Value Creation in Photovoltaic Supply Chain through Market and Product Diversification: Insights from Emerging Building Integrated PV Segment

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Abstract
The recent years in the PV industry have been marked with a severe imbalance of manufacturing capacities and demand, which led to abrupt market shocks and end-product price volatility. Moreover, the Chinese fast-follower producers managed to grasp the significant competitive advantages, both, in terms of scale and technological advancements. Under such conditions, the PV segments in originally technologically advanced countries of the West struggle to reinvent their approach to restart, at least, part of their manufacturing base. The problem is complex while it relates to the domain of policies, technology, product design, logistics, or emerging applications. In this manuscript, the authors proposed a broad reflection on current PV and BIPV trends with a special focus on the value creation in the BIPV supply chain. The reflection was based on the data and know-how derived directly from the industry sources, including the recent PV global events. The discussion leads to the conclusions on the growing importance of the untapped chances resulting from the merging construction and PV industries. The substantial part of the PV value creation is deemed to shift from manufacturing hubs towards the proximity of the projects' locations, which creates chances to increase the balance of the global industry. The topic of the value creation in BIPV is hardly present in the literature therefore the research brings an important contribution, also through the quoted data.

Keywords: BIPV, Solar Façade, Solar Tile, Product Value

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1. Introduction

The origins of the PV industry could be dated back to 1893 to the discovery of the photovoltaic effect by Edmond Becquerel. In its essence, the effect consists of generating the voltage and current in the solar cell when it is exposed to the sunlight. The core of solar cell is composed of the semiconductor materials creating p-n junction responsible for the electric field. The collection of light-generated carriers by the p-n junction causes a movement of electrons to the n-type side and holes to the p-type side of the junction. While, the unit solar cell represents the smallest part of the photovoltaic appliance and its size may differ according to the technology employed, the majority of the market still functions with the standard of 6 inches silicon crystalline cells (c-Si). The c-Si technology covers around 96% of the PV market with the remaining 4% occupied by the thin-film (including mainly CdTe and CIGS) and other emerging technologies (Fraunhofer Institute 2019). Certainly, the silicon segment operates with the highest level of technology maturity. The manufacturing facilities, based on the turn-key solutions, enable to reach the highest efficiencies with the lowest unit costs per cell – currently at around 0.1USD/Wp. Moreover, the c-Si would build its competitive advantages over thin-film in the coming years while the emerging propositions, here mainly organic or perovskites, did not enter yet the mass-scale production.

Within the c-Si, monocrystalline cells are formed with the wafers manufactured using a single crystal growth method and have commercial efficiencies between 16% and 25%. Multi-crystalline silicon (mc-Si) cells, usually formed with multi-crystalline wafers manufactured from a cast solidification process, have remained popular as they are less expensive to produce but are also less efficient, with average conversion efficiency around 14-18%. Regardless of the type of cells, they are assembled into the modules of various structures and sizing. On the residential market, the modules of 60 cells are the mainstream. As far as the utility-scale is concerned, the cells' quantity rises to 72 so the marginal cost declines.

The cell and module segment stands for the midstream of the PV industry. In the earlier stage, in the upstream segment, the wafers and ingots provide the raw material for cells after the capital and energy-intense production processes. In the downstream, the modules are used for installations, often combined into arrays, together with the mounting systems, the balance of system (BoS), or tracking systems. Due to the scale and the growing importance of the PV globally, each part of the value chain undergoes the technological and organizational transformation. Apart from the equipment's evolution, it is worth to underline the emergence of the new business models in the downstream sector, whether it is off-grid, or on-grid employment.

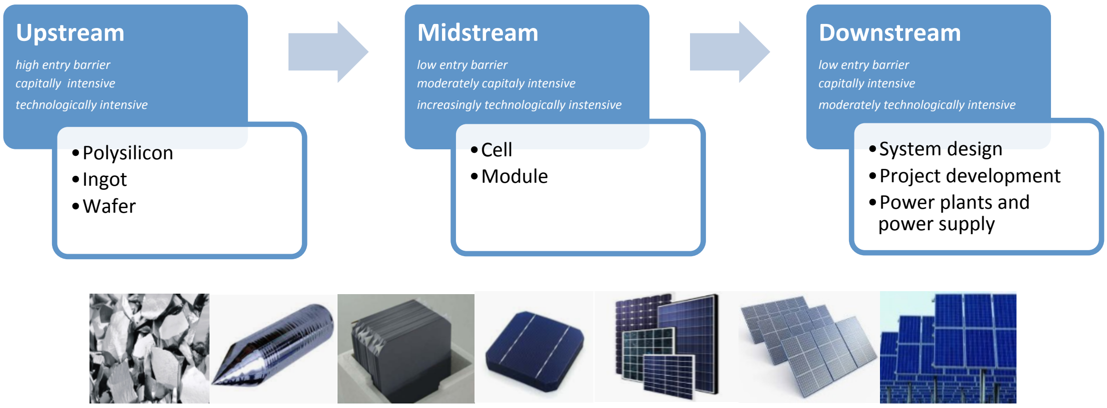

Figure 1. c-Si PV industry value chain

Aside from the technological robustness and fierce competition, the volatile nature has always been a leading characteristic of the PV supply market. This imbalance in supply and demand has cumulated, resulting in the exogenous shocks that have had a tremendous impact on the local manufacturers, regardless of the developed technology. According the pv-magazine Module Price Index (2017, 2018, 2019) and NREL (2018) data, the cell and module prices dropped in 2016 for around 26% and 30% accordingly. The major shock took place from June 2016 to September 2016 when the price adjustments reached the levels of over 20% in cells and modules and over 35% wafers. Although the following months brought a limited rebound for the wafers and cells, the module prices remained under pressure. The downward trend continued to the average price of 0.3USD/Wp in March 2018 (0.21USD/Wp for cells and 12USD/Wp for wafers) (Wang and Kryszak 2020). From the broader perspective, the origins of the dynamic changes in the PV industry could be grouped in three interrelated domains. Firstly, one could point at the lagging technological progress, which was consequence of the low standards and unspecific demand that was not supported with appropriate national polices. Secondly, the chaotic led to the systematic imperfections and overcapacity when the fast-followers of Asia. Finally, the underdeveloped application markets (local and global) exposed unbalanced industry to the substantial business risks of the fluctuating and unpredictable demand.

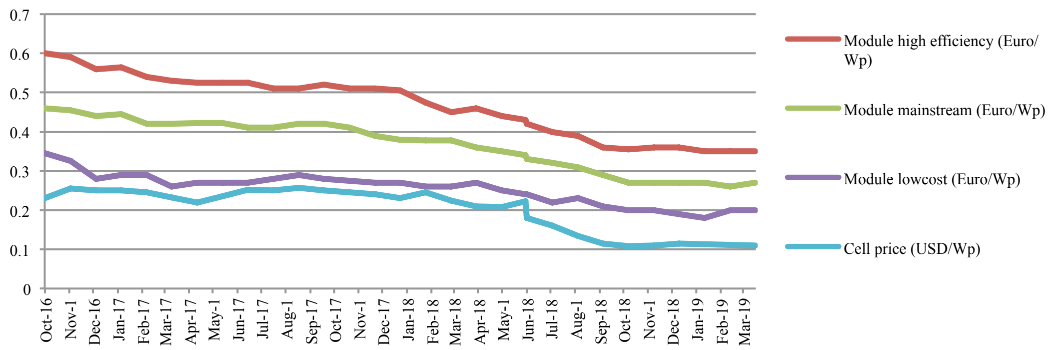

Figure 2. c-Si cell and module price (EUR/Wp, USD/Wp) evolution on the European and American markets (Schachinger 2017, 2018, 2019; NREL 2018; Wang and Kryszak 2020)

With the prices of equipment reaching grid parity point, relatively new aspects of PV limitations started being noticed. Importantly, in the wealthiest locations of the West, where the land is scarce and the public opinion stands as an important factor during the investment assessment, the land availability for the utility and industrial scale projects is not sufficient. Moreover, the electricity grid structure face its own limitations related to the dispersed sources of energy which would be eventually solved with the energy storage systems and micro-grids (Sharma et al 2020). In order to adjust to the changing environment, PV manufacturers strive to meet the requirements of the residential and architectural sectors by expanding their Building Integrated PV (BIPV) offer. Such offer brings multiple benefits to the investors and end-customers while, on the one hand side, the basic idea of electricity generation is guaranteed but, on the other hand, the PV equipment serves the functionality of the construction materials (i.e. insulation or water protection) which, in this case, are not required anymore. Importantly, the PV equipment becomes the carrier of aesthetics value therefore it targets the great vulnerability of the modern PV systems – the lack of aesthetic appeal. The BIPV idea is certainly not new, however only recently it managed to grasp the wider attention, either among the manufacturers or the customers. Often, during the previous stages of market development, the BIPV was confused with Building Applied PV (BAPV) which mimicked BIPV in its essence. After Tabakovic et al (2017) it is crucial to distinguish that, although in BAPV, the modules are attached to building, it happens independently to the building's structure, so the PV has not direct effect on the building functionality per se. In case of BIPV systems, there will be some direct impacts on the building structures and their functionality, especially if some additional, or relatively complex mounting systems are required. Given that, the BIPV stands as an integral element of the structure which implies its replacement with other construction element once the BIPV is removed.

The goal of this research is to explain the potential impact of BIPV on the value creation in the PV value chain. The BIPV manufacturing, and project delivery differs significantly from the traditional, mainstream offer, leaving the chance for smaller entities to compete against the large and established companies. This competition might be not necessary based on the price, but also range of the offer, its quality, lead-times, and innovations involved. The topic of value creation in BIPV segment is new while the literature is scarce. In our research, we would rely mostly on industrial data, which would stand for the main contribution of the article.

2. Methodology and data

This part of the research is solely factual and focuses of the most recent market information (industry data). The goal of the section is to display the relations between the value, the quotations of various PV and BIPV products on the market. The analysis is divided into two perspectives:

a) Value creation – process perspective
a. Size customization
b. Product functionality (rigid to flexible)
c. Colorization
d. Transparency
b) Value creation – product perspective
a. Roof tile
b. Façade

In its essence, the section will follow the works of other scholars, here including: Kuhn et al (2020); Jelle et al (2012); Ceron et al (2013) among others. The data presented in this section was collected from the various industry sources, here including the magazines, reports and scientific journal. Most importantly, the quotation data of the less mainstream technologies was derived from the face-to-face meetings, especially during the PV industry exhibition, in Taiwan and abroad.

3. Results and discussion

The size of mainstream offer is highly standardized. In the silicon segment, the residential market was supplied with the modules of 60 cells while utility scale opted for 72 cells. In the thin-film domain, the offer is less standardized and, in fact, each company has its own sizing which is a derivative of the manufacturing equipment in the given company. Thin-film is produced in the single manufacturing process on, mostly, specific manufacturing lines which would not duplicate across the industry. The BIPV projects, on the other hand, often require unstandardized sizing to fully accommodate the surface. Moreover, the dedicated products, solar tiles included, could be only designed based on unusual sizing, compatible with the roof tiles and construction industry standards. Given that, the niche supply of such modules appeared on the market while the offer was priced well above the mainstream. According to the industry knowledge, the custom-made modules could cost above 1EUR/Wp, although it is worth to point that the quotations in BIPV market are mostly delivered by piece or EUR/m2 and not euro/output power. The customized offer is unique, and produced with limited scale therefore it is often performed by the small and medium size suppliers, often based in the proximity to the projects. The high price needs to compensate the substantially increased labor and marketing costs. The flexibility of manufacturing approach is expected to improve together with the introduction of the third-generation cells which are easily adjustable in terms of size.

The surface BIPV projects' constraints relate not only to sizing, but also to shapes. Firstly, buildings' surfaces do not need to be flat. Secondly, the buildings' mechanical load standards limit the weight of modules and constructions applied on top of them. The flexible offer is light, shape-forgiving, and relatively easy to install. As far as the technology is concerned, the flexibility is offered by variety of producers in the segments of c-Si, thin-film, OPV, or perovskites (near future). The most mature technologies of c-Si and thin-film, reached the expected durability and warranty terms of 10/25 years. The current market prices of the flexible c-Si reach 0.7EUR/Wp, thin-film around 1euro/Wp, and OPV over 1euro/Wp. Similarly, to sizing issue, the value added comes mostly with the expense on the increased labor, but also the niche, customized manufacturing lines, especially in the domain of thin-film.

Unlike the sizing and flexibility which relate to the purely engineering requirements of the projects, the colorization targets the aesthetics. The aesthetics factor is crucial to architects and investors which often hold the authority to facilitate the installations. According to the literature, the aesthetics shortage of the mainstream offer could be cited as one of the main reasons for late wide adoption of BIPV. In contrast, the aesthetics might contribute greatly to the financial feasibility of the projects (Kryszak and Wang 2020). Since colorization is appreciated by the big public, it also contributes to the increase of the BIPV acceptance by society. The colorization of the modules is achieved mostly by the glass printing methods, although few companies deliver solution based on other techniques involving glass light refraction, direct cell coloring, or stickers. The module coloring could be uniform, with single-color, or customized with multi-color (only with print methods). The single color modules tend to be cheaper with the price range of 100-150EUR/m2. The multi-color quotation reaches 200-250EUR/m2. In this case, the modules could serve as the additional source of income, including advertisements with the printing of the particular design. According to the recent market research, the coloring gains wide recognition across various solar cells technologies. In the past, the colored offer related mostly to the thin-film manufacturers which envisioned BIPV as a valid strategy to escape the fierce c-Si competition. Nowadays, the largest c-Si modules producers spotted the chance in BIPV therefore the market expands and one could expect the price to decline in the near future.

The last upgrade, the transparency is currently the most value-added process in the BIPV industry. It requires the cutting-edge technology, extensive labor park investment. Although, the market is still immature leaving the high-risk on the producers' side, the transparent installations gain attention thanks to its appeal, functionality, and exceptional aesthetics. In regards to technology, transparency is achieved differently in case of thin-film and c-Si. For the thin-film, the transparency is achieved through the laser process which effects in the uniform and appealing outcome. On the other hand, c-Si modules base on the glass with the solar cells in between so the effect is only partial. From this reason, one could expect the technology to develop further to fully meet the glass industry expectations. As the products are not of the same quality, the pricing may also differ. We could quote the range of 500 to even 1000EUR/m2 and it stays noticeably above any other BIPV segments. Since the certain level of opacity is reachable to the OPV and perovskites technologies (but also to quantum-dot process), the market might evolve to the lower prices for the products of comparable quality.

The upgrades of the manufacturing processes could be offered to the market through the supply of components, here including processed solar cells. The components, in the further part of the supply chain, are assembled into the end-products that target the end-customer with applications. With the size customization, improving the functionality (on the cell level), colorization or transparency, these products tend to bring the increased value to the customers, therefore increase the competitive advantages of manufacturers which lead to the potential of reaching higher margins. As it is observed on the BIPV market, the façade and roof tiles managed to gain the broadest acceptance of the customers. Both products offer achieved the relatively maturity processes of manufacturing, with few companies gearing up for the mass scale operation. The market research indicated that the current PV tile's price level fall into the range between 2200-3000EUR/kWp. For most of products, the tiles display the power class falling into range 130-150Wp/m2.

As far as the façade segment is concerned, the data is less abundant which comes as a consequence of the high level of customization in the façade market. The prices to the end customer vary greatly in function of the processes employed to deliver the goods, here mostly: size customization, coloring, restructuring. One could provide the approximate quotations of: around 100EUR/m2 for basic black frameless modules, around 100-150EUR/m2 for single-color frameless module, around 200-250EUR/m2 for multi-color ceramic printed frameless modules. Due to the substantial difference of the module power classes (in respect to solar cell technologies and coloring options) it is not a common practice to provide the quotations based on the Wp unit.

Table 1. BAPV and BIPV investment comparison (based on the case study)

	size customization	**restructuring**	**coloring**	**transparency**
PV rooftile	end-customer price: 2200-3000EUR/kWp , factory price: around 1.4 EUR /Wp (130-150Wp/m2)	factory price: around 1.1 EUR /Wp (flexible module of relatively low efficiency)	factory price: over 2 EUR /Wp for terra cota PV tile (around 100Wp/m2)	-
PV façade	factory price: basic frameless option 100 EUR /m2, the cost of resizing in function of material waste and number of cuts	factory price: around 1 EUR /Wp (OPV, flexible), changes in the solid structure in function of employed cover glass and thickness of the modules -100-300 EUR /m2	factory price: single color ceramic printing 100-150 EUR /m2, multi-color ceramic printing 200-250euro/m2 , UV printing 150euro/m2, colored cover glass 150-200 EUR /m2, sticker method 150 EUR /m2	factory price: 500-1000 EUR /m2 (in function of technology and transparency)

Based on the market data derived directly from the suppliers

4 Conclusions

In this research authors' goal was to analyze the current ways in mainstream PV industry to increase the value-added of the products in BIPV segment. According to the data presented the BIPV creates the substantial chance to the producers. Regardless the manufacturing cost side, which was not the topic of this research, industry data clearly indicates the great nominal difference between the quotation of mainstream and niche BIPV offer. Starting from the basic size and shape customization, through product design towards the most sophisticated transparent modules, the magnitude of mark-up might indicate the shortage of the suppliers. The market is fragmented, without clear leaders and the standardization. Moreover, taking into consideration the early industry phase of growth, one could assume the existing chances to the smaller and well-positioned (also locally) entities, which are currently not able to hold their competitive advantages under hostile market conditions and ever increasing scale capacities. The BIPV stands for separate market, driven by distinctive requirements and the complex customer service. Due to the supportive polices towards PV, and BIPV specifically, the industry evolution would certainly accelerate in the years to come.

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