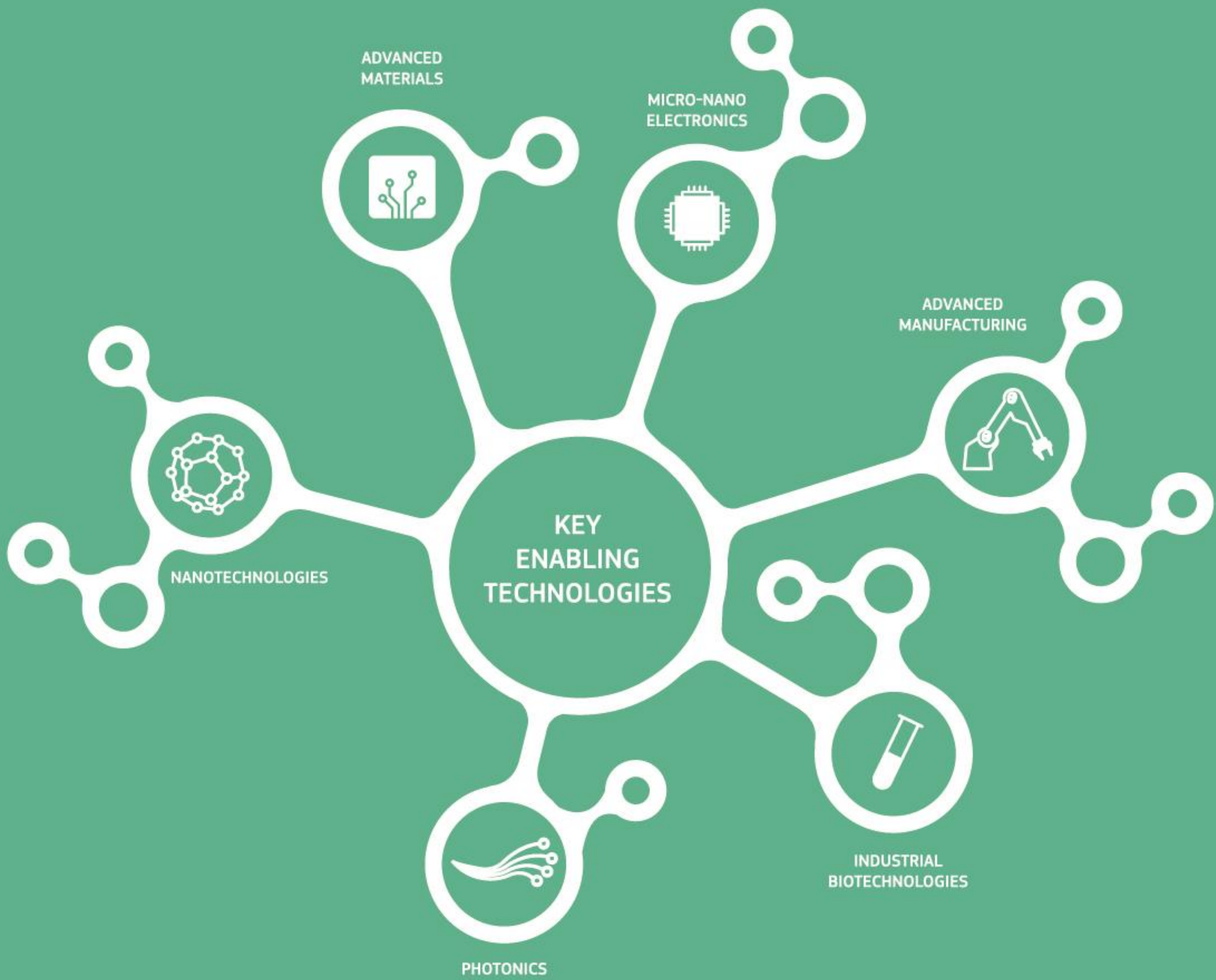
European Commission

KETs OBSERVATORY PHASE II



PEROVSKITE SOLAR CELLS

Report on promising KETs-based products nr. 3

Contract nr EASME/COSME/2015/026

Internal Market, Industry, Entrepreneurship and SMEs

PEROVSKITE SOLAR CELLS
Report on promising KETs-based products nr. 3

August 2017

KETs Observatory Phase II
Contract nr EASME/COSME/2015/026

Authors: Dr. Kristina Dervojeda (PwC), Mark Lengton (PwC), Anton Koonstra (PwC)

Coordination: EUROPEAN COMMISSION, Executive Agency for Small and Medium-sized Enterprises (EASME), Department A – COSME, H2020 SME and EMFF, Unit A1 – COSME; DG for Internal Market, Industry, Entrepreneurship and SMEs, Unit F.3 - KETs, Digital Manufacturing and Interoperability

European Union, August 2017.

Executive summary

The current report aims to provide stakeholders with an analytical base helping to strengthen cross-regional cooperation mechanisms to boost the deployment of Key Enabling Technologies in Europe. The report specifically aims to highlight the value chain structure, key players and constraints for the domain of *perovskite solar cells*. It also addresses the key strengths and potential of the EU regions, as well as promising business opportunities and key risks and challenges. Finally, the report elaborates on specific policy recommendations with both immediate focus and longer-term orientation.

Perovskite solar cells represent the fastest-advancing solar technology to date, due to a rapid increase in efficiency and their potential to lower the cost of solar energy. They are viewed as the photovoltaics technology of the future. Nevertheless, perovskite solar cells are still in their early stages of commercialisation, due to a number of concerns related to their stability, toxicity and the associated scaling-up potential.

While for stand-alone perovskite solar cells, a fundamentally new value chain needs to be created, for perovskites used in tandem with silicon, it is possible to partially build on the already existing value chain. Once fully developed, the value chain will connect the key players from multiple EU Member States. The key players of the value chain can be clustered into research organisations and technology suppliers, fine chemical suppliers, substrate suppliers, equipment manufacturers, module developers, large-scale manufacturers, module integrators and installation companies. Europe is particularly strong in research, as well as materials and equipment manufacturing.

At this point, industrial manufacturing and all the subsequent elements of the value chain, including logistics, promotion and distribution, after-sales services, have not yet been established. The situation is similar in other parts of the world. The key constraint of the EU value chain is related to a low large-scale manufacturing capacity in Europe. In the last few years, many companies involved in solar cells business have been pushed out of the market by strong competition from Asian counterparts. Other constraints refer to competition difficulties caused by significantly less stringent safety requirements in Asian countries, and the absence of the market pull. Strong political backing is needed to encourage customers to use renewable energy products. With that in place, products based on perovskite solar cell technology are expected to naturally conquer a highly competitive market position.

Europe is suggested to be in a good position to produce perovskites on a large-scale basis. For that, the perovskite technology has to deliver its promises related to high efficiency, low production cost and stability. The toxicity issues also need to get solved. Besides, a proper political framework needs to be established, particularly the measures ensuring long-term protection of Europe's investment in cutting edge innovations. In this context, the use of perovskites in tandem with silicon-based PV for solar farm applications represents a particularly promising market. This technology also opens up opportunities for SMEs, especially when it comes to the manufacturing of customised products related to stand-alone perovskite solar cells for the European market.

The specific identified measures with immediate focus include measures related to continuing investments in both basic research and research targeted at the highest TRL levels, maximising SME engagement in development and commercialisation activities, developing a fully

operational pilot line, and developing standards for testing stability. The identified measures with a longer-term orientation imply creating new manufacturing facilities in Europe, continuing support by policy makers at all levels, creating favourable framework conditions for European companies, and offering state-of-the-art education and training.

1. Introduction

The current report has been developed in the context of the second phase of the KETs Observatory initiative. The KETs Observatory represents an online monitoring tool that aims to provide quantitative and qualitative information on the deployment of Key Enabling Technologies[1] (hereafter "KETs") both within the EU-28 and in comparison with other world regions. Specifically, the KETs Observatory represents a practical tool for the elaboration and implementation of Smart Specialisation Strategies in the EU regions.

1.1 Background

A key challenge for the EU competitiveness policy is to enable European industry to move to the higher end of the value chain and position itself on a competitive path that rests on more innovative and complex products. For many KETs, this implies a focus on more integrated technologies with the potential of connecting several KETs.

To this end, one of the key tasks of the KETs Observatory implies identifying and describing "promising KETs-based products" and their value chains, and recommending specific policy actions to help the EU industry stay ahead of global competition. Promising KETs-based products here can be defined as emerging or fast-growing KETs-based products with a strong potential to enhance manufacturing capacities in Europe. Such products correspond to KETs areas where Europe has the potential to maintain or establish global industrial leadership - leading to potentially significant impacts in terms of growth and jobs.

1.2 Objectives of this report

In the context of the second phase of the KETs Observatory, in total, 12 promising KETs-based products have been selected for an in-depth analysis of their value chain, the associated EU competitive position and the corresponding policy implications. The selection of the topics stems from a bottom-up approach based on active engagement of regional, national and EU stakeholders through the S3 Platform for Industrial Modernisation[2].

This report presents the results of the abovementioned in-depth analysis for one of the selected top-priority topics, namely **perovskite solar cells**. The analysis is based on desk-research and in-depth interviews with key stakeholders. The report aims to provide relevant stakeholders with an analytical base helping to establish or strengthen cross-regional cooperation mechanisms to boost the deployment of KETs in Europe.

---

[1] Namely Nanotechnology, Micro-/Nanoelectronics, Photonics, Industrial Biotechnology, Advanced Materials and Advanced Manufacturing Technologies

[2] http://s3platform.jrc.ec.europa.eu/industrial-modernisation

1.3 Target audience

The report aims to provide key market insights for perovskite solar cells and identify key directions for action in order to maintain or build Europe's competitive position on the global market. The report specifically targets the EU, national and regional policy makers and business stakeholders who are currently involved in or consider engaging in cross-regional cooperation mechanisms. The report may also be relevant for other key stakeholder groups including academia, as well as different support structures such as cluster organisations, industry associations and funding providers.

2. Key product facts

In the current section, we provide a brief introduction to perovskite solar cells. We also elaborate on the market potential and the importance of this product for the EU competitiveness.

2.1 Introduction to the product

A perovskite solar cell includes a perovskite structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer[3]. It represents the emerging class of thin-film photovoltaic cells. Perovskite materials are efficient at absorbing light and transporting charges, which are favourable properties for capturing solar power[4].

A distinction needs to be made between perovskite devices as stand-alone cells and perovskites used in combination with other photovoltaic technologies, and specifically perovskites on silicon-based photovoltaics (PV).

Perovskite solar cells as stand-alone cells

Perovskite solar cells represent the fastest-advancing solar technology to date, due to the rapid increase in their efficiency[5], namely from 3.8% in 2009[6] to 22.1% in early 2016[7]. While commercial silicon-based cells have an efficiency of 16–20%, perovskite solar cells could theoretically exceed 30%[8]. Interestingly, these results have been achieved with relatively modest investments in terms of funding, time and research efforts, when compared to decades of research on silicon-based cells.

Unlike silicon-based cells, perovskite cells are soluble in a variety of solvents. They can be easily sprayed onto a surface, similar to inks or paints. That property potentially makes perovskite cells much cheaper to manufacture. It also means that the light-gathering film can be attached to flexible materials, which, in turn, opens up a wide range of new applications going beyond rooftop and solar-farm panels[9]. Examples of possible other applications include smart glass, outdoor furniture, portable devices, and

---

[3] Manser J. S., Christians J. A. and Kamat P.V. (2016) “Intriguing Optoelectronic Properties of Metal Halide Perovskites”, Chemical Reviews, 116 (21): 12956–13008.

[4] Yang Y. and You J. (2017) “Make perovskite solar cells stable”, published in Nature on 11 April 2017, available at: https://www.nature.com/news/make-perovskite-solar-cells-stable-1.21807

[5] Manser J. S., Christians J. A. and Kamat P.V. (2016) “Intriguing Optoelectronic Properties of Metal Halide Perovskites”, Chemical Reviews, 116 (21): 12956–13008.

[6] Kojima A., Teshima K., Shirai Y., and Miyasaka T. (2009) "Organometal Halide Perovskites as Visible-Light Sensitizers for Photovoltaic Cells", Journal of the American Chemical Society,131 (17): 6050–6051.

[7] Yang Y. and You J. (2017) “Make perovskite solar cells stable”, published in Nature on 11 April 2017, available at: https://www.nature.com/news/make-perovskite-solar-cells-stable-1.21807

[8] *Ibid.*

[9] Randerson J. (2017) “Spray on and printable: what's next for the solar panel market?”, The Guardian, 4 May 2017, available at: https://www.theguardian.com/sustainable-business/2017/may/04/solar-renewables-energy-thin-film-technology-perovskite-cells

automotive and other electronic applications[10]. Perovskite solar cells also offer flexibility, semi-transparency, tailored form factors and small weight[11].

Despite their high potential, perovskite solar cells are still in their early stages of commercialisation due to a number of concerns. One of the key concerns relates to their *stability*[12]. The cells currently only function for a few months outdoors, whereas silicon solar panels usually have a working guarantee for at least twenty-five years. Weather changes, and extreme light levels, temperature and humidity all cause deterioration of perovskite cells. Reactions with water form hydrates that alter the structures of the crystals so that they cannot absorb visible light. At the same time, heavy encapsulation to protect perovskite solar cells increases their cost and weight[13].

In the past decade, cell lifetime has been extended from a few minutes to six months. Nevertheless, more work is needed to improve their stability. Experts suggest that within two years, a stability of more than a year can be reached[14].

Another concern relates to the *scaling up potential*. High efficiency ratings have so far been achieved using small cells (<1 cm^2), which is convenient for laboratory testing. However, this scale is reported to be too small to be used in an actual solar panel[15].

Finally, another concern refers to *toxicity*, as some of the breakdown products of perovskite cells are known to be toxic as they use lead. At the same time, researchers are actively working on developing non-toxic substitutes, for example, tin[16].

Nevertheless, perovskite solar cells are still viewed as the photovoltaics technology of the future. Considerable efforts can be observed, aiming to increase efficiency and stability, prolong lifetime and replace toxic materials with safer ones[17].

Perovskites on silicon-based PV

Researchers also explore the benefits of combining perovskites with other technologies, for example, silicon, to create so called "tandem cells"[18]. Tandem cells

---

[10] Transparency Market Research (2015) "Perovskite Solar Cell Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2016 - 2026", available at: http://www.transparencymarketresearch.com/perovskite-solar-cell-market.html

[11] Mertens R., Peleg R. "Perovskite Solar", Perovskite-Info, available at: https://www.perovskite-info.com/perovskite-solar

[12] Yang Y. and You J. (2017) "Make perovskite solar cells stable", published in Nature on 11 April 2017, available at: https://www.nature.com/news/make-perovskite-solar-cells-stable-1.21807

[13] Mertens R., Peleg R. "Perovskite Solar", Perovskite-Info, available at: https://www.perovskite-info.com/perovskite-solar

[14] Yang Y. and You J. (2017) "Make perovskite solar cells stable", published in Nature on 11 April 2017, available at: https://www.nature.com/news/make-perovskite-solar-cells-stable-1.21807

[15] Mertens R., Peleg R. "Perovskite Solar", Perovskite-Info, available at: https://www.perovskite-info.com/perovskite-solar

[16] *Ibid.*

[17] See, for example, CHEOPS, a research project on achieving low-cost, highly efficient perovskite solar cells, co-funded by Horizon 2020; more information available at: http://www.cheops-project.eu/

[18] Mertens R., Peleg R. "Perovskite Solar", Perovskite-Info, available at: https://www.perovskite-info.com/perovskite-solar; perovskite cell combined with bottom cell such as Si or copper indium gallium selenide (CIGS) as a tandem design can suppress individual cell bottlenecks and take advantage of the

are optimised to capture different parts of the solar spectrum, and therefore can achieve even higher efficiencies. The current efficiency of the silicon-perovskite tandem cells developed in the laboratory setting already exceeds 25%[19]. While silicon, for example, absorbs the red part of the spectrum, perovskites tend to absorb blue and green photons. Furthermore, putting a perovskite cell on top of silicon promises to be a relatively cheap process. Tandems also allow perovskites to build on the well-established silicon industry's value chain[20].

With the potential of achieving even higher efficiencies and low production costs, perovskite solar cells have become commercially attractive[21], with some start-up companies already promising the first tandem modules on the market within a year[22].

2.2 Relevance to grand societal challenges

Perovskite solar cells have a potential to increase the efficiency and lower the cost of solar energy. To this end, they contribute to tackling the grand societal challenges related to secure, clean and efficient energy, as well as climate action, environment, resource efficiency and raw materials. After hydro and wind power, solar photovoltaic (PV)[23] energy is the third most important renewable energy source, when it comes to global installed capacity[24].

The European Industrial Initiative on solar energy[25] has set a strategic objective to improve the competitiveness and ensure the sustainability of PV technology and to facilitate its integration into the electricity grid. As the cost of the technology continues to decrease, while electricity prices remain high, PV is predicted to earn a competitive position in the energy sector[26].

2.3 Market potential

There are several companies that sell chemicals and materials for perovskite solar cell-related R&D. However, **at this point, no company offers perovskite modules for sale**. A few companies announced that they are actively working on launching the production of perovskite modules on a commercial basis (for example, Oxford

---

complementary characteristics to enhance the efficiency. From Rühle S. (2017) "The detailed balance limit of perovskite/silicon and perovskite/CdTe tandem solar cells", Physica Status Solidi (a) 214, no. 5 (2017).

[19] Service R.F. (2016) "Perovskite solar cells gear up to go commercial", Science, 9 December 2016, Vol. 354, Issue 6317, pp. 1214-1215; available at: http://science.sciencemag.org/content/354/6317/1214.full

[20] *Ibid*.

[21] Wang U. (2014) "Perovskite Offers Shot at Cheaper Solar Energy", The Wall Street Journal, 28 September 2014

[22] Randerson J. (2017) "Spray on and printable: what's next for the solar panel market?", The Guardian, 4 May 2017, available at: https://www.theguardian.com/sustainable-business/2017/may/04/solar-renewables-energy-thin-film-technology-perovskite-cells

[23] Around 85% of all new PV systems, though, are based on crystalline silicon technology, which is now mature. Source: https://setis.ec.europa.eu/european-industrial-initiative-solar-energy-photovoltaic-energy

[24] https://setis.ec.europa.eu/european-industrial-initiative-solar-energy-photovoltaic-energy

[25] *Ibid*.

[26] *Ibid*.

Photovoltaics[27] in the United Kingdom, and Saule Technologies[28] in Poland)[29]. The actual commercialisation of perovskite photovoltaics is likely to happen only by 2019–21[30].

The overall PV market promises to exhibit continuous growth and offers substantial business opportunities. It has been estimated that in 2030, PV could supply up to 15% of the overall electricity demand in the EU, which is about 7 times more than today[31]. The global cumulative installed capacity of solar PV electricity systems is predicted to be more than triple from 2013, reaching over 440 GW[32].

In this context, experts see a market potential for both stand-alone perovskite cells and tandem cells, given the abovementioned stability and toxicity issues get solved. The perovskite solar cells promise to be highly competitive. By 2025, the perovskite solar cell market is expected to reach 182 million EUR[33].

Stand-alone perovskite solar cells can be made in different shapes and can be put on different carriers. That opens up a wide range of potential application areas, making it possible to produce customised solutions (while the flexibility of, for example, silicon-based solar cells is highly limited). Experts suggest that this application area represents a niche market, for example, for the automotive sector such as car roofs, dashboards or windows (since perovskites can be semi-transparent). Here, an expected lifetime is 4-6 years, which is considerably shorter than the one for the solar farm panels (20 years) that tandem applications currently target, and which can be achieved faster than the stability requirements for solar farm tandem applications (see below). As a result, ***in some niche markets, the stand-alone perovskite products might get introduced faster than tandem modules***.

Perovskites in tandem cells are, in turn, predicted to become a larger industry, as a result of their anticipated massive application in rooftop panels and solar farms. Some experts suggest that by 2030, all silicon-based cells will have perovskites embedded into them. However, perovskites are not likely to penetrate the whole silicon-based PV market at once. If the proper framework is set in place (and particularly the measures

---

[27] Oxford PV plans to combine perovskites with silicon to produce tandem cells for rooftop panels.

[28] Saule Technologies is a Polish start-up that designed a low-temperature method for manufacturing flexible photovoltaic perovskite cells. The company is working on the development of a flexible and semi-transparent cell based on PET foil. Source: https://www.perovskite-info.com/saule-technologies; Saule Technologies reported having a working prototype perovskite module that can power small electronic devices. Source: Jacoby M. (2016) "The future of low-cost solar cells", Chemical & Engineering News, Volume 94, Issue 18 (2 May 2016), pp. 30-35

[29] Jacoby M. (2016) "The future of low-cost solar cells", Chemical & Engineering News, Volume 94, Issue 18 (2 May 2016), pp. 30-35; this conclusion has also been confirmed by our interviewees

[30] Lux Research, cited in Jacoby M. (2016) "The future of low-cost solar cells", Chemical & Engineering News, Volume 94, Issue 18 (2 May 2016), pp. 30-35; this conclusion has also been confirmed by our interviewees

[31] European Commission (2015) "Perspectives on future large-scale manufacturing of PV in Europe", JRC Science and Policy Report

[32] *Ibid*.

[33] Reportlinker (2015) "Perovskite Photovoltaics 2015-2025: Technologies, Markets, Players", published on 22 December 2015, available at: http://www.prnewswire.com/news-releases/perovskite-photovoltaics-2015-2025-technologies-markets-players-300196713.html

aiming to protect on a longer term Europe's investment in cutting edge innovations), a few hundred MWp or few GWp could be produced in the next 5-10 years in Europe[34].

To conclude, both stand-alone and tandem developments have to deal with high levels of uncertainty due to the early stages of development of the perovskite solar cell technology.

2.4 Importance for the EU competitiveness

More renewable energy can enable the EU to cut greenhouse emissions and make Europe less dependent on imported energy. Furthermore, boosting the renewables industry can also encourage technological innovation and create new jobs in Europe[35].

For perovskites on silicon-based PV, there are still equipment facilities present in Europe (e.g. SolarWorld AG or Q-Cells). However, if the adequate framework[36] is not set in place within the coming 5 years, particularly the measures ensuring long-term protection of Europe's investment in cutting edge innovations, the capacity to leverage these existing facilities to market perovskite-based PV devices is likely to be lost to the advantage of competitors from Asia or the United States. Furthermore, there is a risk that once tandem modules become a standardised commercial product, their production will move to Asia, similarly to what happened to silicon-based module production a few years ago.

At the same time, perovskite solar cells offer an opportunity for Europe to create *new* manufacturing facilities. In case of perovskites on silicon-based PV, it could be possible to develop new superior manufacturing facilities with state-of-the art efficiencies exceeding the possibilities offered by the existing manufacturing facilities, located both in Europe and other parts of the world.

In case of stand-alone perovskite modules, the customisation opportunities make it attractive to produce them locally, with sufficient margins (in contrast to highly standardised products), which opens up promising business avenues for European players.

[34] Based on interviews with experts

[35] https://ec.europa.eu/jrc/en/research-topic/renewable-energy

[36] The framework here refers to the whole business environment in which the EU companies need to operate, including tax regime, possible subsidising of electricity and other costs, access to low interest investment, protection of the EU market from the non-EU products (e.g. with heavier duty taxes), protection from Intellectual Property (IP) looting etc. The latter aspect, namely lack of protection on the IP side, was emphasised by the stakeholders as being particularly harmful for the EU business climate (which is reported to be constantly damaged by the non-EU competitors profiting from the EU-made IP).

3. Value chain analysis

The current section addresses the value chain structure, key players, as well as the key identified constraints.

Stand-alone perovskite solar cells and perovskites on silicon-based PV each imply their own specific value chain. Both value chains, however, are not yet fully established, with large-scale manufacturing and all the subsequent components still being at the early development stage. While for stand-alone perovskite solar cells, a fundamentally new value chain needs to be created, for perovskites used in tandem with silicon, it is possible to partially build on the already existing value chain. Once fully developed, the value chains will connect the key players from multiple EU MS.

3.1 Value chain structure

Figure 3-1 presents the value chain structure for the modules of stand-alone perovskite cells. It encompasses three dimensions: (1) value-adding activities; (2) supply chain; and (3) supporting environment.

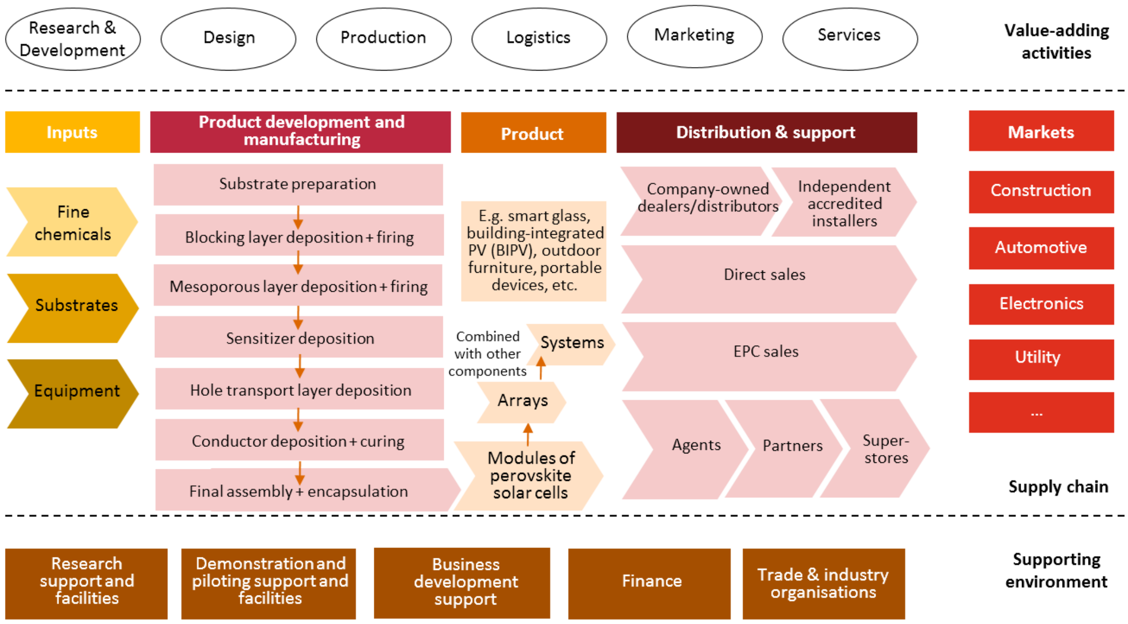


FIGURE 3-1: Value chain for the modules of stand-alone perovskite solar cells[37]

Six key value-adding activities can be identified, ranging from research & development to the provision of after-sales services such as operation, maintenance and repair.

[37] Product development and manufacturing elements are based on Ibn-Mohammed T. et al. (2017) “Perovskite solar cells: An integrated hybrid lifecycle assessment and review in comparison with other photovoltaic technologies”, available at: https://www.researchgate.net/publication/317569861_Perovskite_solar_cells_An_integrated_hybrid_lifecycle_assessment_and_review_in_comparison_with_other_photovoltaic_technologies; distribution and support elements are based on Frost and Sullivan (2014) “Global Solar Power Market”, available at: https://www.slideshare.net/FrostandSullivan/global-solar-power

Although the value chain activities are presented as a linear chain, in practice, however, they often are intertwined, with multiple feedback loops embedded into the innovation trajectory (e.g. with input from market intelligence and/or services feeding back to R&D, design and production). The value adding activities are thus organised in a non-linear fashion as a cluster of multiple interrelated and partially parallel activities.

The supply chain dimension highlights the key steps of the supply chain from the input/output point of view. The main inputs of the supply chain include fine chemicals (including perovskites and other materials), substrates (e.g. coated glass, steel plates and flexible substrates) and equipment (e.g. for atomic layer deposition systems, encapsulation etc.).

The manufacturing process consists of several distinctive steps, starting from substrate preparation, and ending with final assembly and encapsulation (the typical steps[38] are presented in Figure 3-1). These steps result into the modules of perovskite solar cells, which at this point have only been produced in a laboratory setting, and are of size that is too small for commercial application. For example, the size of modules developed by imec is 15 x 15 cm^2, with an intention to expand to 30 x 30 cm^2. Nevertheless, these sizes are among the largest that currently exist in the world. There are only a few research groups working on it at the moment. For the actual commercial use, the size of at least 1 m^2 would be required. The produced modules could then be assembled into arrays, and when combined with other necessary components, form the final systems for the end user.

When addressing marketing, distribution and services, we have visualised the key channels of the overall solar power market (which are likely to hold also for this specific product). This part of the value chain, however, does not yet exist in practice for perovskite solar cells, and any related remarks thus have a theoretical nature.

As outlined before, the end product can be used in many different markets, including (but not limited to) construction, automotive, electronics and utility. A high flexibility offered by perovskite solar cells makes them potentially applicable in a wide range of areas[39]. However, the related developments are still at an early stage and take place in a laboratory setting.

Finally, the supporting environment consists of a wide range of organisations that influence and support the supply chain, including R&D institutions, organisations offering support with demonstration and piloting, as well as business development support, financial institutions (investors), and trade & industry organisations.

Figure 3-2 presents the value chain structure for the modules of perovskites on silicon-based PV. This structure heavily resembles the value chain of the silicon-based modules, and leverages on the existing well-established industry. Therefore, it will not

---

[38] Although different processes are used, and specific steps may vary.

[39] It is important to note that flexible silicon modules also exist; however, their commercial application is reported to experience challenges (e.g. due to the need for heavy encapsulation that jeopardises flexibility). Amorphous silicon-based cells are already used for multiple indoor applications.

be examined in more detail in the context of this report. The key differences when compared with the value chain for stand-alone perovskite solar cells, include inputs, steps of the manufacturing process, end products and targeted markets.

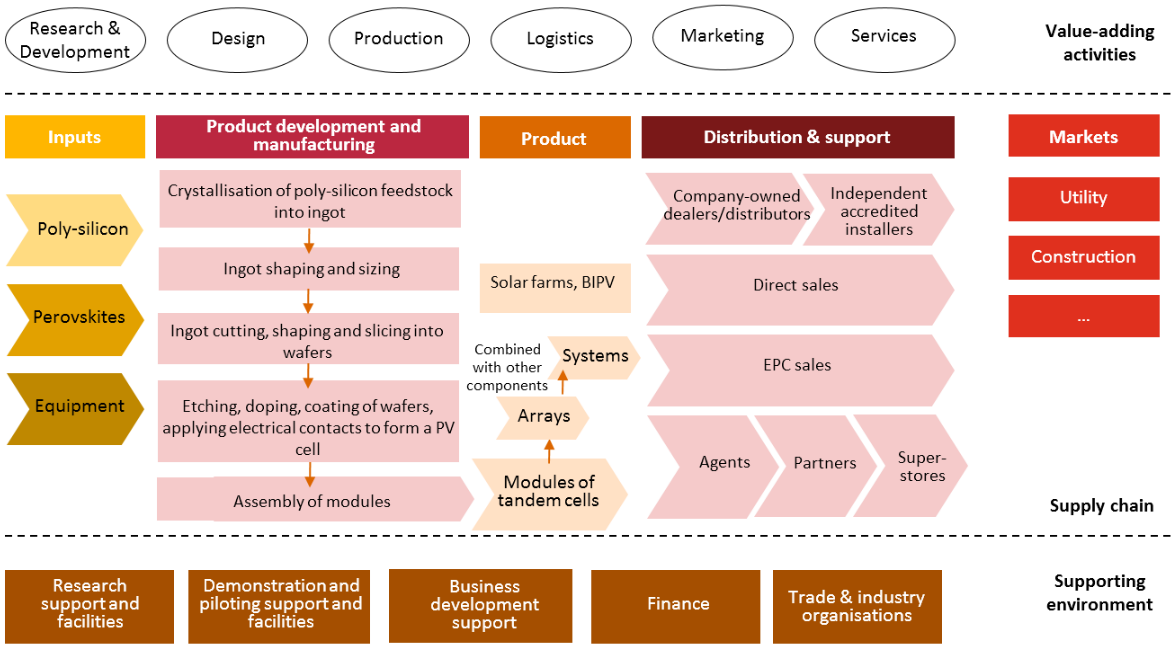


FIGURE 3-2: Value chain for the modules of tandem cells[40]

This value chain can thus be created by advancing the existing value chain of silicon-based PV. Oxford PV aims to start augmenting existing silicon-based solar factories both in Europe and outside, and to gradually roll it out to most silicon-based solar factories. This change is expected to be disruptive for the industry, since it leads to a substantial increase in efficiency, which can hardly be obtained by incremental improvements of the silicon-only PV.

3.2 Key players

In general, the key actors of the perovskite solar cell market can be clustered into the following main groups:

- ***Research organisations and technology suppliers***: in laboratory settings, the solar cells are being created by a few research groups located in different parts of Europe. Most of the research groups use their own equipment, not suitable for large-scale production. Special attention is paid to exploring which configurations lead to the best performance, including efficiency, stability and other functionality requirements.
- ***Fine chemical suppliers***: some of them are small companies, including early-stage start-ups, specialising in the development of specific materials that form the core of the solar cells; others are large

[40] Product development and manufacturing elements are based on "The China Solar Energy Market", available at: http://slideplayer.com/slide/1619375/

companies, for which this activity represents part of their wide portfolio of activities; these organisations typically provide materials used for the non-core parts of the solar cells, for example, for the elements used to extract the charges that are generated by the solar cells. At this point, the volumes are still relatively small and are measured in kilos.

- ***Substrate suppliers***: these organisations provide the substrates or carrier materials used for the production of perovskite solar cells. The most popular carrier material is glass (or silicon in the case of tandem developments); other materials include, for example, plastic foil and steel plates.
- ***Equipment manufacturers***: this group refers to large companies producing equipment for manufacturing the elements going into and around the solar cells, for example sputtering and atomic layer deposition systems, encapsulation.
- ***Module developers***: these are typically research organisations bridging academia and industry and developing module process technology; currently, there are a few research groups working on cell optimisation; however, it is being done in a laboratory setting on a small scale, not leading to an actual commercial product.
- ***Large-scale manufacturers***: currently, this step has not yet been reached on a commercial basis. Some companies, however, consider launching these activities in the future.
- ***Module integrators into specific application areas*** (e.g. roof tops, facades, windows, cars etc.): currently, this step has not yet been reached on a commercial basis.
- ***Installation companies:*** this step has not yet been reached on a commercial basis.

The Table below presents some illustrative names of relevant players. Some of the listed companies have headquarters outside the EU; nevertheless, these companies were also included due to their active presence on the European market. The list should by no means be considered exhaustive.

TABLE 3-1: Mapping of key market players[41]

Organisation types/Value-adding activities	**Research & development**	**Design & prototyping**	**Production**	**Logistics**	**Marketing**	**Services**
Research organisations and technology suppliers	CSEM[42] (Switzerland) Tyndall National Institute (Ireland) Università degli Studi di Roma 'Tor Vergata'/CHOSE	CSEM (Switzerland) Tyndall National Institute (Ireland) Università degli Studi di Roma 'Tor Vergata'/CHOSE		*This part of the value chain has not yet been established.*		

[41] The list of organisations presented in this table should not be considered exhaustive. It is rather an illustrative representation of organisations currently active in the value chain of perovskite solar cells (either stand-alone or tandem).

[42] Centre Suisse d'Electronique et de Microtechnique (Swiss Center for Electronics and Microtechnology)

Organisation types/Value-adding activities	Research & development	Design & prototyping	Production	Logistics	Marketing	Services
	(Italy) Solliance[43] (Netherlands) EPFL (Switzerland) Fraunhofer (Germany) University of Oxford (United Kingdom) Salford University (United Kingdom) Aalto University (Finland) EMPA (Switzerland) Flamac (Belgium) Hasselt University (Belgium) AMBER (Spain) EURECAT Technology Centre (Spain) IMO-IMOMEC (Belgium) Josef Stefan Institute (Slovenia)	(Italy) Solliance (Netherlands) EPFL (Switzerland) Fraunhofer (Germany) University of Oxford (United Kingdom) Salford University (United Kingdom) Aalto University (Finland) EMPA (Switzerland) Flamac (Belgium) Hasselt University (Belgium) AMBER (Spain) EURECAT Technology Centre (Spain) IMO-IMOMEC (Belgium) Josef Stefan Institute (Slovenia)				
Fine chemical suppliers	Dycotec Materials (United Kingdom) Dyenamo (Sweden) MERCK[44] (United States) DSM (Netherlands) Mitsubishi Chemical Europe[45] (Germany/Japan) Greatcell Solar[46] (Australia) TCI Europe (Belgium/Japan) Strem Chemicals[47] (United States)	Dycotec Materials (United Kingdom) Dyenamo (Sweden) MERCK (United States) DSM (Netherlands) Mitsubishi Chemical Europe (Germany/Japan) Greatcell Solar (Australia) TCI Europe (Belgium/Japan) Strem Chemicals (United States) Umicore				

[43] Solliance is a partnership of R&D organisations from the Netherlands, Belgium and Germany

[44] With production facilities also in Europe

[45] *Ibid.*

[46] Greatcell Solar Limited, formerly Dyesol Limited, is engaged in the up-scale and commercialisation of perovskite solar cells through the provision of a range of products and services, including materials, consulting, research and development (R&D), collaborative product development, licensing, training, and turnkey manufacturing and laboratory facilities. It operates in Australia, Asia, Europe and North America. Source: http://www.reuters.com/finance/stocks/companyProfile?symbol=DYSOY.PK

Organisation types/Value-adding activities	**Research & development**	**Design & prototyping**	**Production**	**Logistics**	**Marketing**	**Services**
	Umicore (Belgium)	(Belgium)				
Substrate suppliers	Corning[48] (United States) AGC Glass Europe[49] (Netherlands/ Japan) Tata steel (Netherlands) Saint-Gobain (France)	Corning (United States) AGC Glass Europe (Netherlands/ Japan) Tata steel (Netherlands) Saint-Gobain (France)				
Equipment manufacturers	Meyer Burger (Switzerland) Von Ardenne (Germany) Applied Materials (United States) Evatec (Switzerland) BENEQ (Finland) Picosun (Finland) ASM MicroTechnology (Finland) Oxford Instruments (United Kingdom) AIXTRON (Germany)	Meyer Burger (Switzerland) Von Ardenne (Germany) Applied Materials (United States) Evatec (Switzerland) BENEQ (Finland) Picosun (Finland) ASM MicroTechnology (Finland) Oxford Instruments (United Kingdom) AIXTRON (Germany)				
Module developers	CSEM (Switzerland) imec (Belgium) Fraunhofer (Germany) CHOSE (Italy)	CSEM (Switzerland) imec (Belgium) Fraunhofer (Germany) CHOSE (Italy)				
Large-scale manufacturers[50]			Solaronix (Switzerland) Oxford PV[51] (United Kingdom) Saule Technologies[52] (Poland) Greatcell Solar[53] (Australia) TCI Europe[54]			

[47] With production facilities also in Europe
[48] *Ibid.*
[49] *Ibid.*
[50] These companies are currently looking into the possibility of organising a large-scale production of perovskite solar cells (some as stand-alone, others as tandem cells); however, no actual manufacturing takes place at this moment. Some other companies looking into this include LG, Mitsubishi, BASF, MERCK, EDF, Total, DSM.
[51] Start-up that looks into the ways of launching large-scale manufacturing of tandem cells
[52] start-up that looks into flexible (plastic) module manufacturing
[53] Material supplier, plans to move down the value chain

Organisation types/Value-adding activities	Research & development	Design & prototyping	Production	Logistics	Marketing	Services
			(Belgium/Japan)			
Module integrators		Onyx Solar[55] (Spain)				
Installation companies	*This part of the value chain has not yet been established.*					

The main European players are reported to work in collaboration with each other at different levels, mainly via Horizon 2020 projects (for example, CHEOPS project[56]).

For stand-alone perovskite solar cells, there are only a few start-ups currently looking into their production on a commercial basis. In case of perovskites on silicon-based PV, manufacturing can be performed by companies already producing silicon-based PV. Many of these companies, however, are located in Asia[57], where the framework conditions are reported to be more favourable (e.g. due to governmental subsidies, tax reductions etc.).

3.3 Key constraints

Several key constraints have been identified in the value chain for perovskite solar cells, relevant to both stand-alone and tandem solar cells.

Low large-scale manufacturing capacity in Europe

Europe is currently lacking manufacturers who would be able to bring all the abovementioned elements together. This can be partially explained by the fact that in the last few years, many companies involved in solar cells business have been pushed out of the market by strong competition from Asian counterparts. Interestingly, the manufacturing process of solar cells is fully automated, with only a few people involved. That makes the labour cost component relatively insignificant. What is reported to be specifically favourable in Asian countries are the framework conditions created for companies by local government (e.g. subsidies, tax reductions and similar measures).

A promising example refers to Oxford PV that recently acquired a former photovoltaic pilot facility in Germany. The intention is to launch large-scale manufacturing activities in Europe. That facility aims to start manufacturing products of 1m^2 in size. That can be considered the most advanced commercial development of perovskite solar cells so far in Europe. This facility could take a role of integrator of the components mentioned above. However, more such companies would be needed in Europe.

[54] Considers scaling up the manufacturing process of perovskite solar cells
[55] Onyx is exploring the possibilities of the technology on a small demonstration basis specifically for BIPV (building-integrated photovoltaics).

[56] http://www.cheops-project.eu/

[57] Between 2010 and 2014, many EU-based solar cell and module manufacturers moved to Asia.

Significantly less stringent safety requirements in Asian countries

Experts report that, for example, in China, many safety requirements related to the production process (i.e. process safety management) that would be obligatory in Europe do not get properly followed. That allows local companies to save time and costs in case of errors (e.g. by minimising the need to put the production process on hold to correct an error). Although it should by no means be viewed as a good practice example for European companies, it makes it more challenging for European companies to compete with their Asian counterparts.

The market pull still needs to be initiated

The development of the associated products is currently driven predominantly by technology push. Strong political backing is needed to encourage customers (both end-user companies and end-users themselves) to use renewable energy products, and, in this case, specifically solar energy products.

There is a need for incentives for the market to take it up, for example, by pushing the electrification of mobility (including solar powered cars[58]), encouraging green buildings (energy-efficient, energy-neutral and energy generating) and similar initiatives. stimulating the use of solar power It needs to be done by the government more explicitly, by raising strong awareness in society about the benefits, offering financial incentives to do so and (in some case) making it compulsory to use renewable energy options.,

With that in place, products based on perovskite solar cell technology are expected to naturally conquer a highly competitive market position. That could be achieved based on the benefits offered by perovskite solar cells, namely higher efficiency, lower costs, flexibility and customisation.

[58] https://www.dasolar.com/solar-energy/solar-powered-cars

4. Analysis of the EU competitive positioning

The current section elaborates on the strengths and potential of the EU regions, key risks and challenges, as well as the opportunities for the EU regions to strengthen their competitive positioning.

4.1 Strengths and potential of the EU regions

In this sub-section, we address the potential for developing large-scale manufacturing in Europe, expected Europe's global position in 2030, key competitive advantages of Europe, as well as regions that could be in the lead.

Potential for developing large-scale manufacturing in Europe

Europe is suggested to be in a good position to produce perovskites on a large-scale basis. For that, the perovskite technology has to deliver its promises related to high efficiency, low production cost and stability. The toxicity issues also need to get solved. Besides, a proper political framework needs to be established, particularly the measures ensuring long-term protection of Europe's investment in cutting edge innovations, as outlined above. Europe also needs to constantly keep innovating, to maintain its technological leadership position.

Furthermore, experts suggest that for perovskites to make a true impact for Europe, there is a need to develop products that could be used for *massive power generation*, measured in gigawatts of power. To this end, ***the use of perovskites in tandem with silicon-based PV for solar farm applications represents a particularly promising market***. This focus would justify a need to create a large production capacity in Europe.

For perovskites on silicon-based PV, there are still equipment facilities present in Europe. For example, SolarWorld (Germany) and Q-Cells (Germany; owned by South Korea) operate in Europe. As mentioned above, so far, the activities of Oxford PV represent the most advanced attempt to commercialise this technology and launch large-scale manufacturing. At the same time, similar developments currently take place also in the United States, Japan, Korea and other countries.

Stand-alone perovskite solar cells also open up multiple business opportunities for Europe, especially when it comes to customisation. Their flexibility makes it possible to manufacture tailor-made products, based on customer demand and preferences. That, in turn, makes Europe a sensible choice for manufacturing the products for the European market. At the same time, the Asian and American markets are likely to be better served by local companies, given the abovementioned need for geographical proximity to the customer.

The abovementioned business opportunities make it an attractive field for SMEs, as the operations related to cutting, coating and assembly can be done by small companies.

Europe's global position in 2030

So far, this technology has already demonstrated high efficiency, and the results are constantly improving. These results have been achieved with a relatively modest financial support from the government.

With the stability issue solved, the toxicity levels proven to be acceptable and the economic rationality demonstrated at large scale, it could thus be an established technology on the market, stemming from collaboration of small and large companies. Some experts predict that by 2030, all silicon-based solar cells will have perovskites on them. There is a potential for Europe to play a central role in this development.

Key competitive advantages of Europe

The key competitive advantages include the following:

- **Strong technical knowledge and history of PV technology** in Europe, especially when it comes to research, material and equipment manufacturing;
  - Europe is reported to have the best research capacity in this field (this capacity is not present in China, for example).
  - While comparable efforts can be observed in the United States, they are reported to be at much earlier stages of development.
  - The most advanced companies in the field of material and equipment manufacturing are reported to be located in Germany.
  - In terms of skills and expertise, Europe can be considered the strongest region in the world for PV development.
  - At the same time, the production capability of Europe was weakened in the past years, due to force competition from Asia. If the PV industry is not given a reboost in the coming years, then this capability is likely to be completely lost.
- **Respect for confidentiality issues**: in Asia, there is reported to be a greater risk of information leaks related new technological developments (e.g. better ways of producing) through employees that move from one company to another or via Intellectual Property (IP) sharing duties imposed on the EU companies operating in China. In Europe, experts report observing more respect to these issues from the employee side.

Regions that could be in the lead

Experts report that the value chain activities, and primarily research & development, are currently organised not at the level of specific regions, but as **activities of individual actors spread across diverse EU regions**. The most prominent research groups can be found in countries like Germany, Belgium, Netherlands, Switzerland, Ireland, United Kingdom, Italy, Spain, and Finland.

The abovementioned research groups often work in collaboration with each other, as well as with related companies, both small and large. Solliance[59] is an example of such

[59] http://solliance.eu/

a collaborative effort. It is a partnership of R&D organisations from the Netherlands, Belgium and Germany, working in thin film photovoltaic solar energy (TFPV). Various state-of-the-art laboratories and pilot production lines are jointly used for dedicated research programs, which are executed in close cooperation with the solar business community.

4.2 Key risks and challenges

The key risks and challenges include:

- **Need for perovskite technology to demonstrate low cost**: low cost potential needs to be demonstrated based on the actual pilot line production, not based on theoretical estimations;
- **Need for perovskite technology to demonstrate stability**: solving the stability-related issues will take time, and it poses a technological risk.
- **Need for perovskite technology to demonstrate low/acceptable toxicity**: currently lead is used in PV for stability. It is exempt from REACH. If, however, in the future, lead will get banned for use by regulation, it would jeopardise the existence of the whole perovskite solar cells industry.
    - Multiple alternatives to lead are currently being explored, but so far, none of them proved to be fitting. At the same time, existing research suggests that perovskite solar cells contain a relatively insignificant amount of lead[60].
    - Interestingly, a preliminary analysis showed that the layers of lead used in perovskite solar cells are so thin, that the energy needed to produce the solar cell modules would emit more lead than the modules themselves[61].
    - Hardly any research has been done on whether the perovskite solar cells can be recycled. A complete lifecycle needs to be taken into account, going beyond the content of the product itself. Specifically, it is crucial to look at what is needed to manufacture the product, and whether and to what extent it can be recycled after its use.
    - The results of the life cycle assessment could be decisive for the future of the industry. In case of a positive outcome, they could be used for attracting more governmental support and acceptance by consumers. However, in case of obvious risks, companies may prefer not to disclose the actual data.
- **Need for new regulation and standards** to accommodate the emerging application areas (e.g. perovskites in car windows and building walls): these standards and regulations need to be ready in time in order not to slow down the development of the market.

[60] The amount of lead in a single car battery is enough for hundreds of square metres of perovskite solar cells. Source: https://www.theguardian.com/sustainable-business/2017/may/04/solar-renewables-energy-thin-film-technology-perovskite-cells

[61] Based on interviews with experts; An example of efforts to perform such an analysis can be found within CHEOPS project (funded by Horizon 2020). The final results of this analysis are expected to become available in 2018.

  - Some initiatives have already been launched, for example, standards for thin-film PV, however they are of a broader orientation and may not be sufficient when it comes to specific application areas.
- **Risk of not acting fast enough and thereby losing the leading position**: at this point, Europe is reported to be ahead of the rest of the world when it comes to the development and commercialisation of perovskite solar cells. At the same time, active attempts to develop the abovementioned activities also take place in the United States, Asia and Australia.
- **Risks and challenges related to Intellectual Property rights**: there is a need to secure granted and defendable patent portfolio for European companies. Asian companies tend to regularly copy technologies developed in Europe. Prosecution is typically a costly procedure, is therefore especially challenging for small companies. As a result, the R&D efforts of the EU risk to be freely capitalised by Asian companies.
- **Need for support to PV industry from policy makers at all levels**: stakeholders suggest that once the PV industry gets the top priority at the policy level, the situation regarding the development and commercialisation of perovskite solar cells is likely to improve dramatically. Some positive developments for PV industry can already be observed. For example, Germany's Bundesrat has passed a resolution to ban the internal combustion engine starting in 2030[62]. In line with these developments, Volkswagen AG, for example, plans to roll out four affordable electric vehicles in the coming years[63].

4.3 Opportunities for the EU regions

There is a need to build on strong points of each region (smart specialisation) and create a pan-European value chain. Stakeholders report, however, that currently, it would be too early to talk about the strong points of specific regions, as the key players are scattered across different EU regions. They typically get engaged into the value chain via joint collaborative efforts that often are of cross-regional nature.

Specifically, this area opens up opportunities for SMEs and offers them a prominent role in the value chain, especially when it comes to the manufacturing of customised products. SMEs need to be supported in terms of getting acquainted with the value chain, the opportunities it provides and the roles they could play in it. In this context, the regional dimension could play a prominent role. Specifically, regional SME support centres could be established in a select number of regions, active in this domain. These SME support centres could be united in a network that would be regularly exchanging expertise and share access to facilities.

There is a clear need for a fully established production line that could demonstrate every step of the manufacturing process and calculate every cost associated with it in a real production environment. With such a pilot line, Europe

[62] https://www.forbes.com/sites/bertelschmitt/2016/10/08/germanys-bundesrat-resolves-end-of-internal-combustion-engine/#5690751560bd

[63] https://www.bloomberg.com/news/articles/2017-04-18/vw-plots-tesla-attack-with-line-of-four-affordable-electric-cars

would be the first in the world. It has to be initiated soon, so that the pilot line is ready in the next 3-5 years. Otherwise, the momentum will most likely be lost, and other regions of the world will have established it themselves. This pilot line would have a pan-European orientation, engaging key players from different EU regions.

5. Policy implications

The current section aims to present specific policy recommendations on what needs to be done in order to strengthen the EU competitive position regarding this product in the coming years, and specifically on how to enable European industry to move to the higher end of the value chain. We elaborate on measures with both the immediate and longer-term focus.

5.1 Measures with immediate focus

The following measures with immediate focus have been identified:

- **Continuing investments in research (both basic research and research targeted at the highest TRL levels):**
  - Since this area rapidly evolves, the EU funding for research needs to be continuously supported. Horizon 2020 and the subsequent framework programmes play a central role in this context. For Europe to be able to keep its competitive position, it is vital not only to make sure that the current R&D developments reach the market, but also that it keeps innovating and improving what has been achieved so far.
  - Besides basic research, dedicated funding should also be allocated to the demonstration of integrated production capabilities, by means of dedicated pilot line projects (as will be outlined below).

- **Maximising SME engagement in development and commercialisation activities:**
  - There is a need to overcome the short-term orientation of SMEs and engage them in activities with a longer-term focus (at least 3-5 years ahead).
  - SME engagement could be stimulated by initiating support centre projects for SMEs, for example, in the context of Horizon 2020 or COSME programmes. Such projects would explicitly target SMEs and offer guidance, coaching and business development support.

- **Developing a fully operational pilot line:**
  - The support to creating dedicated pilot lines needs to be continued. The process of applying for funding, however, needs to be significantly accelerated, in order to stay ahead of the rest of the world.
  - So far, the focus of existing pilot lines has mainly been on fundamental research and initial testing.
  - There is a need to demonstrate the feasibility of every step of the production process and calculate every cost associated with it in a real-life production environment. For that, a fully operational pilot line needs to be established. With such a pilot line, Europe would be the first in the world.

- Such a project could be incorporated into the Work Programme of Horizon 2020. The pilot line needs to be ready in the next 3-5 years in order not to lose the momentum.
- A particular emphasis needs to be given to the dissemination of obtained results. The project participants need to be obliged to report data relevant for a full life cycle assessment.

- **Developing standards for testing stability:**
  - All involved parties should be obliged to report stability data exhaustively. Only through strict and systematic measurements is it possible to observe how modifications make these solar cells more stable. Publications should include details of the testing environment (e.g. humidity, temperature and gas flow), as well as information about encapsulation and light exposure, among other measures[64].

5.2 Measures with longer-term focus

The following measures with longer-term focus have been identified:

- **Creating new manufacturing facilities in Europe**:
  - For perovskites on silicon-based PV, it is possible to develop new superior manufacturing facilities that would allow having state-of-the art efficiencies. These new manufacturing facilities would thereby exceed the possibilities offered by existing manufacturing facilities located both in Europe and other parts of the world.
  - For that, the financial support of regional, national and/or the EU governments would be needed (e.g. regional/national support including structural funds for example, European Investment Bank loans, European Fund for Strategic Investment or other instruments),.

- **Continuing support by policy makers at all levels:**
  - Policy makers play a key role in creating a favourable environment for the development and uptake of solar cells in general, and perovskite solar cells in particular. There is a need for putting a stronger political emphasis on the importance of solar energy and the opportunities the related technologies bring to society.
  - With a stronger political will and incentives from governments at all levels, the consumer interest in these products could be boosted, which creates a wide range of promising business opportunities for Europe.
  - Specific examples could be obliging house builders to incorporate solar panels into every new building or stimulating car manufacturers and consumers to switch to electric cars. The solutions offered by these new

[64] Yang Y. and You J. (2017) "Make perovskite solar cells stable", published in Nature on 11 April 2017, available at: https://www.nature.com/news/make-perovskite-solar-cells-stable-1.21807

technologies also need to be made appealing for consumers and with clear economic benefits.

- **Creating favourable framework conditions for European companies:**
    - The Asian competitors are reported to be actively supported by the local government using multiple means, including reduction of electricity costs, lower taxes, access to low interest investment, subsidies allowing to sell their products on the EU market below their production cost, IP looting etc., all aiming at getting a stronger competitive position on the market of PV devices and enjoying the benefits of the EU funded R&D investments.
    - In addition, their production process is associated with considerable environmental pollution that would not be acceptable in Europe.
    - As a possible retaliatory measure, Europe could introduce environmental or other types of custom duties for Asian products, to make them less competitive on the European market and thereby re-establish a fair level playing field.

- **Offering state-of-the-art education and training:**
    - Special attention needs to be paid to training, in order to ensure the availability of skilled workforce in Europe.
    - There is a need for exposing students to work experience and real manufacturing facilities during their education.
    - One way of improving the quality of (technical) education and for better preparing students for the future workplace, is to replicate real-world situations in the classroom. This principle lies at the core of a 'challenge-driven' university model (see NESTA, 2016[65]), where students work on difficult problems and challenges for which there are no established answers. This approach allows engineering students to contextualise their theoretical learning in relation to how it would be useful in the world around them[66].
    - The new education systems should focus not exclusively on providing new knowledge, but also (and particularly) on training the ability of students to constantly update their knowledge (learning to learn), question existing knowledge, generate knowledge themselves and collectively, in a broader community[67].

---

[65] Mulgan G., Townsley O., Price A. (2016) "The challenge-driven university: how real-life problems can fuel learning", NESTA paper, available at: https://www.nesta.org.uk/sites/default/files/the_challenge-driven_university.pdf

[66] Based on the contributions of PwC NL to "Talent for Europe: Towards an agenda for 2020 and beyond", February 2017, developed together with empirica in the context of "Leadership skills for the high-tech economy" project for EASME/DG GROW of the European Commission

[67] For more detail, the reader is advised to consult the Final Report of PwC (2016) "Vision and Sectoral Pilot on Skills for Key Enabling Technologies", developed for DG GROW of the European Commission

Annex A: List of interviewees

Table A-1: Overview of interviewed stakeholders

Nr	Name	Position	Organisation	Country	Stakeholder type
1	Dr. Tom Aernouts	R&D Leader Thin Film Photovoltaics group	imec	Belgium	Research organisation
2	Dr. Sylvain Nicolay	Head of coating section PV, coordinator of CHEOPS	CSEM, Centre Suisse d'Electronique et de Microtechnique (Swiss Center for Electronics and Microtechnology),	Switzerland	Research organisation
3	Prof. Martyn Pemble	Stokes Professor of Materials Chemistry	School of Chemistry and Tyndall National Institute, University College Cork	Ireland	University
4	Prof. Henry Snaith	Co-Founder and Chief Scientific Officer	Oxford PV	United Kingdom	SME
5	Mariska de Wild-Scholten	Expert in Life Cycle Assessment of Photovoltaics	Smart Green Scans	Netherlands	SME

Acknowledgements

We would like to thank all the interviewees for their time and valuable inputs. We specifically highly appreciate the contributions of Kristian Storm (Research Institutes of Sweden) and Michael Johnson (Skåne European Office).