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SWOT Analysis and Policy Recommendations for Solar Power in the EU Renewable Energy Transition

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Abstract The decarbonization of economic sectors remains one of the most pressing challenges for contemporary society. Solar photovoltaic (PV) system, as a scalable and increasingly cost-effective sustainable energy source, plays a pivotal role in advancing the EU-27's low-carbon transition. Alongside emerging technologies such as Artificial Intelligence (AI), Machine Learning (ML), and Digital Twins (DT), new business models like Energy-as-a-Service (EaaS) are reshaping the energy landscape. This study identifies and analyzes the key strengths, weaknesses, opportunities, and threats (SWOT) influencing solar PV deployment in the EU-27. A systematic literature review (SLR) assesses policy from socio-technological, socio-environmental, and socio-economic perspectives. The findings reveal that regulatory rigidity, fragmented frameworks, limited grid capacity, and underuse of enabling technologies remain significant barriers. In contrast, opportunities lie in adaptive policies, community ownership models, and innovative financial instruments that can foster wider adoption. Socio-environmental challenges, including public misperceptions and land-use conflicts, underline the importance of inclusive and participatory policy design. Overall, this study provides insights to support effective, just, and sustainable energy policies that can advance the EU-27's green energy transition.

Keywords Solar Photovoltaic (PV), SWOT Analysis, Energy Transition, EU-27, Renewable Energy Policy.

1 Introduction

The transition to a low-carbon economy is a critical challenge for 21st-century society, particularly for the European Union (EU), which has set clear goals to achieve climate neutrality by 2050. In this context, the solar photovoltaic (PV) system - due to its potential for scalability, decreasing costs, and compatibility with decentralized energy systems - emerges as an important pillar of the EU-27's sustainable energy strategy. However, the diffusion of solar energy is not merely a technological issue; it is deeply embedded in a complex web of policy frameworks, social, economic, and environmental dynamics.

Recent advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and Digital Twins (DT), along with business models such as Energy as a Service (EaaS), Solar as a Service (SaaS), and Virtual Power Plants (VPPs), are reshaping how solar energy is produced, managed, and consumed. This new position requires coordinated actions among a diverse set of stakeholders, including prosumers, utilities, regulators, investors, and local communities. Despite this progress, the solar energy transition in the EU-27 still faces persistent barriers, especially political ones, that hinder its full socio-economic potential.

This study aims to identify the key factors influencing solar PV deployment in the EU-27 by applying a SWOT (Strengths, Weaknesses, Opportunities, Threats) analytical framework. While numerous studies have explored sustainable energy transition (SET) in Europe, there is a lack of comprehensive, policy-oriented analyses that integrate technological, socio-environmental, and economic dimensions using a structured SWOT approach.

To address this gap, the research conducts a systematic literature review to identify and categorize critical policy drivers and constraints. The analysis is guided by the following research questions: RQ#1: What are the key policy barriers and opportunities shaping the SET in the EU-27? RQ#2: What technological threats must be addressed through policy to advance the sustainable energy transition in the EU-27? RQ#3: What is the main socio-environmental strengths and weaknesses that should inform policy design for the sustainable energy transition in the EU-27? RQ#4: What are the main economic opportunities that can guide effective policy actions for the sustainable energy transition in the EU-27?

By addressing these questions, this study contributes to the understanding of the transition to solar energy in the EU-27. It emphasizes the need for integrated, multi-level policy responses that align technological innovation with social inclusion and environmental priorities. The SWOT framework serves not only as a diagnostic tool but also as a strategic guide for policymakers, researchers, and practitioners seeking to accelerate solar energy deployment in a fair and sustainable way.

The background will present a state-of-the-art review of the solar energy transition in the EU-27. The results section will highlight the main findings of the study, while the conclusion will summarize the key insights to support policymakers and stakeholders and provide recommendations for future research.

2 Background

The countries of the EU-27 have clear ambitions to achieve climate neutrality. The EU-27 has ambitious and clear targets to transform its energy system into a low-carbon, resilient, and inclusive model by 2050 (IRENA, 2025). In this context, solar PV has emerged as a pillar of the EU's strategy to decarbonize its energy sector and reduce dependence on fossil fuels (Costa et al., 2022). The share of SET between 2004 and 2023, the EU almost tripled, reflecting both technological advances and supporting policy frameworks (Eurostat, 2025).

However, despite these advances, the pace and distribution of solar PV deployment remain uneven across the EU. Several nations, especially those in Eastern and Southern Europe, still lag due to political barriers. Acting to reduce these disparities is essential to meeting the targets of the European Green Deal and the revised Renewable Energy Directive (RED III), which requires that at least 45% of final energy consumption comes from SET by 2030 (IRENA, 2025). In this sense, using the SWOT analytical framework to systematically examine the multiple drivers and obstacles shaping the policies underpinning the transition to solar energy in the EU-27 is essential for identifying key leverage points for policymakers, stakeholders, and researchers (Bessin et al., 2025).

2.1 Policy Landscape: Progress and Barriers

Robust policy instruments have supported the expansion of SET in the EU-27. Some initiatives, such as the Renewable Energy Directives (RED II and III), establish binding national targets and promote mechanisms such as simplified licensing for small-scale solar projects with power below 50 kW (IRENA, 2025; Pfeiffer et al., 2025). Furthermore, National Energy and Climate Plans (NECPs) operationalize these directives, defining specific ambitions for each country. Beyond these challenges, significant political weaknesses and political fragility persist. For example, some countries have complex licensing procedures to approve SET projects like solar PV, and subsidy volatility in some member states can reduce investor confidence and impact on the system (IRENA, 2025; Pfeiffer et al., 2025). On the other hand, emerging policy innovations offer some solutions. For example, "one-stop-shop" licensing platforms in some EU-27 countries have reduced approval times, and peer-to-peer (P2P) energy trading schemes have demonstrated the potential to increase rooftop solar PV adoption (Yildizbasi, 2021).

2.2 Socio-Technical Frontiers and Remaining Threats

Although the sharp drop in solar PV costs (82% since 2010) is making solar PV more competitive compared to fossil fuels (European Commission, 2025a), technical challenges persist and need to be addressed to unlock solar energy's full potential. In this context, a pressing issue is grid integration. The variability and decentralized nature of solar PV require additional grid flexibility to avoid supply-demand imbalances and ensure voltage stability. Furthermore, smart inverters, digital monitoring systems, and Battery Storage Systems (BSS) are essential to mitigate voltage fluctuation issues in distribution networks (Costa et al., 2022; Pfeiffer et al., 2025).

Another aspect requiring attention is the uneven implementation of enabling technologies (such as advanced forecasting systems and real-time monitoring tools), which remains a barrier. Currently, only nine EU Member States require these tools for distributed solar PV operators (Hoppmann et al., 2024). Blockchain-based solutions have shown promise for improving transparency but raise new challenges regarding cybersecurity and data governance (Yildizbasi, 2021). Continued investment in R&D, digital infrastructure, and grid modernization will be critical to maintaining the EU-27's technological leadership. Therefore, collaborative innovation ecosystems that connect technology providers, utilities, and research institutions can contribute to piloting solutions for scalable deployments (Costa et al., 2025).

2.3 Socio-Environmental Dynamics: Community Support and Challenges

The strength of the EU-27 solar agenda lies in public support. Around three-quarters of EU citizens, driven by high levels of environmental awareness, support expanding solar PV capacity. Community energy initiatives, local cooperatives, and citizen-led projects have strengthened social engagement and acceptance, particularly in Western and Northern Europe (IRENA, 2025; Sovacool, 2025).

Innovative land-use models such as agrivoltaics (combining agricultural production and solar generation) have demonstrated the potential to increase land productivity while simultaneously producing clean electricity. However, wider adoption depends on supportive policies, technical guidelines, and robust stakeholder consultation processes (Pascaris et al., 2021; Costa, 2024).

Ensuring environmental sustainability also requires rigorous site selection, ecological safeguards, and participatory planning frameworks. Fostering trust through transparent decision-making and equitable benefit-sharing mechanisms is vital to ensuring long-term social support for solar energy expansion.

2.4 Socio-Economic Implications: Growth and Equity

The socioeconomic impacts of solar energy present substantial opportunities and significant risks. In 2022, the European solar sector employed approximately 648,000 people, with annual job growth projected at 9% as deployment increases (Hemetsberger, 2023). However, employment remains concentrated: about three-quarters of jobs are in Germany, Spain, and Poland, reinforcing regional disparities (Hemetsberger, 2023).

Beyond direct employment, the expansion of solar PV also generates co-benefits, including improved air quality, lower energy poverty rates, and greater energy security (Hemetsberger, 2023).

Realizing these benefits requires enabling structures that mobilize investment, encourage local supply chains, and ensure affordable financing for those involved in this type of energy, especially families and communities. Public-private partnerships (PPPs), cohesion funds, and tailored local strategies can amplify socioeconomic gains while strengthening social equity.

3 Methodology

Adopting a systematic literature review (SLR), this work assesses the political factors influencing the expansion of solar PV, analyzing technological, socio-environmental, and socio-economic aspects. The SLR approach guarantees a structured and transparent examination of scholarly sources by establishing explicit criteria for selection, screening, and synthesis (enhanced through content analysis to systematically interpret and categorize the material) thereby enhancing the review's replicability and trustworthiness (van Dinter and Catal, 2021). Using this method, the study seeks to consolidate current insights, pinpoint gaps in the literature, and propose avenues for future research (Fig.1).

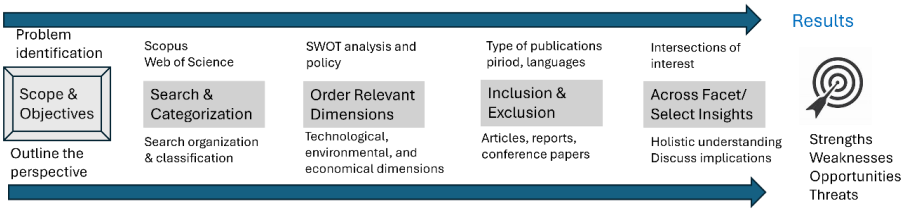


Figure 1. Schematic Overview of the Research Process
Source: Elaborated by the authors.

3.1 Database Planning, Source Curation, and Data Retrieval

After a preliminary review of several top-ranked journals to identify relevant keywords and concepts, we conducted a detailed search on Web of Science (WoS) and Scopus. The results were exported in RIS format and then imported into a spreadsheet for processing. Once the two databases were combined, duplicated records and invalid entries were eliminated to ensure a cleaner dataset. The screening process was conducted in two phases: first, a preliminary check of titles and abstracts to discard unrelated studies, and then a detailed full-text review to verify their relevance to the research objectives. This procedure was carried out according to clearly defined inclusion and exclusion parameters.

The keywords identified for the review include: "Solar PV," "generation," "production," "strength," "advantage," "weakness," "barrier," "challenge," "opportunity," "threats," and "risk." Based on these keywords, four separate queries were developed and applied to two databases: Web of Science (WoS) and Scopus. The queries are as follows*:1. ("Solar PV") AND ("generation" OR "production") AND ("strength" OR "advantage*")*. 2 ("Solar PV") AND ("generation" OR "production") AND ("weakness" OR "barrier*" OR "challenge*")*. 3. ("Solar PV") AND ("generation" OR "production") AND ("opportunity" OR "market potential"). 4. ("Solar PV") AND ("generation" OR "production") AND ("threats" OR "risk")**

Constructing four distinct queries, each aligned with one component of the SWOT framework, ensured that the literature search systematically captured publications addressing each strategic dimension. This approach increases the rigor and completeness of the review by making sure that relevant studies are not overlooked and that each aspect of the solar PV transition is thoroughly examined.

Articles were included if they were written in English, were indexed in WoS or Scopus, were published between 2019 and 2024, used primary data, referred to EU-27 countries, and specifically focused on policies supporting the diffusion of solar PV within the EU-27. Articles were excluded if they were duplicates, did not meet the inclusion criteria for the analysis, or lacked a relevant discussion of solar PV policies within the EU-27 context.

The initial search produced 306 articles. After removing 93 duplicates, 213 records remained. Of these, 49 were excluded for not meeting the inclusion criteria, resulting in 164 articles selected for final analysis.

3.2 Rationale for a Multidimensional Analytical Approach

Solar PV systems are not only technological infrastructures, but also socio-technical systems embedded in regulatory, cultural, and economic contexts. Technical aspects such as grid capacity, forecasting tools, and enabling technologies directly influence

the feasibility and efficiency of solar integration. However, these technical factors are deeply intertwined with socio-environmental considerations, including public acceptance, land-use conflicts, and community engagement, which can facilitate or hinder the diffusion of solar PV technologies. Furthermore, socio-economic variables such as government incentives and local capacity building determine the accessibility, economic viability, and long-term sustainability of solar energy systems (Hemetsberger, 2023). By adopting a holistic perspective encompassing these three domains, the study aims to identify not only operational barriers but also systemic enablers that can inform more inclusive and effective policy design. This multidimensional approach ensures that the SWOT analysis captures the full complexity of solar energy policies and clarifies how strategies can be developed that are technically sound and socially equitable.

3.3 SWOT as an Analytical Lens

In this study we employ the SWOT framework to systematically evaluate solar energy deployment in the EU-27. SWOT is particularly suited for this analysis because it captures both *internal* (strengths/weaknesses) and *external* (opportunities/threats) factors shaping energy transitions, enabling a holistic assessment of policy, socio-technical, and socio-economic dimensions (Bessin et al., 2025). The framework's flexibility accommodates the EU's diverse regional contexts, from advanced markets like Germany to emerging solar adopters like Romania (IRENA, 2025).

a) Definition of SWOT Dimensions

1. Strengths: *Internal advantages* that accelerate solar deployment (e.g., robust EU renewable policies, high public acceptance) (European Commission, 2025a).

2. Weaknesses: *Internal barriers* (e.g., fragmented permitting, grid integration gaps) (European Commission, 2025b).

3. Opportunities: *External conditions* that could be leveraged (e.g., agrivoltaics, P2P energy segment) (Pascaris et al., 2021).

4. Threats: *External risks* beyond immediate control (e.g., global supply chain disruptions, land-use conflicts) (Pascaris et al., 2021; Sovacool, 2025).

b) Justification for SWOT

- Policy Relevance: SWOT aligns with the EU's need for *multidimensional* policy design, bridging gaps between technical potential and real-world deployment (Trigkas et al., 2024).
- Stakeholder Utility: The framework's simplicity aids communication with policymakers, industry, and civil society (Costa et al., 2021; Sousa and Costa, 2022].

- Comparative Advantage: Unlike purely quantitative methods (e.g., cost-benefit analysis), SWOT integrates qualitative socio-political factors critical to energy justice (Tellarini and Gram-Hanssen, 2024).

To develop this research, electronic spreadsheets were used to organize and process the dataset, code articles, and perform basic content analysis by categorizing policy drivers and barriers, quantifying their frequency, and cross-tabulating them by thematic group.

4 Results and Discussion

This section presents the main findings on policies aimed at boosting solar PV in the EU-27.

4.1 RQ#1: What are the key policy barriers and opportunities shaping the sustainable energy transition in the EU-27?

To address RQ#1, Table 1 presents a structured matrix summarizing the key policy barriers and opportunities influencing the EU-27's SET. This matrix groups the findings into thematic clusters that emerged from the SLR and the SWOT analysis: Financial Instruments and Economic Signals, Network Infrastructure and Spatial Planning, and Citizen Engagement and Social Acceptance. Each cluster highlights how the reviewed studies converge on the dual need to combat persistent weaknesses and external threats while unlocking actionable opportunities through targeted policy measures.

Cost & Finance illustrates how unstable or misaligned subsidies can distort price signals and cause unintended rebound effects. At this point, the evidence emphasizes the importance of well-calibrated incentive structures and innovative contracting frameworks (such as hedging tools) to align retail trading conditions with prosumer confidence in investments.

Data & Knowledge is the barrier posed by limited forecasts, outdated metering interfaces, or insufficient knowledge sharing about local distributed energy resources (DERs). The matrix shows that public policies can address these gaps by supporting robust forecasting tools, digital engagement platforms, and open access to performance data, thereby guiding smarter investment and consumption behaviors.

Table 1. Policy barriers and opportunities for the EU energy transition

Thematic Group	Policy Barriers	Policy Opportunities
Grid & Infrastructure	Weak grid connections Insufficient infrastructure upgrades Limited grid capacity for PV/EV Net metering design flaws Grid connection	Upgrade grid infrastructure Expand storage solutions Enable flexible local grids Integrate rooftop PV with electric vehicles (EVs)
Cost & Finance	Overreliance on tariffs Short-term or unstable subsidies Poor incentive design Cost vs. spatial trade-offs ignored	Stable R&D funding Smart subsidy design Risk-hedging instruments Incentives for efficiency PV
Social & Cultural Acceptance	Moral licensing gaps Public misperceptions Resistance to rooftop aesthetics Weak peer effects	Correct misperceptions Promote positive narratives Peer influence tools Demonstration projects
Data & Knowledge	Lack of forecasting Insufficient open data Poor sitting data quality	Invest in forecasting tools High-resolution spatial data Comparative analysis
Land Use & Siting	Poor rooftop potential usage Inefficient large-scale land PV Location barriers Conflicts with agriculture/biodiversity	Support rooftop PV first Promote agrivoltaics Dual land use (PV + farming) Integrated siting models

Source: Elaborated by the authors based on Guaita-Pradas (2020), Quax et al. (2022), Galvin (2021), González et al. (2021), de la Nieta et al. (2020), Liu et al. (2021), Dias et al. (2019) and Zhong et al. (2021).

Grid & Infrastructure and Land Use & Sitting highlight the role of connection bottlenecks and land-use conflicts, which can delay the deployment of sustainable energy. The combined results indicate clear opportunities for coordinated sitting strategies, dual-use land-use models such as agrivoltaics, and improvements in local grid capacity.

Finally, Social & Cultural Acceptance points to the behavioral and cultural factors that can block or facilitate the transition. Weaknesses include insufficient local participation or negative perceptions of rooftop aesthetics, while opportunities emphasize community co-creation of policy pathways, improved information provision, and the use of storytelling and design to promote positive energy cultures.

It should be noted that this matrix intentionally focuses on policy barriers (Weaknesses and Threats) and levers for action (Opportunities). While Strengths (such as the EU's advanced research capacity, mature grid infrastructure in many regions, and high public awareness of climate goals) strongly support the viability of these opportunities, they are not explicitly presented in this matrix, as they represent existing capabilities rather than gaps or future levers. These existing strengths, however, are discussed throughout the study as part of the contextual foundations that make the identified policy pathways realistic and actionable.

So, taken together, the clustered matrix clarifies where policymakers should prioritize reforms to remove obstacles and scale solutions that accelerate the EU's SET.

4.2 RQ#2: What technological threats must be addressed through policy to advance the sustainable energy transition in the EU-27?

The analysis of technological threats, related to Response RQ#2, highlights several critical barriers that must be addressed through policy interventions to promote a successful and equitable energy transition across the EU-27. These threats include infrastructure constraints, data and forecast gaps, inflexible regulations, underdeveloped enabling technologies, and inefficient land use practices (Table 2).

4.2.1 Grid Infrastructure Constraints and Forecasts and Data Deficiencies

Inadequate grid infrastructure (especially in remote, rural, and island areas) restricts the integration of DERs such as solar PV and EVs. Without a modernized grid, the deployment of sustainable energy is limited. Therefore, policies should prioritize investments in grid modernization, support microgrid solutions, and promote flexible and community-based energy systems. Reliable forecasting of sustainable energy generation and access to high-quality spatial data are vital for effective

planning and grid stability. Gaps in these areas hinder location decisions and efficient system operation. Therefore, targeted policies should support investments in advanced forecasting tools, including AI and ML, and ensure open access to up-to-date, high-resolution spatial datasets.

Weak grid connections and limited capacity, Insufficient forecasting capabilities, and poor quality or missing spatial and sitting data remain central barriers that require coordinated responses to strengthen infrastructure and improve planning.

Table 2. Socio-Technological Threats to the Sustainable Energy Transition in the EU-27

Technological Threat	Description	Policy Response Needed
Weak grid connections and limited capacity	Remote areas and islands face poor grid access; existing infrastructure can't handle increased PV/EV loads.	Invest in grid upgrades, enable microgrids, and support decentralized energy systems.
Insufficient forecasting capabilities	Lack of accurate forecasting for distributed SET generation affects grid stability and planning.	Fund advanced forecasting tools using AI/ML and integrate them into grid management.
Poor quality or missing spatial and sitting data [29]	Inadequate data hinders the optimal placement of SET.	Develop high-resolution, open-access spatial datasets.
Limited integration of rooftop PV with EVs	Rooftop solar and EVs are not yet fully integrated into local energy systems.	Promote integrated PV+EV infrastructure and flexible local trading frameworks.
Lack of enabling technologies (e.g., blockchain, smart meters)	Secure, decentralized transaction systems and real-time monitoring tools are underutilized.	Support deployment of enabling technologies through R&D funding and standardization.

Source: Elaborated by the authors based on Tellarini and Gram-Hanssen (2024), Russo and Bertsch (2020), Lin et al. (2022), Nagarajan et al. (2025) and Malik et al. (2022).

4.2.2 Synergies between Rooftop PV and EVs

Despite strong potential, the integration of rooftop solar PV with EV charging infrastructure remains underexploited due to technical, financial, and regulatory hurdles. Limited integration of rooftop PV with EVs continues to hold back the full benefits of decentralized energy systems. Clear incentives, simplified permitting, and integrated planning are needed to unlock the benefits of combining solar PV with electric mobility.

4.2.3 Underutilized Enabling Technologies

Lack of enabling technologies (e.g., blockchain, smart meters) remains a critical weakness. Essential digital technologies, such as blockchain for secure energy transactions, smart meters, and robust data management systems, are not yet widely deployed. This underutilization limits transparency, flexibility, and consumer participation. Therefore, policy measures should accelerate the adoption of these technologies through R&D support, standardization, and incentives. The energy transition requires not only clear rules and financial support, but also strategic investments in infrastructure, digitalization, and innovative technologies that enable smarter, more resilient, and decentralized energy systems.

4.3 RQ#3: What is the main socio-environmental strengths and weaknesses that should inform policy design for the sustainable energy transition in the EU-27?

The socio-environmental dimension of the SET in the EU-27, related to RQ#3, highlights a complex interaction between community involvement, local perceptions, and the way sustainable energy systems intersect with land use. The analysis of identified strengths and weaknesses shows that social factors can be either powerful drivers or critical barriers, depending on how they are addressed in policy design (Table 3).

Table 3. Socio-Environmental Strengths and Weaknesses for Sustainable Energy Policy in the EU-27

Category	Factor	Description	Policy Implication
Strength	Community ownership models	Local ownership increases acceptance and long-term engagement.	Promote cooperative and community-led energy projects.
Strength	Participatory policy design	Involving citizens to enhance legitimacy and effectiveness.	Participatory mechanisms in energy policy.
Strength	Behavior changes campaigns	Public campaigns can shift norms and increase adoption of SET.	Fund and scale up awareness and behavioral initiatives.
Weakness	Resistance to rooftop aesthetics	Visual concerns reduce support for rooftop PV.	Encourage aesthetic design standards and incentives.
Weakness	Conflicts with agriculture/biodiversity	Poor sitting can create land-use tensions.	Promote dual-use models (e.g., agrivoltaics).

Source: Elaborated by the authors based on Galvin (2021), Kerscher et al. (2024), Domenech et al. (2021) and Pascaris et al. (2020).

4.3.1 Key Strengths

One of the most significant strengths is the growing emphasis on Community ownership models. Local ownership models, such as community microgrids or cooperatives, have demonstrated strong potential to increase social acceptance, foster trust, and ensure that sustainable energy projects reflect local priorities and values. This Participatory policy design aligns technical solutions with social realities and enhances long-term sustainability.

Equally important are Behavior changes campaigns, which help motivate lasting shifts in energy use and support the adoption of decentralized, cleaner solutions.

Such measures complement technical and economic incentives by fostering a cultural shift towards sustainable practices.

4.3.2 Key Weaknesses

Socio-environmental barriers continue to pose significant challenges. Resistance to rooftop aesthetics, especially regarding rooftop photovoltaics in residential areas, can generate opposition and slow adoption. Additionally, Conflicts with agriculture/biodiversity remain a persistent challenge. Poorly planned siting of sustainable energy infrastructure can clash with agricultural productivity, biodiversity protection, or culturally valued landscapes. Without integrated land-use planning, tensions are likely to persist.

4.3.3 Implications for Policy

To address these weaknesses and leverage the social strengths, the EU-27 must institutionalize collaborative governance, adopt strategic communication to counter misinformation, and ensure context-sensitive, culturally acceptable design. Policies should also promote dual-use land models, such as agrivoltaics. Aligning Community ownership models, Participatory policy design, and Behavior changes campaigns with targeted actions for known weaknesses will help ensure that the energy transition earns trust and broad support across diverse EU communities.

4.4 RQ#4: What are the main economic opportunities that can guide effective policy actions for the sustainable energy transition in the EU-27?

The SET in the EU-27 is supported by multiple economic drivers capable of stimulating local industries and strengthening Europe's position in the sustainable energy field. An important economic lever is supporting local entrepreneurial ecosystems, where new business models - such as community microgrids and energy cooperatives - can expand the decentralized generation of sustainable energy, boosting the local economy (Table 4).

Table 4. Socio-Economic Opportunities for Sustainable Energy Transition in the EU-27

Opportunity Area	Description	Policy Implication
P2P Energy System	Integrate P2P trading into energy policy and market design.	Boost decentralized energy for more consumer input and innovation.
Aggregator Incentives	Design fair reward systems for aggregators and prosumers.	Stimulate local energy markets and ensure equitable value distribution.
Enabling Technologies	Support blockchain, AI, and forecasting tools.	Improve market efficiency, transparency, and grid stability.
Industrial Ecosystems	Strengthening ties between firms, R&D, and supply chains.	Build resilient, competitive clean tech industries.
Innovation & Performance	Incentivize innovation and performance in energy services.	Drive cost-effective and scalable solutions.
Data Infrastructure	Improve spatial and open data quality.	Enable evidence-based siting and planning.

Source: Elaborated by the authors based on Bessin et al. (2025), Ruokamo et al. (2023), Biggar and Hesamzadeh (2024) and Jurasz et al. (2024).

There is also a need for flexible financial mechanisms, such as targeted financing for emerging businesses interested in promoting energy storage, smart grids, and Enabling Technologies. By diversifying financial tools beyond conventional subsidies, policies can help reduce financial risks and accelerate the viability of cutting-edge solutions.

Advancing synergies between SET and digitalization is another promising lever. Promoting digital tools that allow households and small businesses to monitor, trade, and optimize energy use can reduce costs and empower consumers to take a more active role in the market through P2P Energy System models and clear Aggregator Incentives. At the same time, expanding workforce skills development programs will ensure that small and medium-sized enterprises (SMEs) and local installers can keep pace with technological change.

In the industrial sphere, strengthening Industrial Ecosystems by promoting supplier diversity along the sustainable energy value chain (from component manufacturing to systems integration) will reduce import dependence and open new market

segments for EU-based companies. Policies can further boost Innovation & Performance by encouraging technology transfer and knowledge exchange partnerships between the EU-27 and reliable international allies to expand national know-how.

So, investing in robust Data Infrastructure is essential to support transparent markets, enable smart grid management, and unlock the full benefits of integrated renewable energy and digital technologies.

5 Conclusions

To identify and analyze the key elements of SWOT influencing solar energy deployment in the EU-27 and answer the key research questions, this work focused on examining policy, socio-technology, and socio-economic dynamics shaping the diffusion of solar PV systems. The study reveals that while significant advancements in PV technology and cost reductions have driven adoption, policy fragmentation and regulatory rigidity remain critical weaknesses.

RQ#1 confirms that policy barriers such as inconsistent subsidies and rigid regulations are consistently highlighted in the literature as major weaknesses (e.g., [33,34] limiting solar PV diffusion.
RQ#2 shows that strengths like decentralized energy models and growing prosumer participation are broadly supported in recent studies, which reinforce their importance for resilient systems.
RQ#3 indicates that opportunities such as adaptive policy frameworks, community ownership, and enabling technologies (e.g., blockchain, smart meters) are frequently highlighted in the literature (e.g., (Ruokamo et al., 2023; Biggar and Hesamzadeh, 2024) as important levers to expand adoption and enhance grid integration.
RQ#4 demonstrates that threats related to socio-environmental acceptance, uncertain markets, and grid limitations are confirmed by multiple authors, underlining that without policy coordination and local engagement, these factors could delay targets.

This work contributes by combining policy, socio-technical, and socio-economic perspectives in a single SWOT matrix, offering practical insights for policymakers and researchers to align technological innovation with effective governance and social acceptance.

A main limitation is that some papers do not clearly indicate the country context, requiring careful cross-checking to interpret findings accurately. Future research should ensure clear geographic identification and investigate how renewable energy production and consumption evolve together with other high-energy-demand technologies, like EVs and BSS, to build truly integrated low-carbon pathways for the EU-27.

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References

Bessin, A., Serra-Adroer, J., Debonne, N., and van Vliet, J. (2025) Location determinants of industrial solar photovoltaics and onshore wind turbines in the EU. *Renewable and Sustainable Energy Reviews.* 210 115257. https://doi.org/10.1016/j.rser.2024.115257

Biggar, D.R. and Hesamzadeh, M.R. (2024) Optimal retail contracts with contractible uncertainty. *Energy Economics.* 136 107769. https://doi.org/10.1016/j.eneco.2024.107769

Costa, E. (2024) Industry 5.0 and SDG 9: a symbiotic dance towards sustainable transformation. *Sustainable Earth Reviews.* 7 (1), 4. https://doi.org/10.1186/s42055-024-00073-y

Costa, E., Horta, A., Correia, A., Seixas, J., Costa, G., and Sperling, D. (2021) Diffusion of electric vehicles in Brazil from the stakeholders' perspective. *International Journal of Sustainable Transportation.* 15 (11), 865–878. https://doi.org/10.1080/15568318.2020.1827317

Costa, E., Teixeira, A.C.R., Costa, S.C.S., and Consoni, F.L. (2022) Influence of public policies on the diffusion of wind and solar PV sources in Brazil and the possible effects of COVID-19. *Renewable and Sustainable Energy Reviews.* 162 112449. https://doi.org/10.1016/j.rser.2022.112449

Costa, E., Vicente, P., and Reis, E. (2025) Driving Innovation Through Cross-Sector Collaboration with Higher Education Institutions. In: *INTED2025 Proceedings,* IATED, pp. 2045–2053. https://doi.org/10.21125/inted.2025.0581

Costa, E., Wells, P., Wang, L., and Costa, G. (2022) The electric vehicle and renewable energy: Changes in boundary conditions that enhance business model innovations. *Journal of Cleaner Production.* 333 130034. https://doi.org/10.1016/j.jclepro.2021.130034

de la Nieta, A.A.S., Paterakis, N.G., and Gibescu, M. (2020) Participation of photovoltaic power producers in short-term electricity markets based on

rescheduling and risk-hedging mapping. *Applied Energy.* 266 114741. https://doi.org/10.1016/j.apenergy.2020.114741

Dias, L., Gouveia, J.P., Lourenço, P., and Seixas, J. (2019) Interplay between the potential of photovoltaic systems and agricultural land use. *Land Use Policy.* 81 725–735. https://doi.org/10.1016/j.landusepol.2018.11.036

Domenech, B., Calleja, G., and Olivella, J. (2021) Residential photovoltaic profitability with storage under the new Spanish regulation: a multi-scenario analysis. *Energies.* 14 (7), 1987. https://doi.org/10.3390/en14071987

Eurostat. (2025) Renewable energy statistics, European Commission. Brussels, retrieved on Jully 14, 2025 at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics

European Commission. (2025a) Solar energy: Energy, Climate change, Environment. Belgium, retrieved on Jully 14, 2025 at https://energy.ec.europa.eu/topics/renewable-energy/solar-energy_en

European Commission. (2025b) Analysis of barriers for innovative forms of solar PV deployment and associated recommendations – Final report. Brussels, retrieved on Jully 14, 2025 at https://data.europa.eu/doi/10.2833/7277923

Galvin, R. (2021) Identifying possible drivers of rebound effects and reverse rebounds among households with rooftop photovoltaics. *Renewable Energy Focus.* 38 71–83. https://doi.org/10.1016/j.ref.2021.06.002

González, A., Sendra, C., Herena, A., Rosquillas, M., and Vaz, D. (2021) Methodology to assess the circularity in building construction and refurbishment activities. *Resources, Conservation & Recycling Advances.* 12 200051. https://doi.org/10.1016/j.rcradv.2021.200051

Guaita-Pradas, I. and Blasco-Ruiz, A. (2020) Analyzing profitability and discount rates for solar PV plants. A Spanish case. *Sustainability.* 12 (8), 3157. https://doi.org/10.3390/su12083157

Hemetsberger, W., A.D., S.M. (2023) *EU Market Outlook for Solar Power 2023–2027.* Belgium.

IRENA. (2025) *Regional energy transition outlook: European Union.* Abu Dhabi, retrieved on Jully 14, 2025 at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jun/IRENA_OUT_RETO_EU_2025.pdf

Jurasz, J., Tomczyk, P., Bochenek, B., Kuriqi, A., Kasiulis, E., Chen, D., et al. (2024) Solar-hydro cable pooling–Utilizing the untapped potential of existing grid infrastructure. *Energy Conversion and Management.* 306 118307. https://doi.org/10.1016/j.enconman.2024.118307

Kerscher, S., Koirala, A., and Arboleya, P. (2024) Grid-optimal energy community planning from a systems perspective. *Renewable and Sustainable Energy Reviews.* 199 114485. https://doi.org/10.1016/j.rser.2024.114485

Lin, S., Zhang, C., Ding, L., Zhang, J., Liu, X., Chen, G., et al. (2022) Accurate recognition of building rooftops and assessment of long-term carbon emission reduction from rooftop solar photovoltaic systems fusing GF-2 and

multi-source data. *Remote Sensing.* 14 (13), 3144. https://doi.org/10.3390/rs14133144

Liu, J., Grubler, A., Ma, T., and Kogler, D.F. (2021) Identifying the technological knowledge depreciation rate using patent citation data: a case study of the solar photovoltaic industry. *Scientometrics.* 126 (1), 93–115. https://doi.org/10.1007/s11192-020-03740-x

Malik, S., Duffy, M., Thakur, S., Hayes, B., and Breslin, J. (2022) A priority-based approach for peer-to-peer energy trading using cooperative game theory in local energy community. *International Journal of Electrical Power & Energy Systems.* 137 107865. https://doi.org/10.1016/j.ijepes.2021.107865

Nagarajan, K., Rajagopalan, A., Bajaj, M., Raju, V., and Blazek, V. (2025) Enhanced wombat optimization algorithm for multi-objective optimal power flow in renewable energy and electric vehicle integrated systems. *Results in Engineering.* 25 103671. https://doi.org/10.1016/j.rineng.2024.103671

Pascaris, A.S., Schelly, C., Burnham, L., and Pearce, J.M. (2021) Integrating solar energy with agriculture: Industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. *Energy Research & Social Science.* 75 102023. https://doi.org/10.1016/j.erss.2021.102023

Pascaris, A.S., Schelly, C., and Pearce, J.M. (2020) A first investigation of agriculture sector perspectives on the opportunities and barriers for agrivoltaics. *Agronomy.* 10 (12), 1885. https://doi.org/10.3390/agronomy10121885

Pfeiffer, A., Poulin, F., Orator-Saghy, S., Rajal, B., Gölz, S., and Raats, P. (2023) *Analysis of barriers for innovative forms of solar PV deployment and associated recommendations.* Brussels.

Quax, R., Londo, M., van Hooff, W., Kuijers, T., Witte, J., van Sark, W., et al. (2022) Assessment of spatial implications of photovoltaics deployment policies in the Netherlands. *Solar Energy.* 243 381–392. https://doi.org/10.1016/j.solener.2022.07.048

Ruokamo, E., Laukkanen, M., Karhinen, S., Kopsakangas-Savolainen, M., and Svento, R. (2023) Innovators, followers and laggards in home solar PV: Factors driving diffusion in Finland. *Energy Research & Social Science.* 102 103183. https://doi.org/10.1016/j.erss.2023.103183

Russo, M. and Bertsch, V. (2020) A looming revolution: Implications of self-generation for the risk exposure of retailers. *Energy Economics.* 92 104970. https://doi.org/10.1016/j.eneco.2020.104970

Sousa, C. and Costa, E. (2022) Types of Policies for the Joint Diffusion of Electric Vehicles with Renewable Energies and Their Use Worldwide. *Energies.* 15 (20), 7585. https://doi.org/10.3390/en15207585

Sovacool, B.K. (2025) The low-carbon risk society: Dilemmas of risk–risk tradeoffs in energy innovations, transitions, and climate policy. *Risk Analysis.* 45 (1), 78–107. https://doi.org/10.1111/risa.14667

Tellarini, C. and Gram-Hanssen, K. (2024) “If something breaks, who comes here to fix it?”: Island narratives on the energy transition in light of the concept of practice architectures. *Energy Research & Social Science.* 114 103617. https://doi.org/10.1016/j.erss.2024.103617

Trigkas, S.J., Eleftheriadou, N., Boukouvala, M.C., Skourti, A., Koukouli, M., and Kavallieratos, N.G. (2024) Exploring Opportunities and Challenges: SWOT Analysis for Advancing Smart Tech Solutions in Managing *Lymantria dispar dispar* Infestations in Forests of the European Union. *Forests.* 15 (10), 1805. https://doi.org/10.3390/f15101805

van Dinter, R., Tekinerdogan, B., and Catal, C. (2021) Automation of systematic literature reviews: A systematic literature review. *Information and Software Technology.* 136 106589. https://doi.org/10.1016/j.infsof.2021.106589

Yildizbasi, A. (2021) Blockchain and renewable energy: Integration challenges in circular economy era. *Renewable Energy.* 176 183–197. https://doi.org/10.1016/j.renene.2021.05.053

Zhong, T., Zhang, K., Chen, M., Wang, Y., Zhu, R., Zhang, Z., et al. (2021) Assessment of solar photovoltaic potentials on urban noise barriers using street-view imagery. *Renewable Energy.* 168 181–194. https://doi.org/10.1016/j.renene.2020.12.044