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Cost-of-ownership forecasting for photovoltaic production equipment

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ABSTRACT

The recent decline in module market prices is the most telling sign of a need for continuous reductions in PV production costs. With this in mind, the cost efficiency of production processes is, next to stable product quality, a vital objective in the planning of production facilities. In this paper, the lessons learned in the area of cost-of-ownership (COO) forecasting methodologies for manufacturing equipment will be analyzed and evaluated for their potential application to investment decisions in the PV industry. This paper will analyze the cost structure of the PV industry with the aim of underlining the importance of a systematic cost-of-ownership approach.

Mature industries like the automotive industry have continuously optimized their cost structure during the last decades. Their ongoing success illustrates the tremendous cost saving potentials of photovoltaic manufacturers, who are still in an 'early stage' of mass production. Further development will require the adaptation and implementation of proven concepts and methodologies from other industries.

To depict the cost-saving potentials in PV manufacturing, a high-level cost structure for the crystalline PV supply chain is shown in Fig. 1. The short lifetime of production equipment, which is caused by rapid technological progress, leads to a large share of depreciation costs (approximately 20% for an assumed equipment lifespan of five years). Reducing the initial cost is, therefore, a promising cost-saving measure, especially since these costs are transparent and can be easily compared by every investor.

Nevertheless, the initial costs only account for a minimal portion of the overall costs throughout the equipment lifetime. The less tangible subsequent costs of the equipment, which occur during the operation phase and the further utilization phase, make up 80% of the total costs. Among these subsequent costs, the expenses for intermediate products (metallurgical-grade silicon, polysilicon, wafers and cells) represent the largest fraction. Besides, the consumption of further resources like energy, water, chemicals, pressured air and slurry represents another major portion of the total costs. For example, the electricity costs in the production of monocrystalline ingots account for approximately one third of the overall production costs.

Some subsequent cost items like energy consumption are highly dependent on equipment, and the selection of premium equipment may lead to considerable cost savings during the lifetime of the process. Achieving a high degree of transparency on all cost items is therefore a prerequisite for any systematic investment decision, and any subsequent costs need to be assessed in relation to this investment decision.

Any comparison of alternative equipment requires that the initial and subsequent cost items be made tangible. A better availability and comparability of the equipment data is beneficial to both the end user and the machine builder, who seeks to justify premium prices for the high-quality equipment. The subsequent costs need to be forecasted based on various planning assumptions. More precisely, the (future) production environment needs to be defined. Production planning data such as the production program, electricity prices or the labour costs may vary greatly between different production facilities and locations. Detailed cost analysis of equipment can only be conducted in consideration of a set of (likely) usage scenarios and the future production environment.

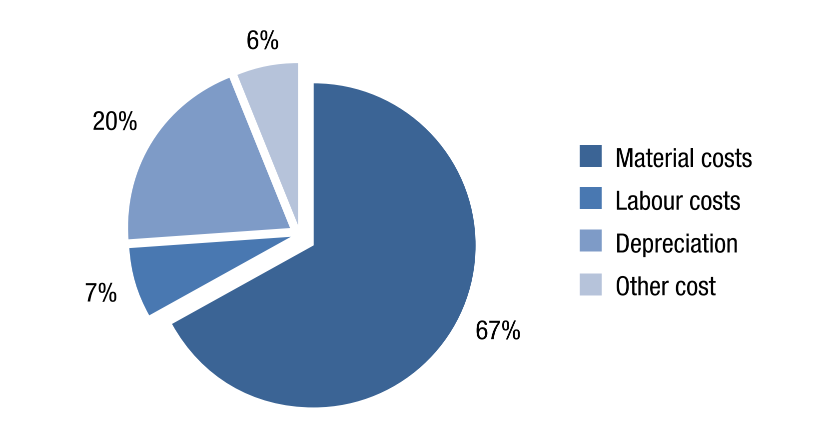

Figure 1. Exemplary cost structure of a crystalline PV supply chain (Fraunhofer IPA).

"Detailed cost analysis of equipment can only be conducted in consideration of a set of (likely) usage scenarios and the future production environment."

In synthesis, the subsequent costs are – as in most industries – the dominating cost drivers in the life cycle of PV equipment. At the same time, these cost items are less tangible than the initial investment costs, and are therefore often not considered appropriately in investment decisions. To enable manufacturers to take better decisions during the facility planning process, a life cycle-orientated and holistic cost management approach is beneficial.

The concept of life cycle costing

Total cost of ownership (TCO) refers to the total cost of acquiring, installing, using, maintaining, changing, and getting rid of an item over an extended period of time, a concept that was initially developed for IT software and hardware [1]. The term life cycle costing (LCC) is more commonly used in relation to industrial goods such as machinery.

The life cycle costing approach classes the equipment or even the entire facility as a product of sorts which undergoes a number of life cycle phases (initiation phase, planning phase, implementation phase, operational phase, disposal/

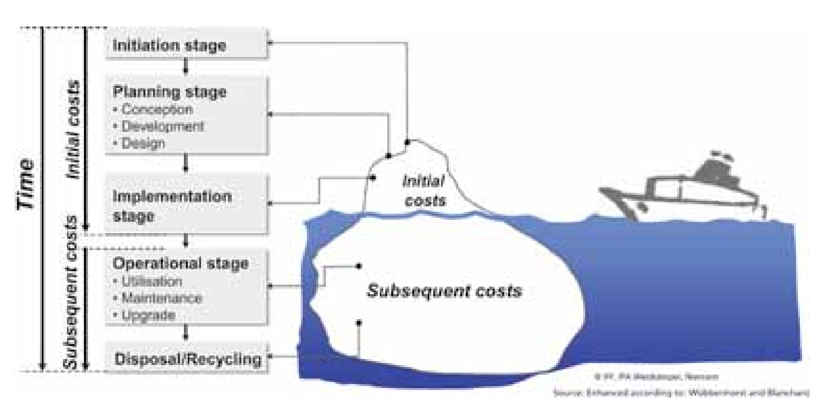

Figure 2. Life cycle cost of an industrial product [2].

recycling phase). Each phase sees the introduction of different cost items that each depend on the assumed usage scenario. In most industrial sectors, the initial costs only account for the lesser share of the total costs; however, these costs are the most visible and traditionally play a dominant role in investment decisions (see Fig. 2).

Benfits of implementing life cycle costing

All significant cost items must be taken into account in order to enable sound investment decisions. Life cycle costing can support the gathering and analysis process by using cost breakdown structures (CBS), which define and categorize the cost items for each life cycle phase. This may cover costs for set-up, various process materials, unscheduled downs, maintenance and energy. Due to the different characteristics of production equipment, the applied cost structures need to be flexible and easily extensible. Table 1 shows some of the benefits for end users and machine builders that can be gained by applying life cycle costing [3].

On the one hand, end users benefit from a higher transparency on the future production costs, which in turn allows for a more comprehensive cost assessment of production equipment and production lines. As a consequence, the risks of an investment decision like the need for a higher-performing power connection can be mitigated at an early planning stage.

The gathered data can then be used as the foundation for service contracts, e.g. for determining the optimal maintenance interval. During the equipment's operating time, the life cycle data collected can be considered from the perspective of capacity and cost planning.

"Life cycle costing enables machine builders to quantify and communicate the capabilities of their products in a structured way."

On the other hand, life cycle costing enables machine builders to quantify and communicate the capabilities of their products in a structured way. The gathered life cycle cost data can be used during the product design process, allowing for analyzing and prioritizing of future design changes in cooperation with customers and suppliers. Furthermore, the usage modalities and further requirements from the end users allow the machine builder to better plan service contracts.

In industrial sectors like the automotive industry, there appears to be a strong tendency towards a life cycle view on equipment costs. Machine tool builders, for example, are obliged by OEMs to forecast and guarantee the subsequent costs of the machine in question for a defined lifetime under certain operating conditions [4], thereby offering alternatives that can easily be assessed by the end user.

In summary, the life cycle costing approach leads to advantages for end users and machine builders. Several industries employ this cost calculation approach which covers the initial cost as well as subsequent costs for the equipment or the production line. However, in the PV industry, structured approaches are often not applied and important cost categories are not incorporated. In order to put into effect the benefits of the holistic LCC approach, several challenges need to be addressed, as discussed in the following section.

Challenges for implementing life cycle costing

To implement an effective and efficient life cycle costing concept, several challenges need to be addressed and mastered [5]:

- The equipment performance data needs to be gathered and modelled by the machine builder.
- The future usage scenarios for the equipment or the production line need to be gathered and modelled by the end user.
- The life cycle cost calculations for different equipment need to be standardized to make them comparable.
- The life cycle costing approach needs to be supported by suppliers and end users.

The forecasting of all relevant subsequent cost items is a challenge for the machine tool builder. Even for such basic equipment performance indicators as the mean time between failures (MTBF), the machine builders often rely solely on expert opinions, because, even for mature products, sufficient operational performance data is hard to find. This is the result of intellectual property conflicts and a lack of a structured data gathering and analysis approach.

Secondly, the life cycle costs depend strongly on the future usage scenarios of the equipment. Such end-user planning assumptions as periods of operation, basic process parameters, the prices for resources and the expected capacity utilization of the equipment need to be defined explicitly. The subsequent costs account for a larger share of the total costs for equipment with high utilization than for equipment with low utilization. Furthermore, when considering equipment as parts of production systems, the interdependencies between the equipment and the entire system must be analyzed. The reliability of a single piece of equipment can have a strong effect on the economics of the entire production system. The positioning of equipment of low reliability at the bottleneck of a production line leads to a fluctuating

Benefits to the end user	Benefits to the machine builder
Transparency on the costs throughout the entire life cycle	Differentiation from competitors through transparent cost structures
Mitigation of investment risks	Determination of optimization measures in product design
Improved capacity and cost planning during the equipment lifetime	Improved capacity planning for services (e.g. maintenance and repair)
Foundation for maintenance and repair contracts	Extension of service offerings

Table 1. Benefits for end users and machine builders.

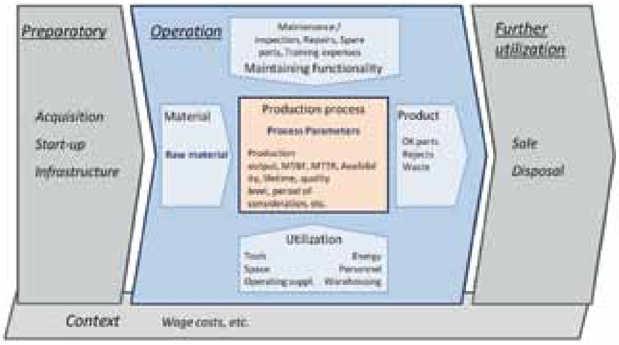

Figure 3. Forecasting model for life cycle cost (VDMA norm 34160).

material flow and thereby decreases the performance of the entire production facility. Based on the defined usage scenarios, the machine builder needs to forecast the process's Key Performance Indicators (KPIs) like yield, scrap rate, material consumption per unit as well as required maintenance intervals, which are used for the life cycle cost calculation.

Lastly, a standardized model (cost breakdown structure) for the life cycle cost forecasting needs to be applied by the different machine builders to allow the end user to compare equipments. Today, the cost specifications provided by machine builders in the photovoltaic industry are often quite diverse. In order to get the most out of a standardized life cycle costing approach, the participation of a number of market players is required. With this approach, the overhead costs implicated by manifold proprietary calculation schemes of different end users will be reduced.

Models and tools for life cycle costing

A number of proprietary and standardized models and tools for life cycle costing have been developed, with large market players in other industries such as Bosch and Daimler taking to enforcing proprietary models and guidelines for life cycle cost specifications that need to be fulfilled by their suppliers. These company-specific standards offer benefits to the OEMs themselves but result in overhead costs for the suppliers.

Industry independent models

Standardized models like the VDMA norm 34160 [6] have been developed which offer a structured approach for the forecasting of machine and plant life cycle costs. In this situation, the end user and the machine builder can issue bids and tenders in a standardized way based on the individual context conditions of the end user (see schematic in Fig. 3). The model specifies relevant production context characteristics and a cost breakdown structure. The cost items are categorized according to the preparatory, the operation and the further utilization phase and are extensible to additional detail levels and cost categories.

> "Defined characteristics such as the periods of consideration and the expected resource prices have a significant influence on the life cycle costs of equipment."

The context describes the production environment of the equipment throughout its lifetime. Defined characteristics such as the periods of consideration and the expected resource prices have a significant influence on the life cycle costs of equipment, and therefore need to be carefully estimated by the end user. For the preparatory phase, the costs of the acquisition and start-up

Life Cycle Forecast according to VDMA Standard Sheet 34160

For equipment X

Code	Name	Supplier	Customer	Value(€)	
LCC	**Lifecycle Cost Forecast**				**3,500,000.00 €**
E	**Preparatory Costs**				**540,000.00 €**
E1	Acquisition costs	400,000.00 €		400,000.00 €	
E2	Infrastructure costs	100,000.00 €	40,000.00 €	140,000.00 €	
E3	Other costs associated with the preparatory phase	- €	- €	- €	
B	**Operating Costs**				**2,860,000.00 €**
D1	Periods under consideration			10	
B1	Annual operating costs	192,000.00 €	94,000.00 €	286,000.00 €	
IH1	Maintenance & Inspection	*30,000.00 €*	- €	30,000.00 €	
IH2	Scheduled repairs	*22,000.00 €*	*20,000.00 €*	42,000.00 €	
IH3	Unscheduled repairs	140,000.00 €	- €	140,000.00 €	
RK1	Occupancy costs		*12,000.00 €*	12,000.00 €	
MK1	Material and raw material costs		13,000.00 €	13,000.00 €	
EK1	Energy costs		*14,000.00 €*	14,000.00 €	
HB1	Production and process materials		- €	- €	
EN1	Disposal costs		- €	- €	
PK1	Personnel costs	- €	- €	- €	
WK1	Tool costs		- €	- €	
RU1	Set-up costs		- €	- €	
LK1	Warehousing costs	- €	23,000.00 €	23,000.00 €	
SO1	Other operating costs	- €	12,000.00 €	12,000.00 €	
V	**Further utilization costs**	**- €**	**100,000.00 €**		**100,000.00 €**
V1	Dismantling	- €	120,000.00 €	120,000.00 €	
V2	Residual value	- €	20,000.00 €	20,000.00 €	
V3	Other costs related to further utilization	- €	- €	- €	

Figure 4. Sample tender according to VDMA 34160 [6].

of the equipment needs to be considered; the required operation infrastructure is also incorporated in this cost category. Costs related to the processed and consumed materials, the process outcome, the maintenance as well as the machine utilization are considered for the operation phase. For the further utilization phase, an analysis is conducted of the cost and benefits for the reuse as well as the recycling of the equipment. On the one hand, the machine may require a special treatment for recycling and will therefore incur additional costs at its end of life. On the other hand, however, the machine may have a significant residual value after the period of consideration and can be re-used for other applications.

All these cost factors need to be considered prior to making the best investment decision. In real life, many cost elements are not easily available for the machine builder or the end user. Nevertheless, even estimating these cost drivers based on expert opinions is better than just leaving them out of consideration. An exemplary high-level life cycle cost calculation in alignment with the VDMA 34160 is depicted in Fig. 4, where every depicted category of the model is broken down in more detailed cost items.

When applying industry-independent standard models to particular equipment types, the degree of unintentional flexibility for the data specification and interpretation is rather high. To give an example, the production output in terms of 'units per hour' is a rather generic description for its application to different production environments like automotive assembly and solar cell manufacturing.

Industry-specific models

Industry-specific models and guidelines can ease the data exchange between customers and suppliers and can therefore reduce the overhead costs for all partners. These models provide an adjusted and more detailed cost breakdown structure. Several industry-specific standards and guidelines like the SEMI E35 norm [7] for the semiconductor, flat panel and optoelectronic industries have been developed and adapted to the specific product and processes of a manufacturing sector. These models and guidelines incorporate the specific requirements of the industrial sector and allow the market players to perform their life cycle cost calculations in a uniform way.

Characteristics of the photovoltaic industry

Most photovoltaic production equipment is designed according to the specific requirements of photovoltaic products and production processes. During the operation phase, the equipment is integral to the production lines and processes highly standardized products. Therefore, and in contrast to more flexible machine tools, the usage scenario and the most relevant cost items of the equipment can be easily forecasted. Consequently, the development and application industry-specific standard models and guidelines for life cycle costing for each manufacturing stage like crystal growing, wafer manufacturing, cell manufacturing and module manufacturing is feasible. Their application would bear additional benefits for the participating market players through well-defined cost categories and reduced overhead costs.

Life cycle cost tools to support investment decisions

Different software tools can be applied for the support of the life cycle cost calculation as part of the investment decision process. These tools support the definition of cost breakdown structures, gathering and maintaining of the basic planning

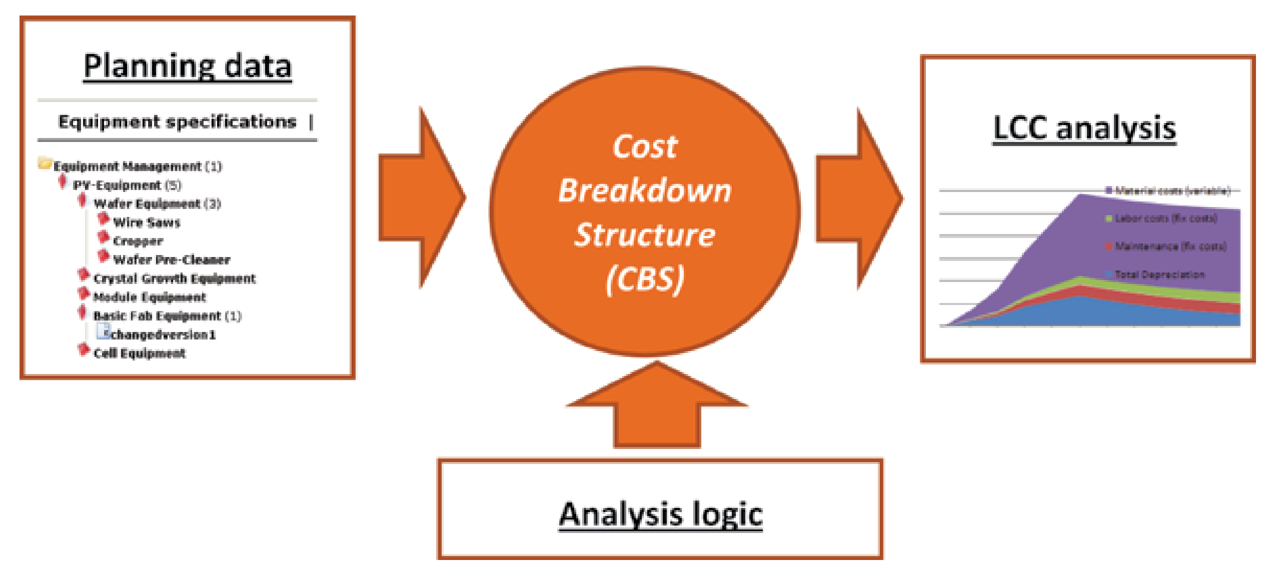

Figure 5. Principles of life cycle costing analysis tools.

data and the equipment data as well as the definition and execution of the cost analysis, as shown in Fig. 5.

Several life cycle costing tools are currently available on the market that offer the possibility of flexibly defining cost breakdown structures and the execution of customizable analysis functionalities like side-by-side comparison, net present value calculation and sensitivity analysis. While these tools are, for the most part, designed to support the product or service design process by considering different design options, many companies just apply simple proprietary spreadsheet tools. It is often the case that these tools do not obey the standard models and neglect some of the life cycle phases and cost categories described in this paper.

The integration between these life cycle costing tools, the facility planning process and the procurement process is vital to support the data exchange between all stakeholders. Any facility-planning decision may influence the selection and the configuration of particular equipment, i.e. through changing the expected throughput for equipment. On the other hand, the forecasted life cycle costs for the equipment may influence other design decisions for the facility.

In summary, software tools to support the forecasting of the life cycle cost of products are available on the market, but need to be adapted or customized to the specific characteristics of photovoltaic production equipment. Alternatively, spreadsheet tools can be used; however, regardless of the approach, standardized models and a closer integration to the facility planning and purchasing processes need to be targeted by the manufacturers.

Summary

Photovoltaic manufacturers need to maintain a strong focus on production cost reduction in order to safeguard their future competitiveness. To do so, any investment decision for production equipment or production lines need to be based on sound cost estimations, which incorporate the initial costs but also any subsequent costs during the lifetime. In general, the costs in the operation phase and the further usage phase of equipment are less tangible but account for the major share of the total life cycle costs. Therefore, these cost items need to be gathered, analyzed and incorporated in the investment decision.

In comparison with the proprietary cost calculation models and tools, standardized life cycle costing models reduce the overhead costs for the participating market players. Applying these models and guidelines can lead to a significantly improved knowledge exchange between machine builders and end users. Several industry-independent and industry-specific models and guidelines have been developed, but none of them is specifically designed for the needs and production environment in the PV industry.

Therefore, these models need to be adapted or customized to the specific production equipment and process characteristics of the photovoltaic industry, which calls for a close integration between the facility planning process and the purchasing process. Consequently, the awareness and transparency of life cycle cost during the facility planning process is improved, which contributes to the establishment of more cost-efficient production facilities.

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