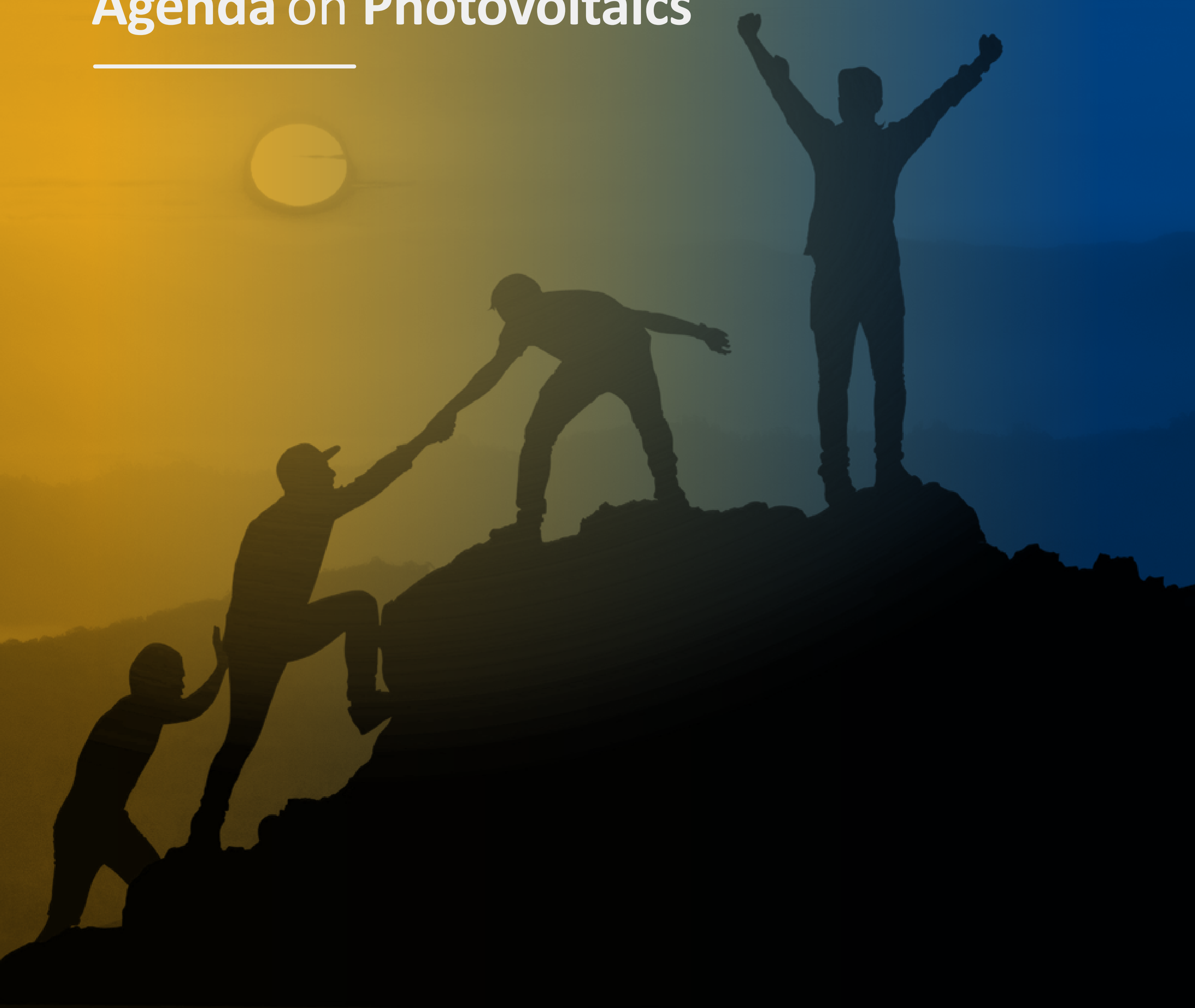
SUMMARY

Strategic Research and Innovation Agenda on Photovoltaics



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Cover picture

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A European Strategic Research and Innovation Agenda for PV responding to this decade's priorities

The European Green Deal, the Fit for 55 package, the Paris Agreement, Horizon Europe, and even the 2020 European Recovery Plan have placed climate neutrality by 2050 at the heart of Europe's socio-economic future. More recently, the REPowerEU strategy for energy independence from Russia demonstrates a wish by the European Commission for Member States to bring forward clean energy investments planned for later in the decade as early as possible.

Electricity is projected by many to be the cornerstone of decarbonized modern energy systems across the globe, and solar and wind are the key energy sources to deliver this electricity in sufficient quantities affordably and sustainably. Solar Photovoltaics (Solar PV) is already a very cost-effective and climate-friendly technology for generating electricity. [(1)] According to the International Renewable Energy Agency (IRENA), the electricity production costs of PV have fallen by 82 % since 2010. [(2)] Solar PV will thus play a prominent role to achieve EU's clean energy targets and global sustainability goals. However, to grow the PV industry in Europe and to become a major player of the clean energy transition, the sector must rapidly ramp up manufacturing capacity and successfully address further challenges related to device innovation, manufacturing, integration, sustainability and circularity.

The Strategic Research and Innovation Agenda (SRIA) developed by ETIP PV with significant input from EERA-PV covers photovoltaic science, technology, and applications in Europe. Broken down into five interlocking "Challenges" for research & innovation, it sets out the current performance of PV technology and explains why and how to go further with a clear message – we must act fast and NOW!

Energy system transformation

The European Green Deal has set clear targets for the energy system transformation by specifying at least a 55 % reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050 [(3)]. To reach this goal, the cumulative PV capacity in the EU and the UK would need to climb from 137 GW [(4)] in 2019 to 455-605 GW, according to the European Commission's Joint Research Centre [(5)]. Solar Power Europe has called for more: 1 TW of PV capacity by 2030 through an accelerated deployment scenario [(6)].

Sector integration

There is an increasingly converging view on the need for deep electrification of most economic sectors, with solar

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(1) IPCC, 2022: *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

(2) International Renewable Energy Agency (IRENA), "Renewable Power Generation Costs in 2019", June 2020.

(3) Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')

(4) Jäger-Waldau, A., Kougias, I., Taylor N., Thiel, C., "How photovoltaics can contribute to GHG emission reductions of 55% in the EU by 2030", *Renewable and Sustainable Energy Reviews*, Volume 126, 2020, https://doi.org/10.1016/j.rser.2020.109836 pg. 1

(5) Ibid.

(6) SolarPower Europe, "RePower EU with Solar: The 1TW EU Solar Pathway for 2030", March 2022

PV in Buildings. © Alius

PV in combination with conversion of electricity to other forms of energy and products (P2X) playing a vital role. Solar energy will become the foremost supplier of our carbon-free primary energy in scenarios for cost-optimal 100 % renewable energy systems [7].

Digitalisation

Energy systems with high penetrations of PV and wind need to be flexible. To accommodate the variability in the output of these sources and to optimise the need for storage and conversion, consumption must follow supply to a greater extent than today. Digital technologies applied to the energy system allow at least three things:

1. consumers to exploit their potential to shift the time when they consume, automating decisions on when loads need to be switched on or off [8]
2. the dispatching of electricity storage devices, particularly batteries, which are spread around the energy system, often small, quick-reacting
3. optimal dispatching of large loads relevant to P2X (electrolysers, for example)

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(7) LUT University and SolarPower Europe, 100% Renewable Energy Study, April 2020.
(8) European Commission Report, "Progress on competitiveness of clean energy technologies 4 & 5- Solar PV and Heat pumps" October 2021.

Not only should Europe have access to energy from PV, but it should also have access to the means of producing the PV generating devices itself.

Energy Freedom

European PV materials, cell, module and inverter production underpins the desired sovereignty in key technology areas – especially in the highly relevant energy sector – and promotes greater supply chain resilience for the post-Corona period through a strength-oriented European focus.

Box 1: Meyer Burger, Solar, *Production in Germany: Strategic Innovation Leadership as a Cornerstone for European Energy Sovereignty*, August 2021. Pg. 3

Boosting the penetration of PV in Europe's energy system will reduce energy imports (total value in 2019: 270 billion EUR), which is of vital strategic and political importance and of great economic interest. Europe can produce renewable energy at an affordable cost and supply it at prices that vary according to conditions within its borders, and largely – freak weather excepted – within its control. Installation rates of PV in Europe must increase fast and steadily.

EU private R&D spending on PV declined from about EUR 2 billion in 2010 to EUR 1.4 billion in 2018 as the manufacturing industry collapsed. Expanding European production of PV materials, solar cells and modules as well as the strengthening of European production in the field of PV technology will bring private R&D spending levels back up.

Box 2: European Commission Report, *Progress on competitiveness of clean energy technologies 4 & 5 - Solar PV and Heat pumps" October 2021* August 2021. Pg. 3

Not only should Europe have access to energy from PV, but it should also have access to the means of producing the PV generating devices itself. Asian suppliers are capable of manufacturing high quality and high-performance PV. In response, concrete, targeted support measures for the solar sector in Europe are necessary now and for the next five years – particularly measures (including funding – see Box 2) to support made in Europe innovative PV technology as it is beginning to be commercialised. PV's low cost compared to fossil fuels or nuclear energy, especially in an energy system that includes other forms of renewable energy, storage and P2X technologies, will be attractive for industry, helping the competitiveness of the wider European economy. Under a medium-pace solar energy transition scenario prepared for Solar Power Europe, the levelized cost of energy (LCoE) would be less in 2040 than under a slower energy transition scenario maintaining fossil fuels for longer.[9]

(9) Fig 0.9 comparing the LCOE of the 'Moderate' and 'Laggard' scenarios from Solar Power Europe's 2020 report *Renewable Europe How To Make Europe's Energy System Climate-Neutral Before 2050*

Boost PV manufacturing capacity

PV manufacturing in Europe is currently small scale and centered on modules; cell production lines are almost non-existent, though capacity is starting to increase in both areas, especially in the frame of the Solar Manufacturing Accelerator [10] and the European Solar Initiative [11]. To advance further, Europe must focus on advanced high-performance PV and on lean and green manufacturing. There are clear pathways to high PV module efficiencies through upgrades of existing production lines, installation of new production lines, and market entry of novel technologies such as perovskite on silicon tandem modules, [12] which are detailed further in the SRIA.

EU a technological frontrunner

The European PV sector holds world-class technological expertise in the field of photovoltaics. From 2015 to 2017, the EU was fifth in the total number of PV patents and third in the number of "high value" PV patents, according to an October 2021 European Commission Report on the progress on competitiveness of clean energy technologies. [13] While the EU can claim a podium finish for now, the report predicts China overtaking the EU in these types of inventions. Creating a thriving manufacturing industry will delay, perhaps indefinitely, the day that happens.

It is estimated about 14,000 direct permanent jobs could be created off the back of annual production of 20 GW (from wafer to module). In installation, operation and maintenance of commercial and industrial solar systems, more than 100,000 long-term jobs could be created. The influence of the PV industry on the job market is significant.

Box 3: IPVF, *Solar Europe Now – Call to Action for a Solar-Inclusive Green Deal*, May 2020

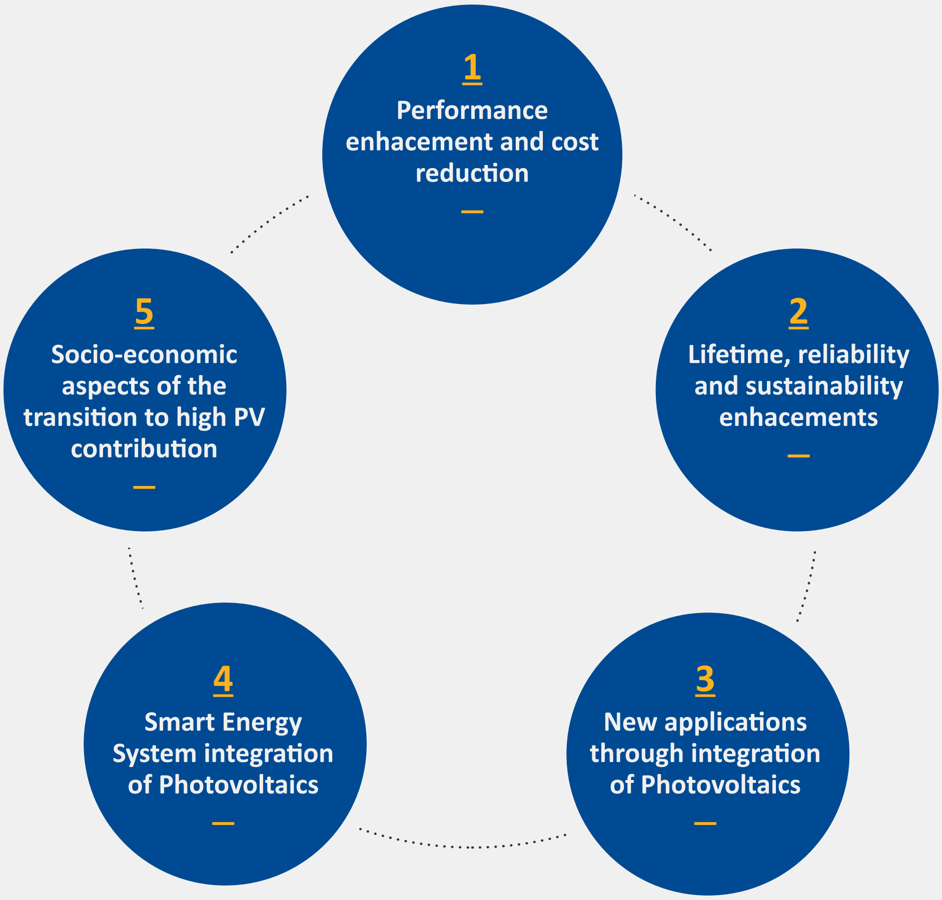
There is still work to do to bring PV manufacturing back to Europe so that it can claim a fair share of the global industry. Today only 1-2 % of the capacity needed by 2050 is installed. In 2019, China made almost all PV wafers, three quarters of the world's cells and 70 % of its modules. [14] Europe must increase its share of these markets and as the SRIA shows, be the region where advanced cell or module architectures, manufacturing technology and integration in new applications are piloted. Europe is well positioned in research and development to hone and bring to market these innovative technologies. It is essential to develop industry capacity alongside Europe's R&D capabilities to keep the region a frontrunner in technology development in the boom years that lie ahead. Rapid cost reduction in setting up PV manufacturing capacity, coupled with a large increase in demand for the various forms PV can take and targeted action from policymakers, should trigger "made in Europe" PV and job creation (see Box 3).

(10) Solar Manufacturing Accelerator (SoMA), see Solar Manufacturing Accelerator- ETIP PV (etip-pv.eu).
(11) European Solar Initiative (ESI), see European Solar Initiative.
(12) Oberbeck, L. IPVF Report, "European Solar Manufacturing – Does it make sense?", May 2021.
(13) European Commission Report, "Progress on competitiveness of clean energy technologies 4 & 5- Solar PV and Heat pumps" October 2021.
(14) IEA PVPS *Trends 2019 in Photovoltaic Applications* Fig 4.3, Fig 4.4, Fig 4.5

Summary of the SRIA Recommendations

ETIP PV and numerous other contributors and stakeholders including EERA-PV have developed a SRIA through a sector-wide consultation and contributions from the European R&I community. The SRIA identifies the R&I priorities for the years to come and seeks to guide policymakers on the ways to support the development of solar energy in Europe.

To achieve a massive rollout and integration into the energy system of solar PV, at affordable cost and in a sustainable way, several challenges must be addressed. The PV generation cost must further be reduced, and PV modules must be developed for a wide range of applications, while the industry must improve circularity of the entire value chain to successfully lead the energy transition. The SRIA identifies five challenges.



As such, through the SRIA and these 5 objectives, we have identified the key challenges to be addressed for Europe to maintain its world-leading position in research and development and to make sure solar PV fulfils its true potential.

Key R&I challenges	Rationale
Overarching challenges **Energy transition and strategic value chain**	Solar PV is a key building block for the energy transition and has great potential for both sustainable large-scale manufacturing and deployment in Europe. And we regain manufacturing strength, at least in part, through advanced, high-performance value chain segments.
Challenge 1 **Performance enhancement and cost reduction**	Cost reduction and performance enhancement of solar PV has been extremely successful in past decades, but very large-scale deployment of PV with integration into the energy system and our living environment requires even further cost reduction. Performance enhancement is a lever for cost reduction and an enabler for efficient use of available areas.
Challenge 2 **Lifetime, reliability and sustainability enhancements**	Solar PV is a renewable source of energy, but large-scale responsible use at affordable costs requires the technology and its applications to also be sustainable and circular. Moreover, lifetime and reliability need to be guaranteed, which is especially crucial for highly promising new technologies like perovskites-based PV, which offer great opportunities but do not have a track record yet.
Challenge 3 **New applications through integration of Photovoltaics**	Integration of PV in new applications and products creates huge opportunities for attractive and sustainable large-scale deployment as well as for the European manufacturing industry in the frame of (re)building the strategic value chain, and thus, for job creation. PV integration is critical for mass deployment and is key to efficiently manage the scarce surface area in Europe.
Challenge 4 **Smart Energy System integration of Photovoltaics**	Ambitious further growth of PV deployment requires smart integration into the energy system at all levels: residential, commercial, as well as utility scale. Smart integration of PV, on the other hand, also offers new opportunities as PV becomes an active contributor of (ancillary) grid services improving the reliability of the complete system, aided by real-time monitoring data use and forecasting.
Challenge 5 **Socio-economic aspects of the transition to high PV contribution**	PV can be maximally successful at very large scale if socio-economic and ecological challenges and values are fully considered. This implies contributing to a just energy transition, communicating PV's qualities and opportunities, nature-inclusive system designs, respecting the quality of landscapes, and more. By doing so, broad public and political support can be achieved.

↑ Research project to evaluate the synergies between apple cultivation and agrivoltaics in Rhineland-Palatinate, Germany. © Fraunhofer ISE.

Overarching challenges

Making the energy transition a European success, with PV as a key building block, by:

- Further reducing the LCoE in a sustainable manner to keep/make PV competitive in all parts of Europe while allowing for (the additional cost of) energy system integration and integration in the living environment;
- Making PV available for a wider range of applications, with emphasis on flexible integration (buildings, infra, etc.) and dual functionality (agri-PV/ agrivoltaics, etc.), as well as floating systems;
- Making PV components and systems circular.

(Re-)building the strategic value chain for PV, by exploiting Europe's technological leadership for:

- Manufacturing of high-performance, circular products;
- Large-scale deployment in a wide range of applications;
- Energy system integration.

Challenge 1: Performance enhancement and cost reduction

In the last decade, total costs for polysilicon, wafer, solar cell and module manufacturing have decreased by 75 to 90 %, enabling (silicon) PV to be crowned as the king of electricity markets. However, for PV to fulfil its mission of transforming the energy systems and to accommodate large-scale deployment including energy system integration and integration into our living environment, further cost reduction as well as increased emphasis on efficiency and sustainability is necessary. The focus of this challenge is hence to outline R&I needs for performance enhancement covering all components of a PV system. Performance enhancement, in turn, is an important lever for cost reduction at all levels: components, systems, operation and maintenance, and electricity LCoE.

Objective 1: PV modules with higher efficiencies and lower costs

This objective focuses on improving efficiency and reducing costs of PV modules. It covers the various PV technologies that have already reached industrial maturity level as well as emerging technologies.

R&I Priority	Rationale
Roadmap 1 **Silicon PV modules**	Despite the maturity of this technology, there is still a large potential and need for further innovation in performance, manufacturing, integration and sustainability enabling large-scale deployment of both utility-scale PV as well as integrated PV.
Roadmap 2 **Perovskite PV modules**	Perovskite (thin film) PV is one of the most promising emerging PV technology families. The long-term vision is that it will be produced at very low costs, be highly efficient, stable and represent a broad scope of embodiments: flexible, rigid, opaque, semi-transparent, etc.
Roadmap 3 **Thin-film (non-perovskite) PV modules**	Non-perovskite thin-film PV cells and modules are challenged to achieve high efficiency and long lifetime at competitive production costs. Module efficiencies should be comparable to current PV technologies within 5 years. Manufacturing should quickly achieve comparable costs compared to currently commercial technologies.
Roadmap 4 **Tandem PV modules**	Modules made from tandem (i.e. stacked) PV cells achieve higher efficiency than single-junction cells. Novel material systems, like perovskites, offer the promise of cost-efficient multijunction PV modules. For 2030, these should reach a market share of more than 5 % and should successfully transition to mass market applications, while demonstrating long-term performance comparable to the single-junction technologies, clear advantages in terms of LCoE and in the environmental footprint.

Objective 2: System design for lower LCoE of various applications

This objective focuses on R&D needs beyond the PV module, and on improving the energy yield of systems. For the past decades, the focus of cost reduction & efficiency improvements has mostly been on PV modules, as they have traditionally been the costliest component of a PV system. With the strong reduction of their prices, other parts of the total system and its use become more important for lower LCoE.

R&I Priority	Rationale
Roadmap 5 **Balance of System (BoS) and energy yield improvement**	Focusing R&D on other components and activities, such as installation, operation, energy yield monitoring and improvement, maintenance and decommissioning is now paramount.

Objective 3: Digitalisation of PV

The digital transition presents key opportunities for the PV sector: not only can new digital technologies, such as Big Data, robotics and blockchain, allow for the emergence of new solar business models and for the improvement of existing models, they can also be used to reduce costs and increase performance at almost every point of the value chain.

R&I Priority	Rationale
Roadmap 6 **Digitalization of PV manufacturing**	Introducing digital technologies to reduce cost and increase the quality of PV value chain manufacturing.
Roadmap 7 **Digitalization of PV systems**	Introducing digital technologies to increase energy yield, and to make PV technology suited for all emerging new applications and a dependable component of the energy system of the future.

Challenge 2: Lifetime, reliability and sustainability enhancements

Many gigawatts of solar energy capacity are added worldwide year after year, and the cumulative 1 terawatt (TW) goal could be achieved by 2022. The PV sector must therefore ensure that the installed power capacity can also reliably generate electricity for an extended lifetime. With PV becoming mainstream, it becomes also important to ensure sustainability from an energy, environmental and investment viewpoint.

In line with the material efficiency hierarchy, resources should be kept in productive use as long as possible and at the highest quality possible to enhance the lifetime, reliability, and sustainability of PV technology.

The overall objective is to develop PV components with design for reliability and sustainability as key driver.

Objective 1: Sustainable and circular Solar PV

This objective focuses on reducing PV's impact on our environment, across the entire value chain (production, transport, installation and operation of PV systems) by following the R ladder of sustainability.

R&I Priority	Rationale
Roadmap 1 **Reduce: Low environmental impact materials, products, and processes**	Improving PV technology over the entire value chain and throughout its entire life cycle, with regards to consumption of materials, energy demand and carbon emissions.
Roadmap 2 **Reuse: Design systems and O&M for reuse**	Developing reuse, repair and refurbish strategies of material, to divert about 50 % of the PV "waste" from the recycling path.
Roadmap 3 **Recycle and recover**	Given the longevity of PV components and a continued exponential deployment trajectory towards multi-terawatt scale by mid of the century, design for recycling becomes a critical prerequisite for technology development.
Roadmap 4 **Technologies for sustainable manufacturing**	Investigating ways of reducing both the energy consumption and greenhouse gas emissions in PV production.
Roadmap 5 **Eco-labelling and energy-labelling**	It is imperative to provide up to date, verified and widely accessible life cycle inventory (LCI) data for PV components in data bases (Ecoinvent, GABI, Life Cycle Data information system). It should be evaluated how these databases could be updated through dedicated research.

↑ Drone thermography. © Above Surveying

Objective 2: Reliable and bankable Solar PV

The most effective strategy for reliable and bankable solar PV is to prevent the occurrence of failures via preventive mitigation measures (for e.g. by use of extending testing of products) and by reducing the impact of failures once they are detected via corrective mitigation measures (for e.g. by use of advanced monitoring solutions and field detection techniques). A yield assessment with reduced uncertainties can lead to a much more favourable business model. Procurement is the next important step where extended testing beyond what is prescribed by the standards can increase the confidence of the right choice of PV components. Finally the operation and maintenance (O&M) phase will highly benefit from innovations in terms of cost effective solutions for the estimation of impact of failures in the field.

R&I Priority	Rationale
Roadmap 6 **Quality assurance to increase lifetime and reliability**	The cost decrease in PV modules has led to (and been driven by) innovations, which include the use of new and novel materials. Modules are therefore being produced and sold without a long-term understanding about the performance and reliability of these new materials. Testing procedures and standards have to be adapted to suit new module technologies or reflect new degradation modes.
Roadmap 7 **Increased field performance and reliability**	Novel technologies make the increased reliability and field performance a continuous industry demand. Solutions available on the market will need to be updated to capture innovation trends.
Roadmap 8 **Bankability, warranty and contractual terms**	Researching PV bankability to establish recommendations regarding the warranty and contractual terms. The main equipment to be considered are PV modules, inverters and mounting structures and the contractual schemes will be EPC contract and O&M contract.

Challenge 3: New applications through integration of Photovoltaics

Objective 1: Physical integration of PV into the built environment, vehicles, landscapes & infrastructures

The inherent modularity of PV enables it to be integrated seamlessly into many different objects, allowing space to be used efficiently and attractively. PV-enabled products must meet the requirements of the original product, with EU-harmonised rules to create markets large enough to address cost-efficiently. As most of 'IPV' value chains are in Europe, the integration of PV creates huge opportunities for European value and job creation.

R&I Priority	Rationale
Roadmap 1 **PV in buildings**	Nearly zero energy buildings (NZEB) are enforced as a decarbonisation solution by regulators and require the integration of PV systems into the building´s facades, roof and energy system.
Roadmap 2 **Vehicle Integrated PV**	VIPV supports the electrification of transport systems by converting solar energy directly on the vehicle.
Roadmap 3 **Agrivoltaics and landscape integration**	Agrivoltaics allow for the simultaneous use of land for both agricultural and photovoltaic use, while supporting the decarbonisation of the sector.
Roadmap 4 **Floating PV**	The main market driver for floating solar is the search for area in regions or countries with a high population density.
Roadmap 5 **Infrastructure Integrated PV**	The integration into infrastructural objects such as road pavement, noise barriers, crash barriers, dikes, landfills, flyovers and road roofing.
Roadmap 6 **"Low-power" energy harvesting PV**	Photovoltaic energy harvested in low light conditions or artificial light can be used to power energetically autonomous sensors, internet-of-things devices and other electronics.

Challenge 4: Smart energy system integration of Photovoltaics

Objective 1: Energy system integration

PV is growing strong in independent applications at all levels: on roofs or facades of buildings for both domestic and commercial use, as well as for commercial and utility-scale systems of various sizes. In the years to come, PV should be viewed as active contributors of the integrated grid utilising dependable forecasting tools for improving the reliability of the complete system.

R&I Priority	Rationale
Roadmap 1 **More intelligence in distributed control**	This roadmap aims to add intelligence to the PV systems to be responsive to energy system needs.
Roadmap 2 **Improved efficiencies by integration of PV-systems in DC-networks**	The objectives of this roadmap include the development of systems and solutions for which PV as the energy source is directly connected to DC driven systems to achieve improved efficiencies.
Roadmap 3 **Hybrid systems including demand flexibility**	The objective of this roadmap is to develop systems and solutions for which PV, as an integral contributor of interconnected systems, can offer hybrid solutions that better meet needs of the integrated grid. These hybrid systems include PV, Wind and Hydro with embedded storage, batteries and green hydrogen/fuel cells or gas turbines.
Roadmap 4 **Aggregated energy and virtual power plants (VPPs)**	The objective of this roadmap is to develop systems and solutions for which PV – as an integral contributor of distributed generation – can be pivotal in the development of energy communities. This necessitates a capability to aggregate energy needs and operate a connected system using advanced control features, such as a hierarchical operation with an integrated grid to achieve system optimal solutions.
Roadmap 5 **Interoperability in communication and operation of RES smart grids**	Future inverter systems need to be interoperable from the automation/control and communication point of view and they should provide advanced services including auto-configuration of PV plant components. Current issues include the lack in the harmonization of PV plant control and the use of proprietary solutions for monitoring.

Challenge 5: Socio-economic aspects of the transition to high PV contribution

The energy transition offers great benefits and opportunities, but also poses major challenges to society. The success of the transition depends heavily on its capability to demonstrate the benefits for individuals, companies and society as a whole, while addressing and mitigating the challenges effectively, in a well-balanced manner.

The massive and rapid deployment of additional renewable energy, and in particular solar energy will only be possible if a broad public and political support can be maintained when solar energy becomes a visible part of our living environment. Since several big societal challenges and trends require (additional) space to be addressed, such as the energy transition moving towards sustainable agriculture, increasing biodiversity, providing self-sufficient housing, careful balancing of very different and sometimes competing societal costs and values is key to success.

Objective 1: Higher awareness of benefits that solar PV brings

R&I Priority	Rationale
Roadmap 1 **Wide societal involvement and participation for solar PV deployment**	The implementation of PV on a local level does not coincide with wide-spread acceptance of PV. Increased involvement and direct participation of all stakeholders must be a major objective for the years to come to bridge the gap between technical development of PV and social acceptance of PV technology.
Roadmap 2 **Developing a PV hotbed for urban implementation**	PV is the only renewable energy technology that can enable renewable electricity generation in highly dense spaces throughout Europe. Cities and urban regions will be one of the major boosters for PV installations within the current decade.

Objective 2: Economic & sustainability benefits

R&I Priority	Rationale
Manufacturing phase	If the shares of PV components manufactured increases as a result of a revival of the European solar industry, more than 100 000 jobs in the upstream sector could also be created. The upstream sector encompasses both technical jobs and academic jobs.
Installation phase	The roll out of PV installations creates jobs. These jobs created in the installation phase are spread between vocational jobs, technical jobs and academic jobs.
Operation phase	In addition, the number of people needed for operation and maintenance will increase as the cumulative PV capacity grows and the age of the running PV systems increases.

↑ PV in Buildings. © Solarwatt

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