The European Technology and Innivation Platform for Photovoltaics

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White Paper - ETIP PV Social PV Working Group

Towards Sustainable and Massive Deployment of Photovoltaics: The Nexus of Socio-Economic and Technological Challenges

ETIP Photovoltaics

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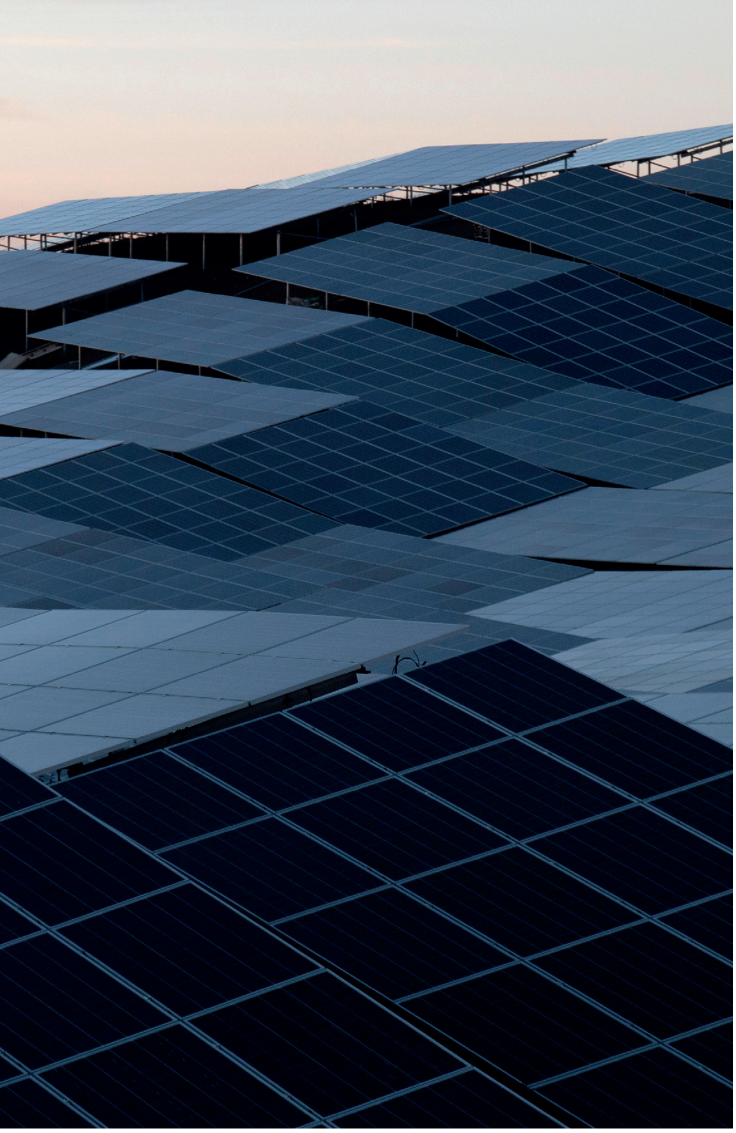

The European Technology & Innovation Platforms (ETIPs) have been created by the European Commission in the framework of the new Integrated Roadmap Strategic Energy Technology Plan (SET Plan) by bringing together EU countries, industry, and researchers in key areas. They promote the market uptake of key energy technologies by pooling funding, skills, and research facilities. The European Technology and Innovation Platform for Photovoltaics (ETIP PV) mobilizes all stakeholders sharing a long-term European vision for PV, helping to ensure that Europe maintains and improves its industrial position, in order to achieve a leadership position within the global PV market.

The experts of the Social PV Working Group of the ETIP PV with contributions from the Reliability and Circularity Working Group developed this publication. They represent leading European research institutes in the PV community, and work to further the objective of an efficient, highly innovative European PV industry with a positive environmental and social impact.

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Introduction

Electricity will be the cornerstone of our future decarbonized energy system. Solar energy and wind energy are the key technologies to deliver this decarbonized electricity in sufficient quantities, at affordable cost, and in an environmentally & societally sustainable way. Solar PV will therefore play a prominent role to achieve the EU's clean energy targets, as well as global sustainability goals. However, the massive roll-out needed in the coming decades of solar energy, its integration into the energy system and into our living environment. And the required circularity of the entire value chain will pose serious technological and non-technological challenges on the further development and deployment of solar PV.

These challenges, notably from a technical point of view, have been described in detail in the Strategic Research and Innovation Agenda (SRIA)[1] developed and published by ETIP PV[2] and EERA-PV[3] in 2021. Yet, to achieve widespread deployment of solar PV and reach the EU's clean energy targets, it is imperative to also address and overcome the significant socio-economic challenges that accompany this transition. Recognizing the interdependence of these challenges is a key insight as addressing technological obstacles without considering the economic and societal aspects will become more and more of an incomplete approach. The intelligence gathered in this white paper is the result of contributions from ETIP PV technical and socio-economic experts. It will play a pivotal role in refining the Strategic Research and Innovation Agenda (SRIA) to underscore the vital nexus of techno-socio-economic challenges for achieving solar PV deployment at the scale necessary to meet the EU's clean energy targets.

More specifically, this white paper will provide an overview of the most pressing and important socio-economic challenges for the further massive deployment of solar PV in our society by focusing on four key dimensions: (1) Social Acceptance, (2) Public Engagement, (3) Skills and Workforce, (4) Environmental and Social Sustainability.

The first chapter will cover the complex realm of acceptance and adoption of solar PV technologies. The chapter explores the recognition of critical raw materials (CRM) in PV manufacturing and the essential steps needed to gain acceptance for their use. Furthermore, it addresses the incorporation of potentially toxic materials within new PV technologies and the importance to understand the associated risks and rewards. The chapter will also probe into the factors shaping the Acceptance of European PV deployment, particularly on residential and utility scale. Lastly, it will examine the evolving landscape of novel true-cost pricing grid tariff schemes and its acceptance by consumers and businesses, shedding light on the opportunities and challenges.

Chapter two delves into public engagement in PV technology adoption, emphasizing active citizen involvement as prosumers in the renewable energy transition. It highlights the need for incentives, administrative adjustments, and integrated support. The chapter explores various factors influencing consumers' PV system choices, such as social, economic, technology usability, and ecological dimensions. It also discusses solutions for enhancing citizen participation and the socio-economic factors impacting technology adoption decisions, with practical use-case examples for illustration.

Chapter three places a spotlight on significant dimensions within the PV industry: workforce development and innovation. It underlines the imperative for re-skilling and up-skilling to align with the industry's dynamic requirements, especially in the context of potentially creating millions of new jobs in Europe. The chapter then delves into strategic approaches for fostering innovation while accommodating evolving workforce needs. It also highlights the significance of gender diversity in the PV sector, reflecting the broader mission of creating an inclusive and diverse industry.

Chapter four is dedicated to Environmental and Social Sustainability, with a focus on three key areas. It starts by delving into the Environmental Impact, employing Life Cycle Assessment (LCA) analysis to scrutinize the ecological footprint of PV technology. It then shifts its focus to Social Impact through Social Life Cycle Assessment (S-LCA), a tool that explores the broader societal consequences of PV deployment and lastly, the chapter underscores the importance of the Environmental, Social, and Governance (ESG) framework in promoting sustainable and responsible practices of PV technologies.

To conclude, the white paper provides a set of recommendations to increase support, fund research and innovation, and engage with stakeholders and policymakers.

[1] https://etip-pv.eu/publications/sria-pv/
[2] https://etip-pv.eu/
[3] https://www.eera-pv.eu/

1.
Social Acceptance

After decades of research and case studies on the not-technical factors for RES development, social acceptance is now recognized both in the scientific and policy agendas as a key element highly affecting technology deployment at different scales, from the individual adoption of devices to the reshaping of the global market. Introduced in the 80s, the notion of Social Acceptance has been refined along a cumulative process of theoretical and empirical research[4]. As a result of this process, it is now well established that social acceptance is a socially constructed outcome that, far beyond the mere process of adoption or rejection of technology innovation by citizens, involves a variety of societal actors (policy makers, businesses, experts, NGO, scientific community, citizens...) and a wide number of multiple factors referred to, e.g., physical, contextual, political and institutional, socioeconomic, social and communicative, cultural, symbolic and ideological, local and personal dimensions[5]. The positive or negative outcome, that is the support or resistance to RES technology deployment, varies a lot in direction and intensity depending on the alignment among the attitudes that characterize the societal actors as emerging from the interplaying of the different factors. A social matrix has been proposed to position the possible outcome of this alignment along two axes: positive-negative Vs active-passive.

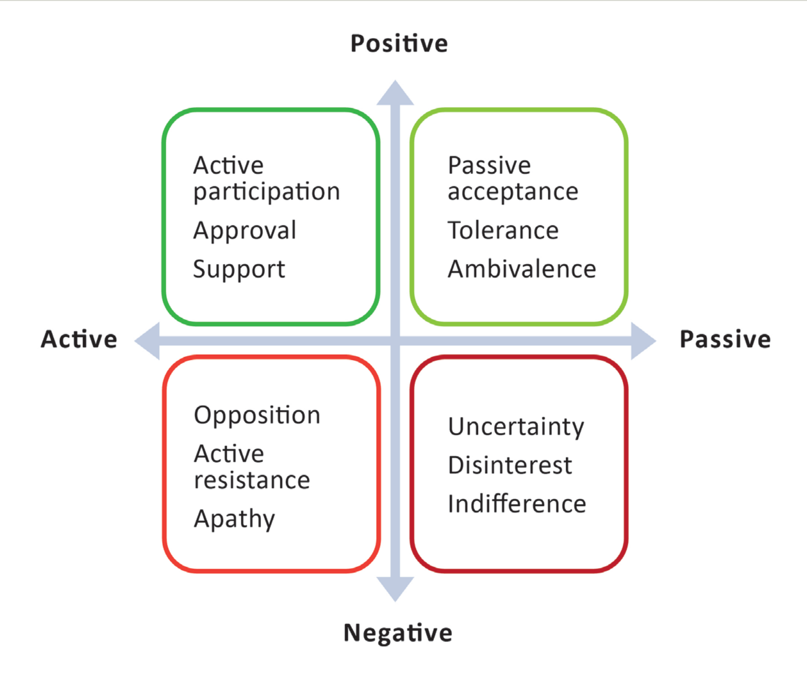


Figure 1.
The social acceptance matrix (Source : Gordon et al, 2007[6])

The factors that determine the social acceptance outcome can be categorized in the so-called triangle of Social Acceptance of renewable energy innovation in which three dimensions of acceptance are identified:

[4] *Research on the social acceptance of renewable energy technologies: Past, present and future - ScienceDirect*
[5] *Social acceptance of renewable energy innovation: An introduction to the concept - ScienceDirect*
[6] *Beyond the triangle of renewable energy acceptance: The five dimensions of domestic hydrogen acceptance | Semantic Scholar*

1 **Socio-Political Acceptance** is the broadest of the three dimensions, operating at the macro or national level. This dimension encompasses how the public and other stakeholders view the policy environment surrounding the deployment of new energy technologies, which is typically gauged through opinion polls.

2 **Community Acceptance** refers to the specific acceptance of siting decisions and renewable energy projects by local stakeholders, particularly residents and local authorities and is often characterized by a time dimension showing a U-curve pattern with acceptance being higher in the proposal and running phase, lower in the implementation phase.

3 **Market Acceptance** or market adoption of innovation that involves all the market actors at different level: consumers whose decisions are affected by a number of communication and societal dynamics steering the consumption choices and investors (industry actors, SMEs and intermediaries) that must choice among alternative technologies.

Figure 2.
The social acceptance matrix (Source: Gordon et al, 2007[7])

Of course, the three acceptance dimensions are strongly interlinked, and it is worth to highlight in particular that the market acceptance by the big companies can strongly affect the socio-political acceptance because they are influential stakeholders in the development of energy policies.

In the following chapter, a number of cases of social acceptance are presented referring to diverse technologies and aspects of PV deployment that can be usefully reported to the diverse dimensions of the triangle. While the acceptance of critical raw materials and toxic materials (par 1.1 and 1.2) mostly relate with the socio-political, the deployment of PV power plants clearly refers to the community acceptance for what concerns the residential scale (1.3.1) and its interplaying with market acceptance for the higher scale of deployment (1.3.2. and 1.3.3). Market and socio-political acceptance can be instead usefully considered to address the challenge of societal actors' compliance with the tariff schemes (1.4).

[7] *Social acceptance of renewable energy innovation: An introduction to the concept - ScienceDirect*

1.1
Acceptance of Critical Raw Materials (CRM) use for PV manufacturing

Critical Raw Materials (CRMs) are pivotal resources for the European economy due to their economic and strategic significance. However, their supply is associated with high risks. These raw materials, mostly metals and minerals, play a significant role in various strategic sectors such as green technologies (including photovoltaics), digital industries, defence, aviation, microelectronics, medical equipment, and everyday devices like smartphones.

Today, numerous key technologies across all industrial sectors continue to rely on the unique physical properties of specific raw materials. According to the International Energy Agency (IEA)[8], achieving global net-zero emissions by 2050 would result in a demand for critical minerals growing by three and a half times by 2030, reaching over 30 million tons. However, the concentration of global CRM supplies in a few countries poses significant geopolitical risks and vulnerabilities in the supply chain. In February 2023, the Commission presented a Green Deal industrial plan for the net-zero age[9], with a focus on boosting the EU's net-zero industry. The Critical Raw Material Act was launched on 16 March 2023 as part of this plan. This document introduces the concept of Strategic Raw Materials (SRMs), which are essential for strategic technologies and vulnerable to shortages. The proposed regulation aims to improve the functioning of the single market by establishing a framework to ensure the EU's access to a secure and sustainable supply of CRMs.

Figure 3:
Summary of the 2030 benchmarks for strategic raw materials as stated in the European Critical Raw Materials Act (Source: European Commission, 2023[10])

[8] https://www.iea.org/reports/critical-minerals-market-review-2023
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023DC0062
[10] European Critical Raw Materials Act (europa.eu)

To reach climate neutrality by 2050, the current worldwide PV module production of roughly 300GW per year will have to be increased by a factor of 5-10 in the coming decade. This will put a large strain on the use of certain CRMs needed for producing PV modules. All CRM's that are used for PV production will not be available for other technologies and therefore society should accept that large CRM amounts will be used in the coming decades for PV module production. In crystalline-silicon PV technology, the main CRMs currently are silver and bismuth. Silver is used as metal contact for the silicon solar cells and although only a few grams of Ag is used per PV module, in 2023 it is expected that the total amount of Ag used for PV module production will amount to around 12% of the worldwide yearly silver production. On the other hand, bismuth is used in some cases for the interconnection of silicon solar cells. For CdTe-based PV modules, tellurium is the main limiting CRM. Finally, for CIGS modules, perovskite-based modules and tandem modules, the main CRM is indium that is used either in the absorber layer or the transparent conductive oxides.

The PV sector ust effectively communicate to society that the use of a certain amount of the above listed CRMs is required and acceptable for PV module production. The PV industry should continue its efforts to further reduce the number of CRMs needed per GW of PV module production. Research and Development (R&D) will need to play a crucial role in this. Beside R&D on lowering the material usage per PV module, PV R&D should also focus on complete or partial substitution of these materials by other less critical materials (e.g. Ag metal contacts can be replaced by Cu or Al metal contacts) and on achieving full and easy recyclability of PV modules (in order to re-use CRMs from old modules for new PV module production).

Europe is currently also working towards re-establishing the whole PV production value chain back in Europe, which is very important from both a security of supply point of view as well as from a socio-economic point of view. However, care will have to be taken that we invest in Europe's production capacity of those PV technologies that are performing best in terms of low CRM usage.

Finally, we note that in this part we focused only on those materials that are directly crucial for the further massive deployment of PV technology. However, linked to this there will also be a need for further massive deployment of storage technologies such as batteries and electrolyzers (for green synthetic fuel production). These storage technologies will also require the security of supply of (other) CRMs .

1.2 Acceptance of Toxic Materials for new PV technologies

Perovskite-based photovoltaics

Hybrid organic-inorganic perovskites are currently one of the most promising materials showing an enormous potential for photovoltaics. It is a highly efficient, easy to process, light-weighted material, and in roughly one decade, this technology has reached at lab-scale a similar energy conversion efficiency as silicon (more than 26%)[12]. Moreover, the PV perovskite materials seem very well suited to be used in tandem with silicon technologies, aiming at solar panels with a power conversion efficiency well above 30%[13]. However, the use of Lead in hybrid perovskite technologies is an important issue to control. Lead has been linked to many health issues in the past and is generally not allowed in consumer products[14].

One of the advantages of perovskite materials for PV lies in the very low quantities of the material that are needed. Perovskite absorber layers for solar cells are around a thousand times thinner than the silicon wafers that are used in traditional solar cells. The very low quantities of Lead used and encapsulation technologies currently under development are therefore a first way to reduce danger to a minimal degree. A recent study has shown that 99% of lead used in a perovskite solar module could be recycled with an optimized process[15]. Researchers are also working toward the replacement of Lead by Tin in perovskite technology. Even though the efficiency and

[11] critical-raw-materials-in-li-ion-batteries.pdf (innoenergy.com)
[12] Low-loss contacts on textured substrates for inverted perovskite solar cells | Nature
[13] Longi claims 33.5% efficiency for perovskite/silicon tandem solar cell – pv magazine International (pv-magazine.com)
[14] https://doi.org/10.1038/nmat4572
[15] Recycling lead and transparent conductors from perovskite solar modules | Nature Communications

stability of tin-perovskite technology is still lacking, results are encouraging, and more work should be done in that direction[16].

Another advantage of perovskite PV is their low temperature solution-based fabrication methods. Perovskites are typically processed below 150°C and the complementary materials for the complete device structure require less than 500°C[17]. In contrast, melting silicon for the fabrication of the wafers needs around 1500°C. These technological differences, among others, have resulted in estimations of the global warming potential of perovskite solar cells higher than that of silicon solar cells, and other inorganic thin film technologies commercially available. Particularly, even though all PV technologies have significantly lower greenhouse gas emissions when compared to fossil fuels, perovskite solar cells have been projected in several studies to emit lower values of kilograms of carbon dioxide equivalents per kilowatt peak than other established PV technologies[18].

Since perovskite-on-silicon tandem technology is generally considered as the solution for the mainstream c-Si PV technology to surpass the single-junction energy conversion efficiency limit, and since Pb-containing perovskites result by far to the best results currently, it will be crucial to convince the society to allow Pb in perovskite-based PV modules in the future. For this, we need more evidence-based facts concerning various PV applications (residential PV, floating PV, Agri-PV, ...)[19,20,21]. Possible approaches include funding research on Sn-based perovskites, encapsulation, and assessing the health effects of Pb in comparison with other toxic materials already present in our daily lives. For instance, Cadmium is well known as a toxic chemical element, and yet science and technology have optimized its content management for CdTe thin film solar cells and Ni-Cd batteries to be socially accepted and commercially available products.

Photovoltaic modules

Today, crystalline silicon modules account for over 96% of the PV module market[22]. These silicon-based modules also contain some materials that can be considered toxic. The impact of these toxic substances is more apparent and problematic at the end-of-life phase. Indeed, these materials can be considered as a disruptive element in the recycling process. A disruptive element is defined as any element that can block the recycling and recovery of materials in the module: either a non-recyclable component, or a recyclable element that is not suited to existing processes. In addition to the fact that a component or its recycling can increase the environmental impact of the end-of-life phase, these disruptive elements imply additional economic costs.

These toxic substances in silicon-based modules include:

- **The presence of fluorine in backsheets:** This remains a constraint from a waste management point of view, and when separating the various components of a panel at the interfaces[23].
- **The presence of lead in the interconnects:** This can be considered a disruptive element to recycling (hazardous substances)[24].
- **Epoxy resin in composites:** This is considered toxic at the end-of-life stage[25].
- **Antimony in solar glass to enhance transparency:** The solar glass is currently not recycled due to the presence of antimony[26].

Therefore, proposed alternatives will be based on the «Design for Recycling» approach, allowing the reduction of toxicity at the manufacturing stage and a better management of the recycling at the end-of-life stage. Among these alternatives, we therefore need backsheets without fluorine, Antimony free glass, biosourced composite materials and lead-free interconnection. Such alternatives are already adopted by some manufacturers but feedback on the impact from a technical point of view (efficiency, durability, degradation...) is still required and these alternatives are therefore not mainstream yet.

16 Tin perovskite solar cells with >1,300 h of operational stability in N2 through a synergistic chemical engineering approach - ScienceDirect
17 https://doi.org/10.1002/aenm.202103534
18 https://doi.org/10.1002/aesr.202000088
19 https://doi.org/10.1016/j.esd.2022.07.003
20 https://doi.org/10.3390/en15238804
21 https://doi.org/10.1016/j.erss.2021.102339
22 Solar - IEA
23 Fraunhofer Institute Report: EoL pathways for PV backsheet (coveme.com)
24 The weekend read: A lead-free future for solar PV – pv magazine International (pv-magazine.com)
25 Epoxy-Silicon Composite Materials from End-of-Life Photovoltaic Panels | Waste and Biomass Valorization (springer.com)
26 Recommendation-on-Addressing-uncertain-antimony-content-in-solar-glass-for-recycling.pdf (solaralliance.eu)

1.3
Acceptance of European PV Deployment

Community and market acceptance are critical factors in determining whether households and communities are receptive to the adoption of PV technologies. PV deployment can take various forms, such as residential installations, or utility-scale projects. Therefore, it is important to explore the acceptance of these different deployment types, as the factors influencing acceptance may vary:

1. **Residential PV:** Acceptance of solar PV at the residential level is influenced by factors like investment costs, information availability, and the potential to save on energy bills. Homeowners, as consumers, may consider solar panels if they are well-informed about the technology and see financial benefits.

2. **Utility-Scale PV:** Large-scale solar PV projects often involve substantial investment, regulatory considerations and relevant impacts on the local landscape and other environmental aspects (e.g. biodiversty., contrast with other land uses...[27]). Acceptance in this case may result from a careful balancing of impact minimizing measures, through proper engagement strategies (see chapter 2) with incentives from economic viability, job creation, and the many environmental benefits of clean energy generation from PV.

The Acceptance of European PV deployment is therefore a multifaceted concept, shaped by various factors interplaying at different levels of the energy system. Understanding these barriers and tailoring strategies to address them is crucial in promoting the broader adoption of solar PV technologies across different sectors and regions. Policymakers, industry stakeholders, and advocates must work collaboratively to overcome these barriers through an effective engagement of the final users and citizens in order to advance the transition to clean, sustainable energy sources.

1.3.1
Acceptance of Residential PV Deployment

The widespread adoption of residential PV systems holds significant importance for Europe's efforts to address climate change, enhance energy sustainability, and reduce greenhouse gas emissions. Results from a recent study conducted by the Horizon Europe project SunHorizon show that several key aspects play a role in shaping this acceptance and primary barriers hindering its widespread adoption[28]:

- **Low Availability of Information:** Residents often lack essential knowledge about PV technology, including how it functions, installation processes, associated costs, and government incentives.
- **Financial Concerns:** The financial aspects of residential PV systems, such as upfront investment costs and payback periods, significantly influence homeowners' decisions to invest in solar technology.
- **Sociodemographic Factors:** Sociodemographic elements, such as income levels and educational backgrounds, play a pivotal role in shaping the acceptance and adoption of PV technology.
- **Personal factors** related to pre-existing knowledge, familiarity and attitudes towards technology, life plans and environmental consciousness[29]

[27] https://doi.org/10.1186/s13750-022-00291-x
[28] Social and market acceptance of photovoltaic panels and heat pumps in Europe: A literature review and survey - ScienceDirect
[29] https://doi.org/10.1016/j.esr.2023.101178

To address the challenges specific to residential PV adoption in Europe, the following key findings and policy recommendations emerge from this study:

1. **Increasing Environmental Awareness:** Raising environmental awareness among residents is imperative. Individuals with a strong environmental consciousness are more likely to adopt PV systems and support the transition to clean energy.

2. **Information Campaigns:** Comprehensive information campaigns are essential for increasing stakeholder knowledge about residential PV systems. Access to accurate and detailed information is crucial for overcoming information barriers to adoption.

3. **Recouping Investment Costs:** Providing clear information on the financial aspects of PV systems is vital. Demonstrating how investments in PV technology can be recouped over time helps alleviate concerns regarding high upfront costs.

4. **Tackling Social Acceptance Issues:** Low social acceptance of residential PV may be linked to perceptions of high investment costs, long payback periods, and the absence of viable business models. Therefore, dissemination activities should focus on addressing these issues, including innovative PV system demonstrations and feasibility studies. Supportive policies, such as grants or loans, can help shift attitudes towards the financial aspects of PV technologies.

Overall, policymakers should adopt a holistic approach that considers the diverse array of stakeholders, encompassing both high and low-income households, as well as Small and Medium Enterprises (SMEs). This approach should also account for the distinct contextual dynamics in both urban and rural settings. In addition to formulating effective measures aimed at eliminating obstacles hindering the widespread adoption of photovoltaic (PV) systems, which may include financial support mechanisms designed to mitigate initial costs and reduce the influence of income disparities on adoption rates, policymakers should prioritize the enhancement of the public perception of the advantages associated with PV installations. Furthermore, there should be a strategic shift towards expanding the deployment of PV systems within low-income households.

Photo: Helena Lopes, Unsplash.com

1.3.2 Acceptance of Utility Scale Deployment

The IEA states that "for projects with low-cost financing that tap high-quality resources, solar PV is now the cheapest source of electricity in history." Spain, Germany, and Italy have already achieved commercial solar grid parity, meaning that the levelized cost of energy (LCOE[30]) for self-consumed commercial solar in these jurisdictions is competitive with retail electricity prices. This makes the outlook for solar PV an attractive investment for both the commercial & industrial (C&I) and utility market. Moreover, the development and realization of large-scale PV projects is typically much faster compared to other options like nuclear, wind and biomass. There is a broad spectrum of applications like BAPV, BIPV, ground-mounted, floating, cable pooling (combining wind and solar) and agrivoltaic (combing food and energy) applications.

A few critical micro and macro socio-economic challenges must be addressed to help strengthen the solar role in the renewable energy transformation from a utility and C&I standpoint. The table below describes these challenges and proposes some solutions:

[30] *LCOE: the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime. (CAPEX+OPEX)/Total Lifetime kWh*

Table 1:
Micro and Macro Socio-Economic Challenges for the Acceptance of Utility Scale Deployment

Micro or Macro Economic Challenge	Definition	Potential Solutions
Countries not meeting their climate targets	Countries falling behind on their climate targets	De-risk debt financing through multi-year auctions, taking lessons learnt from other countries on their success and how they can be implemented nationally or region wide. Moreover, looking at implementing and allowing the use of different solar PV applications like agrivoltaics, floating, rooftop, BIPV, ground projects as not all sites are viable for realizing solar projects. Implementing the Oeko institute mandate for solar rooftop projects. De-risk debt also significantly improves the LCOE of solar PV projects, given WACC has a significant impact according to NREL.
Net Congestion	Overloaded transmission lines with focus on centralized energy production and stopping further connections by TSO and DSOs.	Cable Pooling (combining solar + wind), battery storage and/or green hydrogen production, direct consumption and/or mini grid, flex connections of distributed generation solar PV projects, facilitating permits for TSO and DSO to fortify the grid, decentralized energy production, government mandate for PV projects to balance and maintain the health of the grid
Negative EUR/ MWh prices due to renewable peak loads	Poor forecasting of day ahead yields	Green certificates for hydrogen or the bundling of FCR, aFFR, APEX and spot price to make battery storage feasible, better forecasting of day ahead yields of projects, new out of the box ideas for the real requirement of base and peak loads.
Curtailment	Impact of curtailment and forecasting thereof on the business case of a PV project	Out of the box solutions, multi-stakeholder inter and intra-communication, long term policy support and approaches to implement to be deemed viable for investors to dive into like battery storage, green hydrogen production.
Sole focus on financial yields	Focus on +4.5% IRR with low or no prioritization on circularity, sustainability and or nature inclusivity	Demands governments to award and weigh more heavily on the added value of having projects being more circular (clarity in repowering and decommissioning of projects and the 3Rs (recycle, refurbish and repurpose) and nature inclusive, level of toxicity (PFAS), inclusion of biodiversity, transparency in the LCOE of projects and their IRR and benefiting projects with smaller carbon footprints/LCA (below 400/630 kg/COe/kWp.
Not meeting forecasted production yield	10 – 15% of projects do not meet the expected yield according to kWh Analytics.	Revision of expected p50, p90 by technical advisors/owner engineers and assumptions behind degradation rates, lifetimes, failure rates, irradiation & temperature profiles and PVSyst calculations.
Standardization and acceptance of new applications	Despite overwhelming scientific evidence of synergies for floating and particuarly agrivoltaics – challenge in the acceptance of food + energy solutions and combating water dissipation	Learn from the success of implementation of floating and/or agrivoltaics in certain regions and which crops benefit most, added value by government tenders in combining food+energy and/or dual use of land to compensate for the higher CAPEX costs in new applications like agrivoltaics and floating.
Permits	The difficulty and lengthy process of getting permits for large scale ground projects.	Implementation tools and lessons learnt from the EU commission Renewable Energy Directive to reduce permit times from countries that have implemented it with success.
Merchant Risk for subsidy free projects	Revenue instability and duration when projects are financed by banks in turn challenging the bankability of the project.	Innovative approaches to PPAs (vPPA, corporate PPAs, Cfds, necessity by governments for industry to become carbon neutral.
Local acceptance of PV projects	Resistance of large-scale projects due to horizon pollution or misinformation and no joint benefit. More in details 8 main categories of acceptance determinants have been identified: aesthetic, environmental, economic, project details, temporal, social, construction, and process[31]	Crowdfunding for PV projects, information sessions, requirement for nature inclusivity & biodiversity, sheep grazing and biodiversity friendly mowing policies that are a must have to obtain permits for realization.
Ethics of solar PV projects	Concerns about forced labor in PV modules	Requirement for projects to show mitigation methods that go beyond signed codes of conduct, but include approaches like desktop reviews, factory reviews, traceability protocols, public disclosure of conflict materials, commitment to CSR standards
Labor force needed to execute large scale PV projects	Added GDP value of solar PV projects unknown and challenges in finding talent for the solar PV projects.	Direct and indirect job creation of solar PV projects can bolster political support as it leads to jobs in certification, maintenance, project management, financing, technical due diligence, construction, greenkeeping, academic institute research, policy makers, consultants, R&D innovation. Programs to help talent locally and from abroad to help in the above industries. Further elaborated in 3.1.

[31] https://doi.org/10.1016/j.solener.2020.08.065

1.4
Acceptance of Critical Raw Materials (CRM) use for PV manufacturing

Electricity consumption is mostly demand-driven, i.e., independent of the load situation in the distribution grid or the upstream distribution grid and is hardly influenced by the current and local supply of electricity from renewable energy sources such as PV. This independence of electricity consumption from locally available grid resources and the time-varying nature of energy production from PV leads to both technical and economic inefficiencies, resulting in avoidable costs and technical-organizational challenges for the electricity grid. This decoupling of the grid tariff from the local situation also has disadvantages for electricity consumers and producers:

Consumers with existing flexibility potentially lack both the economic incentives to activate this potential and the information about when and how much flexibility would be of benefit to the system. This economic aspect is reinforced by a factor that is particularly relevant for households when deciding to produce renewable energy (e.g., by installing a PV system): the intention of many prosumers is to produce electricity for their own and local consumption and not for supra-regional distribution. Grid tariffs are a promising instrument to counteract the decoupling of the consumption behavior of consumers and the situation in the local electricity grid or the current production level from renewables, thereby contributing to better coordination of all elements in a local electricity system.

In the 27 countries of the European Union, 27 different tariff systems are applied. The tariffs for the respective grid levels always have one or more of the three conceivable components i) a fixed component, i.e., a lump-sum, ii) a volume-based charge, i.e., a charge per unit of energy and/or iii.) a load-dependent charge, i.e., a charge for tariffing the capacity provided or demanded for the customer. The mainstream introduction of a load-dependent component was recently rated by 90% of the participants in a survey of European energy experts as essential for future grid tariff systems[32]. However, at the household level, the application of a load-dependent component based on the actual measured power (through smart metering) is not mandatory in any country, even though this can help align the generation and consumption patterns with the grid's needs, reducing the need for expensive infrastructure upgrades and improving grid stability, which is a pressing issue in the light of increasing renewable energy within the energy transition.

Load-based grid tariffs can be difficult to implement as there are aspects that might hinder social acceptance. The introduction of load-based grid tariffs will likely lead to a redistribution of costs. Grid tariffs mainly based on a volumetric component induce less costs to households with less electricity consumption. While a load-based component can increase the aspect of true-cost pricing, it will lead to a redistribution of costs, likely in favor of households that consume larger amounts of electricity, and thus possibly in favor of higher income households[33]. Furthermore, if households face higher costs in a load-based system, then consumption patterns need to be altered to avoid higher costs. Another difficulty that arises when designing new tariffs is the fact that an electricity grid provider and a market for electricity might offer different signals to electricity consumers at the same time due to their distinct roles and priorities within the energy ecosystem. The electricity grid provider's primary concern is to ensure the stability, reliability, and safety of the electrical grid. In the electricity market, prices can fluctuate based on factors such as generation capacity, fuel costs, weather conditions, and consumer demand. These market signals indicate the cost of electricity at a given moment and encourage consumers to adjust their usage to align with cost-effective times. The grid provider, however, might issue signals to ensure grid stability, which may not always coincide with market price fluctuations. These signals could involve requests to reduce consumption temporarily to avoid strain on the grid, even if market prices are not significantly affected, or they might issue signals to incentivize consumers to use electricity during

[32] *Nebiolo, Stefano. (2021) The evolution of residential network tariffs in Europe - the opinion of energy experts.* https://bit.ly/3pvlpTp

[33] *Azarova, Valeriya et al. (2018). Exploring the impact of network tariffs on household electricity expenditures using load profiles and socio-economic characteristics. Nature Energy 3, 317–325.*

times when local renewable generation is high, irrespective of actual price developments. Together, alternative grid tariff schemes have a significant impact on electricity consumers' budgets and the characteristics of potential winners and losers remain rather diffuse. These can hinder the social and political acceptance of these substantial changes in how the cost of our electricity systems are recovered.

Future grid tariffs should reflect actual grid usage. A variety of different tariff designs are possible, including a complete abolition of fixed components, load based prices based on daily or monthly 15-minutes load peaks of households, with the possibility to integrate additional price signals based on local PV production forecasts, and concepts for maximizing self-consumption (e.g. through energy communities, self-generation and self-storage, feed-in tariffs, electric mobility or collective generation systems in apartment buildings) should be supported. To illustrate, Figure 4 displays an exemplary load profile of a consumer under one possibility of a true-cost pricing grid tariff system. The low tariff grants a discount during times of high supply (e.g., high local PV production), if the consumer exceeds a certain minimum load threshold (e.g., 2 KW). The high tariff is active during times of high demand, if the consumer exceeds a certain maximum load threshold (e.g., 4KW). This example includes the possibility to vary feed-in tariffs based on the local grid situation.

Further research is necessary to determine optimal tariff systems under different circumstances and how different tariff structures affect households and costs in different ways. Electricity consumers need to be aware of how their consumption patterns can stress or benefit the local grid, and that timing and intensity can be more critical than volume. Clear communication about the benefits of true-cost pricing, such as reduced grid infrastructure costs and increased renewable energy integration, can help build support and understanding among consumers.

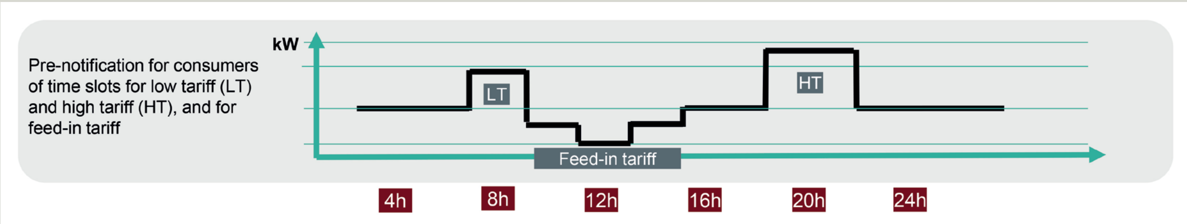


Figure 4:
Example of a true-cost grid tariff system (Source: Own depiction based on tariff-ideas that are being investigated within the project INNOnet[34])

[34] https://projekte.ffg.at/projekt/4478292

2.
Public Engagement

The active involvement of citizens has been recognised as one of the main factors to facilitate a successful energy transition. Consumers can actively contribute to this transition by becoming **prosumers**, which can be defined as "individual citizens, small or medium-sized companies, and public entities that consume and produce renewable energy". This possibility is particularly important in the case of PV technologies, which can be installed, for instance, on building roofs[35].

Moreover, REPowerEU acknowledges that 'the full potential of solar energy for the EU can only be exploited if citizens and communities are provided with the right incentives to become prosumers.' Member States would be requested to establish appropriate incentives and adapt administrative requirements to facilitate prosumption, including providing one-stop shops offering integrated information and support. They should also enable the development of local energy markets and avoid discrimination of self-consumption and peer-to-peer exchanges. The EU would also work with Member States to set up at least one renewables-based energy community in every large municipality by 2025.

Photo: Jonny Gios, Unsplash.com

The main decision factors affecting consumers' choice of PV systems are drawn from several dimensions[36]:

1. The **social dimension** relates to factors such as the appearance of systems in/on the building, social status, the added value given to the building, the innovativeness of technology and energy independence.
2. The **economic dimension** includes factors like implementation and operating costs (which are also associated with the ease of installing and operating a system) and the payback time of the investment.
3. The **technology usability dimension** encompasses factors like the trustworthiness of the technology, the work and time required for installation, the function and quality of the system, the expected comfort level, security of supply, the physical space occupied and the effort involved in operating and maintaining the system.
4. Finally, the **ecological dimension** is typically represented by consumers' ecological orientation or goals.

This chapter presents and discusses the major factors that can trigger citizens' involvement in further adopting PV technologies:

- Solutions to enhance citizens' participation in PV deployment.
- Socio-economic dimensions impacting decisions to implement and use PV technology.

The chapter also provides some examples as use-cases.

[35] REPowerEU acknowledges that 'the full potential of solar energy for the EU can only be exploited if citizens and communities are provided with the right incentives to become prosumers.'
[36] Based on "Support to the key activities of the European Technology platform on Renewable Heating and Cooling- Analysis of heating and cooling consumers" (2019)

2.1
Enhancing citizen's participation in PV Deployment

The role of citizens in accepting and adopting PV technologies is a crucial factor in ensuring their widespread use. The high market penetration potential of PV relies on its modularity as a technology and on the possibility to be deployed in different market segments. In 2022, small to medium scale rooftop PV installations was the largest source of PV deployment in Europe and is it expected to continue growing in the coming years (Figure 5)[37]. In order to achieve these targets, involvement of actors beyond large companies such as citizens, SMEs and local authorities are of paramount importance.

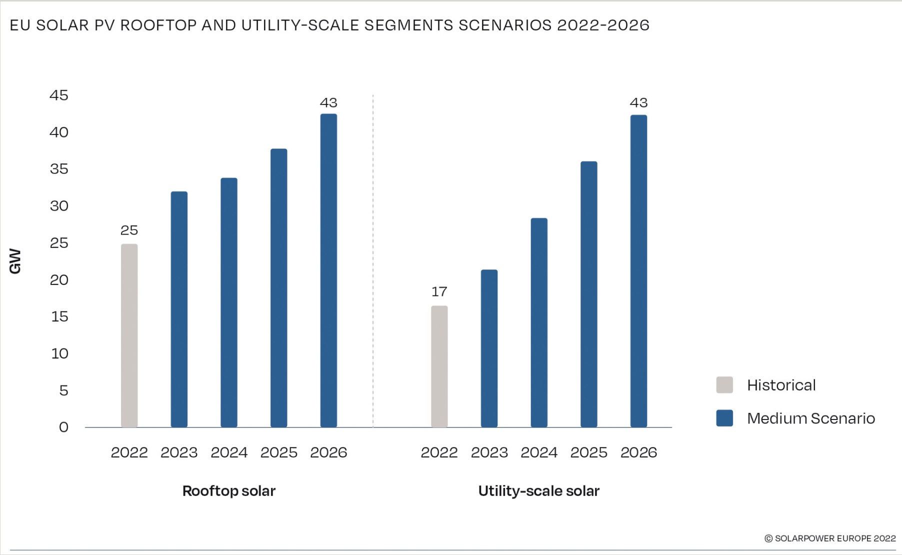


Figure 5: EU Solar PV rooftop and utility/scale segments scenarios 2022-2026 (Source: EU Market Outlook For Solar Power 2022 – 2026[37])

Yet, citizens are somehow reluctant to change their habits and adopt new technologies, such as PV. There is a lack of awareness and knowledge preventing the participation of citizens in PV projects such as energy communities, as shown in Figure 6. Other barriers related to the citizens' participation are the lack of financial resources, lack of time, and trust in neighbours. Satisfaction with the current energy system demotivates citizens to invest in PV systems[38].

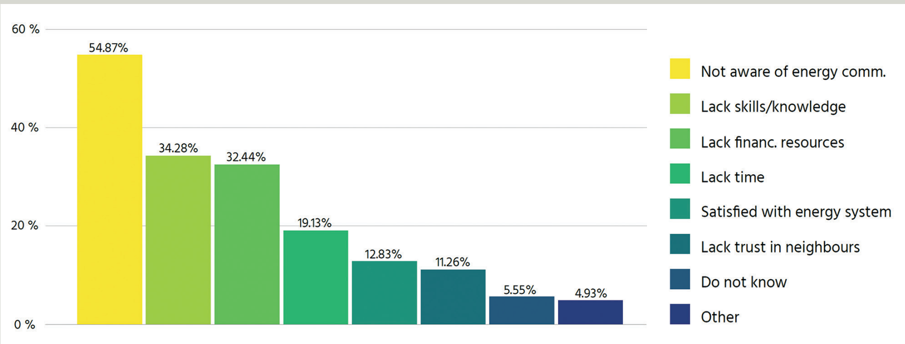


Figure 6: Barriers to the citizens' participation in PV projects such as energy communities (Source: Policy Brief: Putting people at the heart of the energy transition[38])

[37] *"EU Market Outlook For Solar Power 2022 – 2026", Solar Power Europe Report https://www.solarpowereurope.org/insights/market-outlooks/eu-market-outlook-for-solar-power-2022-2026-2*

[38] *Putting people at the heart of the energy transitions. Policy brief prepared by the EU H2020 Projects Comets, Newcomers, SocialRES and SONNET: http://socialres.eu/wp-content/uploads/2022/05/H2020_Policy-brief_final.pdf*

Citizens' participation in PV deployment can be enhanced by showing how fundamental PV is in the mitigation of global warming. The mitigation potential of PV is clearly shown in the graph of Figure 7, which has been included in the sixth assessment report of IPCC. Solar energy is considered by IPCC as the best option to reduce emissions and mitigate global warming.

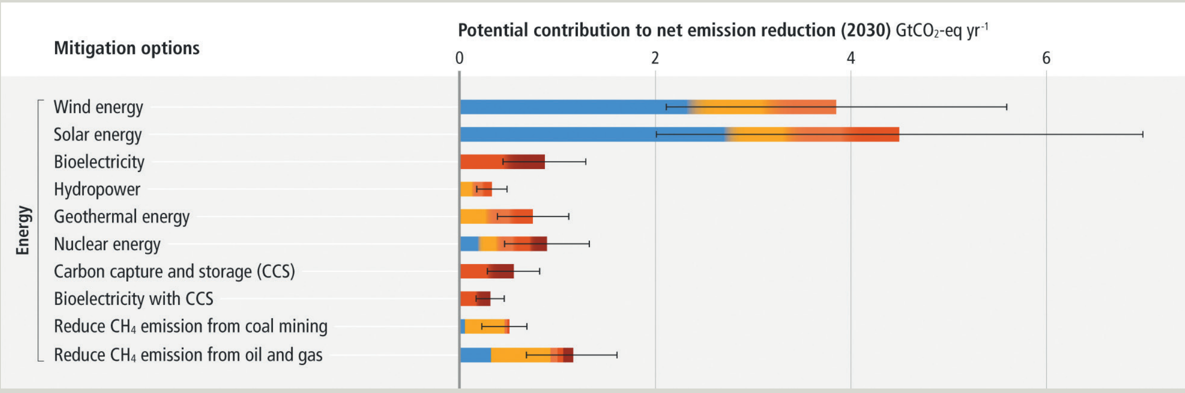
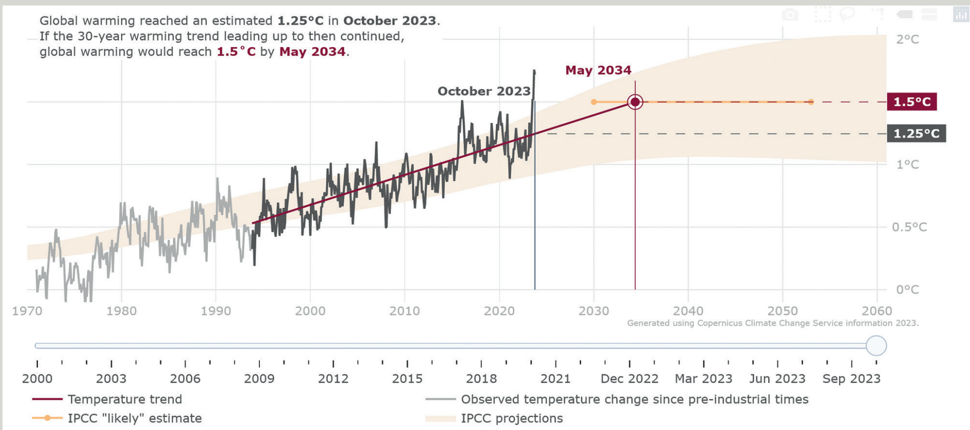


Figure 7:
Mitigation potential of PV (Source: IPCC 6th assessment report[39])

Vital targets in climate change mitigation, such as the Paris Agreement to limit the temperature increase to 1.5°C above pre-industrial levels, can be achieved only with a drastic reduction in CO_2 emissions, otherwise, as shown in Figure 8 below, with the actual trend, we will reach the limit of 1.5 °C in May 2034.

Figure 8:
How close are we to reaching global warming of 1.5°C? (Source: Copernicus Climate Change Service[40])



Otto et al., 2020[41], defines how Social Tipping Interventions can provide a fundamental contribution in limiting global warming to 1.5°C as shown in Figure 9. The scenario SSP 1,1.5°C, shown in the pink color, is the scenario that includes the Social Tipping Interventions and is the only scenario able to respect the Paris Agreement, blue square, in keeping global warming below 1.5°C until 2100.

[39] https://www.ipcc.ch/report/ar6/wg3/figures/summary-for policymakers/IPCC_AR6_WGIII_FigureSPM7.png
[40] Home | Copernicus
[41] Social tipping dynamics for stabilizing Earth's climate by 2050 | PNAS

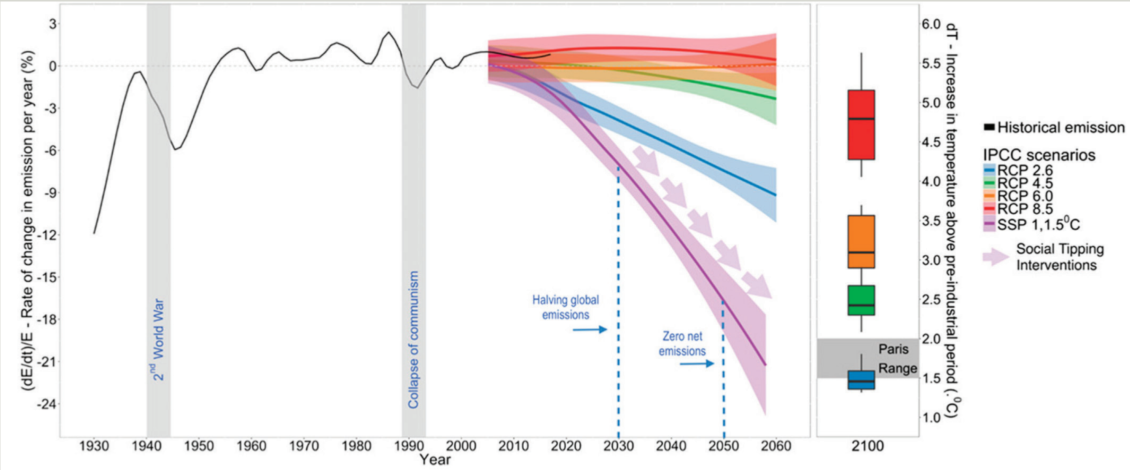


Figure 9:
Rate of change in annual greenhouse gas emissions required for net decarbonization (source Otto et al., 2020[41])

Social Tipping Interventions (STIs) are processes able to rapidly spread technologies, behaviors, social norms and trigger Social Tipping Elements (STEs). Otto et al., 2020, refers to STEs as "subdomains of the planetary socioeconomic system where the required disruptive change may take place and lead to a sufficiently fast reduction in anthropogenic greenhouse gas emissions".

In the context of advancing Social Tipping Interventions such as decentralized energy generation and carbon neutral cities with active citizen participation, photovoltaics serves as a pivotal technology. To delve further into this intersection between decentralized energy generation and citizen involvement, it is essential to explore the various business models and entities that are driving this transformative shift.

Among the most common business models associated with citizens' participation in the energy transition are energy communities, aggregators and crowdfunding platforms. These collective action models facilitate citizens' participation to the energy transition by allowing the consumer to take a more active role in the development of renewable energy projects. Energy communities and crowdfunding platforms empower citizens to become participatory actors, by (1) giving citizens the power to purchase, share and become a member or co-owner of energy projects and (2) giving people the power to choose how their capital is being used. Energy communities can span across a wide range of activities along the energy supply chain, including generation, supply of energy as well as provision to their members of energy efficiency services. Historically, generation, hence the development of renewable energy plants, is the most common activity of energy communities across Europe[42] (e.g. in 2015 in Germany, 635 out of about 900 initiatives were generation cooperatives[43]). Among renewable energy generation technologies, PV is the mostly installed by energy communities, mainly for small to medium size rooftop applications[44] (see also Figure 10 for German energy communities PV installations).

[42] *Lupi V., Candelise C., Almuni Calull M., Delvaux S., Valkering P., Hubert W., et al. "Characterization of European Collective Action Initiatives and Their Role as Enablers of Citizens' Participation in the Energy Transition" Energies 2021 Vol. 14 Issue 24*

[43] *Ö. Yildiz, J. Rommel, S. Debor, L. Holstenkamp, F. Mey, J. R. Müller, et al. "Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda". Energy Research & Social Science 2015 Vol. 6 Pages 59-73*

[44] *Lupi et al 2021, Ibidem*

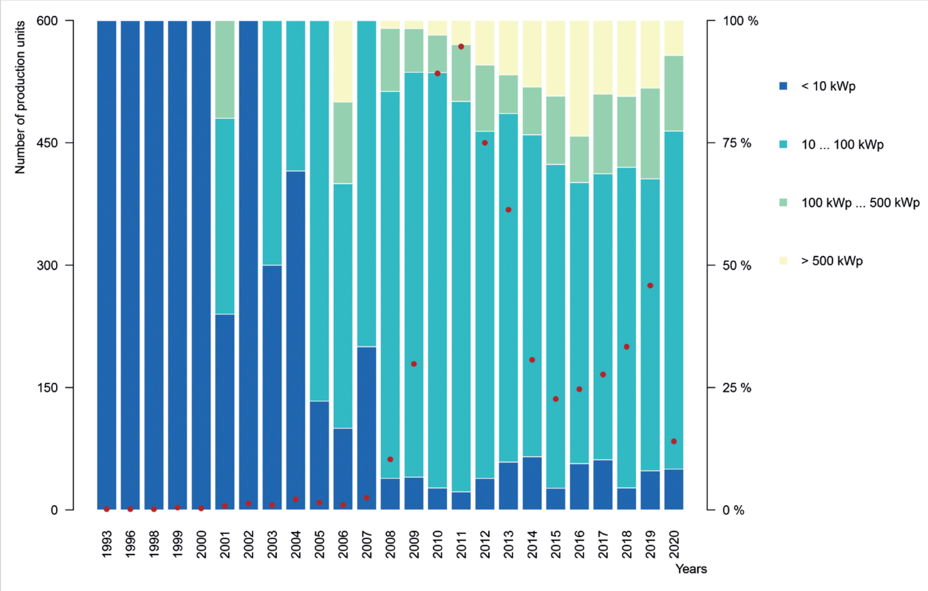


Figure 10: Distribution of size of PV plants installed by energy communities in Germany (right) and number of PV plants (red dots and axis to the left) (Source Wierling, el al. 2021[45])

Installation of PV plants by energy communities has increased since late 2000s also thanks to the generous Feed in Tariff policy support implemented in several EU countries, in particular Germany and Italy, which have de-risked PV investments and made them more approachable and suitable for less technically and financially skilled initiatives as they were energy communities[46]. PV installations by energy communities still accounts for a relatively small share of total PV installation in Europe, e.g. it has been estimated in 2020 that they accounted respectively for 1.7% and 0.07% of the total PV capacity installed in Germany and in Italy[47]. However, the currently evolving European policy and regulatory framework for energy communities (provisions in EU Directive 2018/2001 (RED II) and 2019/944 (IEM) and the relative Member States implementations) is expected to further foster their deployment and PV technologies are expected to play a significant role in it.

Renewable energy aggregators add an additional a layer of participation and aggregation of citizens in the energy system; they operate on behalf of the aggregated prosumers and/or consumers in the wholesale energy market to obtain better deals for the related amount of generation units and/or load units aggregated and named Virtual Power Plants (VPPs). They are labelled “digital utilities” and can be considered as the “utilities of the future” since the amount of energy generation units aggregated is approaching the one generated by traditional power plants managed by utilities. Energy cooperatives, communities supported by aggregators sell the generated electricity in the wholesale energy market achieving more competitive and, therefore, more affordable electricity for their members (Ref: H2020 European project SocialRES[48]).

[45] *Wierling, A., Zeissa, J.P., Lupi, V., Candelise, C., Sciullo, A., Schwanitz, V.J. "The contribution of energy communities to the up-scaling of photovoltaics in Germany and Italy", Energies 2021, 14(8), 225*

[46] *Candelise, C., Ruggieri, G. 2020. Status and Evolution of the Community Energy Sector in Italy. Energies, 13; Wieling at al 201, Ibidem*

[47] *Wierling A. et al, ibidem*

[48] *http://socialres.eu/*

2.2
Socio-economic dimensions impacting decisions to implement and use PV technology

In many cases the adoption of a PV system is an individual or household decision. A key driver here is whether people can afford to invest in a PV system. If that is the case, e.g., supported by subsidies or mortgage arrangements, different other drivers come into play. These may be economical, referring to the return-on-investment expectations (which are uncertain by nature), the perceived contribution to reduction of emissions, bio-spherical values. And last but not least the people you know that already have invested in PV systems, providing you with their experiences regarding the possible hassle of installation, and the evolving norm regarding contributing to the energy transition.

Whereas the informational and normative social influences play a role in individual decisions to adopt a PV system, oftentimes larger PV projects are being organized in more cooperative settings, e.g., by a neighborhood or local community. Hence the decisional context of adopting PV systems ranges from an individual household deciding on adopting a PV system, discussing this decision with neighbours and friends, to collective neighborhood projects where a critical number of citizens must join to make a project feasible.

Many changes and policies in the energy sector rely on and require behavioral adaptations of citizens. This domain addresses a great variety of behaviors, ranging from expensive one-time investments such as insulating a house, habitual behaviors such as modality choice, individualistic choices such as purchasing a heat pump, or choices that require a critical number of neighbors to join, such as participating in a heat network. Some behaviors are more related to social identity, such as the type of car or bike one is driving, whereas other behaviors are hardly noticed by other people, such as lowering the indoor temperature and sitting on the couch with a warm blanket.

In the context of modeling transitional dynamics in the energy system, the behavioral response to different policies is important in estimating the potential impacts of certain combinations of policies. Whereas a plethora of theories is available in qualitatively understanding the motives and drivers of people regarding energy relevant behaviors, in modeling energy systems it is required to have quantitative and causal representations of behavioral responses to different developments.

Modeling behavioral change faces us with the challenge of capturing a wide variety of drivers and processes of very different energy relevant behaviors of many different people that are influencing each other. Whereas in the past mainly economic models were being used for estimating behavioral responses, the "rational actor" that is assumed in these models is not capable of including effects of informational and normative influences in networks of people, habitual behaviors, and more emotional responses towards change.

In the last decade, agent-based models are increasingly being used in the domain of energy relevant behavior. Here, behavioral theories and data are being used to simulate artificial societies of heterogeneous agents that respond to different energy policies, and that influence each other by sharing information or changing norms (for a review, see e.g., Jager, 2021[49]). Agent-based models basically model individual people and their connections, and thus allow for modeling of networks of heterogeneous citizens. This allows for studying the social dynamics of how innovations diffuse through a society, what behavioral/normative barriers may exist, and if tipping points exist in such systems[50].

Agent-based models that are capturing the key drivers and processes guiding behavioral change, and that are parameterized for specific energy relevant cases, are capable of exploring the diffusion dynamics of new technologies and practices. Many applications are available, e.g. on adopting electric vehicles, PV-systems, insulating houses, changing mobility patterns. Hesseling and Chappin (2019)[51] provide an overview of agent-based models specifically targeting the adoption of energy efficient technologies by households.

[49] https://www.sciencedirect.com/science/article/pii/S2352250X21000968
[50] Social norms as solutions | Beijer Institute (kva.se)
[51] https://doi.org/10.1016/j.rser.2018.09.031. ISSN 1364-0321

Increasingly, agent-based models are developed where different behavioral theories are being connected in integrated model architectures. This development is relevant in the context of energy relevant behavior, as many theoretical aspects are important to understand energy relevant behavior. Integrated models can bring together insights on human needs and motivation, normative influences, habitual and imitational processes, persuasion processes and social learning, values and networks, to name a few. In the EU SMARTEES project[52] an integrated model, called HUMAT, was developed and applied to study different cases of social innovations related to energy, such as closing neighborhoods for transit traffic, making islands energy independent, insulating apartment buildings and heat net projects[53].

In the context of modeling energy systems, the value of such agent-based models resides in their numerical input and output, allowing for a formal connection with other energy models. Models that propose particular technical developments can be used as input for agent-based models, and these agent-based models can serve as a testbed for exploring the possible diffusion dynamics of new technology given certain supporting policies. As an output, such agent-based models can produce scenarios of behavioral change, which can for example be translated into changing energy demand, production and storage capacities. Having a representative model of population behavior in the context of energy modeling thus contributes to our understanding of how certain technologies and policies (in combination) may have an impact on the energy related behavior of a population. This may be very valuable for understanding cascading effects, especially when initial resistance to change may rapidly switch towards a broad acceptance, with potential disruptive effects on energy networks.

Photo: Mischa Frank, Unsplash.com

[52] https://local-social-innovation.eu
[53] (PDF) Sensemaking of causality in agent-based models (researchgate.net)

2.3
Use-Case

Solar energy offers many ways to collect and provide consumers with low-carbon and environmentally friendly energy. Private housing or industrial needs are however different in terms of amount of energy needed and type of installation. A use-case is needed to define the relevance of a specific photovoltaic technology for a specific location. The readily availability of such use-cases for the general public can be important to increase the engagement of citizens.

The difference in climatic conditions is especially important for renewables. As they function intermittently, the extractable energy from the sun will be highly dependent on the solar irradiance, but also on the temperature, and on the type of technology used. To facilitate the understanding of such functioning, different parameters must be considered when dimensioning a photovoltaic installation. It is important that every project is carefully considered, to provide the best technological solution considering the amount of energy needed, the geographical location, the space needed for the installation, in order to have the smallest energy payback time for the installation. Figure 7 shows solar irradiance over European countries. The power that can be extracted from this abundant source of energy relies drastically on geographical location. Different technologies might be used to meet a project's needs: agrivoltaics, building-integrated PV, Floating PV or industrial/private housing rooftop are among them.

Agrivoltaics might at the same time help farmers to improve harvest yields and benefit them economically. This technology could be protecting crops from climatic events such as frost, heat waves or drought. A recent study has shown that the potential for agrivoltaics in Europe is around 51 TW[54]. A large part of Europe's energy demand could be filled by such an approach. However, agrivoltaics is still quite unknown to the general public. Strong R&D effort is needed to demonstrate how Agri-PV can provide mutual benefits across the food–energy–water nexus.

On the other hand, building-integrated PV can provide self-consumption energy to companies or residences. It can act as a weather protection and a thermal insulation means. BIPV installation can be applied on roofs, façades or as a shading system. NREL's recent technical report has shown that the installation of BIPV takes 44% less time than the same installation made as a rehabilitation (Observations and Lessons Learned from Installing Residential Roofing Integrated Photovoltaics), proving that solar technology bankability can largely be improved with this strategy[55].

Floating PV efficiency is increased by a good heat transfer in certain conditions, and its use is cost competitive in comparison to land-based installations[56]. The potential of this technology is much higher in southern Europe. It has less risk to conflict with the use of arable land and biodiversity. Its cost-competitiveness depends on grid-connection costs and could be improved via hydropower-based storage. Each technology brings benefits and drawbacks, and the most sustainable solution probably relies on an intelligent mix of these possibilities, strengthened by solid storage possibilities.

If one takes Belgium as an example of a use-case, the average annual solar irradiance is about 1000 kWh/m^2. The electricity consumption per capita in Europe in 2021 was about 1700 kWh per capita and per year, which is also the average electricity consumption in Belgium[57] (Eurostat, Gross electricity production by fuel, EU, 2000-2022). However, in the south of Spain for example, the average irradiance is about the double, around 2000 kWh/m^2. A housing with 10 PV modules of 300 Wp in Brussels could produce around 3000 kWh per year and have an own consumption of 500 kWh only. The same installation in Seville would produce around 5200 kWh and have an own consumption of around 675 kWh (simulation on PV*SOL with a 1-person household and a consumption of 1700 kWh/year)[58].

[54] *Comparative analysis of photovoltaic configurations for agrivoltaic systems in Europe - Ali Khan Niazi - Progress in Photovoltaics: Research and Applications - Wiley Online Library*
[55] *Observations and Lessons Learned From Installing Residential Roofing-Integrated Photovoltaics (nrel.gov)*
[56] *Techno-economic potential and perspectives of floating photovoltaics in Europe - ScienceDirect*
[57] *Electricity and heat statistics - Statistics Explained (europa.eu)*
[58] *PV*SOL online - a free tool for solar power (PV) systems. (valentin-software.com) , simulation with a consumption of 1700 kWh/year/person*

Solar energy production cannot be controlled as it is highly dependent on climatic conditions[59]. To make solar energy more competitive, storage considerations must also be considered. The solar energy production peak is usually in the middle of the day, whereas the energy consumption peak is usually at the beginning and at the end of the day. In this regard, hydrogen electrolysis, batteries or gravimetric storage must systematically be implemented to photovoltaic parks. Profitability is also greatly influenced by the possibility either to sell such energy on the grid, or to store it and use it when it is needed[60,61].

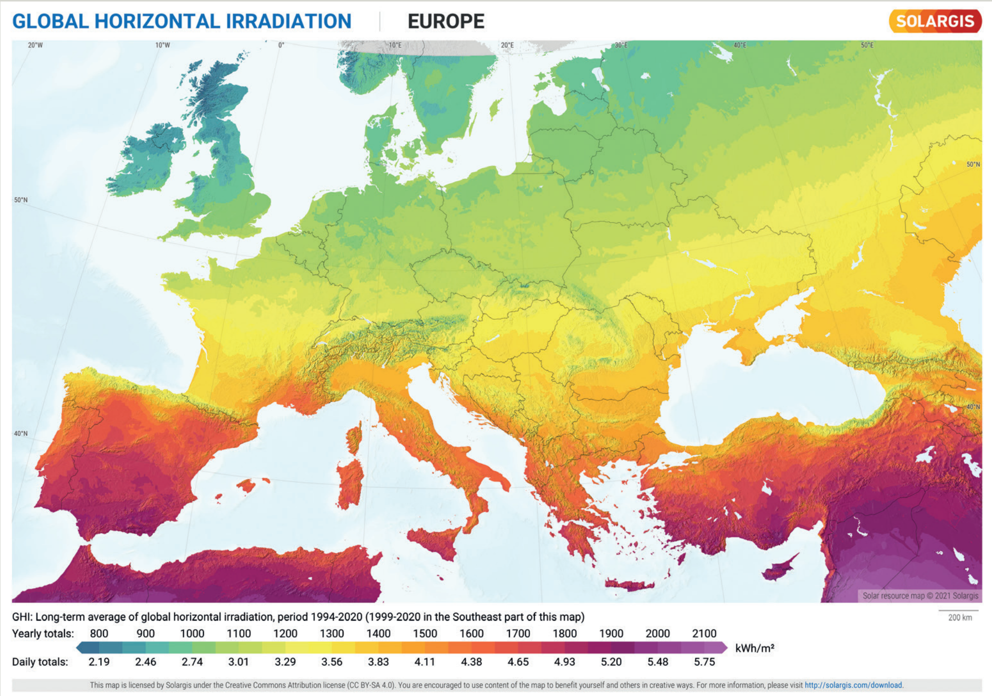


Figure 11:
Solar irradiance over European countries (Source: Solargis[62])

[59] *Where solar is found - U.S. Energy Information Administration (EIA)*
[60] *Grid-connected PV (europa.eu)*
[61] *https://doi.org/10.1016/B978-0-12-809597-3.00518-6*
[62] *Solar resource maps and GIS data for 200+ countries | Solargis*

3.
Skills and Workforce

As the PV sector continues to evolve and expand, addressing the dynamic workforce needs and skill requirements becomes paramount. Chapter three delves into the pivotal aspects of re-skilling and up-skilling within the PV industry, ensuring that the workforce stands well-prepared for the ever-changing demands of this field. The European solar industry poised to create a million jobs by 2025, and even more by 2027, the critical roles steering this growth and the challenges posed by maintaining a qualified workforce are examined in detail.

Furthermore, this chapter illuminates the profound importance of preserving innovation capacity within Europe. Innovation serves as the lifeblood of the PV sector's growth and sustainability. The chapter will explore the strategies and policies imperative for bolstering innovation while simultaneously addressing the evolving skills and workforce needs.

Moreover, this chapter covers the pressing issue of gender diversity within the solar PV sector, drawing insights from the 2022 IRENA gender perspective report. It underscores the urgency of enhancing the representation of women in the industry and underscores the broader objective of fostering a diverse and inclusive workforce that encompasses all minority groups.

In a time of accelerating change, the imperative of ensuring the right skills, achieving gender diversity, and maintaining innovation capacity becomes central in advancing the solar PV sector towards a sustainable future.

3.1
Re-skilling and Up-skilling in the PV sector

Re-skilling and up-skilling are crucial processes aimed at preparing the workforce for the evolving demands of the PV industry. Re-skilling involves equipping workers from various backgrounds and industries with new skills relevant to the PV sector, while up-skilling refers to continuously enhancing the expertise of existing PV professionals.

In Europe, there is a pressing demand for skilled workers, notably within the expanding solar sector. According to the SolarPower Europe Job Report 2023, the EU's solar industry is on track to create one million jobs by 2025, with projections reaching 1.2 million jobs by 2027. This represents a significant increase from the 648,000 individuals employed in the sector at the end of 2022[63].

Several critical roles are pivotal to this growth, including product engineers, design engineers, electrical engineers, factory operators, and construction workers. Among these, design engineers, particularly in the utility-scale segment, face fierce competition for their expertise, intensified by declining STEM student proportions and reduced mathematical proficiency across Europe. Additionally, electrical engineers play a central role in ensuring the proper design and safe grid connection of solar systems, a bottleneck, especially in rooftop PV installations. Construction workers, including roofers, are the backbone of the solar revolution, but shortages are impacting both the rooftop PV and utility-scale markets, exacerbated by the anticipated growth in project commissioning after 2022. Figure 12 depicts the ratio of positions needed for deploying rooftop PV and ground mounted PV.

Photo: Michael Wilson, Unsplash.com

[63] EU Solar Jobs Report 2023 - SolarPower Europe

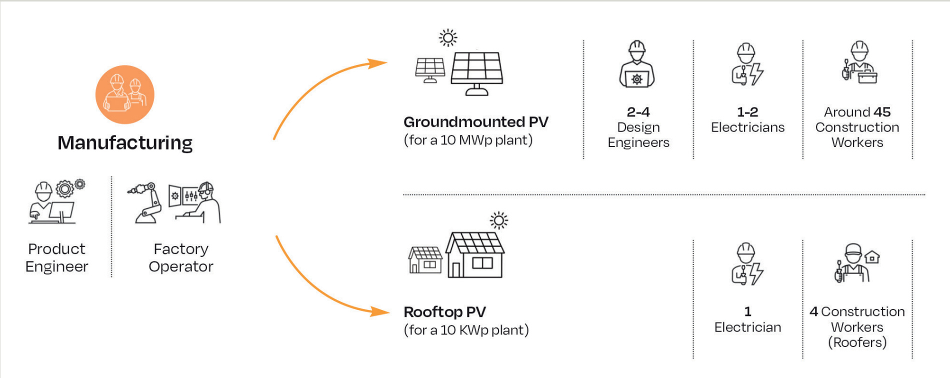


Figure 12: Ratio of positions needed for deploying rooftop PV and ground mounted PV (Source: Solar Power Europe Jobs Report 2023[63]).

To address the skills gap and foster the necessary re-skilling and up-skilling, the following recommendations should be considered:

1. **National Assessments of Skills Gap:** As mandated in REDIII, Member States should invest resources in identifying workforce gaps and skill sets more comprehensively. Regular gathering of precise information for various professions is essential to establish a European plan of action for skills.

2. **Communication & Education Campaigns on Green Collar Jobs:** European education policies should shift to better value manual careers, communicate the need for green jobs, and provide training opportunities. Manual careers should be more highly valued among students and job seekers, with efforts directed at education professionals, public and private employment platforms, VET providers, and local authorities.

3. **Specialised Training for Relevant Professionals:** The training of electricians and construction workers for solar installations should be accelerated, ensuring high-quality work and safety. This specialization will lead to better-equipped workers for the growing solar industry.

4. **Retraining Programs for the Just Transition:** Lifelong training should be encouraged, especially for transitioning industries, with programs developed to prioritize workforce reconversion in jobs needed for the clean energy transition.

5. **Skill-Proofing Energy Policies:** Integrated renovations of buildings and energy policies should prioritize skill availability. Smart subsidy schemes and information access can encourage combined renovation works and clean energy installations.

6. **Cross-Border Recognition of Skills:** Mutual recognition of qualifications and the development of an EU-wide certification standard for electricians should be pursued under the Services Directive and the Renewable Energy Directive. Authorities should accelerate these procedures.

7. **Integration of Solar Sector Needs into Immigration Policies:** The EU should facilitate the entry of workers from third countries to support the growth of the solar sector, aligning with strategic priorities. Talent Partnerships and the EU Talent Pool can play a role in this process. Solar PV, as a vital sector for Europe's challenges, should be central to these mechanisms.

3.2
Maintaining Innovation Capacity in Europe

The deployment of photovoltaic (PV) technology has experienced significant growth, reaching a global cumulative capacity of 1 TW[64]. Among PV technologies, single-junction (SJ) silicon solar modules dominate the market, constituting 95% of the industry. China, with a manufacturing capacity of over 75% across all PV module stages, is a major player, leading to a concentration of supply chains and market imbalances[65]. Diversifying the PV module manufacturing sector could involve exploring innovative approaches, such as PV tandem configurations, in which two solar cells are placed on top of each other. Perovskites have gained traction as top cells in these configurations, resulting in a rapid increase in power conversion efficiency (PCE). Perovskite tandem configurations integrated with silicon technologies have achieved PCEs exceeding 33%[66]. Additionally, thin-film tandems, combining perovskite with CI(G)S bottom cells, have shown promising efficiencies above 25%[67]. Given the latter results combined with established thin-film R&D centers and equipment suppliers in the EU and the USA[68], there might be an opportunity to establish new thin-film tandem PV module manufacturing capacity. This could help meet the growing demand for solar PV by providing the additional supply required.

Martulli et al. (2023)[69] have estimated the costs and the lifecycle GHG emissions of different PV technologies when manufactured either in the EU, China, or the USA as if production were to take place now and out to 2050. The single-junction solar PV technologies considered included PERC, HJT, CIGS, and perovskite PV modules. For the tandems, the focus was on devices in a 2-terminal (2T) and 4-terminal (4T) architecture, containing a perovskite top cell and a CIS or silicon (PERC or HJT) bottom cell. The study evaluates parameters at both the PV module and system levels. At the module level, cost competitiveness and GHG intensity are respectively determined by computing the minimum sustainable prices (MSP) in USD$ per watt and the global warming potentials (GWP) in kgCO_2-eq per watt for each PV device manufactured in the specified locations today. At the system level, the analysis quantifies the levelized cost of electricity (LCOE) in USD cents per kWh and the greenhouse gas emission factor (GEF) in kgCO_2-eq per kWh for residential and utility-scale applications. Below, we outline the main conclusions. For the actual numbers on the indicators, we refer to our pre-registered publication. Please note that while the study does consider regional price differences, it does not consider raw material price fluctuations outside of the current window. Furthermore, in order to have a chance of a viable business case, we need to make the strong assumption of competitive lifetimes and the absence of efficiency losses during upscaling for the emerging PV technologies.

On a residential scale in Europe, PV systems using thin-film tandems manufactured within the EU have a levelized cost of electricity (LCOE) distribution that overlaps with systems utilizing large-scale (1GW) PERC modules manufactured in China. At both utility and residential scales, perovskite/PERC PV systems from China have a slightly lower LCOE than those combining perovskite with CIS technology in the EU. While perovskite/PERC tandems from China have a higher LCOE compared to PERC single-junction modules made in China, perovskite/CIS tandems made in the EU exhibit slightly higher LCOEs, despite significant reductions in greenhouse gas emissions. Looking ahead to 2050, thin-film PV production in the EU and the USA continues to show lower GHG emissions than silicon PVs manufactured in China, even if the energy transition plans of China towards decarbonization come to fruition. Regarding utility-scale PV systems in the EU, perovskite/PERC technology from China is expected to be the most cost-competitive option in 2050, gradually narrowing the gap in the following decades as market share and power conversion efficiency increase. However, with the growth of perovskite market share anticipated after 2035, reductions in LCOE are projected for thin-film tandems produced in the EU, bringing them in line by 2050. Similar trends are observed for PV systems made and installed in the USA. Consequently, these findings suggest that developing production capacity for emerging thin-film tandems, especially perovskite/CIS, could offer additional supply while diversifying the PV supply chain and fastening the decarbonization of power systems in the EU and the USA provided the assumptions made hold true.

64 https://www.pv-magazine.com/2022/03/15/humans-have-installed-1-terawatt-of-solar-capacity/
65 https://www.infolink-group.com/energy-article/solar-topic-chinas-module-exports-drop-further-in-november
66 https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies-rev220630.pdf
67 https://doi.org/10.1021/acsenergylett.2c00707
68 CIGS_White_Paper_2019_online.pdf (cigs-pv.net)
69 https://doi.org/10.5281/zenodo.10001034

3.3
Gender Equality in the PV sector

Gender equality is a pivotal issue in the modern workforce, and the solar PV (photovoltaic) sector is no exception. The solar PV sector accounts for a significant number of jobs in the renewable energy industry, with a projected significant growth by 2030 as outlined in chapter 3.1, and understanding the role of women in this field is essential.

Referring to the 2022 IRENA gender perspective report[70], several key issues related to gender equality in the solar PV industry can be identified:

- **Underrepresentation:** While women make up 40% of the full-time workforce in the solar PV sector as depicted in Figure 13, their representation is significantly lower in technical and leadership positions. Women hold only 32% of STEM positions and a mere 13% of senior management roles.
- **Occupational Distribution:** Women are predominantly employed in administrative roles (58% of the workforce) but are underrepresented in manufacturing segment (47% representation), service providers (39% representation), developers (37% representation) and installers (12% representation).
- **Barriers to Entry and Advancement:** Women in the solar PV industry face barriers related to perceptions of gender roles, lack of fair and transparent policies, and cultural and social norms that hinder their progress and retention in the workforce.

To address the problem of gender inequality in the solar PV sector, the report offers several key solutions. First and foremost, there is a need to raise awareness about gender-related issues and cultivate a culture of inclusivity within the industry. This can be achieved through educational initiatives and open discussions to challenge existing gender stereotypes and biases. Additionally, national policies must undergo significant improvements to promote gender equality, ensuring that women have equal access to opportunities.

Furthermore, it is imperative for companies operating in the solar PV sector to establish fair workplace practices, policies, and regulations that actively encourage diversity and provide equal opportunities for women. This includes creating transparent promotion and hiring processes that prioritize merit over gender. Moreover, support networks and mentorship programs should be established to offer guidance and a sense of community for women in the industry, helping them overcome the unique challenges they may face.

Lastly, achieving gender equality in the PV sector is not an isolated goal; it should be part of a broader objective to diversify the entire workforce, ensuring that it reflects the full spectrum of society, including not only women but also all minority groups.

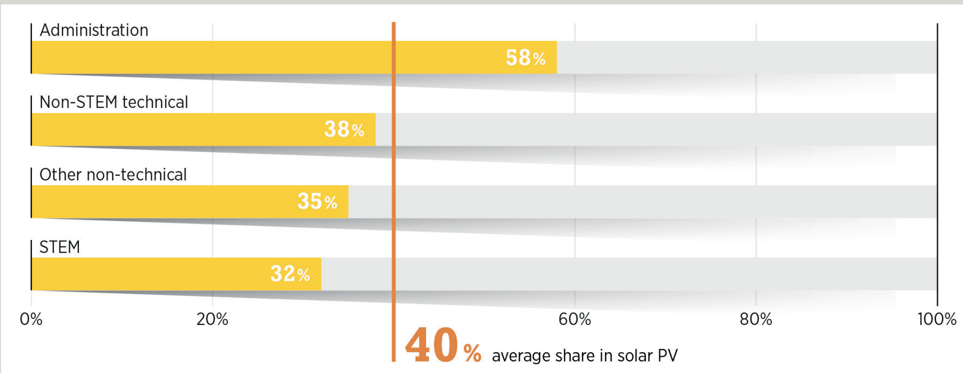


Figure 13: Women in the solar PV workforce, by role (Source: IRENA online solar PV survey, 2021[70])

[70] Solar PV: A Gender Perspective (irena.org)

4.
Environmental and Social Sustainability

The massive deployment of solar PV offers great benefits and opportunities, but also poses major challenges to society. One of these challenges is finding the right balance between minimizing generation costs versus optimising ecological and social effects of solar PV systems. This means that comprehensive Societal Cost-Benefit Analyses are needed to find the optimum path of the energy transition with a large share of solar PV. In other words, as a society we need to optimize the sum of societal costs of solar PV deployment (monetary, aesthetic, social, ecological, etc.) and benefits or values of solar PV deployment (mitigation of climate change, jobs & income, living comfort, etc.). Since it is often not easy, or even not possible to quantify part of the societal costs and benefits, it is important to understand the underlying drivers and how they depend on actions that can be taken.

This chapter therefore focuses on three key areas. It starts by delving into the Environmental Impact, employing Life Cycle Assessment (LCA) analysis to scrutinize the ecological footprint of PV technology. It then shifts its focus to Social Impact through Social Life Cycle Assessment (S-LCA), a tool that explores the broader societal consequences of PV deployment. Finally, the third part emphasizes the importance of the Environmental, Social, and Governance (ESG) framework in promoting sustainable and socially responsible practices of PV technologies.

4.1
Environmental impact - LCA analysis

Environmental life cycle assessment (LCA) is a systematic tool for analyzing the environmental impacts of a product system throughout its life cycle, from the extraction of resources, through the production of materials, parts, and the product itself, to its use and end-of-life (EOL) (reuse, recycling, or final disposal). An LCA analysis is divided in four stages:

1. **Definition of the Scope and the Goal of the Study**
2. **Inventory Analysis**
3. **Environmental Impacts Evaluation**
4. **Interpretation**

In the PV sector, LCA is also the key tool today adopted to set up the environmental regulations and the adopted threshold for the carbon footprint such as used in France for public tenders.

The photovoltaic (PV) sector has undergone both major expansion and evolution over the last decades, and currently, the technologies already marketed or still in the laboratory/research phase are numerous and very different. To assess and compare the energy and environmental impacts of these different technologies, life cycle assessment studies are crucial. In this way, LCA is an important tool that can guide current technological choices at the design level toward sustainable solutions from an environmental point of view, helping therefore to anticipate environmental issues before massive production.

From an environmental point of view, it is relevant to note that the diversification and constant technological improvement that is taking place in the PV industry leads to a large potential for reducing environmental impacts. Gazbour et al (2023)[71] studied the impact of technological evolution by defining four generations of PV modules and comparing their environmental impacts. Results show significant reduction in all

[71] *Gazbour Nouha . 2023. « Solaire photovoltaïque : quel impact sur l'environnement ? » Encyclopédie de l'énergie (blog). 16 mai 2023. https://www.encyclopedie-energie.org/solaire-*

environmental criteria for the later generations of PV modules compared to the GEN1 (2007 – 2014) Depending on the criteria, it varies from 20% to 50% and from 40% to 95% for GEN2 (2018 -2020) and GEN4 (2020 – 2022) modules respectively. This reduction is mainly due to improvements in the value chain in terms of material yield (reduced kerf losses, wafer thickness for silicon, reduced track width for silver) and manufacturing process optimization.

Even though LCA is a common tool used in publications and in the implementation of regulations, there is great variability in the environmental results, which can make decision-making difficult or even impossible[72]. The variability of the obtained results in an LCA study is mainly due to the following parameters:

- Variability in the scope of the study for the environmental assessment of PV systems.
- Lack of transparency and consistency in the key parameters of defined PV systems.
- Variability in the quality of data collected to model PV system components (feedstock, ingot, wafer, cell, module and system).

These limitations can severely affect reliability of environmental results, which makes eco-design decisions difficult. For the sustainability assessment of PV modules, LCA is still an excellent tool but it is highly dependent on the scope of the study, data quality and analysis method. It is therefore mandatory that the PV community develop a new and common approach to evaluate and compare the environmental impact of PV systems. This approach needs to be beyond the carbon footprint and to include all the lifecycle stages and all the environmental criteria (resources depletion, recyclability ...) in the decision making.

In Figure 14, we show an example of how the carbon footprint for panels with a different manufacturing location can be compared via LCA. The colors in the bars represent carbon-emission contributions from the different stages of making a solar.

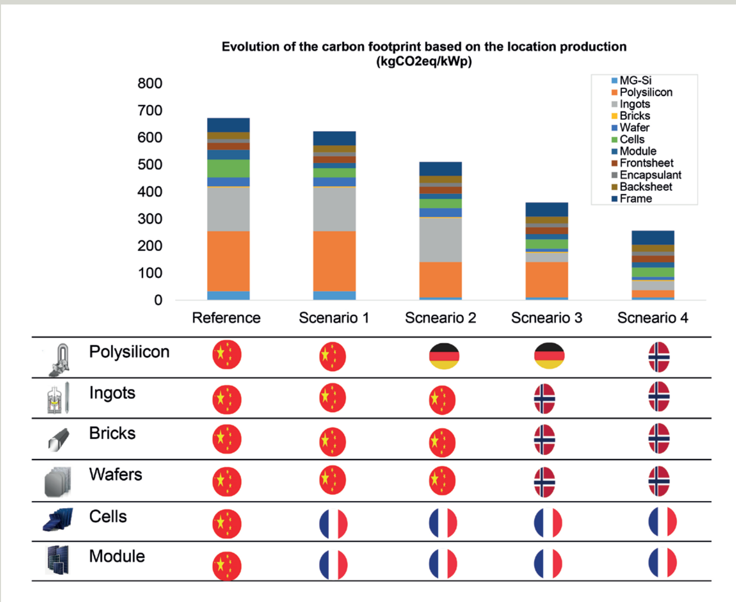


Figure 14: Carbon footprints of different types of solar panels made in China (CN) vs. Europe (RER) panel. (Source: Gazbour 2023[72])

[72] *Gazbour Nouha et al.. 2018. « A path to reduce variability of the environmental footprint results of photovoltaic systems ». Journal of Cleaner Production 197 (octobre): 1607-18.* [*https://doi.org/10.1016/j.jclepro.2018.06.276.*](https://doi.org/10.1016/j.jclepro.2018.06.276)

4.2
Social Impact Assessment and S-LCA

PV systems are socio-technological systems involving not only the physical components such as PV modules, BOS and raw materials in mineral deposits, deployment of new technologies and the operation networks and devices, but also the humans who design and implement the technologies, develop and manage the PV plants on a daily basis and use and consume energy. So, the social processes that accompany the transformations of PV technologies, and the social outcomes that result from the organization and operation of (new) energy systems (in general but where PV will have a leading role) must accompany the decision-making process involved in the sustainable transition. This transition, if it is to work effectively and sustainably, will need to include various forms of social innovation, business models and ad hoc policies created in conjunction with new energy technologies[73]. Additionally, as the PV sector has extensive and global value chains, its deployment and use has pronounced effects on inhabitants, workforce and users in areas along these value chains.

It is thus essential to investigate the social impacts of energy system technologies and specifically PV and while doing so consider these impacts along the full value chain. In this realm, Social Life Cycle Assessment (S-LCA) is widely recognized to be part of Life Cycle Thinking (LCT) (UNEP, 2020). In the area of product evaluation, some methodologies have been developed to support strategies related to the three pillars of sustainability: People, Planet and Profit. Social Life Cycle Assessment (S-LCA) is one of three methodologies that have been developed to assess the sustainability of the three pillars of organizations, products and services, focusing on the People Pillar[74]. S-LCA is the latest methodology among life cycle tools, and the most controversial since it has not reached a methodological consensus yet[75,76].

In the past years, there have been attempts to formalize the S-LCA methodology such as the "Guidelines for SLCA of products"[77] and "The Methodological Sheets for Sub-categories in SLCA"[78], which have provided recommendations on how to conduct the first two phases of S-LCA (i.e., goal and scope definition and life cycle inventory).

As stated in the section 4.1, environmental LCA uses quantitative and comparable indicators to provide a clear representation of the environmental impacts of the product/service under analysis. However, when it comes to S-LCA, this approach cannot be used: due to their complexity, most social impacts are difficult to capture in a meaningful way using traditional quantitative single-criterion indicators[79].

Thus, for the evaluation of the social impact of products, services and organizations, in its “Methodological Sheets for Sub-categories in SLCA" UNEP has suggested a series of specific and generic indicators for each of the identified stakeholders’ sub-categories: Worker, Consumer, Local Community, Society and Actors in the Value Chain. The sheets contain the base definition of indicators and justify each subcategory in its relevance to sustainable development[70]. Nevertheless, even though the UNEP delineation of S-LCA is intended to provide a holistic assessment of social impacts over the entire life cycle of a product/service, it has several limitations. Limitations that must be tackled when trying to clearly and precisely define the social impacts that the life chain of enabling and emerging technologies or of projects related to the sustainable energy transition have.

[73] *DOI: 10.1080/09505431.2013.786989*
[74] *Guidelines for social life cycle assessment of products | UNEP - UN Environment Programme*
[75] *http://doi. org/10.1007/s11367-016-1206-6*
[76] *https://doi.org/10.1016/j.jclepro.2017.10.119*
[77] *guidelines_11mai_fin-sml.pdf (unep.org)*
[78] *S-LCA_methodological_sheets_11.11.13.pdf (lifecycleinitiative.org)*
[79] *https://doi.org/10.1007/s11367-009-0148-7*

Some of those shortcomings are hereby listed:

- S-LCA is a technical approach with a high data requirement that is particularly difficult to satisfy given the nonexistence of basic databases, the subjectivity of the data and the privacy conditions that prevent their full contribution.
- Specific local conditions are typically overlooked in S-LCA, due to lack of specific local data in sufficiently high resolution.
- Given the novelty of the S-LCA approach and the lack of standardization and internationalization, the results are usually difficult to disseminate (and to understand, having to outline the specific methodology used at the same time) and alternative approaches, such as CSR, are sometimes applied instead.

The international and European community's considerations of the need to accelerate the energy transition and the combination with the development of new infrastructure for alternative energy systems creates an opportunity today to insist that energy projects and decisions should explicitly incorporate awareness of social dimensions and impacts on them.

4.3 Environmental, Social and Governance (ESG) framework

The Environmental, Social and Governance (ESG) framework is based on the three named pillars, environment, social and governance. Environmental referring to topics like the reducing waste through the 3 Rs (reduce, reuse and recycle), biodiversity and its carbon footprint, or LCA (see 4.1). Social touching diversity and inclusion (D&I), human rights, health and safety and sustainable/transparent supply chains. Lastly, governance refers to the accountability and risk mitigation of companies.

Below topics are of importance when exploring the promotion and success of both solar EU PV module manufacturing and the development, realization, maintenance and decommissioning of large-scale European PV projects for investors and developers. In particular, the effort and positive development of EU commission initiatives like Net Zero Initiative and the European Green Deal. As argued by Ilze Zumente and Julija Bistrova in their article on the *ESG Importance for Long-Term Shareholder Value Creation: Literature vs Practice*[80] the factors that that can empower for long term value creation include but are not limited to "more qualitative and committed management, reduced uncertainty and risk". Particularly when, and as eloquently stated by Zumente and Bistrova that "ethical concerns and the global movement towards sustainability progressively moves the goal of corporations from short-term profitability to more long-term value creation."

In general, tenders and other procurement practices for Solar PV value price vs that of ethical, circular and fair policies as to attain business case internal rate of returns. Coupled with the use of Critical Raw Materials (see chapter 1.1), ethical fairness of PV modules, how bio-diverse solar PV projects are and the recycling, refurbishment, reuse and reduction of waste and in turn the life cycle analysis/impact (recycling of PFAS, repurposing and/or refurbishment of PV modules during repowering and/or decommissioning and recycling of PV modules that are no longer deemed able to be used for repurposing) are all very important parameters that should be taken into account, but for which now often information is lacking.

[80] https://www.mdpi.com/2199-8531/7/2/127

However, investors for the manufacturing of PV modules and large-scale PV projects can gain confidence in their investments from an ESG standpoint when they take the following into account:

1. **Award criteria to favor PV Modules with low carbon footprint:** Opting during the procurement or technical due diligence process to have award criteria favor PV modules with a low carbon footprint, IS014001 certification, an independently issued LCA study, low CRM usage statements and PV modules that are geared to recyclability (for example no use of PFAS) or are setup for internal recycling of those modules.

2. **Clear decommissioning or repowering plans:** Demanding from engineering procurement and construction companies and/or operations & maintenance companies (O&M) clear decommissioning or repowering plans that show clear routes for when the modules will be repurposed (testing as according to IS2859 AQL standard), recycled and/or refurbished (if needed).

3. **Biodiversity Guidelines:** Implementing methods or guidelines to ensure the increase of biodiversity during the permit and realization of projects through either certification like that of TNO eco-certified parks, or Kiwa Nature Inclusive Solar Parks (NISP) or using Solar Power Europe best practices guideline in integrating biodiversity.

From the social standpoint in the ESG framework, solar PV needs to:

- **Address challenges in the transparency of its supply chains and enhance responsible production:** For example, forced labor concerns specifically in the upstream part of the value chain.

- **Focus on mitigation methods** that extend further than and take accountability above and beyond the code of conduct of its suppliers (and their commitment to procuring/using socially approved components). Keeping in line with the EU Commissions position on keeping forced labor products out of the EU. Furthermore, drafted by the EU Internal Market and International Trade committees and coupled with the directive on Corporate Directive Due Diligence to address the mitigation tactics needed and ramifications of procuring forced labor products.

- **Focus on independent third-party verification of ESG responsible production and traceability:** This can be achieved through supply chain assurance schemes such SolarPower Europe and Solar Energy UK's Solar Stewardship initiative[81] like SEIA traceability protocol and social LCAs (see 4.2). Such schemes should find appropriate recognition in legislation to ensure market uptake of such initiatives and enhanced legislative implementation. In addition, the involvement of quality assurance companies as third party must be ensured for a robust verification process.

- **Focus on technologies and applications that promote biodiversity and sustainability:** This can be achieved by looking at e.g.: transparent bifacial modules that by TNO have been shown to increase soil health. PV modules that are close to 100% recyclable, if not able to be refurbished, or repurposed. Moreover, pushing from the inclusion of nature in large scale PV projects that extends further than sheep alone.

Photo: Jeroen van de Water, Unsplash.com

[81] Solar Stewardship Initiative

Conclusions and Recommendations

The aim of this white paper is to shed light on the multifaceted challenges and considerations that must be addressed in achieving the EU's goal of widespread PV deployment, as outlined in the Strategic Research and Innovation Agenda (SRIA). By bridging the gap between technological and socio-economic considerations, it intends to enrich the discourse surrounding our transition to a sustainable energy system, ensuring that these critical socio-economic dimensions are given due consideration alongside the technical aspects highlighted in the SRIA.

The white paper explores key dimensions of socio-economic challenges related to PV deployment. Notably, these concern social acceptance, public engagement, skills and workforce, and environmental and social sustainability, recognizing the pivotal role they play in achieving the European Union's clean energy targets. In light of these insights, this white paper offers a set of recommendations, which are gathered by the experts of the ETIP PV Working Group, serving as a valuable guide for policymakers, researchers, and stakeholders.

Social Acceptance

The first chapter, delves into the complexity of the acceptance and adoption of PV Technologies, covering various aspects that play a crucial role in defining the future of solar energy in Europe. From the recognition of critical raw materials (CRM) in PV manufacturing to the inclusion of potentially toxic materials, the evolving landscape of pricing grid tariff schemes, and the various factors that shape the Acceptance of European PV deployment, particularly on residential and utility scale, it aims to offer insights into the challenges and opportunities facing the solar industry.

Following recommendations derive from this chapter:

- **Promotion of Sustainable CRM Use and Supply Chain Coordination:** Emphasizing a circular economy approach, focusing on material efficiency, durability, and longevity in solar PV technology and encouraging the substitution of CRMs with viable alternatives, including renewable and locally available materials within Europe notable via supply chain resilience.

- **Align PV Production with Climate Neutrality and Recyclability:** Investing exclusively in European solar PV production technologies that adhere to CRM usage limits and support the EU's 2050 climate neutrality goals. Prioritizing research and development efforts to reduce CRM usage, improve PV module recyclability, and elevate CRM considerations in upscaling decisions. Allocating additional research funding to expedite CRM reduction initiatives, fostering resource efficiency and sustainability.

- **Implementation of novel true-cost pricing grid tariff schemes:** These schemes should be designed to reflect actual grid usage with the possibility to integrate additional price signals based on local PV production forecasts, and concepts for maximizing self-consumption (e.g. through energy communities, self-generation and self-storage, feed-in tariffs, electric mobility or collective generation systems in apartment buildings) should be supported. Clear communication with electricity consumers about the benefits of true-cost pricing, such as reduced grid infrastructure costs and increased renewable energy integration, is essential to building support and understanding among consumers.

Public Engagement

Chapter Two underscores the pivotal role of citizen engagement in driving a successful energy transition, particularly through the emergence of prosumers – individuals, small to medium-sized companies, and public entities actively participating in both renewable energy consumption and production. Recognizing the potential of PV technologies, it becomes clear that enabling citizens and communities with the right incentives is essential. The chapter also highlights that consumers' choices in PV systems are influenced by multifaceted dimensions, encompassing social, economic, technology usability, and ecological factors. With this comprehensive perspective, the chapter not only offers insights into the drivers behind citizens' involvement in adopting PV technologies, but also presents practical solutions and use-cases to enhance their participation in PV deployment.

Recommendations drawn from this chapter focus on ensuring the successful adoption of PV technologies by actively involving citizens and fostering social innovation in the energy sector:

- **Establishing One-Stop-Shops for Support citizen-led PV projects:** Creating dedicated support agencies, acting as one-stop-shops, can help guiding citizens through the development and implementation of their PV projects. Such local-level agencies could provide comprehensive assistance across various domains, encompassing financial, legal, technical, organizational and communication support.
- **Implementing Targeted Capacity Building Programs:** Developing customized capacity building programs tailored for citizens that are interested in PV projects. These programs could equipe individuals with the knowledge and skills necessary to effectively undertake community-based project development and implementation.
- **Fostering Social Innovation through adequate Policy Support:** Promoting social innovation within the energy transition by fostering those through adequate policy and regulatory measures. These can for instance focus on encouraging collective action business models, such as energy communities, that empower citizens to actively participate in renewable energy projects. It can be supported through policies to facilitate their adoption within these innovative business models.

Skills and Workforce

The third chapter highlights the emerging issue of skills and workforce in the PV sector. As the PV industry is about to create over one million jobs in the coming years, the chapter delves into the challenges and opportunities in equipping the workforce with the necessary skills to meet the industry's demand. Moreover, the chapter looks at the role of innovation capacity in the EU, highlighting the imminent need of investing in novel technologies such as perovskite/CIS tandems to maintain the technological lead in Europe. A skilled workforce equipped with the necessary skills is essential to drive PV innovation and technological advancements in Europe. Lastly, gender diversity in the PV sector is covered in chapter three, concluding that addressing gender equality requires concerted efforts to raise awareness, challenge stereotypes, and implement fair workplace practices, ultimately fostering an inclusive culture and providing equal opportunities for women and all minority groups.

The following recommendations were developed to address the critical challenges and opportunities identified for skills and workforce:

- **Integration of PV Technology in Education Standard:** Promoting the incorporation of PV technology topics into early education programs, encouraging collaboration with technical faculties at universities and ensuring PV technology becomes an integral part of electronic, physics, and chemistry-related courses. By actively involving children and their parents, this approach not only sparks interest in future generations but also engages the broader community in learning about and embracing PV technology.
- **Comprehensive European Plan for Addressing the Skills Gap:** Establishing a comprehensive European plan for addressing the skills gap by conducting national assessments of workforce gaps and skill requirements, as mandated in REDIII. Such a data-driven approach will inform a coordinated European strategy for workforce development in alignment with clean energy transition goals (concise set of recommendations outlined in chapter 3.1).

- **Strategic Investment in PV Manufacturing Capacity for Thin-Film Tandems:** Prioritizing investments in the development of PV manufacturing capacity for emerging thin-film tandems, particularly perovskite/CIS, to secure a cost-competitive, low GHG-intensive and diversified supply chain, while accelerating the decarbonization of power systems in Europe.

- **Promoting Gender Equality and Workforce Diversity:** Developing and implementing policies and initiatives to increase the representation of women and underrepresented groups in the solar PV industry. Further, encouraging educational programs, awareness campaigns and transparent workplace practices will help to create a more inclusive and diverse workforce.

Photo: AdobeStock_537638398

Environmental and Social Sustainability

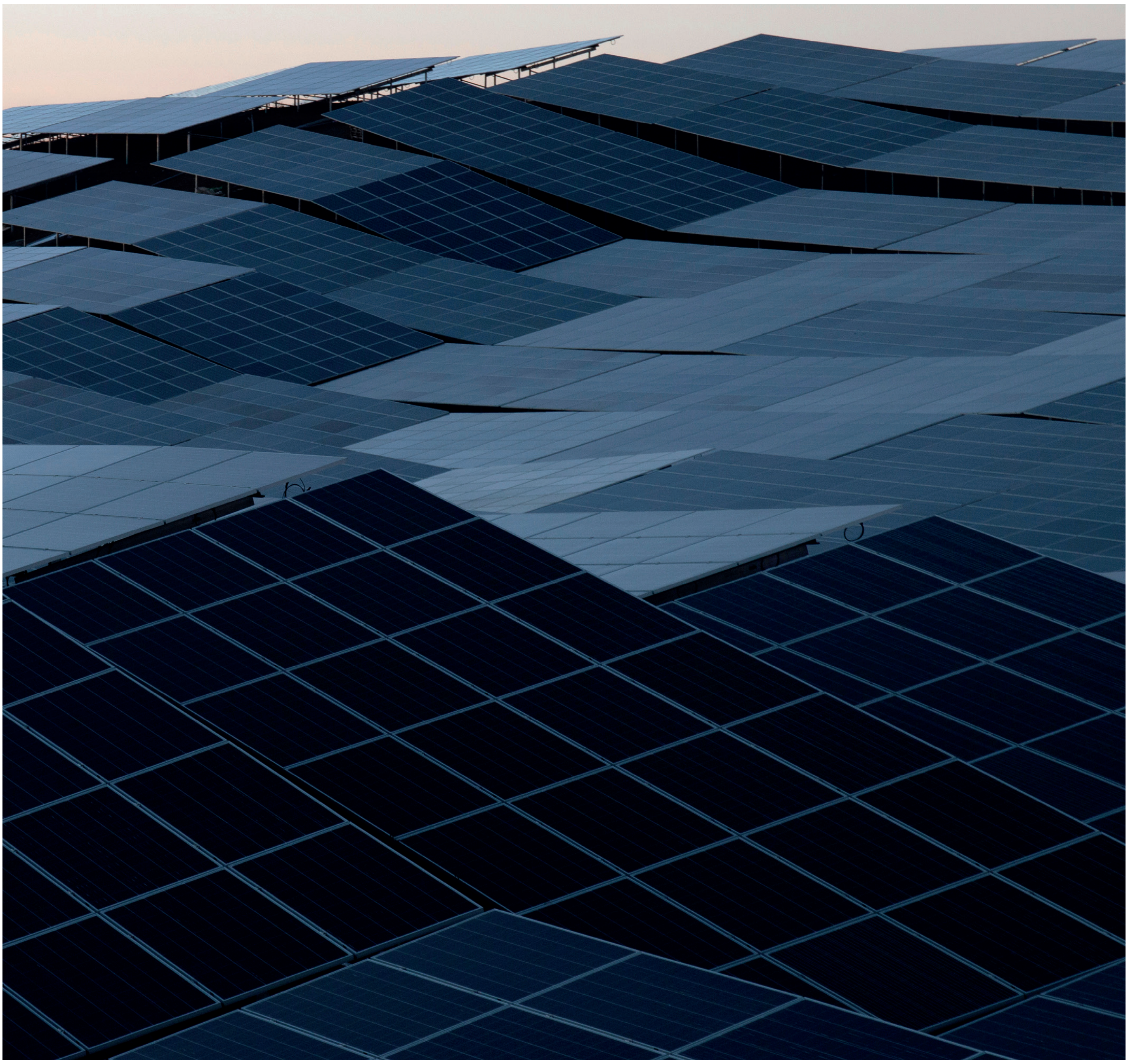
The fourth chapter is dedicated to Environmental and Social Sustainability, with a focus on three key areas. It starts by delving into the Environmental Impact, employing Life Cycle Assessment (LCA) analysis to scrutinize the ecological footprint of PV technology. It also looks into the Social Impact through Social Life Cycle Assessment (S-LCA), a tool that explores the broader societal consequences of PV deployment. Finally, this last chapter underscores the importance of the Environmental, Social and Governance (ESG) framework in promoting sustainable and responsible practices of PV technologies.

The following recommendations derive from this chapter:

- **Develop an updated LCA standard for PV systems:** Reduce the variability of obtained LCA results for PV systems by an updated and common approach to evaluate and compare the environmental impact of PV systems. Reduce the variability in the scope of the study for the environmental assessment of PV systems, improve the lack of transparency and consistency in the key parameters of defined PV systems, and minimize the variability in the quality of data collected to model PV system components throughout the whole value chain.

- **Standardize Social Life Cycle Assessment:** Insist that energy projects and decisions should explicitly incorporate awareness of social dimensions and impacts on them. Developing databases that can be used for S-LCA and that are compatible with data privacy regulations. It is also relevant to promote the increased resolution of local data for S-LCA.

- **Focus on technologies and applications that promote biodiversity and sustainability:** Opt, during the procurement process, to have award criteria that favor sustainable PV modules with low carbon footprint. Implement methods or guidelines to ensure the increase of biodiversity during the permit and realization of PV projects. Address challenges in the transparency of the PV supply chains and enhance responsible production. Focus on independent third-party verification of ESG responsible production and traceability. Demand from engineering, procurement and construction companies clear decommissioning or repowering plans for PV powerplants.



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