instrument for improving environmental value chain management. In: Progress in Industrial Ecology, 2. Jg., 2005, Heft 1, S. 107-131.

HALEY, U. C. V.; SCHULER, D. A. (2011): Government Policy and Firm Strategy in the Solar Photovoltaic Industry. In: California management review, 54. Jg., 2011, Heft 1, Pg. 17-38.

JUNGBLUTH, N.; STUCKI, M.; FLURY, K.; FRISCHKNECHT, R.; BÜSSER, S. (2012): Life Cycle Inventories of Photovoltaics. Version: 2012-1. Uster April 2012.

KREWITT, W. und SCHLOMANN, B. (2006): Externe Kosten der Stromerzeugung aus erneuerbaren Energien im Vergleich zur Stromerzeugung aus fossilen Energieträgern. Stuttgart und Karlsruhe 2006.

LOMBRISER, R.; ABPLANALP, P. A. (2005): Strategisches Management/ Visionen entwickeln, Strategien umsetzen, Erfolgspotenziale aufbauen. 2005.

MARGOLIS, R.; ZUBOY, J. (2006): Nontechnical Barriers to Solar Energy Use: Review of Recent Literature 2006.

MAUTZ, R.; BYZIO, A.; ROSENBAUM, W. (2008): Auf dem Weg zur Energiewende. In: Die Entwicklung der Stromproduktion aus erneuerbaren Energien in Deutschland. Göttingen: Universitätsverlag Göttingen, 2008.

MÜLLER-STEWENS, G.; LECHNER, C. (2011): Strategisches Management/ wie strategische Initiativen zum Wandel führen; der St. Galler General-Management-Navigator. 2011.

SANDÉN, B. A. (2005): The economic and institutional rationale of PV subsidies. In: Solar Energy, 78. Jg., 2005, Heft 2, Pg. 137-146.

UMWELTBUNDESAMT (UBA) (2010): Energieziel 2050: 100 % Strom aus erneuerbaren Quellen. Dessau-Roßlau. Juli 2010.

UMWELTBUNDESAMT (UBA) (2007): Ökonomische Bewertung von Umweltschäden: Methodenkonvention zur Schätzung externer Umweltkosten. Dessau 2007.

WISSENSCHAFTLICHE DIENSTE DES DEUTSCHEN BUNDESTAGES (2004): Der Aktuelle Begriff –°Nachhaltigkeit.
Online im Internet: http://webarchiv.bundestag.de/archive/2008/0506/wissen/analysen/2004/2004_04_06.pdf; Retrieval: 05th September 2012.

Abstract

The Photovoltaic Industry is at a crossroads for change. Improving the sustainability of this complex system requires a thorough understanding of the entire life cycle of the solar module production. The product life cycle is thereby divided into the value added steps of raw material extraction, outsourced production, in-house production, operation, and recycling. Furthermore, the following report distinguishes between social, ecological, and economic sustainability.

The report offers a compacted matrix with all parts of sustainability and each life cycle stage in order to show companies of the photovoltaic industry the sensible areas. This should be a first step for improving the sustainability in the whole life cycle of a solar module.

Keywords: photovoltaic industry; sustainability; social; CML; material flow analysis; costs; macro-environment; stakeholder; LCA

In dieser Reihe sind bisher erschienen:

Nummer	***Autoren***	***Titel***
01/1996	Günther, T. / White, M. / Günther E. (Hrsg.) Schill, O.	Ökobilanzen als Controllinginstrument Download
02/1998	Günther, E. (Hrsg.) Salzmann, O.	Revisionäre Zeit- und Geschwindigkeitsbetrachtungen im Dreieck des Sustainable Development Download
I/2000	Günther, E. (Hrsg.) Schmidt, A.	Auszug aus der Diplomarbeit: Umweltmanagement und betriebswirtschaftlicher Nutzen Eine theoretischen Analyse und empirische Untersuchung am Beispiel ÖKOPROFIT München Download
03/2000	Günther, E. / Schill, O. (Hrsg.) Klauke, I.	Kommunales Umweltmanagement: Theoretische Anforderungen und Einordnung vorhandener Ansätze Download
04/2000	Günther, E. (Hrsg.) Krebs, M.	Aufgaben- und Organisationsstruktur der Umweltpolitik in der Bundesrepublik Deutschland Download
05/2000	Günther, E. / Schill, O. (Hrsg.) Sicker, B.	Umweltfreundliche Beschaffung und Abfallmanagement in öffentlichen Einrichtungen Eine Untersuchung am Landratsamt Bautzen und Klinikum Bautzen-Bischofswerda Download
	Günther, E. / Thomas, P. (Hrsg.) Wollmann, R.	Integration des Instrumentes Environment-oriented Cost Management in die Controllingprozesse von Unternehmen in Entwicklungsländern Ergebnisse der Zusammenarbeit mit dem Pilotvorhaben zur Unterstützung umweltorientierter Unternehmensführung in Entwicklungsländern (P3U) der Deutschen Gesellschaft für Technische Zusammenarbeit (GTZ) Erschienen in den Dresdner Beiträge zur Betriebswirtschaftslehre Nr. 50/01 Download

Fortsetzung:

06/2001	Günther, E. / Berger, A. (Hrsg.) Kaulich, S.	Ermittlung kritischer Erfolgsfaktoren für die Implementierung der Umweltleistungsmessung in Unternehmen, insbesondere für die Maschinenbaubranche Download
07/2001	Günther, E. / Berger, A. (Hrsg.) Scheibe, L.	Konzeption eines Umweltkennzahlensystems zur Umweltleistungsmessung für Prozesse unter Beachtung der in Unternehmen vorliegenden Rahmenbedingungen Download
08/2001	Krebs, P. / Günther, E. / Obenaus, G. (Hrsg.) Bölter, C.	Regenwassernutzung im nicht privaten Bereich Eine technische und wirtschaftliche Analyse dargestellt am Beispiel des Fraunhofer-Institutszentrum Dresden Download
09/2001	Krause, W. / Günther, E. / Schulze, L. (Hrsg.) Huber, V.	Ökologische Bewertung von Reinigungsprozessen in der Oberflächentechnik - Möglichkeiten zum Einsatz integrierter Umweltschutztechnologien Download
10/2001	Wingrich, H. / Günther, E. / Reißmann, F. / Kaulich, S. / Kraft, A. (Hrsg.) Seidel, T.	Vergleichende Untersuchungen zur Wasseraufbereitung mit getauchten Membranen Download
11/2002	Koch, R. / Günther, E. / Fröhlich, J. / Jetschny, W. / Klauke, I. (Hrsg.) Sauer, T.	Aufbau eines integrierten Umweltmanagementsystems im universitären Bereich Download
12/2003	Günther, E. / Berger, A. / Hochfeld, C. (Hrsg.) Tröltzsch, J.	Treibhausgas-Controlling auf Unternehmensebene in ausgewählten Branchen Download

Fortsetzung:

13/2003	Günther, E. / Neuhaus, R. / Kaulich, S. (Hrsg.) Becker, S. / Kornek, S. / Kreutzfeldt, C. / Opitz, S. / Richter, L. / Ulmschneider, M. / Werner, A.	Entwicklung von Benchmarks für die Umweltleistung innerhalb der Maschinenbaubranche Eine Benchmarkingstudie im Auftrag der Siemens AG Download
	Günther, T. / Günther, E. (Hrsg.) Hoppe, H.	Umweltaspekte und ihre Wertrelevanz für die Unternehmen: Eine Zusammenfassung existierender empirischer Forschungsergebnisse. Erschienen in den Dresdner Beiträgen zur Betriebswirtschaftslehre Nr. 81/04 Download
14/2004	Günther, E. / Klauke, I. (Hrsg.) Kreutzfeldt, C.	Herausforderungen für die nachhaltige öffentliche Beschaffung in der Tschechischen Republik im Zuge der EU-Osterweiterung Download
15/2004	Günther, E. / Farkavcová, V. / Hoppe, H. (Hrsg.) Jacobi, R. / Scholz, F. / Umbach, F. / Wagner, B. / Warmuth, K.	Entwicklung eines integrierten Managementsystems bei einem mittelständischen Unternehmen der Entsorgungswirtschaft Verknüpfung von Umweltmanagement und Qualitätsmanagement unter besonderer Berücksichtigung der Transportprozesse in der Entsorgungsbranche Download
16/2004	Günther, E. / Will, G. / Hoppe, H. (Hrsg.) Ulmschneider, M.	Life Cycle Costing (LCC) und Life Cycle Assessment (LCA) – Eine Übersicht bestehender Konzepte und deren Anwendung am Beispiel von Abwasserpumpstationen Download
17/2005	Günther, E. / Hoppe, H. / Klauke, I. (Hrsg.) Deuschle, T. / Friedemann, J. / Kutzner, F. / Mielecke, T. / Müller, M.	Einweg- und Mehrwegtextilien im Krankenhaus – Das Spannungsfeld zwischen Ökonomie und Ökologie Download

Fortsetzung:

18/2005	Günther, T. / Günther, E. / Hoppe, H. (Hrsg.) Mahlendorf, M.	Entwicklung eines Entscheidungsmodells zur Anwendung von Umweltkostenrechnungssystemen: Aktuelle Entwicklungen und Anwendungsbereiche Download
19/2006	Günther, E. / Kaulich, S. (Hrsg.) Kornek, S.	Entwicklung einer Methodik eines integrierten Managementsystems von Umwelt-, Qualitäts- und Arbeitsschutzaspekten unter besonderer Betrachtung des Risikomanagements Download
20/2006	Günther, E. / Lehmann-Waffenschmidt, W. (Hrsg.) Bolze, C. / Ernst, T. / Greif, S. / Krügler, S. / Nowotnick, M. / Schneider, A. / Steneberg, B.	Entschleunigung von Konsum- und Unternehmensprozessen Download
21/2006	Günther, E. / Farkavcovà, V. (Hrsg.) König, J	Ökologische Bewertung von Transportprozessen - Systematisierung und Analyse existierender Bewertungsverfahren und Studien Download
22/2006	Günther, E. / Becker, U. J. /Farkavcovà, V. (Hrsg.) Kutzner, F.	Emissionshandel im Verkehr - Konsequenzen aus einzelwirtschaftlicher Perspektive Download
23/2006	Günther, E. / Hoppe, H. (Hrsg.) Mielecke, T.	Erstellung einer Sachbilanz-Studie und Modellierung des Lebensweges von Operationstextilien Download
24/2007	Günther, E. / Scheibe, L. (Hrsg.) Laitenberger, K. / Meier, K. / Poser, C. / Röthig, D. / Stienen, J. / Tobian, S.	Umweltkennzahlen zur Prozessbewertung Download

Fortsetzung:

25/2007	Günther, E. / Bilitewski B. / Hoppe, H. / Janz, A. (Hrsg.) Greif, S.	Ökonomische Analyse der Rückgewinnung von hochwertigen Metallen aus elektrischen und elektronischen Altgeräten in Deutschland Download
26/2007	Günther, E. (Hrsg.) Steneberg, B.	Beschleunigung und Entschleunigung – eine empirische Untersuchung der Zahlungsbereitschaft für Entschleunigung Download
27/2007	Günther, E. / Becker, U. / Gerike, R. / Nowack, M. (Hrsg.) Friedemann, J.	Analyse von Verteilungswirkungen externer Effekte im Verkehr Download
28/2007	Günther, E. / Hoppe, H. (Hrsg.) Poser, C.	Komponenten und Einflussfaktoren der Umweltleistung eines Unternehmens: Strukturierung und Strukturanalyse auf Basis theoretischer und empirischer Ergebnisse Download
29/2007	Günther, E./ Hoppe, H. (Hrsg.) Laitenberger, K.	Der Einfluss des Umweltschutzes auf die Wettbewerbsfähigkeit von Ländern und Industrien Download
30/2008	Günther, E. (Hrsg.) Meier, K.	Die Umweltleistung in der Umweltberichterstattung von Unternehmen und deren Zusammenhang mit der ökonomischen Leistung Download
31/2008	Günther, E./ Tränckner, J. / Nowack, M. (Hrsg.) Röthig, D.	Betriebswirtschaftliche Analyse der Kapazitätsauslastung in der Siedlungsentwässerung Download
32/2008	Günther, E. / Tränckner, J. / Nowack, M. (Hrsg.) Gaitzsch, G.	Analyse der Auswirkungen des demografischen Wandels auf die Siedlungsentwässerung mit Hilfe des Realoptionsansatzes Download
33/2008	Günther, E. / Scheibe, L. (Hrsg.) Hüske, A.-K.	Hemmnisse in Entscheidungsprozessen Download

Fortsetzung:

34/2009	Günther, E. / Günther, T. / Nowack, M. (Hrsg.) John, S.	Bewertung der Auswirkungen des demografischen Wandels auf die Abwasserbetriebe Bautzen mit Hilfe der Szenario-analyse Download
35/2009	Günther, E. / Hüske, A.-K. / Hutter, K. / Soyez, K. / Stechemesser, K. (Hrsg.) Domke, T. / Geißler, M. / Gornickel, D. / Görtz, A. / Heide, N. / Hentschel, N. / Hildebrandt, S. / Kasten, M. / Loitsch, N. / Schmidt, M. / Starke, M. / Villalba, M.	Hemmnisse umweltfreundlichen Verhaltens Download
36/2009	Günther, E. / Stechemesser, K. (Hrsg.) Bergheim, K. / Gerbaulet, C. /Graßhoff, N. / Kittlaus, B. / Klapper, H. / Plischtil, M. / Rehm, F. / Scheel, R.	Anwendung monetärer und nicht-monetärer Entscheidungs-instrumente am Beispiel von Investitionsentscheidungen der MAN Nutzfahrzeuge AG Download
37/2009	Günther, E. (Hrsg.) Höhne, C.	Life Cycle Costing – Systematisierung bestehender Studien Download
38/2009	Günther, E. / Stechemesser, K. (Hrsg.) Lehmann, K.	Betriebswirtschaftliche Szenarien auf regionaler Ebene im Hinblick auf Einflüsse des Klimawandels Download
39/2010	Günther, E. / Manthey, C. (Hrsg.) Gnauck, C.	Herausforderungen ökologisch-ökonomischer Leistungs-messung – Literaturanalyse und Praxistest im Bereich Holz- und Brückenbau Download
40/2010	Günther, E. / Nowack, M. (Hrsg.) Hentschel, N.	Entwicklung einer Methode zur monetären Bewertung des Wassers für ein Unternehmen unter Einbeziehung des Was-ser–Fußabdrucks Download

Fortsetzung:

41/2010	Günther, E. / Hoppe, H. (Hrsg.) Arndt, S. / Gaitzsch, G. / Gnauck, C. / Höhne, C. / Hüske, A.-K. / Kretz-schmar, T. / Lange, U. / Lehmann, K. / Süss, A.	The Relation between Corporate Economic and Corporate Environmental Performance Download
42/2011	Günther, E. / Poser, C. (Hrsg.) Loitsch, N.	Prüfung der Nachhaltigkeitsberichterstattung von Unter-nehmen – Eine empirische Analyse nach den Richtlinien der Global Reporting Initiative Download
43/2011	Günther, E. / Nowack, M. (Hrsg.) Endrikat, J. / Schlage, F. / Hillmann, J.	Ökonomische und ökologische Bewertung der Auswirk-ungen des demografischen Wandels auf die Siedlungsent-wässerung Teil 1: Entwicklung von Szenariobausteinen für die Sied-lungswasserwirtschaft im Jahr 2050 - Eine Studie auf Basis von Expertenbefragungen Download
44/2011	Günther, E. / Nowack, M. (Hrsg.) Bergheim, K. / Dreuse, A. / Reif, J.	Ökonomische und ökologische Bewertung der Auswirk-ungen des demografischen Wandels auf die Siedlungsent-wässerung Teil 2: Ökonomische Bewertung Download
45/2011	Günther, E. / Nowack, M. (Hrsg.) Müller, J. / Schubert, R. / Woite, M.	Ökonomische und ökologische Bewertung der Auswirk-ungen des demografischen Wandels auf die Siedlungsent-wässerung Teil 3: Ökologische Bewertung Download
46/2011	Günther, E. / Günther, T. / Hoppe, H. (Hrsg.) Krause, M.	Environmental Life Cycle Costing (ELCC) für Produkte der Solarenergie Die Verbindung von Life Cycle Assessment (LCA) und Life Cycle Costing (LCC) – from Cradle to Grave – angewandt auf die Photovoltaik Download

Fortsetzung:

47/2011	Günther, E. / Stechemesser, K. (Hrsg.) Kynast, L.	Anpassung von Unternehmen des Baugewerbes der Modell-region Dresden an den Klimawandel Download
48/2011	Günther, E. / Manthey, C. (Hrsg.) Müller, J.	Formholzprofile als Ausgangsmaterialien für Design-Prozesse: Auswertung von Marktstudien und Durchführung von Experteninterviews Download
49/2011	Günther, E. / Weber, G. (Hrsg.) Herrmann, J. / Michel, S. / Scheel, R. / Seipt, J. / Grasshoff, N. / Klapper, H. / Plischtil, M. / Seifert, J.	Leitfaden zum Stakeholder-Management Download
50/2011	Günther, E. / Nowack, M. (Hrsg.) Schubert, R.	Ökologische Bewertung von zentralen und dezentralen Abwasserentsorgungssystemen Download
51/2011	Günther, E. / Stechemesser, K. (Hrsg.) Herrmann, J.	Warum passen sich Unternehmen nicht an die Auswirkun-gen des Klimawandels an? Hemmnisse und Barrieren gegenüber der Klimawandelan-passung Download
52/2011	Günther, E. / Stechemesser, K. (Hrsg.) Hillmann, J.	Adaptive Capacity as antecedent to Climate Change Strategy A Systematic Literature Review Download
53/2011	Günther, E. / Stechemesser, K. (Hrsg.) Winkler, H.	Die Integration eines Nachhaltigkeitssystems bei einem Energieunternehmen – Eine Fallstudie Download
54/2011	Günther, E. / Weber, G. (Hrsg.) Scheel, R.	Sustainable Business through Voluntary Disclosures: Motivations for Adopting Reporting Guidance, Boundaries and Assurance Download

Fortsetzung:

55/2011	Günther, E. / Stechemesser, K. (Hrsg.) Sonntag, S.	Bilanzierung von Emissionsrechten: Literaturrecherche und empirische Untersuchung europäischer Unternehmen Download
56/2011	Günther, E. / Stechemesser, K. (Hrsg.) Weber, M.-C.	How do water companies adapt to climate change impacts? A literature review Download
57/2012	Günther, E. / Scheel, R. / Nürnberg, A. (Hrsg.) Budzinski, M.	The Differentiation Between Variability Uncertainty and Knowledge Uncertainty in Life Cycle Assessment A Product Carbon Footprint of Bath Powder "Blaue Traube" Download
58/2012	Günther, E. / Scheel, R. / (Hrsg.) Kunstmann, M.	Comparative LCA of Wood from Conventional Forestry and Wood from Short Rotation Coppice Download
59/2012	Günther, E. / Stechemesser, K. / Endrikat, J. (Hrsg.) Bergheim, K.	Integration des Corporate Carbon Footprints in das Vergütungssystem von Unternehmen zur Erhöhung der Umweltleistung Download
60/2012	Günther, E. / Stechemesser, K. (Hrsg.) Gwizdz, J.	Corporate Adaptation to the Impacts of Climate Change in the Logistics and Transportation Industry Download
61/2013	Günther, E. / Bergmann, A. / Scheel, R. (Hrsg.) Laux, J. / Seiler, R. / Vorreyer, V. / Grundmann, D. / Kießling, H. / Pirl, P. / Rühs, S. / Schulze C.	Parameters and Drivers for a Successful and Sustainable Performance of Photovoltaic Manufacturers Download