Delivrable 5.1 - Interim report on sourcing of various kinds of Si-based end-of-life PV panels - mapping of the available amounts at national and EU level

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them.

Document control sheet

Project	RESiLEX – Resilient Enhancement for the Silicon Industry Leveraging the European matrix
Call identifier	HORIZON-CL4-2021-RESILIENCE-01-07
Grant Agreement Number	101058583
Coordinator	Iberian Sustainable Mining Cluster (ISMC)
Work package N°	5.1
Work package title	Silicon recycling from PV modules
Work package leader	COMET TRAITEMENTS
Document title	Deliverable 5.1: Interim report on sourcing of various kinds of Si-based end-of-life PV panels - mapping of the available amounts at national and EU level
Lead Beneficiary	ENVIE 2 E MIDI PYRENEE - RECMA
Dissemination level	Interim (M18)
Authors	RECMA, ENVIE 2 E
Contributors	
Reviewer(s)	RECMA
Issue date	31th October 2023

Index

Executive Summary

This first map of the quantities of photovoltaic panels available at national and European level is broken down into two parts: on the one hand, an inventory of installed photovoltaic powers and then, a projection of the photovoltaic waste flows available in the years to come in EU-27.

An in-depth study was carried out on the 10 countries with the largest photovoltaic installations, representing around 91% of the total solar photovoltaic capacity of the EU-27 in 2022. Two other countries, with high growth potential, complete this first panel.

Each of the main contributors is analyzed according to the following 7 criteria: power installed, electricity generation, regulatory aspects, trends, strenghts, challenges and opportunities.

A forecast of future waste streams from photovoltaic panels is developed in the second part of the report.

Methodology

For this first interim report, the data were compiled, based on public sources, mainly from the Internet. The main sources used for the development of this report are listed below, and have been thoroughly analyzed, relying notably on the generative artificial intelligence model ChatGPT-4.0. Most part of graphs published in the report have been generated with data provided from EurObserv'ER-online-databases. For future reports, the sources will be further developed and benchmarked, based on available data. The recycling & waste streams sourcing will be deeply analyzed.

Sources :

- EurObserv'ER – 2023 – Barometer PV – graphs & tables
- EurObserv'ER-Photovoltaic-Barometer-2023-FR-EN
- EurObserv'ER-online-database-export > graphs (annual & cumutated PV capacity + PV electricity production)
- Eurobserv-er.org-2023-Renewable-Energy-Policy-Factsheet
- EurObserv'ER-Etat-energies-renouvelables-UE27-2022
- Eurobserv-er.org-Germany-2023-Renewable-Energy-Policy-Factsheet
- Slides SOREN
- IEA – Renewables 2020 – Analysis and forecast to 2025
- EPRS | European Parliamentary Research Service - Solar energy in the EU – September 2022
- BP Statistical Review of World Energy – 2022 – 71st Edition
- Energy Strategy Reviews 27 (2020) - An overview of solar photovoltaic panels' end-of-life material recycling
- Le colloque international de l'Eco-Innovation « ECONOV 2022 » - Techniques de recyclage des modules photovoltaïques en fin de vie

- MDPI – Energies 2023, 16, 284. https://doi.org/10.3390/en16010284 - Prediction of the Market of End-of-Life Photovoltaic Panels in the Context of Common EU Management System
- SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025
- IRENA (2019) – Future of Solar Photovoltaic – Deployment, investment, technology, grid interaction and socio-economic aspects
- Becquerel Institute - European Solar PV Data Hub

General mapping in the countries of the EU-27

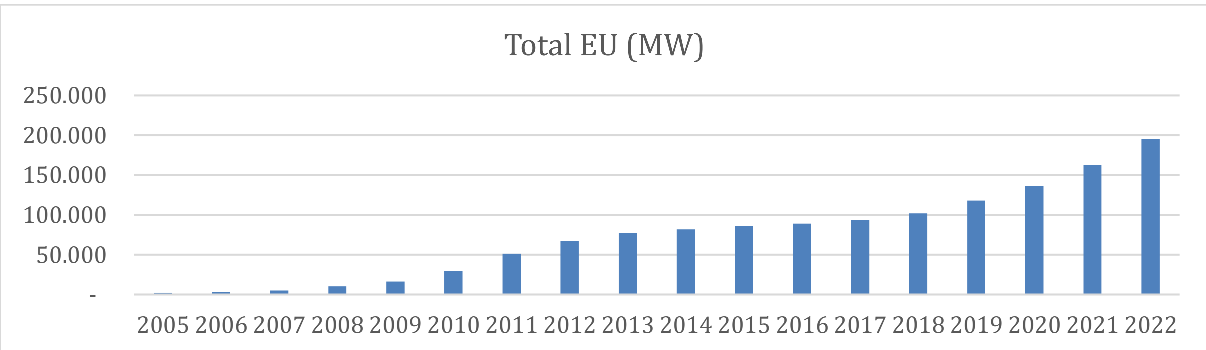
General European context

The European Union, with its 27 member states, has been at the forefront of the global renewable energy transition. Over the last two decades, photovoltaic (PV) energy has become an integral component of the EU's energy mix, signaling the bloc's commitment to a carbon-neutral future.

Power Installed

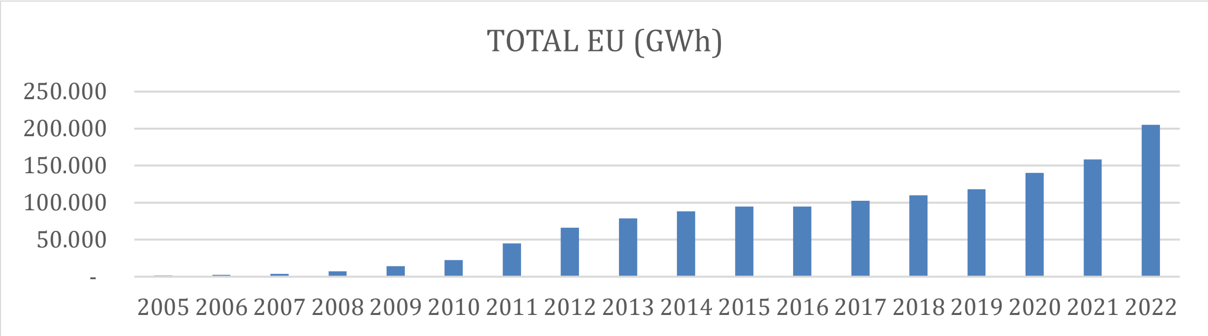
Since the year 2000, Europe has shown a substantial uptick in its solar PV adoption. From a humble beginning (500 MW in 2000), the Europe-27 bloc reached an impressive 195 GW of installed solar PV by 2022. This significant progression marked Europe as one of the leading solar powerhouses globally, accounting for approximately 20% of the world's solar infrastructure. This rise can be credited to the European Union's directives and targets for renewable energy, coupled with individual member state policies and incentives. Countries like Germany, Italy, The Netherlands, Spain and France are major contributors to this growth.

Q2 2023 further amplified Europe's commitment to solar energy. An estimated 11.7 GW of solar installations were set up, marking a substantial increase from 7.97 GW during the same period in 2022. Germany, Spain, and Poland continued to lead this solar revolution, with installations of 2.9 GW, 1.8 GW, and 1.2 GW, respectively. In Q3 2023 around 13.5 GW have been installed, a 32% year-on-year growth. The underlying factors explaining this increase are the decreasing module prices coupled with strong market demand, even as inflationary pressures and component supply constraints pose challenges.



Electricity Generation

With the surge in installed capacity came an increase in solar electricity generation. By 2020, solar PV contributed to around 11% of Europe's renewable electricity, a significant jump from the early 2000s. The increased generation not only reduced the dependence on fossil fuels but also played a role in achieving emission reduction targets. In tangible terms, this is a 205 TWh electricity generation. Projections indicate that by 2025, solar might cater to 18% of Europe's total electricity demand.



Regulatory Aspects

Europe's PV growth cannot be discussed without crediting the Renewable Energy Directive of the EU. This directive was instrumental in establishing renewable targets and motivating member states to embrace solar PV and other renewable energy forms and to achieve 32% renewable energy by 2030.

In the context of the European Green Deal, a €1 trillion package, the EU is fostering an ecosystem where renewable adoption, especially solar, is not just encouraged but becomes imperative to make the continent climate neutral by 2050. National Energy and Climate Plans (NECPs), and the Paris Agreement have also shaped the regulatory landscape, driving ambitions and setting the pace for PV adoption.

The REPowerEU plan pursues the goal of putting more than 320 GW of solar PV on the European grid by 2025. This represents a doubling of the 2020 capacity. By 2030, the European target is to reach 600 GW. Europe aims to replace 9 billion m^3 of natural gas annually with solar energy by 2027.

Trends

- Policy-Driven Surge: Much of Europe's solar growth has roots in its forward-thinking policies. Over the last 20 years, member countries updated their solar targets, on average, every four years, ensuring continuous momentum.
- Economic Feasibility: The cost of solar modules in Europe declined remarkably by over 80% between 2000 and 2022. This made solar power not just environmentally sensible but economically astute.

- Geographic Diversification: The early 2000s saw dominance by nations like Germany. Now, newer players are emerging as solar contenders. The latest data indicates an 18% YoY growth in solar installations in these newer markets.
- Energy Storage: The transition to a solar-heavy energy mix led to a 70% rise in investments in energy storage solutions over the past seven years. This ensures grid stability despite the intermittent nature of solar power.
- Distributed Generation: Solar installations are no longer limited to vast fields. 60% of new installations in 2022 were on rooftops, marking a paradigm shift.
- Technological Advancements: Bifacial modules, which increase energy yields by up to 30%, saw a 200% increase in adoption across Europe in 2022.
- Solar Communities: European cities like Copenhagen and Freiburg (Germany) have witnessed a 40% surge in community solar projects, democratizing energy generation.

Strengths

- Policy Frameworks: Robust and progressive regulatory mechanisms have consistently propelled the sector forward.
- Major Contributors: Key players such as Germany, Italy, The Netherlands, Spain have significantly boosted the European average.
- Technological Advancements: With decreasing module prices and strong market demand, a consistent focus on technological advancements based on a 60% increase in solar tech R&D funding over the past decade has also been pivotal. Home to leading research institutions, Europe saw a surge in solar-related patents, with a 50% increase over the last decade.
- Infrastructure & Grid Integration: Investments upwards of €50 billion in the past decade have modernized the European grid, readying it for renewable integration.
- Investment Climate: Solar investments in Europe crossed €120 billion in 2022, bolstered by supportive policies and an ROI that rivals traditional energy sources.

Challenges

- Supply Chain Disruptions: Recent disruptions, exacerbated by global events, have slowed down installation rates by almost 10% in certain quarters. Global events, including the pandemic and political unrest, indeed led to supply chain disruptions, affecting module availability and leading to an average project delay of six months in 2022.
- Workforce Deficit: A shortage of skilled workforce, currently estimated at a gap of 15,000 professionals, affects project timelines. The current workforce deficit, quantified at 17%, could potentially escalate project costs by up to 10% due to delayed timelines and increased labor costs.
- Module Production: Europe's 1% global share in module production contrasts starkly with China's 80%, indicating a significant dependency and vulnerability to external supply chain shocks.
- Land Availability: With large-scale projects, land acquisition has become a pain point, inflating project costs by an average of 15%.

- Intermittency: The nature of solar, especially in northern regions, can lead to grid instability, requiring an investment of nearly €20 billion in grid-balancing technologies.

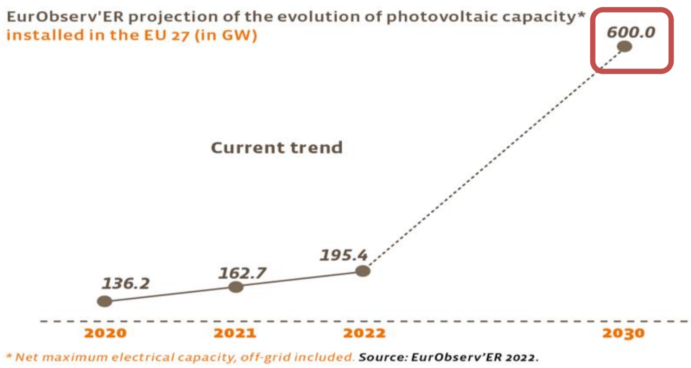
Opportunities

- Manufacturing Resurgence: Europe has the potential to revive its PV manufacturing sector with initiatives like Meyer Burger, a well-known equipment supplier in the solar industry, which could elevate Europe's solar module market share to 20% by 2030.
- Workforce Training: Addressing the workforce shortage presents an opportunity to develop specialized training programs in collaboration with industry stakeholders and create over 50,000 jobs in the next five years.
- Collaborative Efforts: A collective approach, driven by the European Union's resources and influence, can forge a cohesive solar strategy for the continent, with potential savings of €10 billion annually.
- Regional Synergy: Joint solar strategies could drive cost efficiencies, with potential cumulative savings reaching €15 billion by 2027.
- Floating Solar: Europe has 20,000 km^2 of suitable water bodies. Harnessing just 5% can generate an additional 30 GW.
- Hydrogen Production: Solar can play a pivotal role in green hydrogen production, a market expected to touch €150 billion by 2030.
- E-Mobility Integration: With electric vehicle adoption rising, integrating solar can reduce the carbon footprint further, saving up to 50 million tons of CO_2 annually by 2030.

PV capacity scenarios – horizon 2030

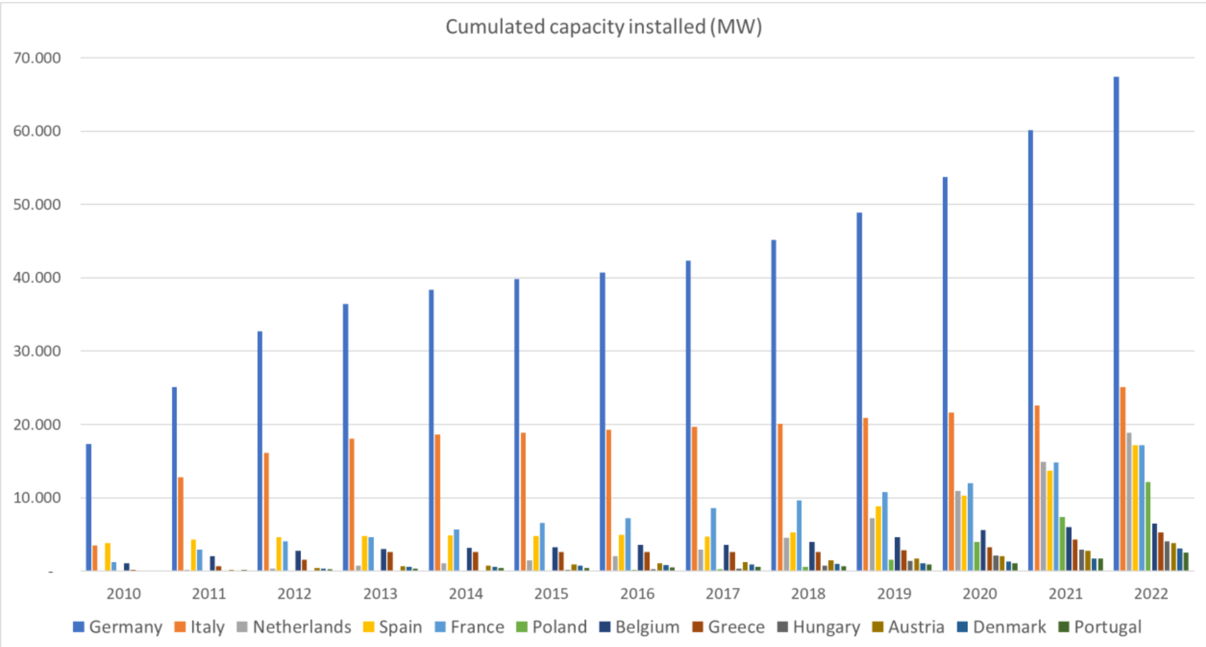
The European Union's solar market is poised for substantial growth, but there is a noticeable gap between the current policy targets and potential solar capacity. The EU needs to adjust its renewable energy targets to reflect the rapidly advancing solar industry, ensuring alignment with global climate goals, especially the Paris Agreement. Each member state's progress towards achieving these solar targets will be crucial in the overall trajectory.

Scenario projection predict a significant growth in the cumulative installed solar capacities which are expected to triple over the next seven years to reach more than 600 GW in 2030, as shown in the figure below.



Main contributors in Europe [27]

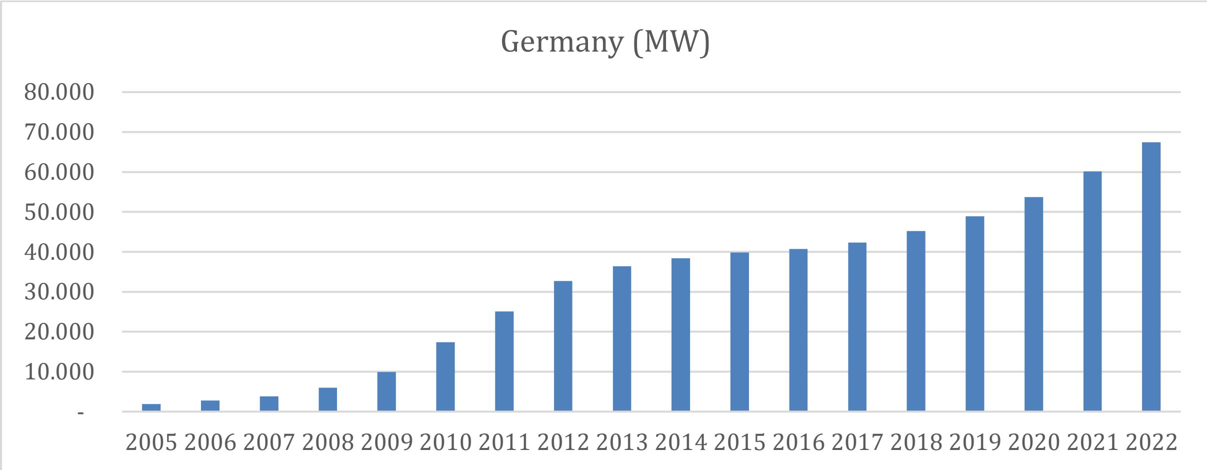
An in-depth review was conducted on the 10 nations with the most significant PV installation, accounting for approximately 91% of the EU-27's total solar PV capacity in 2022. Denmark and Portugal were also included in this analysis due to their respective commitments to NECP PV Capacity Targets of 7.8 GW and 9 GW for 2030.



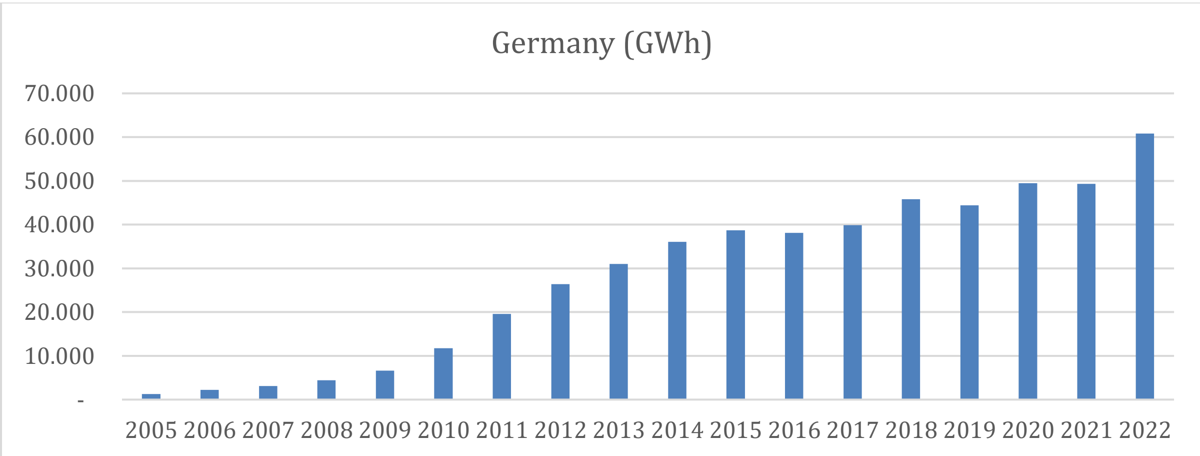
Germany

Germany maintains its leadership in the European solar market, a position it has held for nearly two decades. Its commitment to sustainable energy and progressive policies has positioned it at the forefront of Europe's transition to renewable sources.

1. Power Installed: Starting from humble beginnings with PV installations totaling around 120 MW in 2000, Germany has seen an exponential surge in its solar capacity. By 2022, the nation had achieved an impressive 67.4 GW of solar PV installations, marking a 12% growth from 60.1 GW in 2021. This steadfast commitment to solar power has been powered by the German government's strategic efforts, notably through the Renewable Energy Sources Act (EEG) which introduced feed-in tariffs, guaranteeing a market and return for PV power producers.



2. Electricity Generation: Parallel to the increase in capacity has been the remarkable rise in electricity generation from solar sources. By 2022, the nation's PV systems churned out about 60 TWh, supplying nearly 11% of Germany's electricity needs. On particularly sunny days, PV systems have been known to contribute more than a quarter of the country's total electricity, reflecting the ever-increasing importance of this renewable source in Germany's energy matrix.



3. Regulatory Aspects: The year 2021 ushered in changes to the Feed-in Law (EEG). On the bright side, the self-consumption levy for residential and small commercial systems was removed, boosting investments in these areas. However, larger rooftop self-consumption systems now face new financial burdens, signaling a push towards a tender scheme for this segment.

4. Trends: Germany's solar journey is marked by several trends:

- Decentralization: Smaller, decentralized PV systems dominate the landscape, with rooftop installations becoming ubiquitous across homes, businesses, and farms.
- Cost Dynamics: The dawn of the new millennium has seen PV installation costs in Germany plummet, with solar panel prices reducing by over 80%.

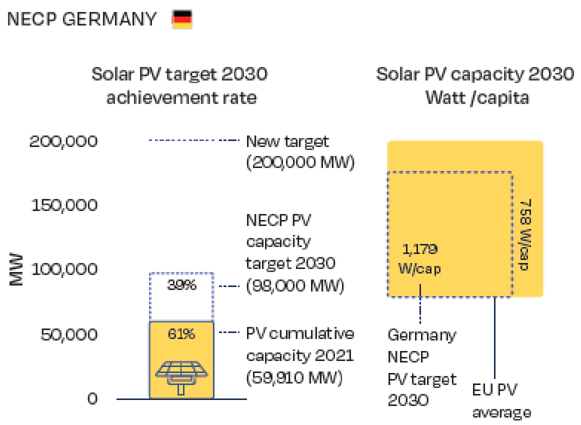
- Innovation and Storage: To combat solar production intermittency, Germany has pivoted towards energy storage solutions, innovative grid management, and integrating PV with other renewables.
- Policy and Regulation: Over time, the EEG has seen numerous revisions, transitioning from fixed feed-in tariffs to auction[1]-based systems determining support levels for fresh installations.

5. Strengths: With more than 70 GW of installed PV capacity and expectations of crossing the 4 million PV installations by 2024, Germany's commitment to solar energy is evident.

Private individuals play a crucial role, with a year-on-year doubling of solar panels installations in Q1 2023. The nation also benefits from around 2.6 million photovoltaic-thermal installations, predominantly utilized for domestic heating and hot water.

6. Challenges: The mid-sized PV rooftop systems, historically significant contributors, have seen dwindling numbers due to regulatory dilemmas. Current support schemes for prosumers may not align well with the ambitious 200 GW target set for 2030. Regulatory complexities and expensive metering systems could deter potential solar and storage prosumers.

7. Opportunities: Germany surpassed its 7 GW photovoltaic capacity target in 2022, and there's optimism about reaching the 9 GW mark in 2023. However, to achieve the goal of 200 GW by 2030, annual installations need a 30% surge compared to previous years.

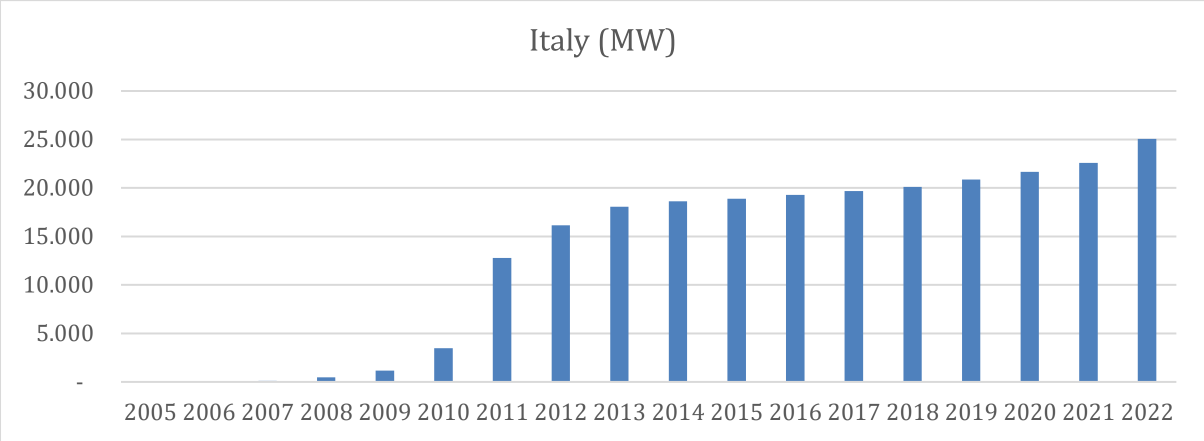


Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-202

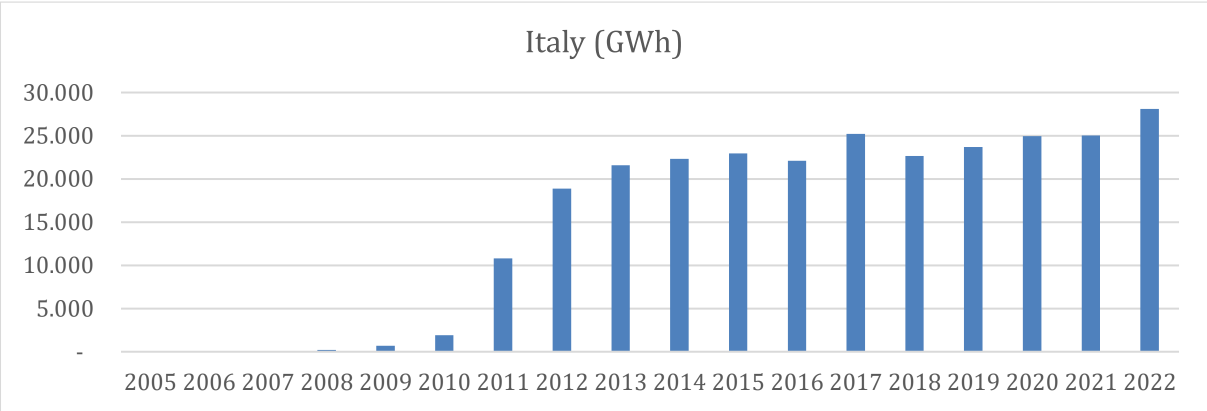
Italy

1. Power Installed: In 2000, Italy's solar PV sector was just starting to gain traction. By 2022, the country had an impressive 25 GW of installed solar PV capacity, largely attributed to its strategic measures including generous feed-in tariffs and tax incentives from the mid-2000s.

[1] An auction is a public sale where goods or services are sold to the highest bidder. It's a method of determining the value of an item through competitive bidding.



2. Electricity Generation: This upswing in solar installations has naturally led to a substantial boost in solar electricity generation. By the end of 2022, Italy was generating a staggering 28 TWh from solar energy alone. This figure represents a significant chunk of Italy's overall electricity consumption, marking a paradigm shift from conventional energy sources to more sustainable ones.



3. Regulatory Aspects

- Feed-in Tariffs and Conto Energia: Introduced in the mid-2000s, the Conto Energia schemes provided a robust incentive mechanism for solar installations. By offering generous feed-in tariffs, Italy ensured that solar energy remained a lucrative prospect for investors and homeowners alike.
- Decentralization and Self-Consumption: As technology evolved and the needs of consumers shifted, Italy adapted its regulatory framework. Recent years have seen a notable shift towards decentralized PV installations, as homeowners and businesses recognize the benefits of self-consumption.

4. Trends

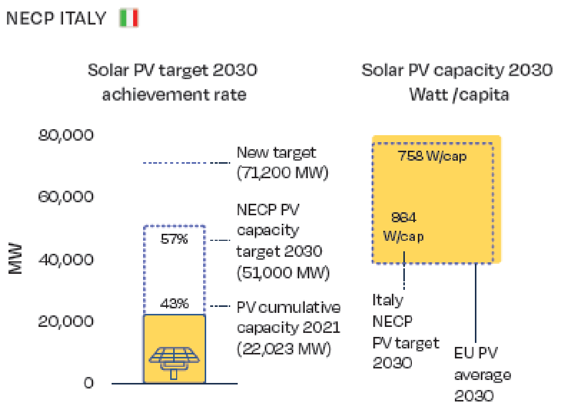
- Feed-in Tariffs and Conto Energia: Crucial for Italy's solar development.
- Decentralization and Self-Consumption: With regulatory shifts, decentralized PV installations are gaining traction, making self-consumption more viable.

- Grid Parity and Market Transition: The decreasing global PV prices, combined with the gradual phase-out of Italy's feed-in tariffs, have set the stage for solar energy to reach grid parity. This not only marks a major milestone for the industry but also signals a broader transition from a subsidy-driven market to one driven by genuine market forces.
- Innovation and Storage: Italy remains at the forefront of solar technology, with a keen focus on integrating storage solutions. This will be crucial in the coming years to address the intermittent nature of solar energy and to ensure a steady power supply.

5. Strengths : The pandemic posed unprecedented challenges, but Italy turned adversity into opportunity. The introduction of a 110% tax bonus, as part of the COVID-19 recovery fund, provided a significant impetus to residential solar and storage installations, underlining the nation's resilience and adaptability.

6. Challenges

- Permitting Issues: Not all has been smooth sailing. One of the most significant challenges has been the cumbersome permitting process. Despite being endowed with abundant sunlight, severe permitting problems have stymied Italy's solar ambitions.
- Access to Land: The interplay between agricultural activities and solar projects has posed challenges, with restrictions on constructing solar PV on agricultural lands.
- Grid Development: A robust grid infrastructure is the backbone of any sustainable energy transition. While the Italian NECP (target : 71,2 GW installed in 2030) has provided extensive insights, it falls short of a concrete vision for the future.



Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

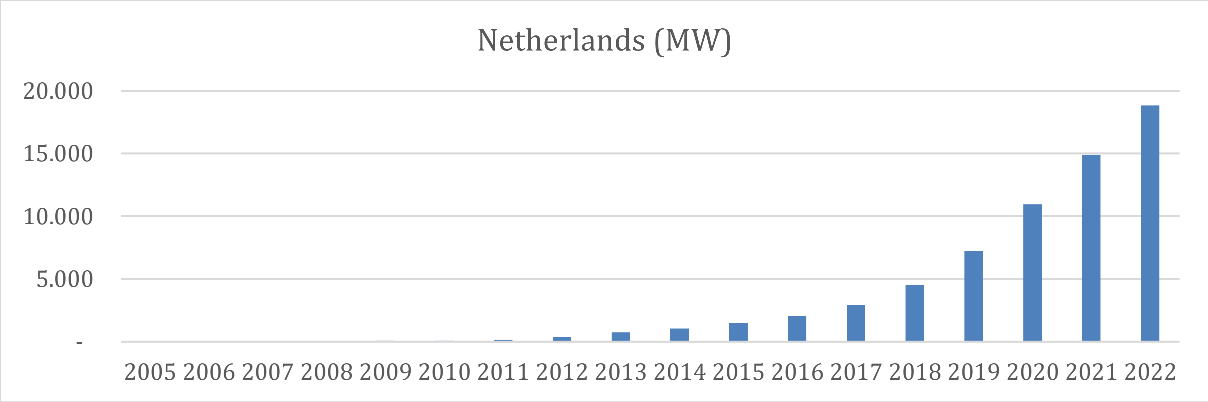
7. Opportunities

- Streamlining Permitting Procedures: A revamped, streamlined permitting process can remove bottlenecks and speed up project developments.
- Expanding Access to Land: By re-evaluating land use policies and promoting concepts like agrivoltaics, Italy can harmonize its agricultural and solar objectives.

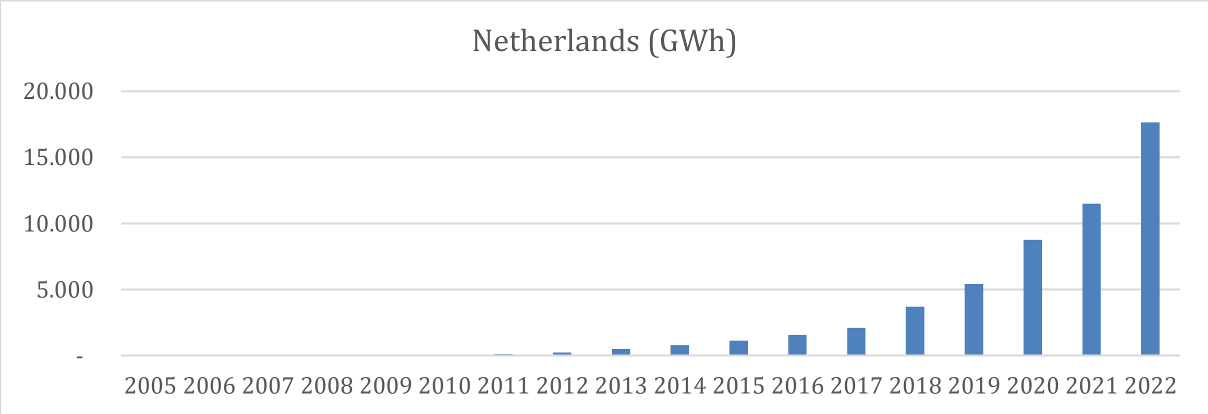
- Grid Modernization: Collaborative efforts between various stakeholders can usher in a new era of grid management, ensuring that Italy's grid infrastructure is future-ready.

Netherlands

1. Power Installed: In the Netherlands, solar PV installations were minimal in 2000. As the world ushered in a new millennium, the country made bold strides towards sustainability. By 2022, nearly 19 GW of solar PV capacity had been installed, reflecting a notable 26% increase (3.9 GW added since 2021). This growth can be attributed to supportive government policies, such as subsidies and tax rebates, which made solar installations both accessible and economically viable.



2. Electricity Generation: The surge in installed capacity led to a significant boost in solar electricity generation. By 2022, the country generated an impressive 17.7 TWh from solar, cementing its role in the Dutch renewable energy portfolio alongside wind and biomass.



3. Regulatory Aspects

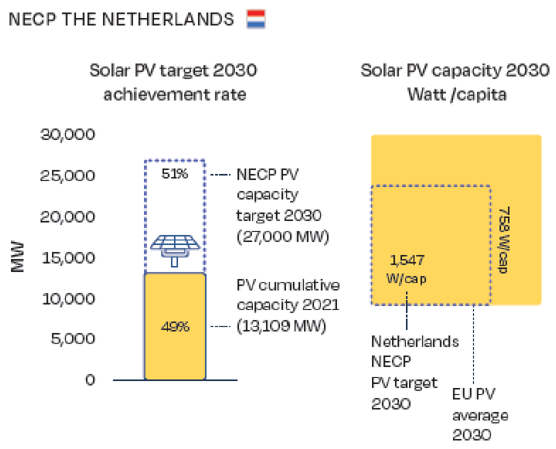
- Net-metering: Primarily driving the residential solar market, this scheme allows homeowners to offset their energy consumption with the solar power they generate.
- SDE++ tendering scheme: Crucial for the commercial, industrial, and utility-scale markets, this scheme, although open to other energy technologies, saw solar securing a majority in the 2021 round.

4. Trends

- Government Support: The Dutch government's strong commitment to the EU's renewable energy targets has facilitated the growth of the PV sector through various subsidies and tax benefits.
- Urban Solar Initiatives: City-based projects, including rooftop installations, public buildings, and even floating solar panels on canals, have become increasingly popular.
- Large-scale Installations: Solar parks have grown in prominence since the late 2010s, often being developed with community collaboration.
- Innovative Integration: In keeping with the Netherlands' innovative spirit, solar installations have begun integrating with existing infrastructure such as highways and water management systems.

5. Strengths

- Commercial Dominance: In 2020, commercial rooftop solar constituted over 40% of the market.
- Innovative Approaches: The exploration of multi-functional PV applications, like floating solar panels and solar carports, showcases the country's innovative approach.
- Robust Pipeline: With an ambitious 12 GW project pipeline, the nation's commitment to expanding its solar capacity is evident to reach the 27GW NECP PV capacity target in 2030.



Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

6. Challenges

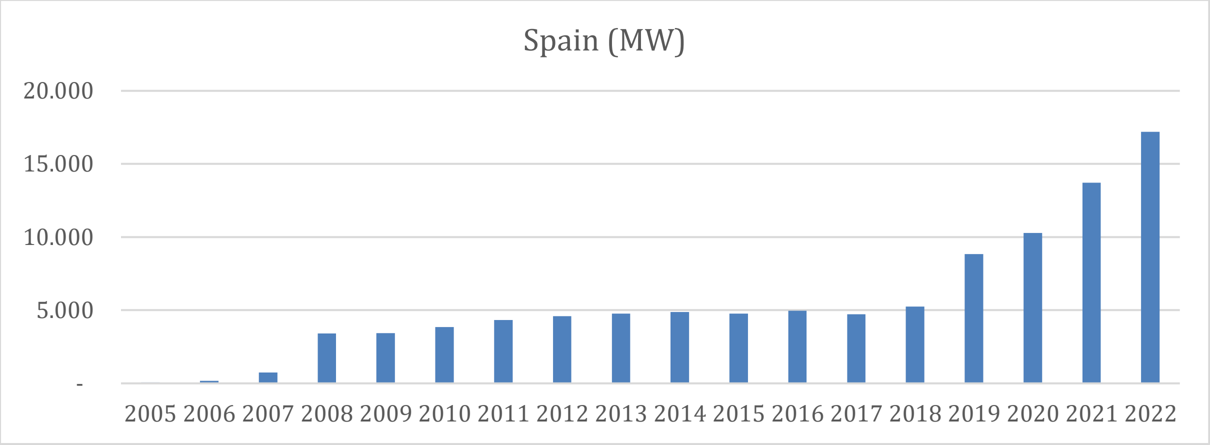
- Grid Connectivity: Delays and limitations, especially at middle and high voltage levels, could disrupt the progress of solar projects.
- Land Procurement: Land scarcity, particularly for large-scale projects, is a major concern. The public's reservations about using agricultural land for solar further complicates matters.

7. Opportunities

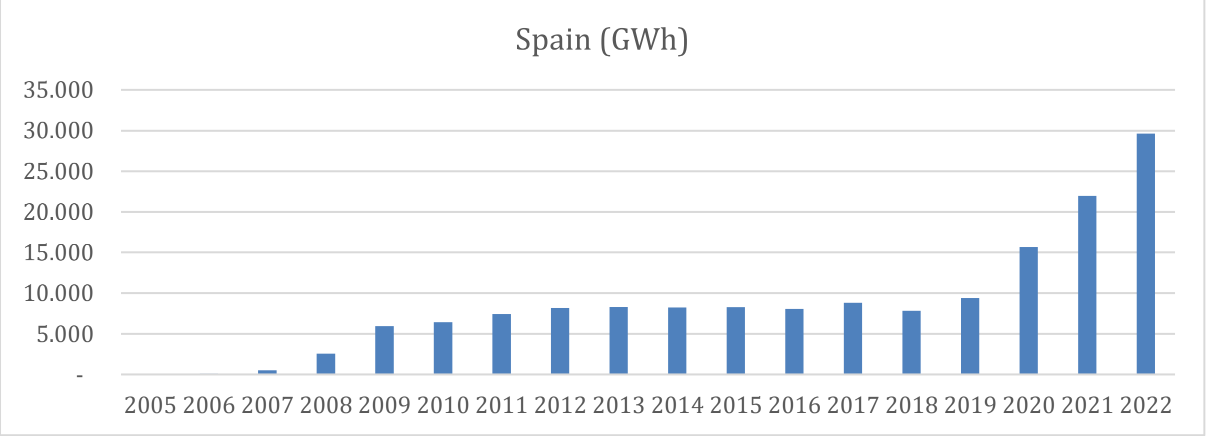
- Residential Market: With over 1.5 million households equipped with solar panels, there's immense potential for growth, especially if political deadlocks on net-metering can be resolved.
- Utility-Scale Market: As the SDE++ scheme matures, it's anticipated that by 2025, solar projects will be developed without any incentives.

Spain

1. Power Installed: In the early 2000s, Spain began its solar journey with only a few megawatts of installed solar PV. Fast forward to 2022, the country now proudly stands with an installed capacity of 17.2 GW. This is a remarkable increase of 3.5 GW (+25%) from 2021, proving Spain's commitment to harness its solar potential. This drastic change can be linked back to the feed-in tariff scheme introduced by the Spanish government, which incentivized PV installations.



2. Electricity Generation: Along with the burgeoning installed capacity, there was a proportional surge in solar electricity generation. By 2022, Spain had produced 29.6 TWh of solar electricity, catering to approximately 10% of its overall electricity demand. Such figures are testament to the country's dedication to renewable energy, especially when considering the variable nature of solar power in the backdrop of Spain's multifaceted renewable portfolio.



3. Regulatory Aspects: The 'sun tax', which once impeded the growth of Spain's rooftop solar market, has now been abolished, paving the way for increased investment in this sector. The Spanish Recovery Plan has also identified PV rooftops as pivotal, reinforcing this commitment with a €450 million investment in 2021 for self-consumption systems.

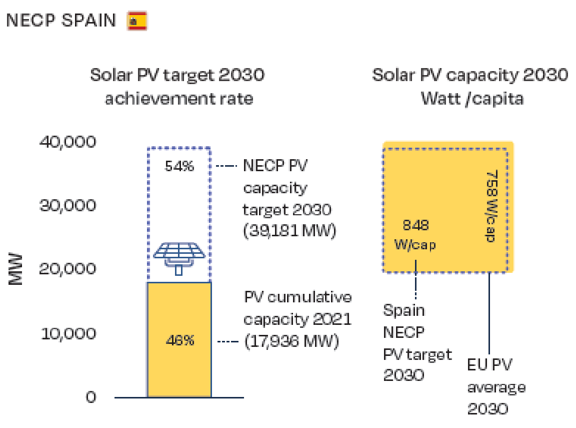
4. Trends

- The mid-to-late 2000s witnessed Spain's solar boom, fuelled by propitious policies, which, however, faced a setback due to abrupt policy shifts and the subsequent economic crisis.
- The subsequent decade witnessed Spain recalibrating its approach with stabilized policies and a rejuvenated focus on solar energy, facilitated by reduced technological costs and auction-based systems.
- Abrogation of the 'sun tax' in 2018 bolstered decentralized PV installations and self-consumption.
- Embracing the erratic nature of solar power, Spain is also veering towards integrating PV systems with energy storage solutions for consistent energy provision.

5. Strengths: Spain's move towards Power Purchase Agreement (PPA) systems, accounting for approximately 3 GW in 2021, signals a strategic shift towards private energy agreements. Moreover, the country's proclivity for subsidy-free solar suggests a maturing market, transitioning away from government subsidies.

6. Challenges: Permitting procedures pose a formidable challenge, decelerating solar project development and straining both developers and administrative bodies. Furthermore, achieving social acceptance remains a significant hurdle, especially in regions undergoing swift solar development.

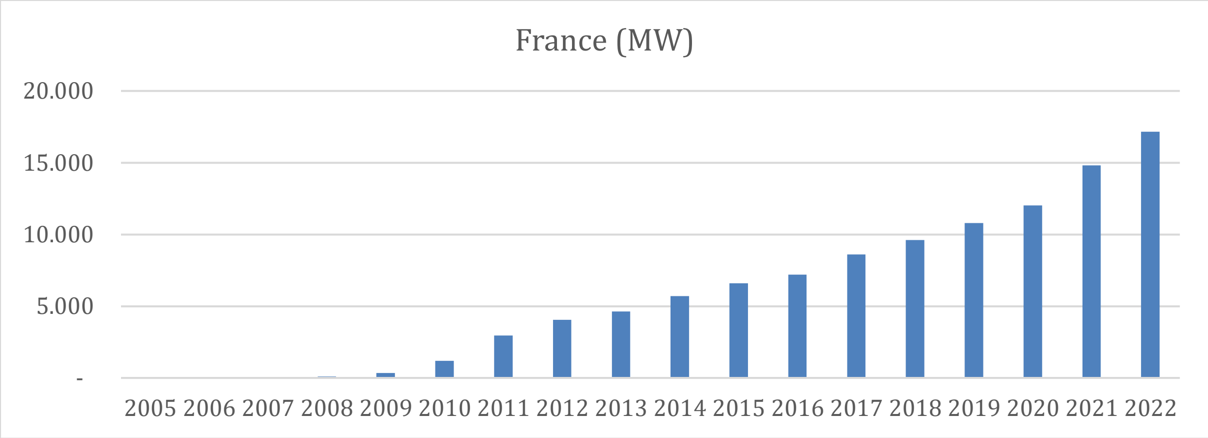
7. Opportunities: As the European Union intensifies its focus on renewable energy, Spain, with its advanced solar industry, could become a primary exporter of both solar technology and expertise. Moreover, with the eradication of the 'sun tax' and governmental financial backing, the rooftop solar segment also holds considerable potential and play a considerable role in reaching the 39.2 GW NECP PV capacity target in 2030.



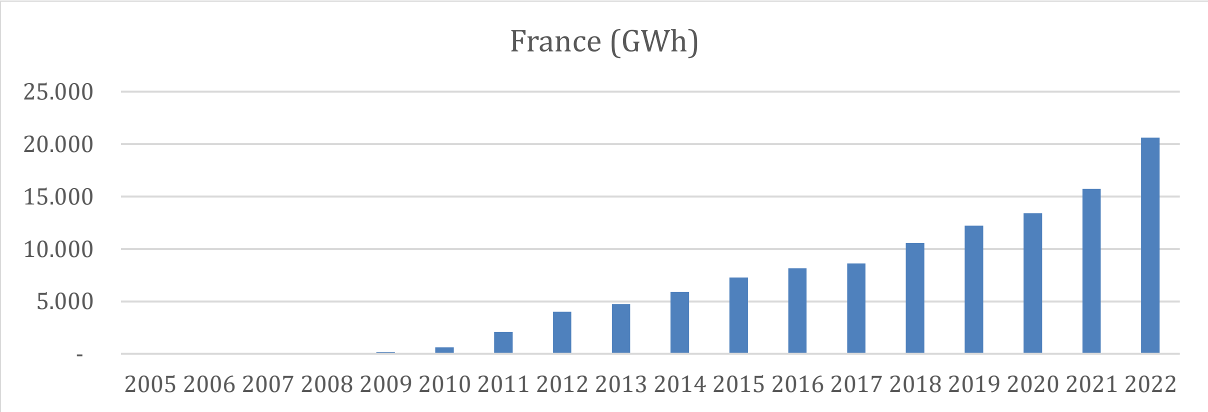
Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

France

1. Power Installed: By 2022, France had achieved a significant milestone with over 17.2 GW of installed solar PV capacity, marking a 16% increase (+2,4GW) from the previous year. This growth can be attributed to a combination of national solar plans, tax incentives, and feed-in tarifs.



2. Electricity Generation: Solar energy's contribution to France's electricity needs has been steadily climbing. By 2022, solar PV systems generated 20.6 TWh of electricity. Additionally, by the end of 2022, solar energy represented 4.7% of the French electrical consumption, an increase of 1.2% from the previous year.



3. Regulatory Aspects: France's commitment to renewable energy is evident through key legislative measures like the 2015 Energy Transition for a Green Growth law and the subsequent Climate & Energy Law. These laws have set ambitious targets aiming to reach between 35.1 GW and 44 GW of solar energy capacity by 2028.

4. Trends

- Strategic national solar plans set clear targets for the solar sector.
- The country's diversified approach combines large-scale farms with decentralized rooftop installations.
- Initiatives increasingly focus on integrating solar power with energy storage solutions.

- Significant investments in R&D, driven by collaborations between academia, industry, and the government.

5. Strengths

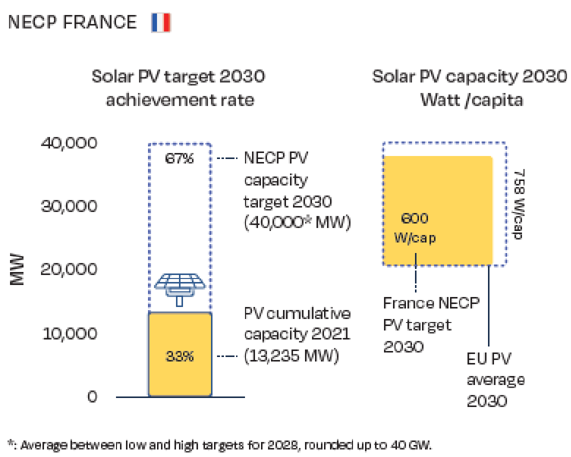
- France boasts of renowned R&D centers like INES and IPVF, positioning it at the forefront of solar innovation.
- The country has taken a pioneering role in innovative solar applications like agri-PV and floating solar.

6. Challenges

- Land usage remains a concern, especially concerning agricultural land.
- Extensive and sometimes ambiguous regulatory processes can hinder project deployment.
- With a set carbon criteria of 550 kg CO2 e/kW, there's a need to ensure sustainable growth in the solar sector.
- While self-consumption of solar energy is on the rise, certain challenges persist, such as the need to enhance its attractiveness and ensure consumers aren't penalized.

7. Opportunities

- The expected growth in solar capacity, with RTE's projection of 70 to 208 GW by 2050, underscores the sector's immense potential. The NECP PV capacity target is set to 40GW in 2030.

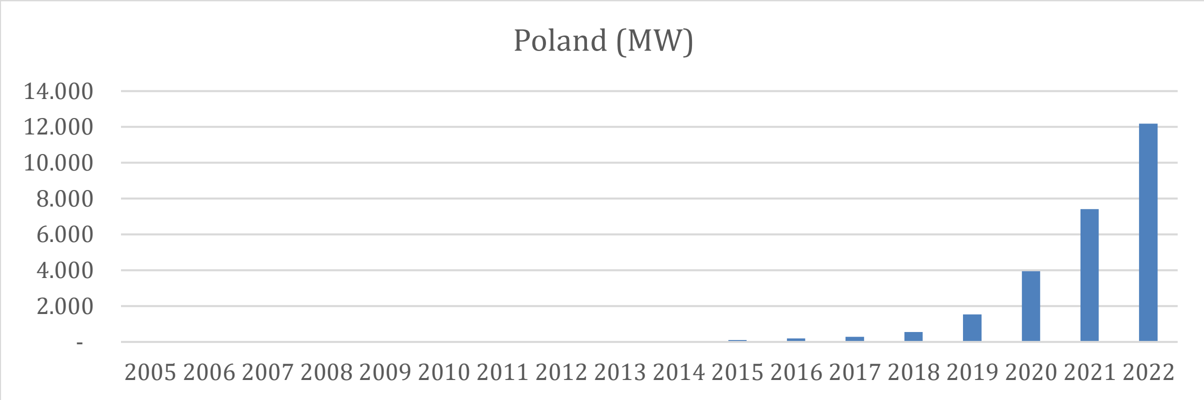


Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

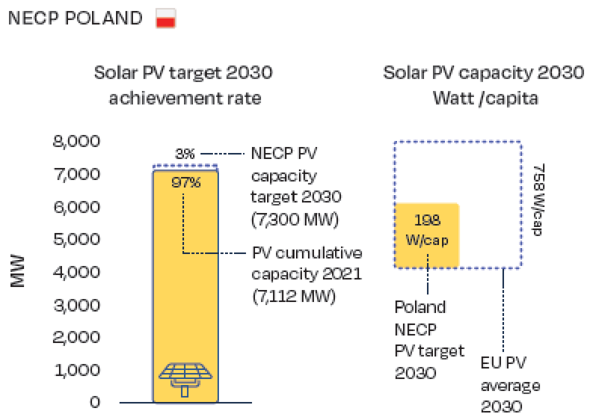
- By resolving administrative challenges, France can accelerate the deployment of solar projects.
- The nation's innovative approaches, like agri-PV and floating solar, can address land competition challenges.

Poland

1. Power Installed: By the year 2000, solar energy in Poland was in its infancy, with only a negligible amount of PV installations. Fast forward to 2022, the country has made remarkable progress by installing over 12.2GW of solar PV capacity, marking an impressive 64% increase (+4.8GW) from the previous year.

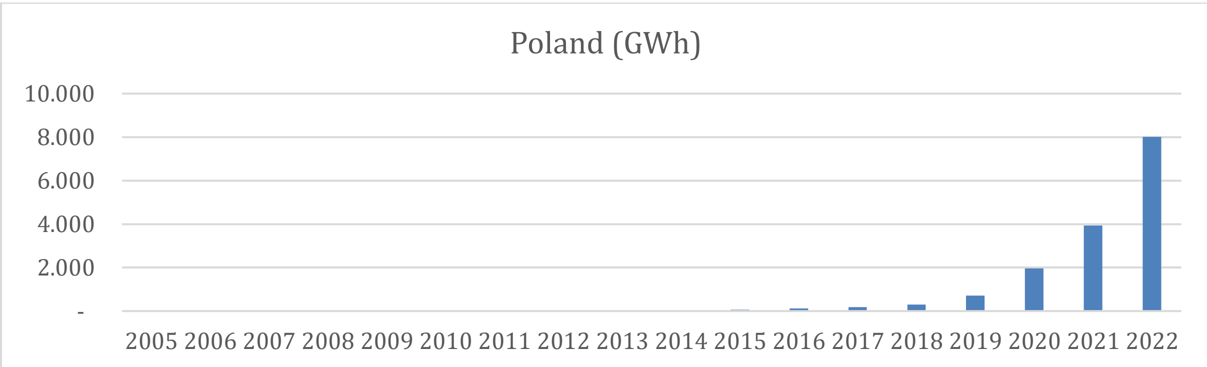


The current PV capacity already largely exceeds the Poland 7.3 GW NECP PV capacity target in 2030.



Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

2. Electricity Generation: With the rise in installed capacity, the generation of solar electricity has proportionately increased. As of 2022, PV energy contributed a commendable 8 TWh to Poland's electricity production, indicating the growing role of solar energy in the nation's power matrix.



3. Regulatory Aspects: Transitioning from net-metering [2] to net-billing [3] in April 2022 represents a key regulatory shift in Poland's solar landscape. Such transitions can have implications for the ROI of many prosumers, potentially affecting the pace of small rooftop system adoption.

4. Trends

- Governmental Initiatives: State-backed initiatives, tax credits, and grants have made solar installations more accessible.
- Community Energy Projects: Grassroots solar projects enable local communities to actively participate in the renewable energy shift.
- Transition from Coal: As global environmental and economic concerns intensify, there's a palpable momentum to shift away from coal. Solar energy, along with wind, is at the forefront of this change.
- Research and Innovation: Investments in solar research signal Poland's commitment to harnessing solar energy more effectively.

5. Strengths: Poland's rapid achievement of its solar targets, the dominance of solar in renewable energy auctions, and the rise of prosumer-driven energy models underline the country's strengths in the solar sector.

6. Challenges

- Grid Availability: Limited grid connection points and external supply chain disruptions are major roadblocks.
- PV Target Achievement: The fast-paced attainment of current PV targets necessitates a reassessment of future objectives.
- Regulatory Hurdles: The untapped potential of Power Purchase Agreements (PPAs) due to regulatory barriers highlights another challenge.

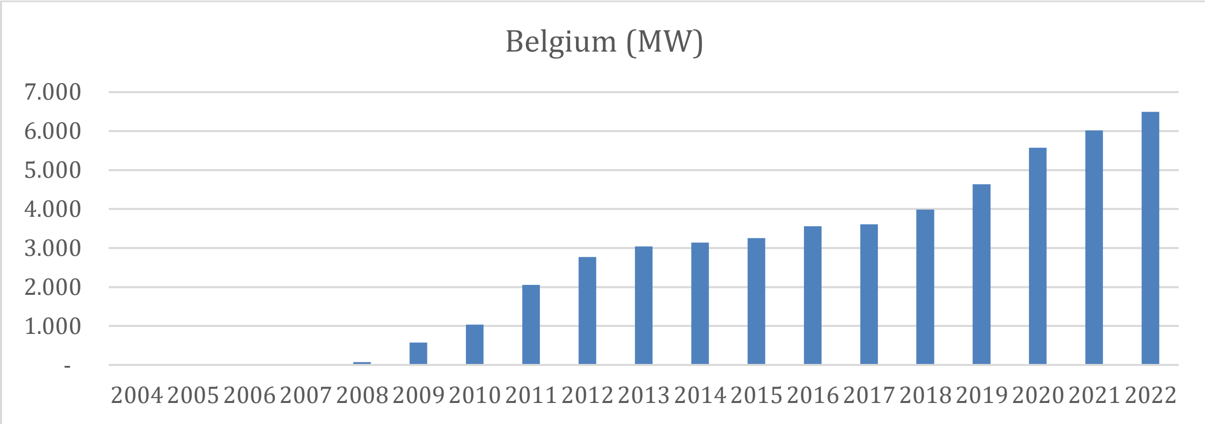
7. Opportunities: Falling renewable energy costs, the impending phasing out of coal, the emergence of innovative energy business models, and increasing environmental consciousness present lucrative opportunities for the expansion of solar energy in Poland.

Belgium

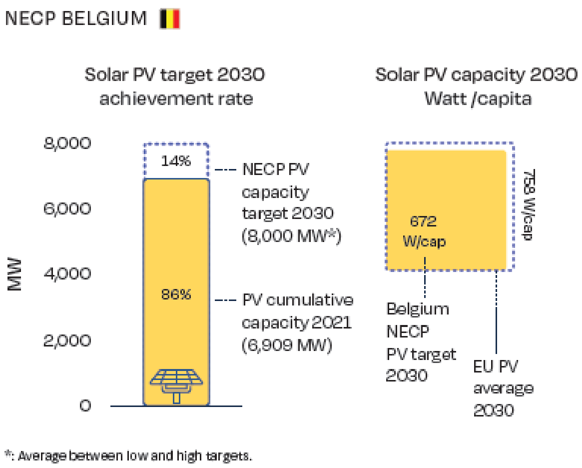
1. Power Installed : At the dawn of the millennium, Belgium's solar PV installations were negligible. The landscape began to change rapidly, especially post-2005. By 2022, Belgium had installed around 6,5 GW of solar PV capacity, an increase of 0.5 GW (+8%) compared to 2021.

[2] **Net-metering** : under net-metering, consumers with PV installations can feed their surplus energy back into the grid. The electricity meter will track both the electricity consumed from the grid and the electricity fed back into the grid. Consumers are usually billed only for their "net" energy usage [the total energy consumed minus the energy fed back into the grid]. Consumers can "store" their excess energy in the grid and retrieve it later without additional costs.

[3] **Net-billing** : In a net-billing scheme, consumers are still able to feed surplus energy back into the grid, but the mechanics of billing change. Instead of being billed for their net consumption, consumers are billed for all the energy they consume from the grid at the retail rate. Separately, they are compensated for the energy they feed into the grid, but this compensation is often at a lower, wholesale rate. This can make solar installations less economically attractive because the difference between the retail and wholesale rates can be significant.

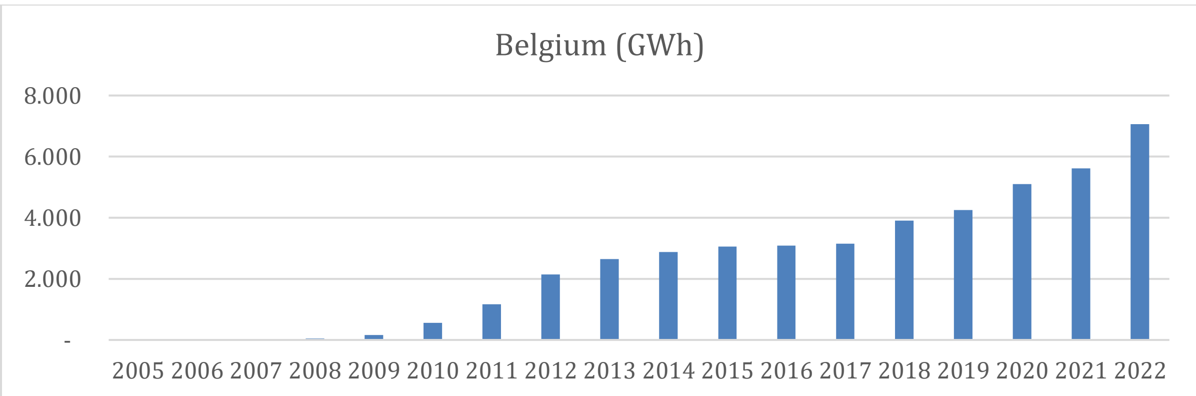


One of the driving factors behind this growth has been the regional green certificate schemes, especially in Flanders and Wallonia, which incentivized PV installations through financial rewards to reach a capacity already close to the 8GW NECP PV capacity target 2030.



Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

2. Electricity Generation : Alongside an increase in installed capacity, there was a corresponding rise in solar electricity generation. By 2022, solar PV contributed to about 5.5% of Belgium's total electricity consumption with a production of 7.1 TWh. This might appear modest in comparison to some nations, but for a country with a relatively cloudier climate, this contribution is substantial.



3. Regulatory Aspects

- Green Certificate Schemes: These are pivotal regulatory tools employed especially in Flanders and Wallonia. They serve as financial incentives to promote the adoption of solar PV installations. Depending on the region, the specifics of these certificates, such as their value and duration, may vary.
- Federal vs. Regional Jurisdiction: Belgium's federal structure divides power between the federal state and the regions (Flanders, Wallonia, Brussels-Capital). This bifurcation has led to the creation of region-specific regulatory norms and incentives, leading to some administrative complexities but also allowing tailored solutions based on regional needs and resources.
- Auction Design in Wallonia: Wallonia has made provisions in its regulatory framework regarding auction design for solar projects. However, there's a need for more clarity in terms of the volume and schedules, ensuring transparency and predictability for investors.
- Net-metering to Prosumer Schemes: Flanders has spearheaded regulatory changes that transition away from net-metering schemes to new models that emphasize demand-side flexibility. These new regulations make consumers more active in the energy market, but they also come with additional responsibilities and benefits.

4. Trends

- Regional Disparities: Belgium's PV growth has not been uniform across its regions. Flanders, in particular, took the early lead, driven by attractive green certificate schemes. Wallonia and Brussels followed, though at a different pace and scale.
- Price Dynamics: The cost of PV installations in Belgium has seen a dramatic decrease since 2000, primarily driven by global trends, technological advancements, and increased competition. This has made solar energy more accessible and economically viable for many Belgians.
- Decentralized Systems: A significant portion of Belgium's solar capacity comes from small-scale, decentralized installations. Many households and businesses have adopted rooftop solar panels, taking advantage of regional incentives.
- Policy Evolution: As the PV market matured, Belgium's regional authorities adjusted their policy instruments. The generous initial incentives, especially in Flanders, were gradually reduced to better reflect the decreasing cost of PV technology.

5. Strengths

- Rapid Growth: Belgium has showcased robust growth in its solar sector, especially post-2005. Regional green certificate schemes, particularly in Flanders and Wallonia, have played a pivotal role in boosting solar adoption.
- Diversified Approach: Belgium's strength lies in its diversified approach to solar energy adoption. From large-scale installations to decentralized systems, Belgium has tapped into various avenues to harness solar energy.
- High Prosumer Count: A considerable number of Belgians are not just consumers but also producers of solar energy. This indicates a high level of public engagement and interest in solar energy, which can be leveraged for future growth.

6. Challenges

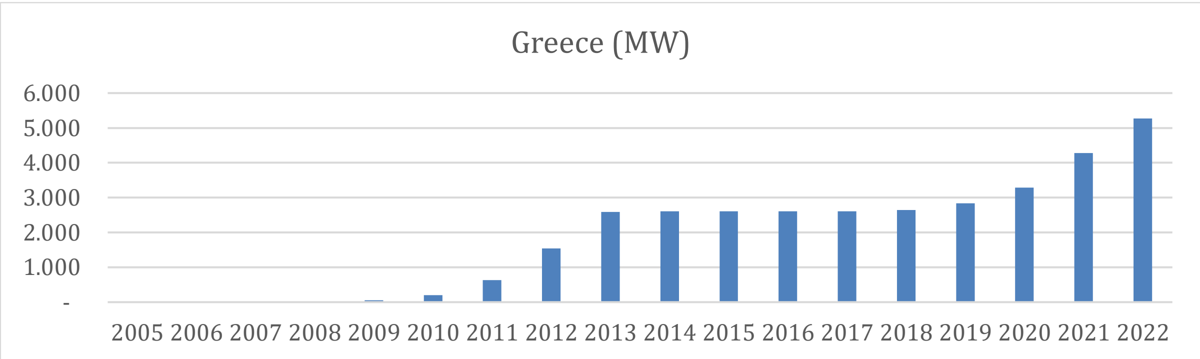
- Complex Administrative Procedures: Belgium's federal structure, with shared powers between regions and the central government, has introduced complexities in the administration of solar projects. This fragmentation can deter potential investors.
- Grid Management: With a growing number of prosumers, there's an imminent need to modernize the grid to manage energy flow. The current grid setup might not be equipped to handle large-scale decentralized energy production.
- Uniform Policy Framework: Different regions in Belgium have their policy instruments, leading to disparities in solar adoption rates across the country. This lack of uniformity might be a deterrent for nationwide solar growth.

7. Opportunities

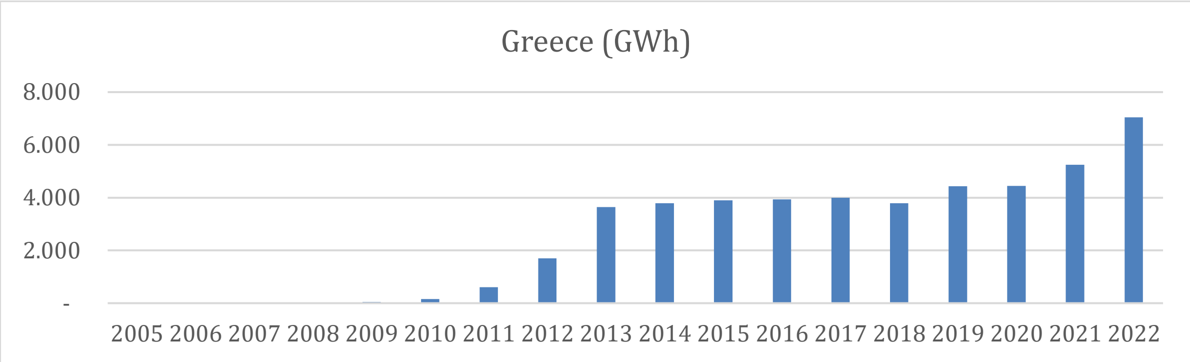
- Untapped Potential: The significant difference between the current NECP target and the potential solar capacity indicates a massive opportunity for growth. With proper strategies in place, Belgium can harness a much larger portion of its solar potential.
- Technological Advancements: As technology evolves, there are ample opportunities for Belgium to adopt newer, more efficient solar solutions. This can further reduce costs and improve solar energy's viability in the country.
- Public Engagement: Given the high number of prosumers, there's an opportunity to engage the public even further, making them active stakeholders in Belgium's renewable energy journey.

Greece

1. Power Installed: Starting the 2000s with minimal solar installations, Greece's PV expansion accelerated remarkably due to its favorable geography and European Union (EU) directives. By 2022, Greece had outpaced many of its European peers by pushing capacity to 5.3GW, marking an increase of 1GW compared to 2021 (+23%).



2. Electricity Generation: Greece's geographical advantages have positioned it as an ideal candidate for solar electricity generation. The growth in installed capacity has significantly impacted the national grid's renewable contribution, with solar production exceeding 7 TWh in 2022. The integration of solar electricity during peak hours, especially during Greece's hot summers, aligns with peak electricity demands, primarily due to air conditioning.



3. Regulatory Aspects

- The feed-in-premium scheme for solar systems up to 500 kW was extended until the end of 2022, signaling strong regulatory support. The potential PV project pipeline has swelled to 85 GW, involving significant national and international energy stakeholders. To simplify the installation process, the Greek government has streamlined the authorization processes since 2020, with a regulatory framework for energy storage coming in Q1-2022.
- Additionally, Greece aims to maintain the auction scheme for solar and wind until 2025, with PV likely securing a majority of the 3 GW total capacity.

4. Trends

- Governmental Initiatives: Feed-in tariffs and tax incentives have been key drivers in promoting solar installations.
- Island Electrification: Decentralized solar projects on islands illustrate how renewables are addressing energy needs in remote areas.
- Tourism and Solar: Integration of solar in the tourism sector, including eco-resorts, showcases the dual benefits of economy and sustainability.
- Research and Innovation: Collaborations with universities and global energy entities are optimizing solar technology for Greece's specific climatic conditions.

5. Strengths

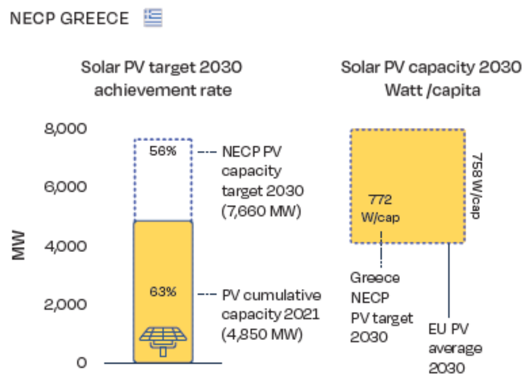
- Strategic Vision: The Greek government's continued support and strategic vision have been pivotal in the rapid expansion of the solar sector.
- Natural Advantage: Greece's geographical location ensures maximum sunlight exposure, enhancing energy generation.
- Investor Interest: The regulatory framework and governmental support have attracted both domestic and international investors.

6. Challenges

- Grid Capacity: The main challenge is the capacity of the grid, with both medium and high-voltage grids facing congestion.
- Residential Market: In comparison to ground-mounted projects, the residential PV market in Greece is still in its infancy.

7. Opportunities

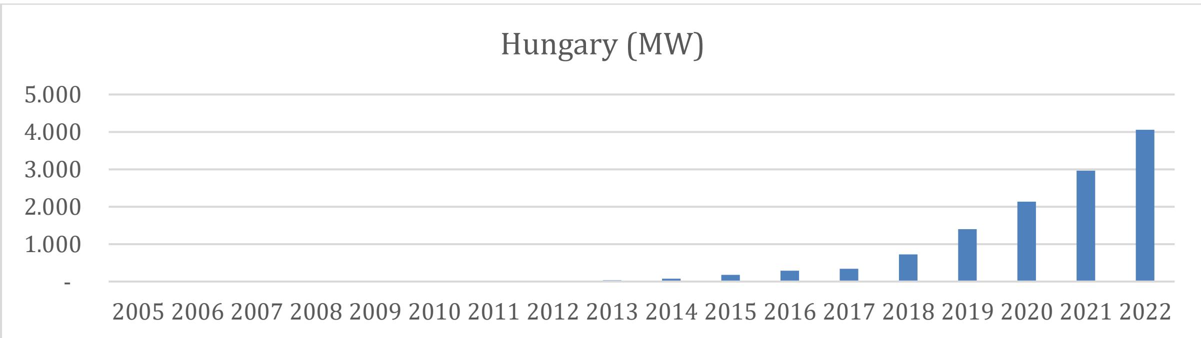
- Residential Solar: The potential for growth in the residential sector is vast, especially with increased awareness and favorable policies.
- Energy Storage: With a regulatory framework in the offing, energy storage can further augment Greece's solar capacity with the opportunity to revise the solar PV target (7.7 GW NECP PV capacity target2030) and align with EU's augmented climate objectives.



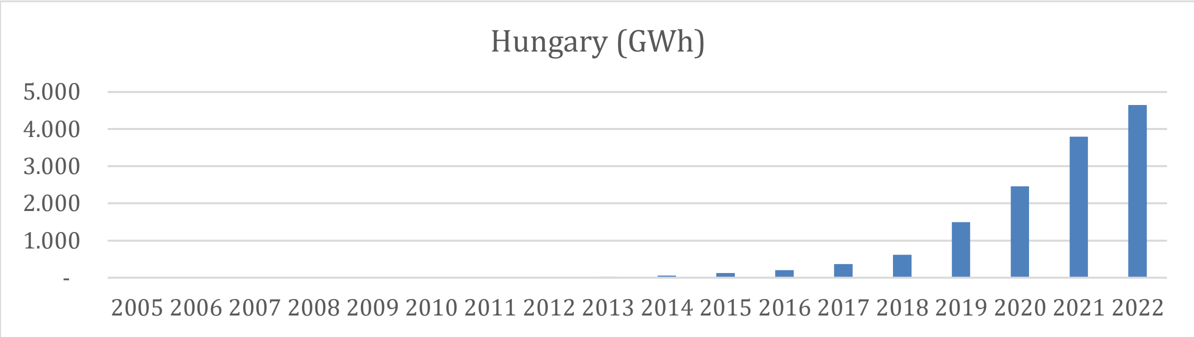
Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

Hungary

1. Power Installed: Hungary, starting with negligible solar installations in the early 2000s, has showcased a remarkable progression in expanding its photovoltaic (PV) capacity. Bolstered by supportive policies and international funding, Hungary's PV capacity soared to 4GW by 2022, marking a rise of 1.1 GW (+37%) in contrast to 2021. Key milestones, encompassing the inauguration of significant solar parks and major private sector undertakings, play a vital role in contextualizing this rapid growth.



2. Electricity Generation: Corresponding to its augmented installed capacity, Hungary experienced a notable surge in solar energy's contribution to the national grid, registering an electricity generation of 4.6 TWh in 2022.

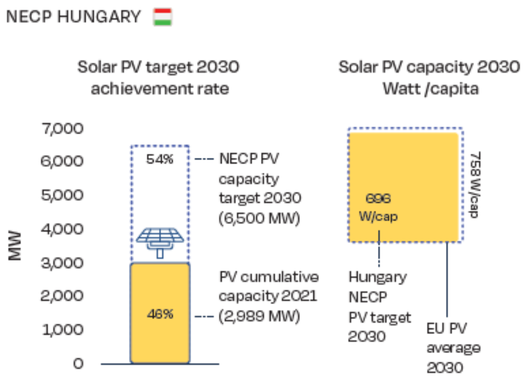


3. Regulatory Aspects: Hungary's focus on alleviating energy poverty found resonance in its newly introduced solar subsidy program, utilizing resources from the EU Just Transition Fund. This, along with other regulatory frameworks, underscores Hungary's commitment to sustainable energy solutions.

4. Trends

- Governmental Initiatives: Diving deeper into Hungary-specific policies, such as feed-in tariffs and grants, offers insights into the governmental support for solar energy.
- Decentralized Energy Systems: Emphasis on community-centric solar ventures portrays the democratization of Hungary's energy landscape.
- Integration with Other Renewables: A comprehensive strategy integrating solar with wind or hydro presents a broader spectrum of Hungary's renewable energy vision.
- Research and Innovation: Collaborations with academic bodies, international institutions, and cutting-edge innovations epitomize Hungary's forward-thinking approach to solar tech enhancements.

5. Strengths: A significant boost in small ground-mount systems and rooftop installations, both in the residential and commercial domains, has energized Hungary's solar market trajectory to place it in good position to reach the 6.5 GW NECP PV capacity target 2030.



Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

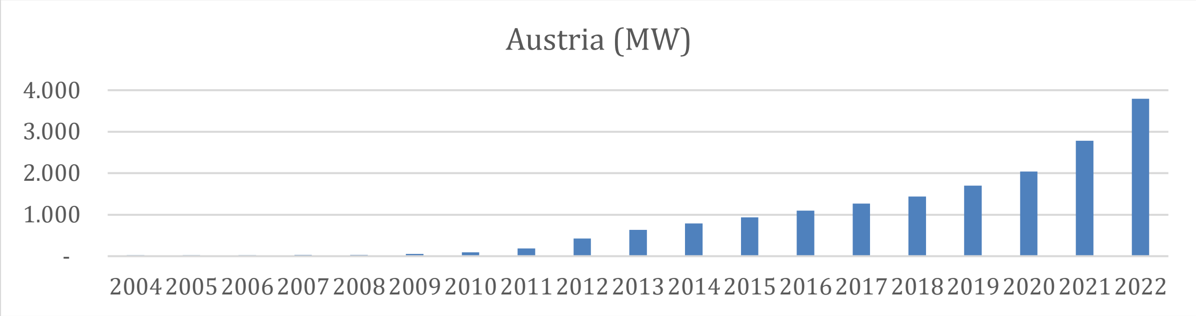
6. Challenges

- Prosumer Development: While acknowledging the potential of prosumers, ambiguity exists in outlining support structures, more so for residential stakeholders.
- Administrative Hurdles: Obscure administrative procedures can potentially stymie the solar sector's rapid advancement.
- Grid Infrastructure: A palpable absence of strategic grid investment plans, combined with the existing challenges for large-scale PV ventures, is a glaring concern.

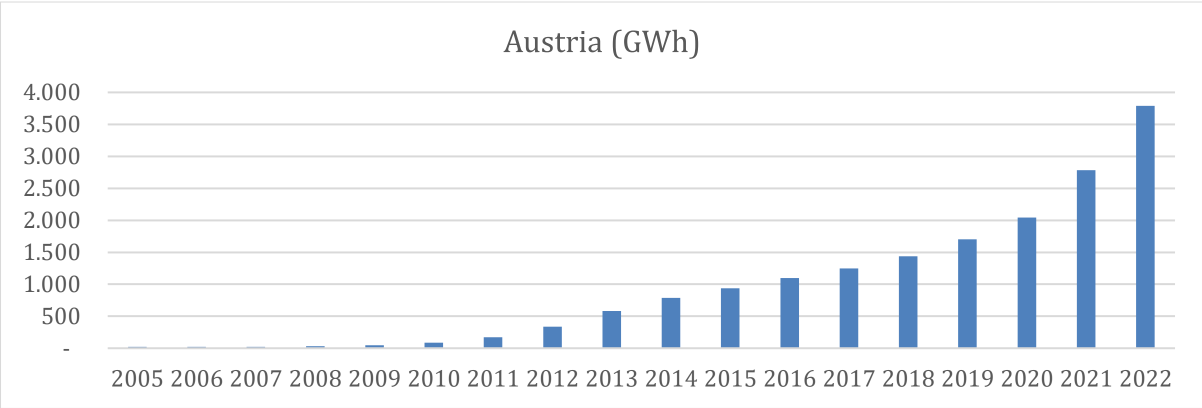
7. Opportunities: The groundswell of interest in smaller solar installations, complemented by governmental backing, opens doors to further market expansion, research collaborations, and cross-sector integrations.

Austria

1. Power Installed: In 2000, Austria's footprint in the solar industry was minute, with solar installations merely in the megawatt range. Recognizing the imperative to diversify its energy sources, the country embarked on a vigorous solar drive. By 2022, Austria had manifested an impressive 3.8 GW of solar PV infrastructure, marking a leap of 1GW from 2021 (+36%).



2. Electricity Generation: Corresponding with its amplified installed capacity, Austria's electricity generation from solar sources burgeoned. In 2022, the solar contribution stood at 3.8 TWh, solidifying its role in the nation's electric grid, aligning with the broader objective of a diversified renewable energy portfolio and carbon reduction.



3. Regulatory Aspects: Integral to Austria's solar advancement are national and regional incentives. These encompassed mechanisms like investment subsidies and green electricity feed-in tariffs, acting as catalysts propelling the solar market's expansion.

4. Trends

- Policy-driven Growth: Federal and regional levels of Austrian governance have orchestrated the rise in solar installations through comprehensive policies, financial impetus, and widespread public engagement.
- R&D and Innovation: A confluence of academic and industry partnerships in Austria has heralded innovations in solar technology, catering specifically to Austria's unique climate.
- Integration with Other Renewables: In a landscape dominated by hydropower, the convergence of diverse renewable sources emerges as a trend, ensuring energy stability.

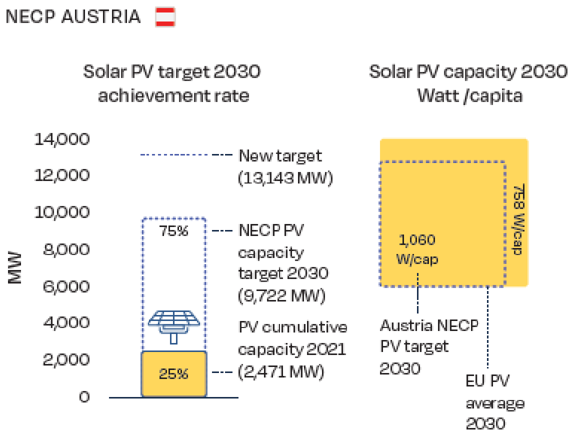
- Community Energy Initiatives: Grassroots energy movements are gaining traction in Austria, with communities steering and reaping the benefits of solar installations.

5. Strengths: Austria's consistent policy push, underpinned by subsidies and tariffs, combined with a strong inclination towards research and community-based projects, positions the country favorably in the global solar market.

6. Challenges

- Grid Overload: The exponential growth of the solar sector strains Austria's current grid infrastructure, especially at distribution touchpoints.
- Workforce Deficit: The solar industry's upswing confronts a paucity of skilled professionals, particularly in the installation domain.
- Bureaucratic Hurdles: Large-scale PV system rollouts face administrative barriers, despite the success of the rooftop program.

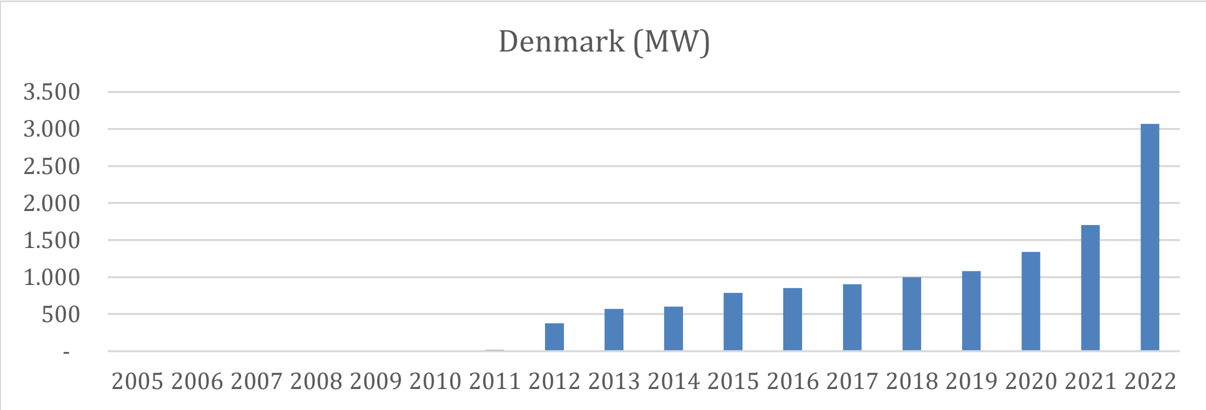
7. Opportunities: According to Hubert Fechner of TPPV, projections indicate Austria's potential to install between 1.2 GW to 1.5 GW annually through to 2030. This momentum could see the country achieving its ambitious target of 13 GW solar capacity by 2030.



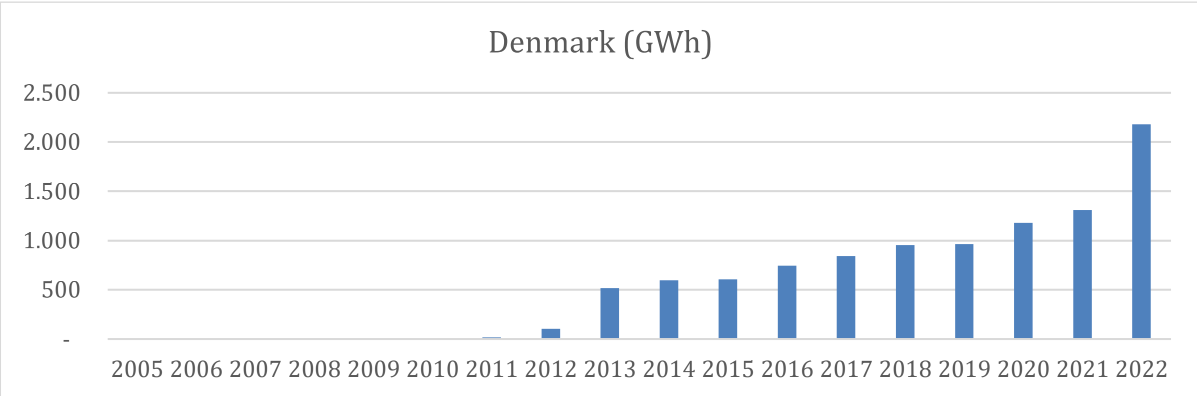
Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

Denmark

1. Power Installed: At the start of the 21st century, Denmark's solar sector was nascent. However, proactive governmental policies and global agreements spurred significant growth. By 2022, Denmark had a solar PV capacity exceeding 3GW. In the first quarter of 2023, this was further supplemented by 236 MW, taking the total capacity to 3.25 GW.



2. Electricity Generation: Parallel to the increase in solar installations, Denmark's contribution from solar energy to the national grid has grown, boasting an electricity production of 2.2 TWh in 2022.



3. Regulatory Aspects: Denmark prides itself on a transparent regulatory framework, especially concerning planning and grid connection. Nevertheless, potential challenges such as the uncertain tariff regime for 2023 pose significant concerns. Stakeholder interactions also present a challenge, especially with potential local resistance to large solar parks and municipal hesitations concerning new renewable projects.

4. Trends

- Governmental Initiatives: Programs like tax incentives, grants, and feed-in tariffs illustrate Denmark's aggressive promotion of solar energy.
- Integration with Wind Energy: As a global frontrunner in wind energy, it's crucial to understand how Denmark integrates solar with wind energy.
- Net-Zero Ambitions: Denmark's goal for a carbon-neutral footprint, with solar energy playing a pivotal role.
- Research and Innovation: The nation's collaboration with educational institutions, global partnerships, and investment in solar technology denotes its dedication to sector advancement.

5. Strengths

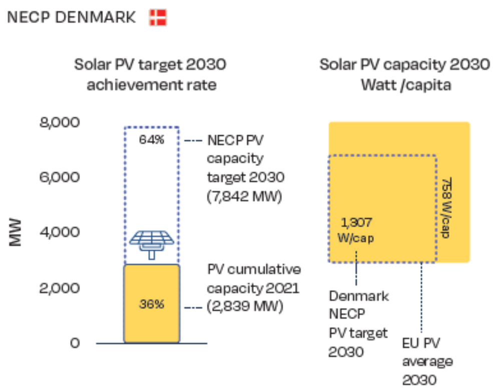
- Ground-mount Utility-scale PV Power Plants: Major contributors to Denmark's gigawatt-level installations in 2021.
- Corporate Buyers & Subsidy-free Model: Denmark's scale was achieved without government subsidies, making corporate buyers the main consumers of solar power.

6. Challenges

- Uncertain Tariff Regime for 2023: This may lead to increased grid connection tariffs, particularly in areas favorable for PV.
- Stakeholder Interaction: Potential local opposition to expansive solar parks.
- Market Uncertainties: Factors such as high module prices and erratic shipping conditions could hinder project completions.

7. Opportunities

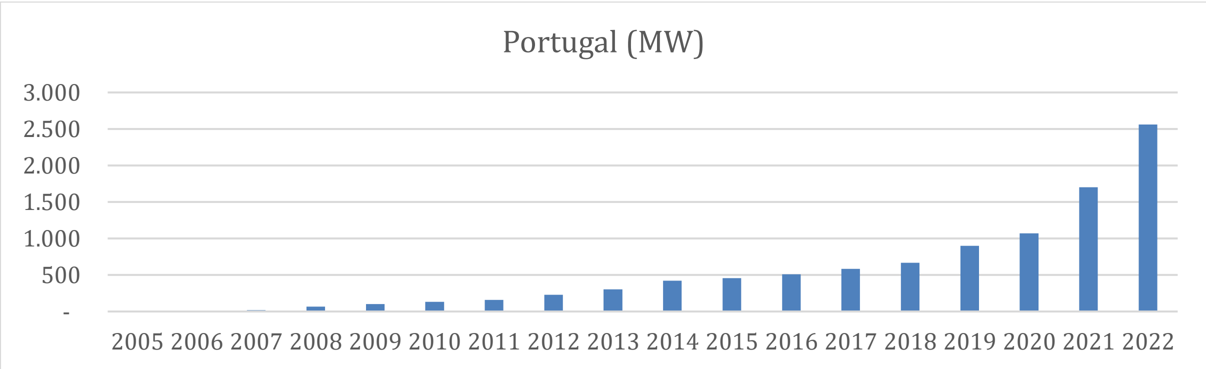
- Hybrid Projects: Growing interest in integrating wind and solar projects.
- C&I and Residential Segments: Despite previous dwindling figures, the current growth in these segments is driven by a mix of financial incentives, environmental idealism, and commercial focus on renewables.
- Denmark's solar market is undergoing a rapid evolution, predominantly propelled by the utility-scale segment. However, segments like C&I and residential are also showing potential. Despite the existing challenges, the trajectory for growth over the next five years looks promising. With strategic interventions and stakeholder collaboration, Denmark is poised to maximize its solar energy potential and reach (or exceed) the 7.8 GW NECP PV capacity target in 2030.



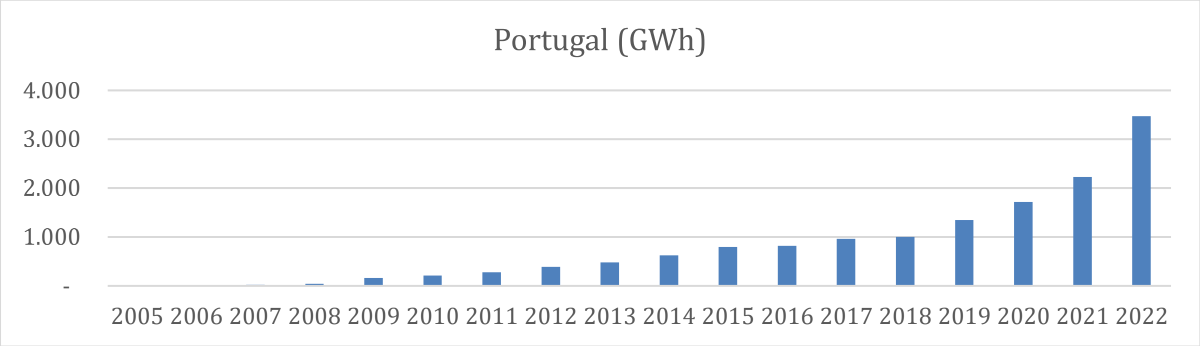
Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

Portugal

1. Power Installed: At the onset of the 2000s, Portugal's solar landscape was fairly understated. A combination of government initiatives and international commitments propelled a steady increase in PV installations. By 2022, Portugal achieved a solar capacity of 2.6 GW, marking a 51% increase from 2021.



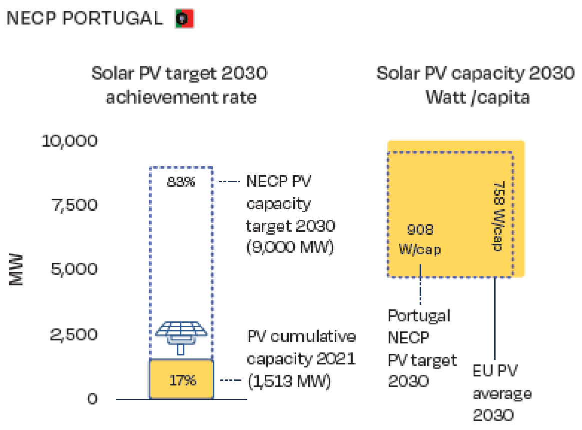
2. Electricity Generation: Corresponding with the increased capacity, Portugal's national grid witnessed solar energy's contribution surge to nearly 3.5 TWh in 2022.



3. Regulatory Aspects: In Portugal, solar energy developers, especially those focusing on large-scale projects, encounter significant obstacles owing to stringent permitting procedures. This is compounded by rigorous environmental impact assessment requirements and extended official response times.

4. Trends

- Portugal's energy plan envisions solar power playing a pivotal role, targeting 80% renewable energy by 2030 and full reliance by 2050. NECP PV capacity target 2030 is set to 9GW.



Source : SolarPower Europe [2021] – EU Market Outlook For Solar Power 2021-2025

- In December 2021, a significant push was made with the announcement of an auction for 262 MW of floating solar PV capacity.
- During the forecast period, residential solar PV's share is poised to grow due to falling costs, supportive policies, and set governmental targets.

5. Strengths

- Solar power's steadily increasing role in Portugal's energy mix.
- Supportive government policies and incentives.
- Positive residential adoption driven by anticipated savings and environmental considerations.

6. Challenges

- The renewable energy mix is undergoing a shift with the rapid rise of wind energy.
- The wind energy sector's growth has been faster than solar over the past decade.

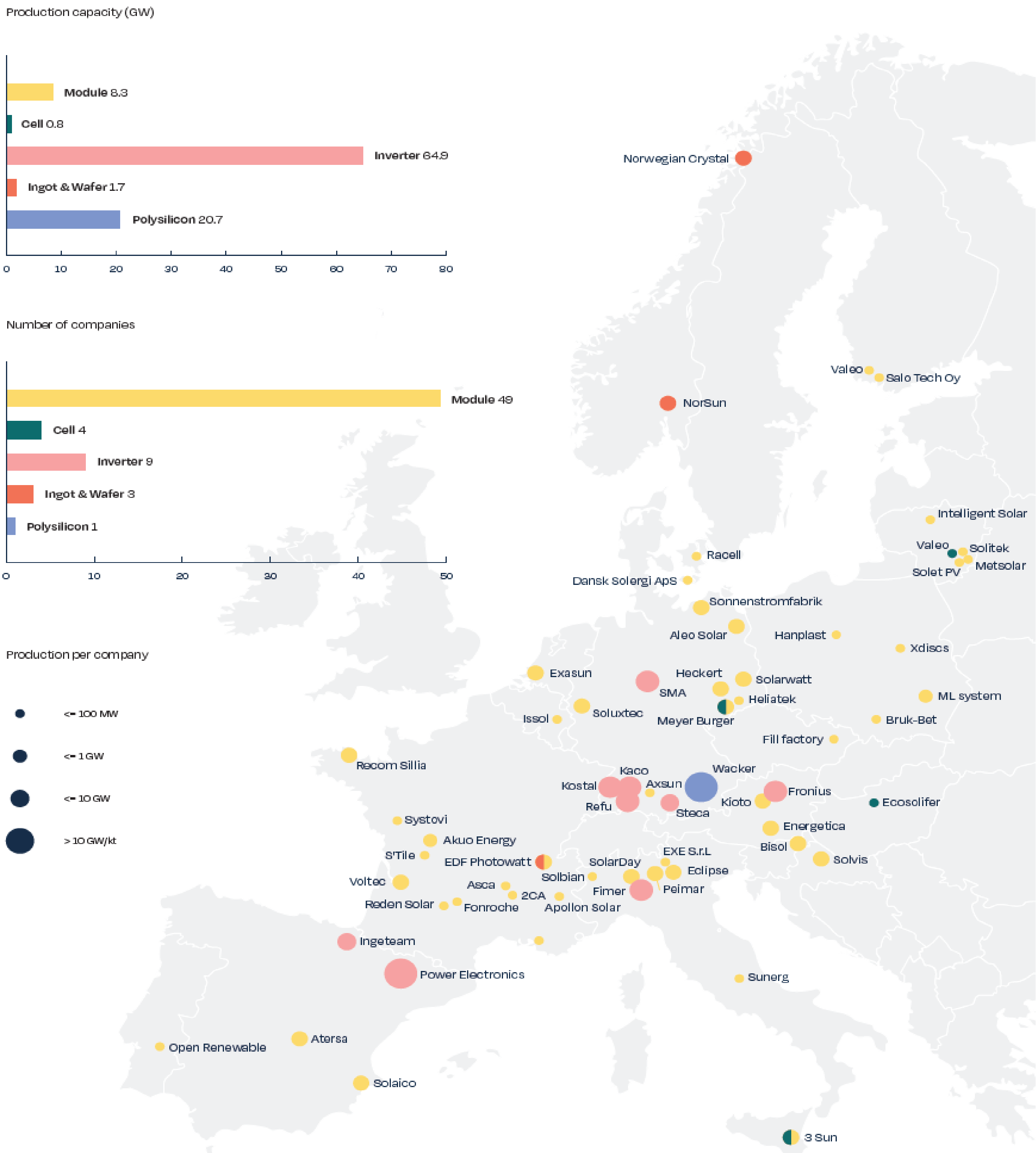
- Regulatory hurdles, including stringent permitting procedures, pose obstacles for large-scale solar developers.

7. Opportunities

- The termination of coal-fired power plants in 2021 offers investment opportunities for solar energy entrepreneurs.
- The new energy plan promises a greater role for solar power.
- Opportunities for residential solar energy are anticipated to grow during the forecast period.

EU Solar PV Manufacturing

EU27 AND NORWAY SOLAR MANUFACTURING MAP



Current Landscape

- Job Intensity: Inverter production provides the highest job density in solar manufacturing.
- Inverter Manufacturers: At least nine major players exist with a combined capacity of 60 GW. Key international leaders include SMA (Germany) and Fronius (Austria).
- Polysilicon Production: Wacker Chemie, based in Germany, is the only EU firm with a capacity of around 60 metric tons, which translates to over 20 GW of cell/module products.
- Silicon Ingots & Wafer Manufacturing: Predominantly in Norway, owing to cost-competitive hydro energy. The EU has an innovative company, NexWafe, that is refining the manufacturing process. They aim to start construction in Germany in 2022 with a 3 GW target by 2025.
- Solar Cell Production: Present capacity is 0.8 GW. Meyer Burger (Germany) and Enel (Italy) are significant contributors and have future expansion plans.
- Solar Module Manufacturing: This sector is bustling with 49 manufacturers in 2021. The majority, however, import cells from Asia due to its lower investment cost.
- China vs. EU: The majority of solar products in the EU are imported, making its manufacturing sector diminutive relative to China.

EU Solar Technology Ecosystem

- Balance-of-System (BOS) Field: EU leads in components like mounting structures, solar trackers, processing materials, and production equipment.
- Solar Battery Energy Storage: Solarwatt, a German company, is noteworthy in this segment.
- R&D Ecosystem: Europe boasts a broad, interconnected R&D network. Key institutions include IMEC (Belgium), Fraunhofer ISE & CST, FZ Jülich, ZSW (Germany), CEA-INES, IPVF (France), TNO (Netherlands), and CSEM (Switzerland).

Opportunities & Initiatives

- The EU solar market is expanding faster than anticipated, paving the way for domestic manufacturing.
- European Solar Initiative (ESI): In collaboration with EIT InnoEnergy and Solar Manufacturing Accelerator partners, SolarPower Europe launched ESI to consolidate the industry and hasten new manufacturing projects. The target is to restore 20 GW PV silicon-to-module manufacturing capacity in Europe by 2025, capturing a significant market share.

Recycling & Waste Streams

Legal aspects

The European Union (EU) has been proactive in ensuring that its member states adopt sustainable practices, especially concerning waste management and resource recovery. The management of Photovoltaic (PV) waste is a significant concern given the rising popularity and deployment of solar panels across the continent. Here's an examination of the relevant EU legislation:

- **Directive 2012/19/EU**: This directive plays a central role in dictating the norms surrounding waste electrical and electronic equipment (WEEE). PV devices fall under this category, and hence, the disposal and management of these devices are primarily governed by this directive. The directive's stipulations include:
  - Recovery Efficiency: Modern PV panel production must adhere to an 85% recovery efficiency rate for secondary raw materials. This stipulation is in place to ensure that the valuable components of these devices are appropriately recycled, reducing the need for virgin materials and curbing environmental impacts.
  - Landfill Restrictions: One of the essential components of the directive is that it prohibits the direct landfilling of end-of-life (EoL) PV panels. This contrasts with practices in some parts of the world where such landfilling is still permitted.
  - Extended Producer Responsibility (EPR): A significant principle enshrined in this directive is the EPR. It mandates that the onus of bearing the costs associated with collecting and recycling PV panels rests with the producers. The term "producer" is expansively defined to encompass manufacturers, distributors/sellers, importers, and any entity engaged in the PV sector within the EU.
  - Reuse of PV Panels: Beyond recycling, the directive also highlights the potential for reusing EoL utility panels. Often, even after a PV panel surpasses its expected lifespan, it retains the capacity to generate electricity. The principal reason users return these panels is a degradation in their performance. Currently, the market for these secondary photovoltaic modules is still nascent and challenging to gauge accurately. However, as technology advances and the volume of EoL panels increases, new methods and markets for managing these panels will likely emerge.

Current state of PV waste recycling in EU

With the exponential growth of solar energy installations, the eventual volume of PV waste will also rise. Recognizing this, several facilities and initiatives are already being put in place to manage this anticipated waste effectively.

Even though the current quantum of PV waste remains limited, some pioneering recycling facilities have been established. These facilities are mainly experimental but demonstrate impressive recycling efficiencies.

- The consortium made up of COMET TRAITEMENTS, RECMA and ENVIE 2 E MIDI PYRENEE recycles French end-of-life panels, including those from the French overseas departments and territories. SolarCycle, composed of COMET TRAITEMETS and RECMA, has more than 12 years of research and development expertise in the field of photovoltaic panel recycling, achieving a recycling rate for crystalline silicon (c-Si) PV modules that exceeds European requirements.

- German firms, Loser Chemie and SolarWorld, are also noteworthy players in the PV recycling domain. Loser Chemie boasts an array of collection points and employs distinctive patented procedures, leveraging both mechanical and chemical techniques, for solar cell recycling. Meanwhile, SolarWorld has carved its niche with a unique c-Si recycling method. These firms however recycle their own PV panels.

Upcycling Research and Techniques

- Mechanical process: This is the most widely used and, to date, the most cost-effective method of recycling panels. After the decanting to separate the frame and the J-box, an increasingly fine grinding of the laminate is carried out, allowing the different components of the panels to be separated and recovered.
- Mechanical Delamination: The primary objective at the outset of upcycling is detaching the glass from the solar cell, a challenge given the intervening layer of EVA (ethylene-vinyl acetate). Mechanical methods, like grinding and crushing, are common approaches. A study reported a commendable 91% glass recovery using triple grinding. Other innovative mechanical techniques have been researched, such as cryogenic processes and the hot knife cut, the latter boasting a 98% glass recovery efficiency.
- Thermal Delamination: Pyrolysis dominates the thermal techniques, facilitating the thermal decomposition of the EVA layer. The process, though effective in terms of material recovery, is marred by high costs, energy consumption, and the emanation of detrimental thermal by-products.
- Chemical Delamination: Chemical techniques utilize inorganic and organic solvents, notorious for their prolonged durations and chemical dependency. Current research endeavors focus on expediting this process. For instance, EVA layer dissolution in toluene through ultrasonic radiation can drastically reduce the process duration to under an hour.
- Post-Delamination Procedures: Subsequent to delamination, the procedures diverge into silicon and metal separation via leaching and etching. The methodology chosen dictates the purity of the salvaged silicon. While comprehensive methods yield high-grade silicon conducive for reuse in PV products, simpler methods yield lower quality silicon.

The finale in the upcycling journey is metal extraction from the resultant solutions post-leaching or etching, typically accomplished via electrolysis, metallic replacement, or chemical precipitation. A comparison of these methods' efficacy revealed respective recovery rates of 89.7%, 87.4%, and 99.5% for silver extraction from PV modules.

Economic concerns

From a purely monetary perspective, PV waste recycling appears uneconomical at present. The costs involved in recycling processes generally outweigh the revenue obtained from selling the reclaimed materials. This might be attributed to the current limited scale of PV waste upcycling, which is more demonstrative than commercial.

Current PV modules utilize less valuable materials (like copper and silver) for cost and efficiency gains in production. While this is a boon for the environment and production costs, it curtails potential revenues from the sale of reclaimed secondary materials during recycling.

The relatively low volumes of PV waste further hinder economic viability. The commercial sustainability of recycling operations is contingent on a steady and significant influx of waste. With global PV waste predicted to range from 1.7 to 8 million tons by 2030, there is an impending increase, but it's essential to have infrastructure in place ahead of time.

Economic constraints loom large. Given the current scale of PV waste, the economic justification for large-scale upcycling operations is weak. The revenues generated from selling recovered materials struggle to offset the operational costs of recycling, especially when compared to the recycling of other WEEE wastes.

However, the situation isn't bleak. The EU's Extended Producer Responsibility (EPR) system presents a pivotal framework. Under this system, producers are obligated to manage the post-consumer phase of their products, incentivizing them to invest in and promote recycling. This, coupled with the EU's rising material recovery targets, fosters an environment conducive to the evolution of recycling technologies. The goal is twofold: to bolster economic feasibility and mitigate environmental footprints.

Prediction of the amount of PV waste in EU-27 by 2050

Installation Dynamics

There have been two distinct periods of significant growth in PV installations in the EU:

- **2010-2012:** This period saw a surge in PV installations. Such growth patterns can typically be attributed to favorable government policies, decreasing costs of PV technology, and increased awareness about sustainable energy sources.
    - Slowdown**:** Post-2012, there was a noticeable decline or stagnation in PV investments in several major EU countries, including Germany, France, Italy, Spain, Czechia, and Belgium. Such downturns can often be attributed to saturation of the initial market incentives, policy shifts, or economic factors.
- **2019-2025:** This is the current and predicted boom period for PV installations. The resurgence can be due to enhanced global focus on renewable energy, technological advancements, and renewed government incentives or commitments towards greener energy.

Methodology for the prediction of PV waste streams

The methodology and working assumptions [service Life of PV Panels, recycling constraints, input data & mass index, PV technology distribution, market dynamics, technological shares and shifts,…] considered to estimate end-of-life PV panels to be processed by 2050 in the EU-27 are detailed in the following scientific article : Prediction of the Market of End-of-Life Photovoltaic Panels in the Context of Common EU Management System, by Adrian Czajkowski, Agata Wajda, Nikolina Poranek, Shubhangi Bhadoria and Leszek Remiorz, *Energies* 2023, *16*(1), 284, 27 December 2022, https://doi.org/10.3390/en16010284.

This report focuses only on presenting the estimates and conclusions detailed in the scientific article. These will be analyzed more thoroughly and contextualized with available PV panel recycling data, notably from PV Cycle, SOREN, BEWEEE, and Stichting Open, in the upcoming report.

Results and discussion

Based on the data and adopted assumptions, the cumulated mass stream of PV waste in selected years in all EU countries was estimated. The results are presented in the Table below.

Mass Streams of PV Waste in Selected Years in EU Countries [Mg]

Country	2030 C	2030 TF	2040 C	2040 TF	2050 C	2050 TF	Country	2030 C	2030 TF	2040 C	2040 TF	2050 C	2050 TF
Austria	2037	281	89.658	11.834	559.152	57.300	Italy	3295	455	1.808.372	238.682	2.882.255	295.364
Belgium	194	27	299.619	39.546	1.003.980	102.885	Latvia	0	0	144	19	1541	158
Bulgaria	0	0	98.451	12.994	328.332	33.646	Lithuania	0	0	6994	923	65.123	6674
Croatia	48	7	4286	566	21.001	2152	Luxembourg	2326	321	11.127	1469	40.268	4127
Cyprus	48	7	4937	652	60.884	6239	Malta	10	2	7080	935	37.764	3870
Czechia	57	8	198.518	26.202	408.311	41.842	Netherlands	4942	682	146.002	19.270	3160.302	323.858
Denmark	291	40	74.829	9877	624.125	63.958	Poland	0	0	10.312	1361	1.433.374	146.888
Estonia	0	0	679	90	79.766	8174	Portugal	194	27	42.767	5645	750.512	76.910
Finland	388	54	1435	189	77.839	7977	Romania	0	0	126.866	16.745	269.265	27.593
France	1260	174	682.889	90.133	3.055.308	313.098	Slovakia	0	0	50.995	6731	103.079	10.563
Germany	199.226	27.509	3.752.604	495.295	10.256.687	1.051.072	Slovenia	19	3	22.876	3019	70.710	7246
Greece	97	13	249.140	32.883	685.940	70.293	Spain	5039	696	450.060	59.402	2.742.414	281.034
Hungary	0	0	16.456	2172	442.638	45.360	Sweden	388	54	9950	1313	538.453	55.179
Ireland	29	4	201	27	308.712	31.635	Total	219.886	30.362	8.167.248	1.077.972	30.007.735	3.075.096

C—crystalline technologies (I generation); TF—thin film-technologies (II generation).

Source : MDPI – Energies 2023, 16, 284. https://doi.org/10.3390/en16010284 - Prediction of the Market of End-of-Life Photovoltaic Panels in the Context of Common EU Management System.

Germany is anticipated to lead in PV waste streams, with almost 200,000 Tons (Mega grams) by 2030.

The waste from first-generation PV panels will be greater than that of second-generation panels. The recycling of the smaller volumes of second-generation PV waste will need a separate process, leading to higher costs. Germany consistently produces the largest PV waste annually. Other countries with high installed PV capacities include Italy, France, Spain, and the Netherlands.

The profitability threshold for PV waste recycling is set at a waste stream of 19,000 tons/year. Based on this threshold, EU countries are categorized into four types depending on their projected PV waste streams.

- Countries with waste streams consistently above this threshold include Germany, France, Italy, Netherlands, Ireland, Sweden, Romania, Poland, and Portugal.
- Countries with fluctuating waste streams around this threshold are Spain, Hungary, Greece, Denmark, Czech Republic, Bulgaria, Belgium, and Austria.
- Countries (Slovakia and Estonia) which exceed this threshold occasionally but not consistently.
- Countries which do not meet or exceed this threshold in the provided data : Croatia, Cyprus, Finland, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

The Table below highlights the dates of achieving profitability criterion for PV waste recycling installation.

2028	2032	2033	2034	2035	2037	2038	2043	2046	2047
Germany	Spain	Italy	Belgium Czechia France	Greece	Austria Bulgaria Denmark	Netherlands	Hungary Poland Sweden	Estonia	Ireland Romania

Source : MDPI – Energies 2023, 16, 284. https://doi.org/10.3390/en16010284 - Prediction of the Market of End-of-Life Photovoltaic Panels in the Context of Common EU Management System.

Conclusions

EU Climate Policy & PVs

- The EU emphasizes the development of renewable energy, with photovoltaics (PV) being a key technology.
- This push aligns with the Sustainable Development Goals (SDG).
- Rapid PV development has occurred recently, with projections indicating a continued increase in their electricity production share.

PV Waste Management

- After their 20-35 year lifespan, PV panels will generate waste.
- EU legislation classifies PV panels as WEEE waste, setting recovery requirements.
- The preferred waste management approach, aligning with the circular economy, is recycling. Specifically, upcycling is advocated for its high recovery rate, which includes various mechanical, chemical, and thermal processes.

Current PV Waste Scenario

- The present recycling facilities for PV panels are few, mainly due to the small waste streams and subsequent lack of profitability.
- However, predictions suggest that by the end of the 2020s, there'll be a significant surge in PV waste, especially in Germany, the largest EU market. By 2030, Germany will produce over 100,000 Tons of PV waste and nearly 16 times more by 2050.
- Overall, the EU will generate over 1 million Tons of PV waste annually between 2035-2037 and 2044-2050. By 2050, this figure will reach 5.34 million Tons annually, with a cumulative total exceeding 33 million Tons.

Economic Perspective

- The European PV waste market is varied, impacting the profitability of recycling.
- Larger waste streams make recycling more economically viable.
- By 2028, Germany will reach profitability, followed by countries like Spain, Italy, Belgium in the 2030s, and Hungary, Poland, Sweden in the 2040s.
- Based on the economic analysis of PV waste streams:
    - Germany, France, and Italy will have profitable recycling systems with stable supplies.
    - Spain, Hungary, and Greece will have conditionally profitable recycling systems without stable supplies.
    - Slovakia, Estonia, and Croatia will have unprofitable central recycling systems without stable waste supplies.

Potential Solutions

- The Extended Producer Responsibility (EPR) system ensures the financing of PV waste management, even when unprofitable. However, some countries will require more funding.
- One potential solution is the creation of a unified EU market for PV waste, allowing collective management instead of individual state-based approaches.