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A Review of Policies for the Rollout of Rooftop Solar PV in Ireland

Authors: Lisa Ryan, Joe Wheatley and Nadiya Saba

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1. Introduction

Governments worldwide are making efforts to reduce greenhouse gas emissions and limit climate change consistent with their obligations under the Paris Agreement. Ireland's Climate Action Plans (CAPs) detail targets and policy measures for Ireland up to 2030. Increased reliance on domestic renewable energy sources is a long-standing policy objective and is a cornerstone of climate action. CAP2023 (Climate Action Plan, 2022) has a renewable electricity target of 80% in 2030. To achieve this, at least 22 GW of grid-connected renewable capacity is envisaged, of which 2.5 GW is sub-utility scale.[1] This report examines policy measures that facilitate the deployment of sub-utility scale non-new grid solar photovoltaics (PV) i.e. PV technology integrated into existing or new residential, commercial, and public sector infrastructure. While such installations are likely to form a small part of the total installed renewable capacity in 2030, they are important for several reasons. Firstly, climate action is required across all scales and in every economic sector to meet increasingly challenging emissions targets. Secondly, evidence gathered for this report suggests the current 2.5 GW target is achievable and could be exceeded given favourable policy and cost developments. Thirdly, the longer-term evolution of the distribution network, distributed generation and storage merits early attention from policymakers.

Meeting Paris Agreement climate goals requires an urgent transformation of existing energy systems, a fact that is well understood by civil society. Uniquely, the low cost of rooftop solar PV enables individuals, businesses and communities to participate directly in this energy transformation by exploiting their existing private infrastructure for power generation with minimal local environmental impact. At the same time, adopters may perceive a benefit in terms of increased energy autonomy and resilience. Interventions by policymakers can further assist these positive trends by lowering barriers to adoption through financial incentives, streamlined permitting processes and, in some cases, mandates.

Ireland has seen a remarkable surge in solar PV capacity in recent years from a low base. 680 MWp of grid-connected capacity was installed by June 2023 (ISEA, 2023). This is a more than 10-fold increase compared to 2018 (World Bank, 2023). At utility-scale, 0.8 GWp and 1.5 GWp solar were successful in RESS-1 and RESS-2 respectively, with a further 0.5 GWp RESS-3 accepted in October 2023 at a strike price of 10c/KWh (Eirgrid, 2023a). Just over half (371 MWp) of the installed solar capacity in Ireland in June 2023 is utility-scale (> 1 MWp) (ISEA, 2023). Two-thirds of the sub-utility scale capacity (208

[1] Sub-utility scale or "distributed" solar PV installations are less than 1 MW capacity and usually have a significant element of self-consumption.

MWp) is rooftop micro-generation, spread over nearly 60,000 installations (ISEA, 2023). ISEA projects that up to 1 GWp will be installed by the end of the year, making solar the fastest-growing new energy technology in Ireland. Installed capacities to date can be compared with the CAP2023 target of 5.5 GWp for utility-scale solar and 2.5 GWp of sub-utility solar (Climate Action Plan, 2022).

This report surveys potential policy measures to support sustainable growth in solar PV that have recently been implemented or proposed in other jurisdictions. These measures can be assessed to determine their relevance to Ireland. The best policy opportunities for further solar development identified in this report are in the following areas:

- Low-income household supports
- Special arrangements for shared solar in apartment buildings
- Increasing landlord investment incentives
- Local authority mandates
- Self-consumption and battery storage
- Strengthening of policy measures for commercial and public spaces
- Solar mandates for car parks and depots
- Long-term vision for the distribution network

The report is organized as follows. In Section 2 we review the solar market from a global perspective with a focus on uptake rates, costs and supply chains. Section 3 examines barriers to adoption and specific policy support measures used internationally to support solar PV. In Section 4 we review barriers to adoption in Ireland and the current policy environment. It also provides quantitative modelling results for rooftop solar PV and battery storage adoption by Irish households that illustrate how policy and cost developments influence installed capacities. In Section 5, some specific areas for further solar PV policy development in Ireland are identified. Based on these findings, it is concluded that the combined potential for deployment of small-scale solar PV in residential and non-residential settings may be greater than currently assessed.

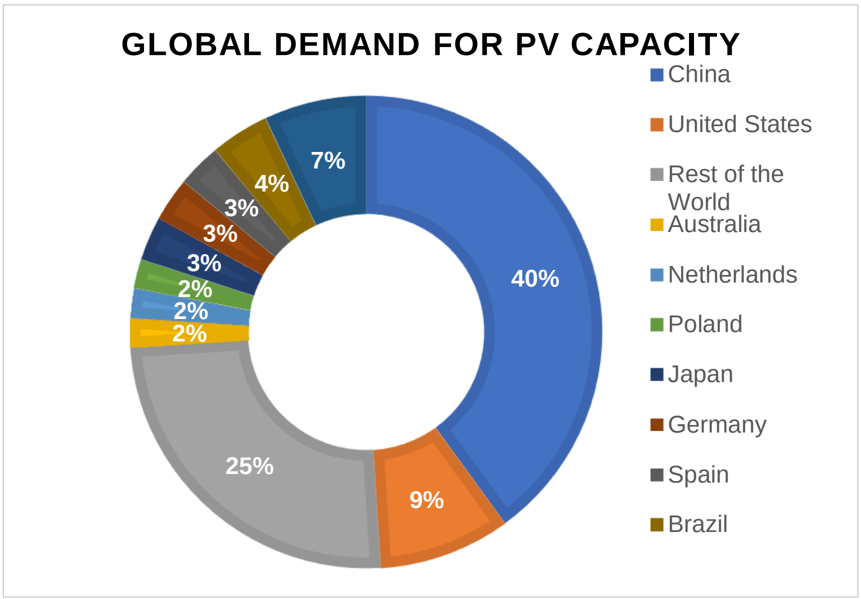
2. The global solar PV market

While Silicon solar cells were invented in the 1950s, they have only become of real significance for energy markets in the last decade. PV module prices have declined dramatically over the last decade, primarily due to falling costs leading to increased demand and increased scale of manufacture. Along with globalisation, this has led to a substantial improvement in the competitiveness of this technology. Indeed, solar PV has been described as the "cheapest energy source in history" (IEA, 2022a).

Solar energy is also available at scale. The global roof surface area suitable for solar PV installation has been estimated at 36 billion m^2, or 4.7 m^2 /capita, leading to a potential for rooftop photovoltaic of 8.3 PWh/y, roughly 1.5 times the 2015 global residential electricity demand (Gernaat, D.E.H.J., et al., 2020). Ground-mounted PV systems have a far larger potential. Solar PV is the fastest-growing power source, with the IEA (IEA, 2023) estimating that it will account for 14.7% of all installed generation capacity by the end of 2023. Generation increased by a record 179 TWh globally (up 22%) in 2021 to exceed 1000 TWh, demonstrating the second-largest absolute growth among renewable technologies in 2021, after wind (IEA, 2022a).

2.1 Demand

Figure 1 summarises global demand for PV capacity. Figure 1i. shows Global installed capacity for 2022, ii. shows the segmentation of PV installation from 2013 - 2022 and iii. shows the top 10 countries for installation and cumulative installed capacity in 2022.



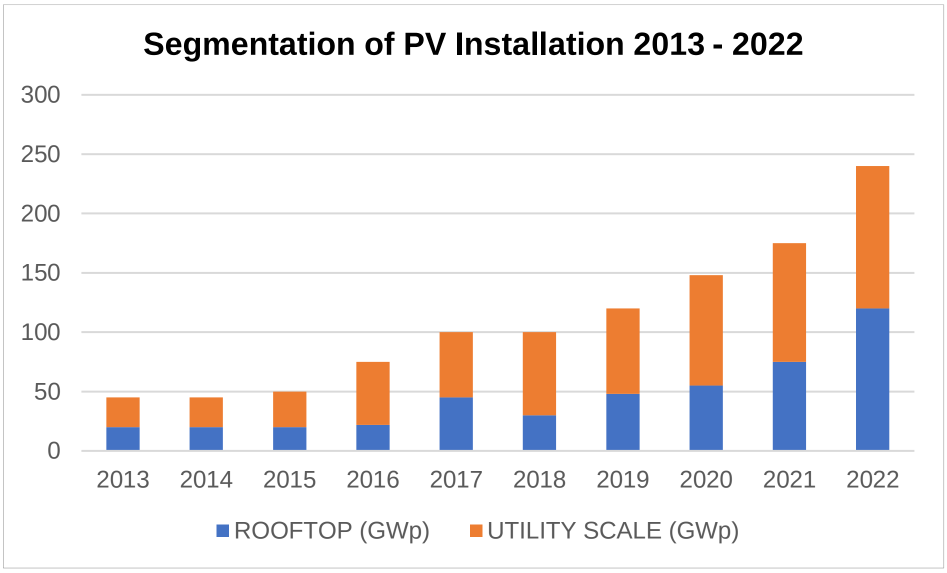


TABLE 1: TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2022

FOR ANNUAL INSTALLED CAPACITY			FOR CUMULATIVE CAPACITY		
1	China	106 GW	1	China	414,5 GW
(2)	*European Union*	*38,7 GW*	(2)	*European Union*	*209,3 GW*
2	USA	18,6 GW	2	USA	141,6 GW
3	India	18,1 GW	3	Japan	84,9 GW
4	Brazil	9,9 GW	4	India	79,1 GW
5	Spain	8,1 GW	5	Germany	67,2 GW
6	Germany	7,5 GW	6	Australia	30 GW
7	Japan	6,5 GW	7	Spain	26,6 GW
8	Poland	4,9 GW	8	Italy	25 GW
9	Australia	3,9 GW	9	Korea	24,8 GW
10	Netherlands	3,9 GW	10	Brazil	23,6 GW

Note: The European Union grouped 27 European countries in 2022, out of which Germany, Spain, France, the Netherlands and Italy also appear in the Top Ten, either for the installed capacity or the annual installations. The European Commission is a member of IEA-PVPS through its Joint Research Centre (EU-JRC).

Figure 1i. – iii.: The Demand Side

Source: IEA-PVPS, 2023, Solarpowereurope

In 2022, global PV installed capacity reached 1.2 TWp with the installation of 240 GWp of new systems. Several countries exceed penetration rates of 10% and solar PV has emerged as a major, long-term contributor to cost-competitive electricity generation and emissions reduction in the energy sector. Notably, the Chinese market remains dominant, accounting for 106 GW (44% of new capacity) and totalling 414.5 GW of cumulative capacity, more than double that of Europe. However, Europe demonstrated strong growth in 2022, led by Spain, Germany, Poland, and the Netherlands. This was fuelled in part by high electricity market prices. In the Americas, the market contracted due to trade issues and grid connection backlogs, except for Brazil, which nearly doubled its previous year's new capacity. India also showcased significant growth with 18.1 GW, mostly in centralised systems, and

Japan remained steady at 6.5 GW. PV penetration rates exceeding 10% were observed in nine countries, with Spain, Greece, and Chile leading above 17% (IEA-PVPS, 2023).

Rooftop and utility-scale segments of the PV market experienced significant growth in 2022. These market segments were nearly evenly split, with 48% of the new capacity installed on rooftops. The increasing share of the rooftop segment has been a consistent trend since 2018, driven by the opening of new markets in various countries and the declining costs of PV systems, making them more accessible to residential and commercial investors. Notably, countries like China, Brazil, Germany, Poland, and Australia witnessed substantial volumes and market shares in the rooftop segment, exceeding 2.5 GW (IEA-PVPS, 2023).

New technological innovations in rooftop and utility-scale PV are appearing including building-integrated PV (BIPV), utility-scale floating PV, bifacial PV, and vehicle-integrated PV (VIPV). Some of these are currently marginal but could develop in the coming years (IEA-PVPS, 2023). It is notable that the solar industry demonstrated remarkable supply and cost resilience during the challenging 2020-2022 period.

2.2 Supply

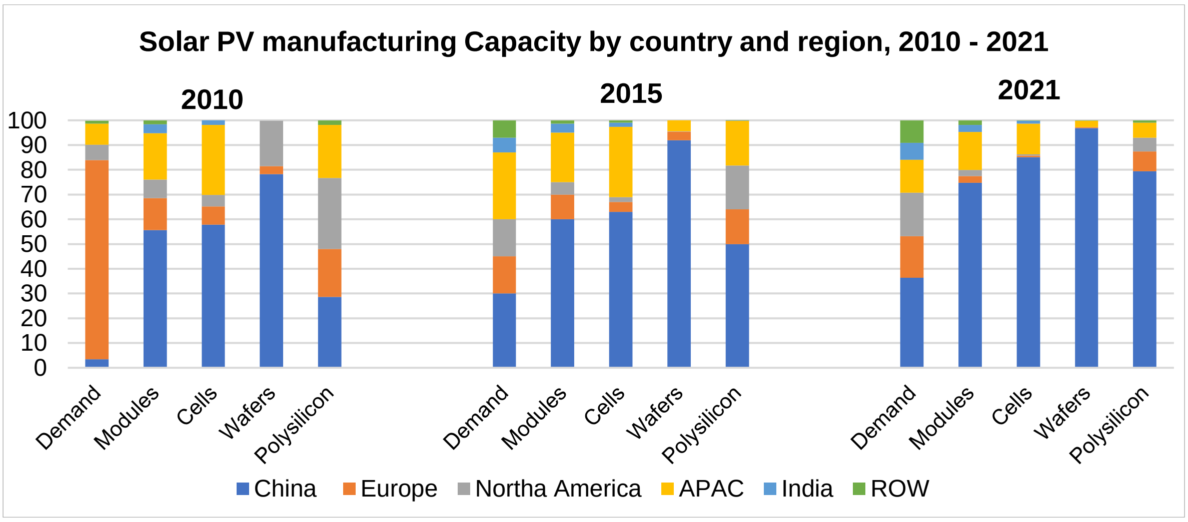


Figure 2: The Supply Side

Source: IEA, 2022b

Figure 2 summarizes the Solar PV manufacturing capacity by country and region between 2010-2021.

Over the past decade, global solar PV manufacturing has undergone a seismic shift, essentially relocating from Europe, Japan, and the United States to China. China's investment of over USD 50 billion in new PV supply capacity, a figure ten times that of Europe, has yielded the creation of approximately 300,000 manufacturing jobs across the solar PV value chain since 2011. Presently, China dominates all manufacturing stages for solar panels, polysilicon, ingots, wafers, cells, and modules, with 80% of global manufacturing capacity. This is double China's share of global PV demand. Notably, Chinese companies are the world's top ten suppliers of solar PV manufacturing equipment. The consequences of this shift have been to substantially drive down worldwide solar PV costs (IEA, 2022b).

To ensure the security and resilience of solar PV supply chains, the IEA has outlined five pivotal policy action areas. These encompass diversifying manufacturing and raw material supplies, de-risking manufacturing investment, prioritising environmental and social sustainability, fostering innovation, and bolstering recycling capabilities. These measures collectively aim to cultivate a supply chain that supports solar PV growth, navigates disruptions, enhances sustainability, and fuels the global transition toward cleaner energy systems (IEA, 2022b).

Secure supply chains remain pivotal for sustainable growth and the global transition to cleaner energy systems. However, diversifying a supply chain comes with its challenges. While the United States, Europe, and India have expressed interest in nurturing domestic solar PV supply chains, their current contribution to the global workforce in this field is limited. Neglecting investments in their labour markets while reducing reliance on imports could potentially hinder global PV deployment due to labour shortages. These regions currently have scarcity of specialised workers throughout the PV supply chain, from manufacturing to installation. Surmounting this challenge requires targeted endeavours such as educational initiatives, certification courses, and partnerships, with aligned governmental policies (IEA, 2022b). In conclusion, the transformation of the solar PV manufacturing landscape and China's strategic dominance underscores the imperative for robust and diversified supply chains.

2.3 Prices and supply chains

The fall in photovoltaic manufacturing costs below €1/W was a key driver of the rapid growth seen in solar capacity globally (IEA, 2020). The cost outlook and supply chain risks are briefly reviewed below.

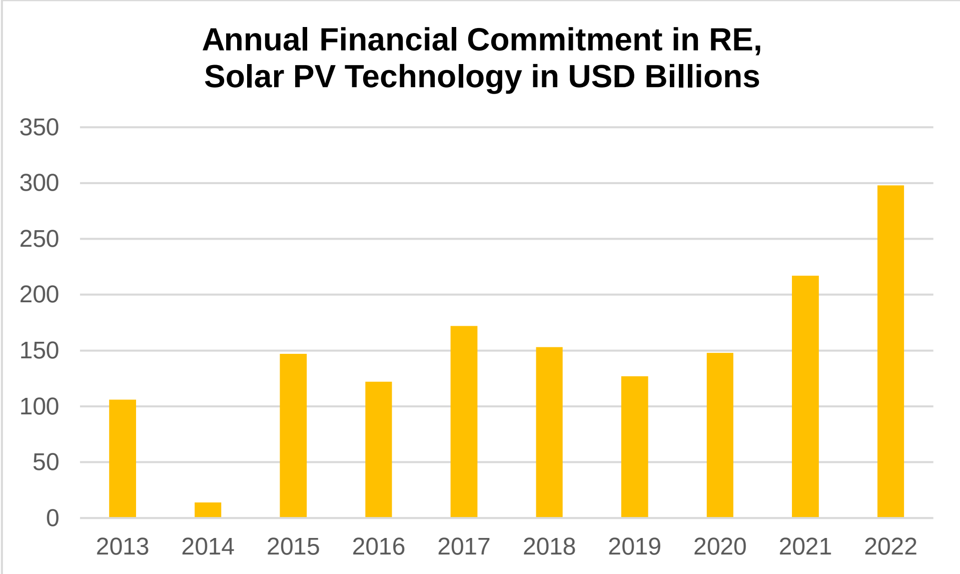


Figure 3: Global Annual Financial Commitments of Solar PV

Source: IRENA, 2023b

Figure 3 (IRENA 2023b) shows the global annual financial commitments in solar PV over the last decade in USD billions. The landscape of solar photovoltaic (PV) technology has undergone a striking metamorphosis in recent times, characterized by a substantial reduction in costs and exponential growth in adoption rates. Falling costs increase demand, leading to greater economies of scale and further cost falls (virtuous cycle) (Agdas, D. & Barooah, P., 2023).

Manufacturing Costs and Supply Chain Diversity:

Maintaining equilibrium in solar PV manufacturing costs across regions is important to ensure a diverse and resilient supply chain. Production costs exhibit significant disparities across various components and geographic locations. For instance, module costs vary from as low as USD 0.24/W in China to USD 0.33/W in Europe. China's cost advantage can be attributed to its efficiencies in energy consumption, investment strategies, and labour utilisation. In comparison, production costs in the Association of Southeast Asian Nations (ASEAN) are 5% lower due to its relatively moderate labour costs, whereas India's costs are higher by 9%. Costs in the US, Europe, and Korea are 20-35% higher, influenced by a range of factors. Ensuring a robust supply chain necessitates emerging markets matching China's efficiency through the synergies of economies of scale and integration (IEA, 2022b).

Module Assembly and Material Trends:

Module production assembly comprises a substantial share of total costs, approximately 40-50%. Cell manufacturing comes next in terms of cost, driven by raw material prices such as silver. Manufacturing costs fluctuate due to variations in overhead expenses, labour, and depreciation factors. Despite the volatility in material costs, China's competitive advantage is in low electricity prices which translates into cost-effective polysilicon production. Conversely, Europe and Korea face the challenge of higher electricity prices, leading to a doubling of polysilicon production costs. Moreover, the upward surge in commodity prices impacts module costs, notably polysilicon, which experienced a fourfold increase by 2022. The escalation in polysilicon prices has had a ripple effect on ingot and wafer manufacturers, contributing to a roughly 25% increase in module costs. The rising prices of other materials, such as silver, tin, copper, and aluminium, contribute to a 25-35% rise in module production costs. These cost escalations have direct implications for pricing and influence the clientele base (IEA, 2022b).

Overall investment Costs and Policy Considerations:

When developing policies for renewable energy, it is important to take into account the full cost of electricity generation. For solar PV, these costs reflect the collective investment made in the entire PV system, encompassing components like modules, inverters, cables, mounting structures, installation, grid development, land leasing and financing. In the US, balance-of-system costs are estimated to account for 71% of utility-scale solar PV installation costs (IEA, 2022b).

Capital Requirements and Policy Formation:

Capital allocation plays a pivotal role in shaping decisions within solar PV manufacturing and policy. The demand for higher investment within specific segments of the supply chain poses increased risks and compromises feasibility. Facilities focused on polysilicon, ingots, and wafers are particularly capital-intensive and the capital requirements vary with location. The higher costs experienced outside China stem from equipment and construction expenses, further exacerbated by the comparatively higher costs of manufacturing equipment. It is imperative to consider the intricacies of capital allocation as they impact strategic decisions and the overall effectiveness of policies (IEA, 2022b).

Cost of Capital:

IRENA (2023) emphasizes that the Cost of Capital (CoC) is a pivotal determinant of the total price to purchasers of electricity from renewable power generation technologies. The accuracy of assumptions used for the CoC is crucial, as inaccuracies over time, between countries, or across technologies can significantly misrepresent the cost of electricity, potentially leading to flawed policy decisions. In line with this, IRENA (2023) conducted a comprehensive survey across 45 countries spanning six continents to assess the CoC of renewable power generation technologies. The results unveiled a nuanced perspective on the Weighted Average CoC of various countries concerning solar PV, as depicted in

Figure 4. Recognizing the influence of the Cost of Capital on the solar PV sector amplifies the significance of its understanding within the broader context of manufacturing costs, supply chain diversity, and investment considerations. The following figure 4 shows us the weighted Average CoC of different countries for solar PV (IRENA, 2023b).

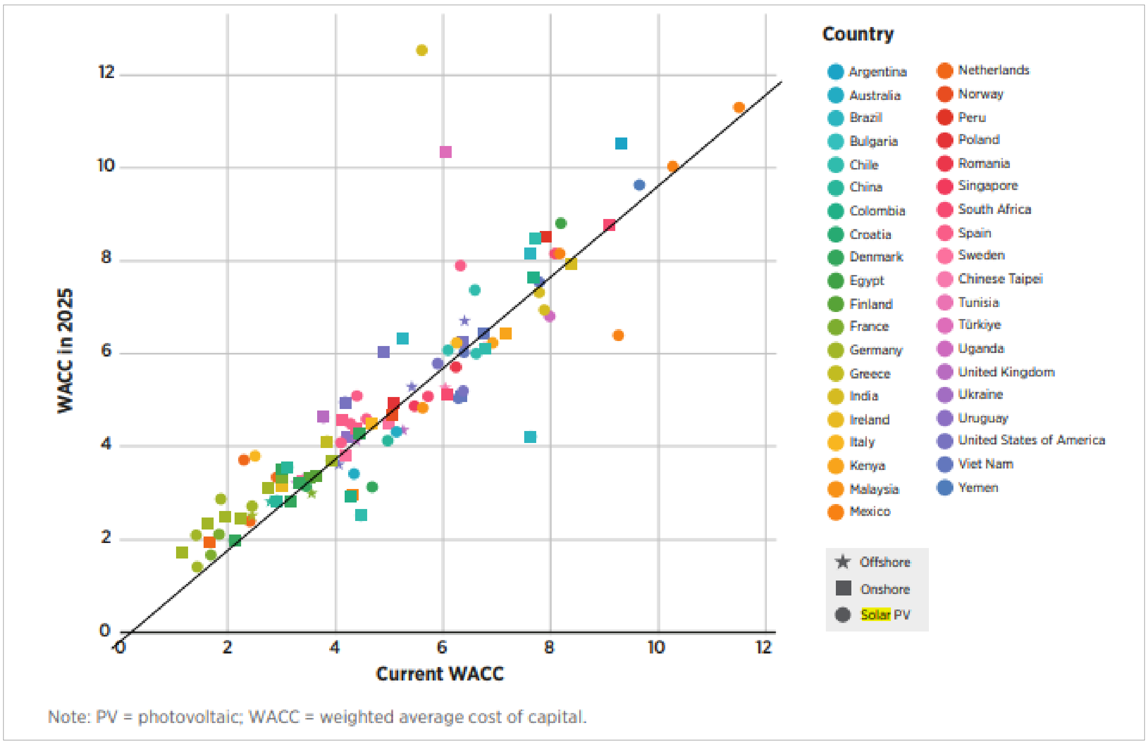


Figure 4: Photovoltaic current weighted Average CoC vs in 2025

Source: IRENA, 2023b

3. Policy support measures for Solar PV

In the 2015 Paris Agreement States agreed to limit global warming to well below 2°C above pre-industrial levels by sharp reductions in their greenhouse gas emissions (UNFCCC, 2015). To support the twin aims of climate change mitigation and energy security, the European Commission developed the EU Solar Energy Strategy, (2023) as part of the REPowerEU initiative. This strategy focuses on overcoming outstanding obstacles and challenges within the solar energy sector, laying out a series of initiatives aimed at accelerating the adoption of solar technologies. The objective is to achieve 320 GW of solar photovoltaic capacity in the EU by 2025 and nearly 600 GW by 2030 compared to 200 GW in 2022. In addition, the Commission introduced a suite of measures related to permitting renewable energy projects, which have been incorporated into the political consensus regarding the revision of the Renewable Energy Directive (2009/28/EC). These new legislative provisions are expected to further hasten the expansion of solar energy within the EU (EU Solar Energy Strategy, 2023). 38 GW of solar capacity was added in the EU in 2022 (IEA, 2023).

Figure 5 shows a traditional schematic model given by Hu & Popiolek (2014) illustrating the likely impacts of PV policy support on society. It is often the case that there are multiple policy objectives, with a wide range of alternative outcomes depending on the policy mix employed. Yu, H.J.J., & Geoffron, P. (2020) state that policy priorities vary from one country to another and depending on the situation, the policy objectives to support renewable energies such as solar PV generally focus on (1) energy security (energy supply diversification), (2) climate change mitigation (energy transition, GHG emission reduction), (3) improved access to energy or a reduction in energy poverty (energy equity), and (4) socio-economic development (jobs, economic growth).

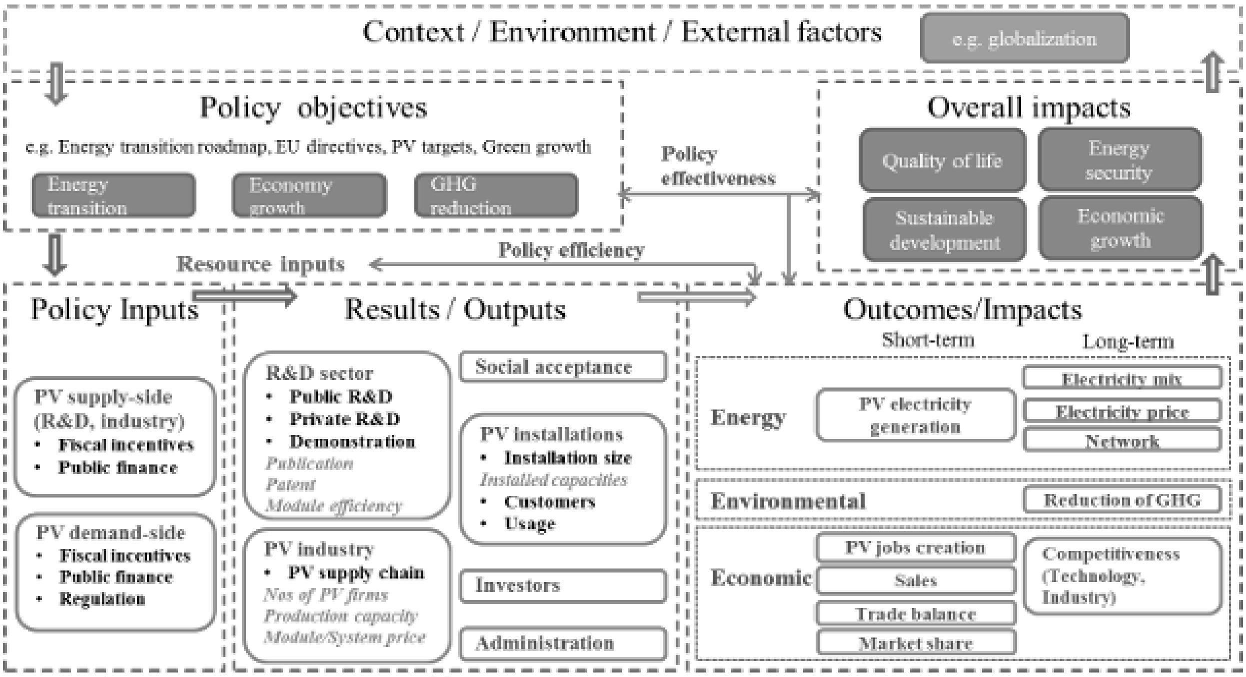


Figure 5: A Traditional Schematic Model of Policy Support

Source: 2014-berlin-julie-hyun-jin-yu.pdf (energy-evaluation.org)

A central goal of energy policy is to stimulate and incentivise a transition to a low-carbon energy system (Cuenca, J.J., et al., 2023). Markets for environmental technologies are highly dependent on government intervention, and, with few exceptions, these markets have also been "policy-driven" (Quitzow, R., 2015). The IEA (2022a) has categorized policies into the following categories: *Payments, finance, and taxation, Regulation, Payments and transfers, Targets, plans and framework legislation, Grants, Strategic plans, Information and education, Codes and standards, Taxes, fees, and charges and Performance-based policies*. The IPCC (2023) categorises policies as *Regulations and Standards, Taxes* *and Charges, Tradable Permits, Voluntary agreements, Subsidies and other incentives, R&D and Information policies*. Policymakers typically select a range of measures together with the allocation of resources (Yu, H.J.J., & Geoffron, P. 2020).

Countries have implemented a mixture of policy supports to accelerate their energy transitions and these policy mixes play a vital role in solar PV. Some of the most common individual policy mechanisms include National Renewable Energy Targets (RETs), contracts for difference (RESS), feed-in-tariffs (FiT), net metering, investment tax credits, low-interest bank loans or green finance, building codes, reductions in VAT or import duties on solar panels, low solar tariffs, solar panel mandates, relaxation of permitting rules, etc.

As micro, “distributed” clean energy generation, rooftop solar PV occupies a unique place in Ireland’s clean energy transition. O’Shaughnessy, E. (2023) identifies three trends shaping the future of rooftop PV (1) an evolving policy and regulatory context (2) the market reaction to that evolving context (3) the transition from early adoption to mass diffusion. About 60,000 rooftop systems have already been installed in Ireland and modelling presented later in this report suggests that more than 200,000 could be installed by the end of 2030 in a favourable but not unrealistic cost scenario (ISEA, 2023). Globally, 25 million rooftop systems have been installed and IEA expects that this could grow to as many as 100 million households by 2030 (IEA, 2022a).

3.1 Barriers to adoption

Some of the main barriers to the adoption of rooftop solar PV are discussed in this section. Many of the same considerations also apply to distributed ground-mounted systems.

One of the primary concerns for potential rooftop PV adopters is the initial capital investment required for setting up solar infrastructure (Hyvonen, J., et al., 2023). Even when the long-term benefits are clear, high upfront costs or lack of credit can be a deterrent, particularly for individuals or businesses with limited financial resources. For instance, a study conducted by Best, R., et al., (2019a) showed that higher net wealth is generally associated with a higher likelihood of adoption. Households that have mortgages, that spend more on electricity, and that pay higher average electricity prices are more likely to intend to adopt.

Other factors that exert influence include the property tenure (Zhang, Y., et al., 2023), household composition favouring multi-person households and detached houses, and a multitude of socio-demographic and financial considerations, coupled with personal characteristics and motivations (Ruokamo, E., et al., 2023). Further, positive inclinations toward installing photovoltaic systems are driven by factors such as income, education, awareness of renewable energy policies, and a belief in the environmental benefits of solar energy (Rengasamy, M., et al. 2020). Notably, the inclination toward installation is also influenced by neighbourhood peer effects (SEAI 2023a and Section 4.3), market speculation (Lan, H., et al., 2020), and the principle of imitation (Rode, J. & Weber, A, 2016). Many homeowners still hold reservations about embracing rooftop solar PV technology, primarily due to its substantial initial investment and extended payback times (Rengasamy, M., et al., 2020). Agdas, D. & Barooah, P., (2023) emphasise that analysing the economic viability of rooftop solar PV is quite challenging, as its inherently complicated life-cycle analysis is further exacerbated by dependence on weather, utility pricing strategies that change frequently, and lack of both long-term granular data about rooftop solar systems and individual household-level financial data (Section 4.3).

The success of residential rooftop photovoltaic system adoption hinges on various barriers like public perception, market readiness, and robust governmental support (Alrawi, O.F., & Al-Ghamdi, S.G., 2023). The advantages of distributed generation range from cost savings to increased self-consumption, participation in local energy markets, governance empowerment, and diminished carbon footprints (Cuenca, J.J., et al., 2023). The pervasive influence of social norms and attitudes on residential rooftop photovoltaic adoption underscores the significance of cultivating a positive and supportive energy culture (Abreu, J., et al., 2019).

Appropriate policy measures can help lower the entry barriers while maintaining economic efficiency and avoiding over-incentivisation. However, the intermittent nature of solar power generation poses another challenge. Unlike conventional energy sources, solar power production is subject to weather conditions and daylight availability. This intermittency necessitates effective energy storage solutions, such as batteries, which can add to the overall system costs. Balancing the supply-demand dynamics while maintaining grid stability becomes a complex task, requiring sophisticated infrastructure and management systems.

If these challenges can be overcome, rooftop solar PV has the potential to revolutionize the way energy is generated and consumed at the micro level. As technology continues to advance and costs decrease over time, addressing these economic and analytical barriers becomes pivotal to making rooftop solar PV a more attractive and accessible choice for homeowners. By finding innovative solutions to mitigate the initial investment burden, optimizing energy storage systems, and gathering comprehensive data to inform economic assessments, the transition to rooftop solar PV can be expedited.

Moreover, governments and regulatory bodies have a significant role to play in expediting the adoption of rooftop solar PV. Implementing favourable policies, offering incentives, and promoting financial support mechanisms can go a long way in encouraging owners to make the switch to solar energy. As the global focus on sustainability intensifies, collaborating efforts from all stakeholders can drive the growth of rooftop solar PV, making it a vital pillar in the renewable energy landscape.

3.2 Frequently used support mechanisms

Policy support remains a principal driver of solar PV deployment in most of the world (IEA, 2023). The motivation for these policies (IEA, 2023) is energy security, direct CO_2 mitigation (Hu, H.J.J., & Popiolek, N., 2014) or to support the energy transition (Yu, H.J.J., & Geoffron, P., 2020). There is a large academic literature on the common solar policy support mechanisms. Some of the most frequently encountered are:

1. **Feed in Tariff** (FiT) is a tariff guarantee. This is the most commonly applied incentive system in the world. FIT practices differ in each country. These differences are the incentive application period and how the incentive is applied. Incentives are applied differently in each country for periods between 10 and 25 years, depending on the type of consumer and the installed PV capacity. Distinct FIT incentives can be applied with either fixed values, market values or changing values (Kılıç, U., & Kekezoğlu, B., 2022). Time-of-generation tariffs are another important variation of FiT (see FiP below).

2. **Net Metering** (NM) is a special case of FiT that allows residential and commercial customers who generate power to sell the unutilized electricity back to the utility company at the full retail price. The utility company credits rooftop solar PV users for all excess solar energy sent to the utility system. This system guarantees that no electricity is wasted and that ordinary householders that generate extra solar power can sell it and compensate for their investment (Al-Sharafi, E.A. et al., 2023). In NM, the retail price commonly reflects the average (not marginal) system costs and is based upon a fully allocated, historic cost-rate making methodology (Yan, G., & Han, L., 2023).

3. **Investment Tax Credits** (ITC) is a government tax incentive. When individuals or companies file their taxes, the government provides a cashback on the annual taxes, usually computed as a percentage of the overall solar PV installation cost. Moreover, when the utility company offers subsidies to installers of rooftop solar PV systems, they can be excluded from income taxes. Therefore, the utility rebate for installing rooftop solar systems is subtracted from the system costs before calculating the tax credit (Al-Sharafi, E.A. et al., 2023).

4. **Premium Guarantee** (PG) is the method of selling the produced energy to the market and taking the difference between the sales price and the market price as a premium. It can also be applied as a fixed premium guarantee. In this system, predetermined fixed premiums are fixed premiums given to the producer until the price of the energy sold reaches the market sale price level. Fixed premium guarantee offers investors a predictable market (Kılıç, U., & Kekezoğlu, B., 2022).

5. **The Quota System** (QS) is a system that requires a certain part of the generated electrical energy to be supplied from renewable sources. Here, the quota surplus can be sold to other consumers who cannot meet the energy quota. The quota system can be supported with green certificate applications (Kılıç, U., & Kekezoğlu, B., 2022).

6. **Feed-in-Premium** (FIP) is a more market-oriented solution that better reflects market price dynamics. PV power is sold based on the electricity spot market price, and generators receive a premium on top of the market price. Because the government only pays the premium, policy costs will be largely reduced compared with the FIT system (Yu, H.J.J., & Geoffron, P., 2020).

7. **Power Purchase Agreement** (PPA) is another effective way to limit the risks led by FITs. Here the methodology is to use tenders based on the price mechanism of purchasing electricity produced by renewable energy sources. The company that suggests the lowest price wins the contract (Yu, H.J.J., & Geoffron, P., 2020).

8. **R&D Supports** consist of a variety of grants, loans, and subsidies to help remedy technological spillovers and encourage future cost reductions. Public R&D can compensate for a firm's underinvestment caused by uncertainty and market failures. Renewable energy technologies can be augmented by Public R&D expenditure on other technologies and resulting knowledge spillovers (Grafstrom, J., & Poudineh, R., 2023).

9. **Renewable Portfolio Standards** (RPS) mandate firms to have a certain percentage of their total electricity production or delivery sourced from renewable energy. An alternative for the firms is to purchase renewable energy certificates. A downside found with RPS is that they can reduce the trade performance in a country by inducing extra costs on its industries and encouraging imports rather than own development by domestic firms where trade is free (Grafstrom, J., & Poudineh, R., 2023).

10. The list provided above is not exhaustive. Other economic and non-economic instruments include LI: Low-Interest Bank Loans; NRET: National Renewable Energy Targets; TBC: The

Technical Building Code; RID: Reducing the Import Duty on Solar Panels; LST: Low Solar Tariff; REL: Renewable Energy Law; MRSP: Mandatory Rooftop Solar Panels; RECs: Renewable Energy Certificates, etc.

Policy instrument choices are shaped by specific needs, resources, and circumstances. The policy choices available to Ireland are shaped by the country's particular regulatory, economic, and energy context. This policy context for solar PV includes a relatively isolated "island" power grid with weak interconnection, the present high retail price of electricity, wholesale price volatility, gas dependency, a relatively low solar resource with high seasonality, high network costs, high standing charges and a low installed solar PV base compared to many other EU countries. Finally, the country's very challenging carbon budgets must be considered as this may demand stronger policy measures than would otherwise be the case.

3.3 Policy support measures of selected countries

The countries of north-western Europe share a similar solar resource with similar seasonality to Ireland. Schardt, J., & te Heesen, H., (2020) undertook a study involving 32,744 installed rooftop PV systems across Europe from 2015 to 2019. Their empirical analysis found mean specific yields for the Netherlands of 947 kWh/kWp, equivalent to a capacity factor of 10.8%. Belgium had a capacity factor of 10.9%, Luxembourg 11.1%, Germany 11.3%, France 12.5%, and Italy 13.6%.

Solar policies in a selection of European countries with low specific solar yields are reviewed below. The analysis is based on data from organizations including the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), the Department of the Environment, Climate and Communications (Ireland), and the Department of Agriculture, Food and Marine (Ireland).

1. **United Kingdom** (UK): Like Ireland, the UK experiences a similar temperate climate with moderate sunlight levels. The UK has been rapidly expanding its solar capacity for some years, thanks to advancements in technology and government incentives. The "Green Deal," introduced in 2013, established a framework that facilitates energy-efficient enhancements for homes and businesses. This policy enables individuals to invest in improvements by utilizing a specialized loan, which is repaid using the savings anticipated from reduced fuel bills. In 2014, a Contract for Difference (CfD) policy supplanted the previous Renewable Obligations system. Tailored to support large-scale renewable projects exceeding 5MW, the CfD scheme provides crucial backing for commercial-scale solar PV projects among other renewable initiatives. In 2022, the policy "Extending the VAT relief available for the installation of energy-saving materials (ESMs)" was enacted, offering a zero rate

for ESM installations. However, in the absence of further legislation, this will revert to a 5% reduced rate, commencing from 1 April 2027. Collectively, these policies underscore the UK's commitment to advancing solar PV adoption and sustainable energy practices while making investments in renewable projects more accessible and appealing to both consumers and businesses (IEA, 2023).

2. **Belgium:** Despite its northern location, Belgium has seen a growth in solar energy adoption due to supportive policies and increasing cost-effectiveness of solar technologies. Belgium's commitment to solar energy is exemplified by a diverse set of policies. The "*Brussels SolarClick programme for public buildings*" was launched in 2016 and implemented in 2017. This initiative targets the augmentation of solar panel installations on governmental buildings across the Brussels region. With a specific focus on schools, hospitals, administrative buildings, and more, the program's ambition was to cover 85,000 square meters of public rooftops with solar PV panels by 2020.

   In 2017, Belgium introduced the "*Brussels zero interest green loan for residential sector*". Under this policy, homeowners and authorized renters in the Brussels region are eligible for a green loan to fund energy improvement projects within their residences. This encompasses a spectrum of enhancements, including solar PV panel installations, heat pumps for both hot water and heating, and solar water heaters.

   Moreover, Belgium has taken significant steps to incentivize solar technology adoption with the "*VAT reduction on solar panels, solar water heaters, and heat pumps*", introduced in 2022. Dwellings less than a decade old can avail of a reduced VAT rate of 6%—a substantial drop from the standard 21%. This favourable rate applies between April 1, 2022, and December 31, 2023, inclusive. By offering financial incentives, Belgium seeks to catalyse solar adoption, making the transition to cleaner energy sources more economically viable for its citizens (IEA, 2023).

3. **Netherlands:** The Netherlands has a comparable climate and solar potential to Ireland. The Dutch government has been promoting renewable energy, including solar, and the country has been investing in solar installations on rooftops, along highways, and in various other innovative ways. The "*Energy Tax Rebate*" incentivises collective sustainable electricity generation efforts, such as installing solar panels on school or shed roofs. Through the "*Renewable Energy Grant Scheme (SDE+)*" subsidies are granted over 12 or 15 years, depending on the technology used. This scheme, extended to SDE++ in 2023, even allows for banking excess production for use in later years, ensuring efficient energy use. Another approach involves "*Crediting Electricity Supplied to the Grid*" wherein households with surplus solar-generated electricity can contribute back to the grid and receive a credit for the unused energy, with rates varying across providers. Additionally, the

"*Sustainable Energy Investment Grants (ISDE)*" offers businesses and individuals grants to offset the cost of energy-saving equipment like heat pumps, solar water heating systems, and biomass boilers. This policy, active from 2016 to 2020, supported a broader adoption of sustainable technologies, with budgets for each grant year announced in advance. These policies underscore the Netherlands' commitment to fostering renewable energy adoption and promoting energy efficiency (IEA, 2023).

4. **Denmark:** Denmark, like Ireland, has a moderate climate and a coastal location. Denmark's experience showcases that even countries with similar geographic characteristics to Ireland can achieve significant solar energy contributions through the right policies and investments. Denmark's commitment to renewable energy is exemplified through its forward-looking policy of "*Technology neutral tenders*" which was first introduced in 2021. This innovative approach has gained the approval of the European Commission (EC), marking a significant step toward bolstering the country's electricity production from renewable sources. Under the umbrella of the EU State aid rules, Denmark has secured EUR 400 million in aid to support its renewable energy endeavours. This financial support will be allocated through a competitive bidding process, set to be extended until 2024. This inclusive strategy signals a level playing field for various technologies, including solar PV. By embracing a technology-neutral approach, Denmark positions itself at the forefront of renewable energy development, fostering a diversified and sustainable energy landscape for the future (IEA, 2023).

5. **Germany:** Germany is a global leader in solar energy despite its relatively low solar irradiance levels. This success is attributed to its supportive policies, strong solar industry, and effective use of solar technology. Its experience demonstrates that solar energy can be effectively incentivised even in regions with less abundant sunlight. Initiated in 2015, the "*Ground-mounted PV Auction Ordinance*" exemplifies Germany's commitment to solar power. Tailored exclusively for ground-mounted solar PV installations, the auction system encompasses projects with capacities ranging from 100 kW to 10 MW per project. In 2016, the "*Subsidy for solar PV with storage installations*" was introduced. This program offers a comprehensive support mechanism, including soft loans of up to EUR 2,000 per kW for the solar PV system. Additionally, a capital grant covering up to 25% of the eligible solar PV panel cost is provided, amplifying the feasibility and appeal of solar PV systems coupled with storage. The "*Landlord-to-Tenant Electricity Act 2017*" offers bonuses to landlords and tenants that incentivise self-consumption of landlord-owned solar PV systems generation by their tenants. The "*Omnibus Energy Act*" of 2018 envisages 4 GW each for wind and photovoltaic panels within the next three years. In 2020, the "*Package for the future - Expansion of renewable energies*" abolished

a cap on solar PV build-out. Most recently, the "*JenErgieReal regulatory sandbox*" of 2022 created a platform in the city of Jena for the development and implementation of cutting-edge technologies, spanning large-scale electrical storage systems, solar PV, solar thermal systems, and electric vehicles, alongside charging stations. Collectively, these policies demonstrated Germany's dedication to a renewable energy future (IEA, 2023).

3.4 Table of recent support measures for Solar PV

Table 1: List of solar PV support measures adopted internationally during 2022-2023.

Policy Name	Country	Year	IPCC Policy Type	IEA Policy Type
Inflation Relief Package 2	Austria	2022	R&D	Payments finance and taxation
Funding '5B Maverick' solar farm tech boosts scalable ultra-low-cost solar solutions	Australia	2022	Subsidies and Other incentives	Strategic Plans
Powering Australia - Community Solar Banks	Australia	2022	Information Policies	Payments finance and taxation
VAT reduction on solar panels, solar water heaters and heat pumps	Belgium	2022	Taxes and Charges	Payments finance and taxation
Increase in grants for thermal insulation of roofs and installation of photovoltaic systems on homes	Cyprus	2022	Information Policies	Grants
EUR 8 million for small houses' energy efficiency	Estonia	2022	Subsidies and Other incentives	Payments finance and taxation
France 2030 investment Plan"- Investment in renewable energy innovation	France	2022	R&D	Public Procurement
JenErgieReal regulatory sandbox	Germany	2022	Regulations and Standards	Regulation
Photovoltaics on the Roof programme	Greece	2023	Subsidies and Other incentives	Payments finance and taxation
Enhanced supports for businesses through Solar PV Scheme	Ireland	2023	Subsidies and Other incentives	Performance-based Payments
Zero or Reduced VAT	Ireland	2023	Taxes fees and Charges	Taxes fees and Charges
Solar Capital Investment Scheme (SCIS) under TAMS	Ireland	2023	Subsidies and Other incentives	Performance-based Payments
Rooftop Revolution	Ireland	2022	Strategic Plans	Strategic Plans
New planning permission exemptions for rooftop solar panels on homes and other buildings	Ireland	2022	Strategic Plans	Targets Plans and Framework legislation

Clean Export Premiums	Ireland	2022	Taxes and Charges	Payments and transfer
Clean Export Guarantee	Ireland	2022	Subsidies and Other incentives	Grants
VAT (Flat rate Farmers)	Ireland	2022	Taxes and Charges	Taxes fees and Charges
Energy for the countryside programme	Poland	2023	Subsidies and Other incentives	Payments finance and taxation
Subsidies for solar panel installation in the agro-industry	Portugal	2022	Subsidies and Other incentives	Grants
EUR 457 million for wind and solar	Romania	2022	Subsidies and Other incentives	Grants
Grants to public sector entities for investment in solar PV plants	Slovak Republic	2023	Subsidies and Other incentives	Grants
2023 subsidies for large-scale solar PV	Switzerland	2023	Subsidies and Other incentives	Payments finance and taxation
Auction scheme for large-scale solar PV	Switzerland	2023	Subsidies and Other incentives	Payments finance and taxation
Extending the VAT relief available for the installation of energy-saving materials (ESMs)	UK	2022	Taxes and Charges	Taxes fees and Charges

Source: IEA Database, 2023

4. The potential of small-scale solar in Ireland

The solar resource potential of Ireland is lower than in most other countries, which implies a higher levelized cost of energy (LCOE) for solar PV. This may explain why the country has been slow to recognise the value of this indigenous resource. Low irradiance is partly offset by the fact that lower ambient air temperatures improve the efficiency of solar panels (Dubey, S., et al., 2013) Unlike wind power, for example, Ireland cannot claim to have a competitive advantage in solar energy. Nevertheless, Ireland is witnessing very rapid growth in the deployment of solar PV.

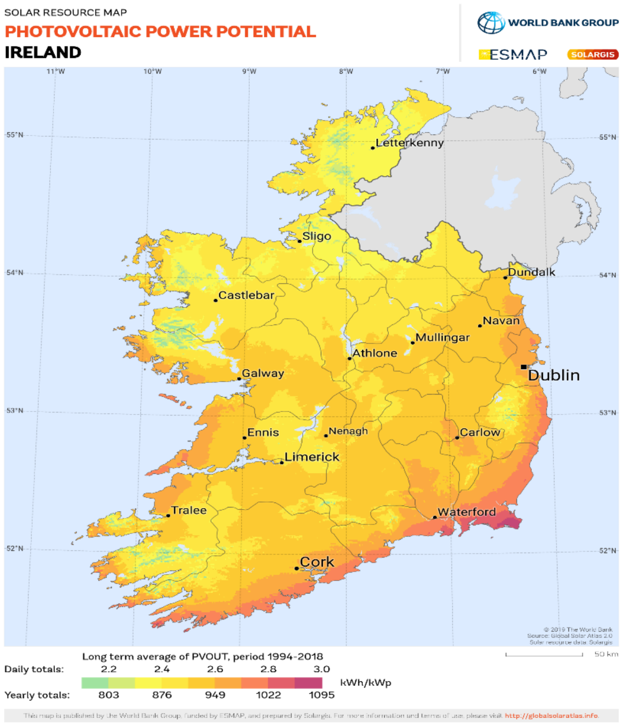
The country's solar resource can be characterized as follows. The country receives the most sunshine between 1100 and 1600 hours. The peak (May-June) is 5 to 6.5 hours of daily sun, while December is the least sunny at 1-2 hours. The southeast gets the most sun, averaging over 7 hours a day in early summer. Cloud cover is high, at over 50%, greatly reducing the energy reaching the surface and available for PV generation. Clear days may achieve 75% of the potential solar irradiance, while sunless days get 20-25%. The energy reaching the surface ranges from 40-47% (March-September) to 30-37% (Oct-Feb) (Murphy, F., & McDonnell, K. 2017).

In their Country Factsheet for Ireland, the World Bank Photovoltaic Power Potential Report (World Bank, 2023) provides a useful baseline snapshot for 2018. Ireland's average solar resource potential, measured by global horizontal irradiance (GHI), is estimated at 2.5 kWh m^{-2}. While this is the lowest number of all countries assessed (even lower than Norway up to 60°N due to greater cloudiness), in reality, most North-Western European countries have a not dissimilar potential at below 3 kWh m^{-2}. Mediterranean countries have solar potentials closer to 4 kWh m^{-2}. Despite this, the "PV equivalent area" for Ireland based on a 2018 per capita electrical energy consumption of 5,672 kWh is only 0.94% of the land area.[2] These numbers are of course sensitive to the photovoltaic efficiency which continues to improve incrementally. Seasonality is also very important in Ireland. The PV seasonality index[3] falls is 4.49 indicating high seasonal variations in solar energy generation during the year. 85% of the world's population live in countries with seasonality of less than 2 (World Bank, 2023).

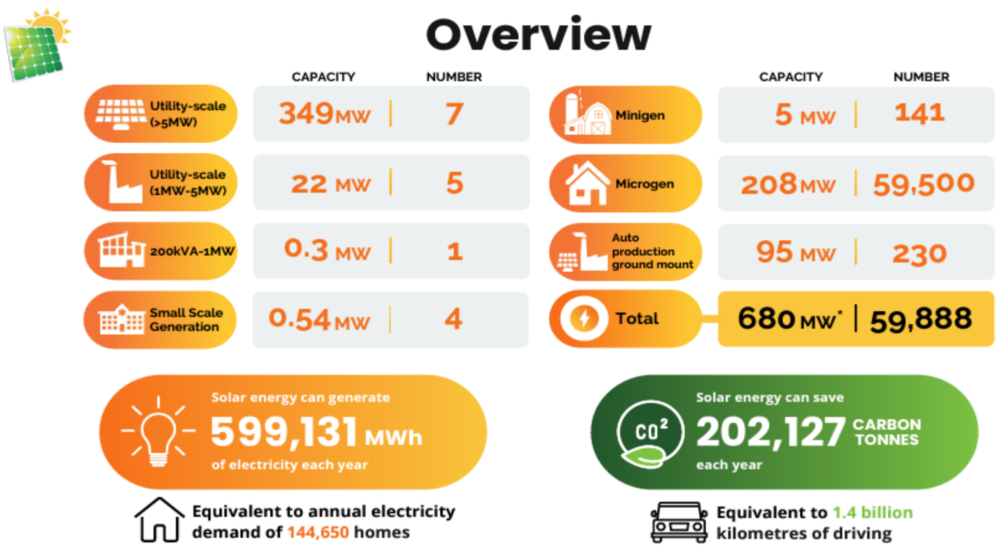
The World Bank analysis also indicates a 2018 levelized cost of electricity (LCOE) for utility-scale PV in Ireland in the range of 0.13-0.16 €/kWh. This can be compared to the 0.07292 €/kWh solar strike price achieved in the RESS1 auction held in September 2020, although the RESS-3 auction in 2023 had a higher strike price of 0.10047 €/kWh. Figure 6 shows a solar PV resource map and installed solar capacities by category as of June 2023. Total PV capacity reached 680 MWp. The installed capacity in 2018 was only 29 MWp. This can further be verified using SEAI Solar Atlas (2023), which is a digital map of Ireland's solar energy resources from SEAI. It provides detailed information on solar irradiation, as well as the details and approximate locations of both grid-connected and planned solar farms.

[2] The share of a country's land area that would need to be covered in solar PV to deliver energy equivalent to the electricity consumption averaged over a year.

[3] The ratio between the expected PV output of the highest month and the lowest month.



Source: Solar resource maps and GIS data for 200+ countries | Solargis



Source: Irish Solar Association, 2023

Note: EirGrid data shows 310MW utility-scale installed capacity in 2023 (EirGrid. 2023b).

Figure 6: Ireland’s solar resource (top) and estimated June 2023 uptake (bottom)

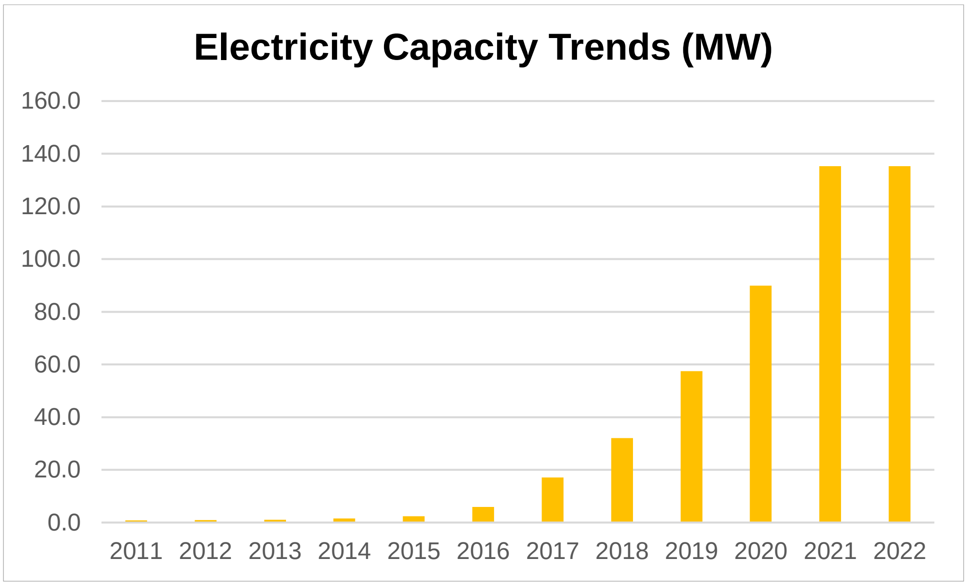


Figure 7: Ireland's Electricity Generation Trends using Solar PV

Source: IRENA, 2023a

Figure 7 (by IRENA 2023a) shows that solar energy generation in this country is growing exponentially. Generation in 2020 exceeded 60 GWh, more than three times greater than in 2018. La Monaca, S., & Ryan, L. (2017) showed that while earlier research indicated that it was not feasible in Ireland, falling costs can render solar PV financially viable even at the household level. This is further elaborated in Section 4.3 of this report using an agent-based model (ABM). Following table 2 (by EirGrid 2023b) shows the all Island solar generation, penetration and supply capacity for the year 2022 and Jan – Sep 2023.

Table 2: All Island Solar Capacity[4]

All Island		2022	Jan - Sep 2023
Solar Generation	Avg (MW)	15	64
	Max (MW)	112	416
	Total (GWh)	132	420
Solar Penetration (% of Demand)	Avg (%)	0.3%	1.4%
	Max (%)	3%	9%
Oversupply (Estimated)	Avg (MW)	5	4
	Max (MW)	1,295	1,105
	Total (GWh)	41	29
Oversupply %	Avg (%)	0.1%	0.1%
	Max (%)	29%	25%

Source: EirGrid (2023b)

[4] Solar energy reporting in Ireland began in April 2023. Some initial data may be unreliable due to new solar farms being in a commissioning/testing phase.

4.1 Rewards and challenges of rooftop solar

An independent consultancy report commissioned by SEAI (SEAI, 2022b) describes the benefits and challenges associated with rooftop systems in Ireland. There are notable benefits when solar PV is deployed on pre-existing infrastructure, such as roofs, in comparison to ground-mounted systems.

- Capital Expenses: Capital costs are generally lower due to leveraging existing infrastructure and the smaller spatial requirements of these systems, although costs could increase if roof renovations or reinforcement are necessary.
- Mounting and Installation: The necessity for racking and mounting infrastructure is often reduced for these systems, dependent on the roof type. This reduction also leads to lower installation costs compared to ground-mounted alternatives.
- Authorisation: Installing solar PV on rooftops typically simplifies permission processes due to its non-disruptive nature to existing activities and lack of extra land requirements. Nonetheless, factors like safety and noticeable reflections need consideration.

Nevertheless, these systems also come with significant challenges and limitations:

- Space Limitations: The available rooftop area, can be the primary constraint on the potential PV capacity a premise can accommodate.
- Panel Alignment: Installing systems on existing rooftops might necessitate placing panels at suboptimal angles, deviating from the optimal orientation for maximum annual energy yield.
- Structural Enhancement: Solar panels, along with their mounting systems and wiring, impose an average weight of 10-20 kg/m^2 on the roof. Additional forces from wind and maintenance can further compound this. While this is usually manageable, in some instances, it could surpass the roof's load-bearing capacity, requiring structural reinforcement. Regulations and safety standards for installers are also set by SEAI and pertinent here (SEAI, 2017).
- Shading: The reliance on existing infrastructure could limit the ability to prevent shading from adjacent objects, structures, buildings, or trees. Although it's possible to conduct case-specific analysis to determine if installing partially shaded panels is financially viable, generally, placing solar panels in shaded areas is discouraged.

4.2 Costs

Solar technology promises environmental and economic benefits to sub-utility scale adopters such as individuals or businesses. The cost dynamics of solar panel installations are quite complex and have been investigated by many different researchers. Research by Zander, K.K., et al. (2019) underlines that installation costs have a central role in influencing the selection of a photovoltaic system. Guaranteed years of selling excess solar power to retailers (Rengasamy, M., et al., 2020, Campoccia, A., et al., 2014) and a generous feed-in tariff are also important influencing factors.

Careful financial assessment is of particular importance in an Irish context because the solar potential is low by international comparison. For households, the initial system cost ranges from €5,000 to €15,500, covering installation and related charges (EnergyD, 2020a). Rooftop installations have been incentivised since 2018 by an SEAI (2023a) grant. This grant is currently €900 per kWp up to 2kWp, with an additional €300 for each kWp up to 4kWp, capped at €2400 (SEAI, 2023a), effectively narrowing the installation cost range to €3,200 – €13,100 (EnergyD, 2020a). At the more economical end, standard 2 kWp panels may be cost-effective, while at the upper end, an 8 kWp system, a power diverter, and a substantial battery setup, may appeal to some households when feed-in tariffs (FiT) are generous. The annual return often exceeds 10% in the first year and increases with time if electricity price inflation is high. These returns contrast with the modest returns associated with traditional bank savings accounts and the uncertain potential of stock market investments. Moreover, simple tax considerations further enhance the appeal of solar panels compared with other investments because the returns on a financial asset are taxed while the profits from an investment in a solar PV system are not (EnergyD, 2020b). A study by Mountain, B., & Szuster, P. (2015) shows that households who make substantial capital investments in rooftop PV installations achieve a return on investment comparable to accepted utility-scale standards. In principle, a well-designed photovoltaics system can offer climate action along with credible financial returns.

4.3 Quantitative modelling of solar PV uptake by Irish households

The rooftop solar resource within the EU is "vast and underutilised" according to the European Commission (EU Solar Energy Strategy, 2022). In Ireland, the technical potential of residential rooftop solar PV has been estimated at ≈13 GWp (Bódis et al. 2019, Joshi & Deane 2022), compared to the current peak power system demand of ≈5-6 GW.

Despite its higher unit installation cost relative to utility-scale PV, policymakers have long recognised the value of household investment in rooftop solar. There are several reasons for this. Rooftop solar has a very low environmental impact, does not necessarily require new grid development and does not compete with other land uses. When combined with a battery energy storage system (BESS) (Bertsch, V., et al., 2017), PV-BESS boosts the self-sufficiency[5] and resilience of the household power supply. Indeed, self-consumption, rather than exports to the grid, is the cornerstone of EU policy for rooftop solar energy (EU Directive, 2018). PV-BESS may also offer increased benefits to the broader grid in future e.g. system peak load reductions and other system services.

Agent-based models (ABM) can offer insights into the impact of policy measures on solar PV technology uptake. This approach has been widely applied (for a review see Alipour et al. 2021). These models attempt to take economic and individual influences, as well as physical and technical barriers, into account. Overcoming the barriers to the adoption of rooftop solar technology will play an important role in achieving the transition to renewable energy sources. For example, in Italy, an agent-based-model conducted by Danielis et al. (2023) predicted that, given the preference structure of homeowners, the continuing decline in costs, and social interaction, 40–45% of homeowners will have a PV system installed by 2030, thanks in part to an existing investment tax credit policy. Also, Yan & Han (2023) showed that there is a large cross-price effect with respect to residential electricity prices indicating that rooftop solar is a strong substitute for utility-provided electricity. This is driven, in part, by a residential rate design that primarily recovers fixed system costs through volumetric charges.

One limitation of this type of empirical modelling is that it requires rich data inputs which may not always be available. Such inputs are available in Ireland for residential settings, but less so currently for non-residential settings, as previously discussed in this report.

Information on the attitudes of Irish households to solar PV was gathered in a 2018 household survey (Meles et al., 2022) and used as input to an ABM.[6] Other datasets employed include BER building energy ratings (SEAI, 2022a), and historical hourly electricity demand patterns at the household level from the Commission on Energy Regulation (CER, 2012). The latter is used to capture the correlation between a household's power demand and solar generation from hourly to seasonal timescales. Some outputs of the modelling studies carried out at UCD Energy Institute are described briefly here. This modelling work was supported by DECC.

As a relatively high-latitude country, solar capacity factors in Ireland vary strongly depending on roof section orientation and season (Table 3; World Bank, 2023). The distribution of available roof areas for solar PV can be estimated from BER and these also depend on building type (i.e. two-storey versus

[5] Self-sufficiency is the share of household annual electricity consumption that is self-generated.
[6] We modelled the future behaviour of 759 residential owner-occupiers captured by the survey.

bungalow). For modelling simplicity, all roof sections are assumed to have a 30^0 pitch and one of the azimuth angles of Table 3. A random shading effect reduces the economic viability of some roof sections. Panel efficiency is assumed to increase from a 2015 value of 0.16 kWp m^{-2} to 0.23 kWp m^{-2} in 2030 due to technological improvement (Fraunhofer Institute for Solar Energy Systems, 2023).

Table 3: Capacity factors by aspect and season for an unshaded 30^0 pitched roof at Birr Co Offaly assuming solar panel efficiency of 2015.

Aspect	summer	winter
South	0.129	0.053
SW	0.125	0.047
SE	0.124	0.048
West	0.113	0.034
East	0.112	0.035
NW	0.099	0.023
NE	0.098	0.023
North	0.092	0.019

Falling solar panel costs, a high retail electricity price and a high feed-in tariff (FiT) paid to residential producers by network suppliers[7] are expected to favour PV uptake by households. These elements are present in a "Base Scenario" used here. The levelized cost-of-energy (LCOE) for rooftop solar in Ireland falls from 11 c/kWh (our current estimate) to 8 c/kWh in 2030 for a 6 kWp PV-only system on an unshaded south-facing roof, consistent with standard PV cost projections (IRENA, 2017, 2018, 2019). Retail electricity prices are assumed to remain high in the Base Scenario at 30 c/kWh in 2030. It is further assumed that FiT declines to 9 c/kWh compared to a current value of ≈18 c/kWh. The current SEAI PV grant is removed at the beginning of 2025.

The financial utility of solar PV adoption is complex and is approached as follows. An agent considering PV-BESS identifies the system with optimal return on investment based on net-present-value (NPV) maximization (La Monaca, S., & Ryan, L. 2017), given their electricity usage pattern, rooftop constraints and retail electricity price expectations. The effective PV-BESS lifetime is taken to be 20 years (Bertsch, V., et al., 2017). Loan finance is assumed and cash flows are discounted at a personal discount rate of 7%. It is further assumed that electricity price expectations remain anchored at 2%

[7] The FiT paid to households with installed solar capacity less than 6kVA is called the "Clean Export Guarantee" (CEG). CEG is set by network providers on a market basis.

despite the price moves of recent years. Revenues from FiT are taxed at 40% above a €200 tax disregard.

In addition to the physical constraints and financial aspects outlined above, the ABM also captures social influence effects and individual barriers to adoption such as attitudes to unfamiliar technologies and risk aversion. These important features are obtained for each agent by calibration of the model to the survey data. Each simulation run tracks the adoption decisions by 759 surveyed homeowners in bi-monthly time steps to determine PV system choices.

4.3.1 Solar PV and battery storage uptake projections

Table 4: Projected uptake of rooftop Solar PV by Irish households

PV-BESS uptake rates and installed capacities at the end of 2025 and 2030 in the Base Scenario. Annual solar energy generated and total household energy imported and exported to the grid in 2025 and 2030 are also given. These results are averages over.

year	uptake %	SAR %	installed GW	storage GWh	demand TWh	solar TWh	imports TWh	exports TWh
2025	13	35	1.18	0.32	6.4	0.7	6.1	0.4
2030	21	59	2.34	1.06	6.4	1.4	5.8	0.8

Modelling results for the Base Scenario are given in Table 4. Here, the energy flow (TWh) values assume a constant 1.15 million houses available for rooftop PV, with household mean annual electricity demand fixed at 5.5 MWh. Table 4 shows that 21% of households will have adopted solar PV by the end of 2030 with solar generating 22% (1.4 TWh) of the household electricity demand. However, about half of this electricity is exported to the grid rather than self-consumed. The projected PV capacity is 2.3 GW, corresponding to an effective mean capacity factor of 7%. The “storage attachment rate” (SAR) reflects the share of households with solar PV systems also installing a battery storage system.

The sharp rise in the SAR shown in Table 4 and Figure 8 (a) is one of the interesting predictions of the modelling. A total of 1 GWh of storage is present by the end of 2030 when almost 60% of installations include a battery. The strong BESS uptake in the Base Scenario is driven by falling battery prices and by a high retail price of electricity (p_e) relative to FiT.

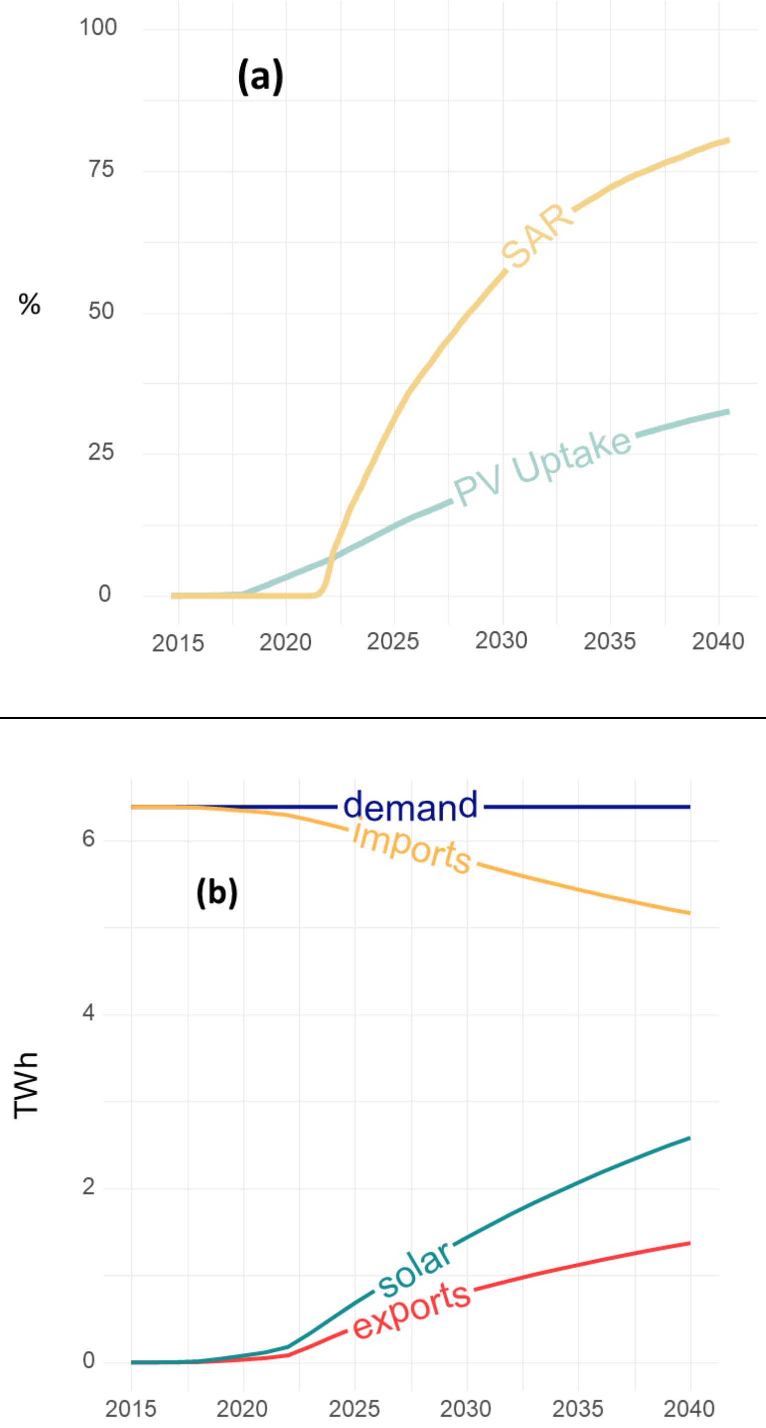


Figure 8: (a) & (b)

Figure 8 (a) Forecast % uptake of solar PV and storage attachment rate (SAR) from 2015 to 2040 in the Base Scenario. (b) "Solar" gives the total solar energy generated in TWh, "imports" gives total energy imported from the grid, and "exports" is the total energy exported to the grid. Total household energy demand is fixed at 6.4 TWh.

Figure 8 (b) shows that the energy generated by rooftop PV is evenly split between a reduction in energy imports and increased exports to the grid. Note that the modelled installed capacity in 2040 (4 GWp), is still well below the estimated technical engineering potential of ≈13 GWp (Joshi, S., & Deane, P. 2022). This reflects the role played by economic and other barriers to adoption in the ABM.

There are marked differences between solar installations that include battery storage and those that do not. Table 5 compares PV-only and PV+BESS installations in 2030.

Table 5: Projected Self-Consumption metrics for Irish rooftop solar PV adopters

Average 2030 installed capacities and self-consumption metrics for PV-only and PV-BESS adopters.

system	mean battery (kWh)	solar (MWh)	self-consumption	self-sufficiency
All	4.4	6.1	46%	47%
PV-only	0	3.3	41%	25%
PV+BESS	7.5	8.1	50%	63%

Installations that include BESS tend to be larger. The average battery size for BESS adopters is 7.5 kWh. Storage adopters have far higher self-sufficiency metrics compared to PV-only adopters (63% versus 25%).

4.3.2 Sensitivity to feed-in tariffs and electricity prices

FiT has been considered an effective policy measure for rooftop solar PV in many countries. To test this for Ireland, a counterfactual "No FiT" scenario was modelled for residential customers where feed-in tariffs are not introduced. All other assumptions, including the timing of grant removal, are unchanged. The results of this analysis are shown in Table 6.

Table 6: Projected uptake of rooftop solar in the absence of a feed-in tariff policy

Solar uptake and installed capacities at the end of 2030 in a counterfactual scenario with no FiT policy. Also shown is a scenario with a lower 2030 retail electricity price.

scenario	uptake	SAR	installed	storage	demand	solar	imports	exports
	%	%	GW	GWh	TWh	TWh	TWh	TWh
No FiT	17	65	1.1	0.9	6.4	0.8	5.9	0.3
Low p_e	20	37	1.9	0.6	6.4	1.3	5.9	0.8

The installed rooftop solar capacity falls to 1.1 GW in 2030 in the absence of FiT. This is less than half of the 2.3 GW capacity of the Base Scenario (Table 4). However, the PV uptake rate falls modestly from 21% to 17%, showing that PV installations tend to be smaller in the absence of FiT. Surprisingly, despite the reduced PV capacity, the installed storage is only slightly lower compared to the Base Scenario (0.9 GWh vs 1 GWh).

A "Low p_e" scenario is also shown in Table 6. In this case, the retail price is assumed to fall to p_e = 20 c/kWh but FiT remains at 9 c/kWh in 2030 as in the Base Scenario. Despite the lower electricity price, solar PV uptake and installed capacity are only slightly reduced in this case. However, SAR falls to 37% with total installed storage of only 0.6 GWh (versus 59% and 1 GWh in Table 4).

In summary, Tables 4 & 6 show that feed-in tariffs are an effective policy measure that strongly incentivise rooftop PV. However, a lower price spread between FiT and p_e tends to lower the incentive to adopt storage. This was also noted by Castaneda,M., et al. (2020). From Table 5, storage significantly improves self-sufficiency and self-consumption metrics for solar PV adopters.

The following general conclusions can be drawn from the modelling of PV-BESS uptake by Irish households. Firstly, there is a potential for rapid and sustained uptake of rooftop solar PV by Irish owner-occupiers in response to high retail electricity prices, generous feed-in tariffs and lower solar technology costs. This is confirmed by the most recent uptake data (ISEA, 2023). In the favourable but not unrealistic Base Scenario of Section 4.3.1, residential solar PV uptake alone could account for most of the 2.5 GW non-new grid 2030 target of the 2023 Climate Action Plan. However, an important additional aspect for policymakers to consider is the choice of policy measures to incentivise greater solar PV capacity can also significantly impact the level of battery storage installed. Residential battery storage may play an important role in the energy transition. The implication for distribution grids is also an arena for policy as discussed further in Section 5.2.

5. The Irish policy context

5.1 The current policy mix

Ireland has implemented a series of policies (IEA, 2023; Government of Ireland, 2023; SEAI, 2023b) to promote renewable energy systems in buildings. The "*Renewable Heat Deployment Programme (ReHeat)*" introduced in 2007 offered grants for retrofitting or installing renewable heating systems in buildings. The "*Greener Homes Scheme*" initiated in 2007 provided grants for renewable energy-based heating systems, with significant applications for solar thermal, biomass, and heat pump technologies.

This was followed by the "*Community Grants*" launched in 2015, which aims to enhance energy efficiency and integrate renewable sources in shared community buildings and businesses.
In 2017, the "*ACA (Accelerated Capital Allowance) & Triple E*'' program offered tax incentives to encourage investment in energy-efficient products and equipment by businesses. Following this, in 2018 the "*Ireland Better Energy and related programs for buildings*", including the "*Better Energy Homes*" initiative, was introduced to take over from ReHeat and the Greener Homes Scheme, extending grants to homeowners for various energy-efficient upgrades, including solar thermal and heat pumps. Ireland adopted solar PV-specific policy measures in 2018 in response to a better understanding of the improving cost dynamics for households (La Monaca, S., & Ryan, L. 2017). A new "*Solar PV Grant Scheme*" supported residential installations. "*TAMS (Targeted Agricultural Modernisation Scheme)*" was introduced in 2020 to support solar PV and battery storage installations in agriculture.

At utility scale, the "*Renewable Electricity Support Scheme*" (RESS) began in 2020, aiming to achieve the 70% (now 80%) renewable electricity target by 2030, including support for utility-scale (> 1 MW) solar electricity generators. The "*Micro-generation Support Scheme (MSS)*" 2023 offers capital grants for micro-generation installations in the range of 7 kWp-1 MWp, with grants from €2,700 to €162,600. These grants typically support 20-30% of the investment cost. Ireland also lowered the VAT rate on solar panels installed under a "supply and fit" contract. The "*Clean Export Guarantee*" (residential feed-in tariff) was introduced in 2022. Grant support from the SEAI for homeowners purchasing a battery ceased at the same time. The "*EXEED*" program was also introduced, which incentivizes energy efficiency in businesses. In 2023, the Irish government introduced the "*Solar Capital Investment Scheme (SCIS)*" under TAMS, which offers higher grants for solar PV investments, while a reduced VAT rate on solar panels to enhance affordability.

The MSS described above offers €300/kWp for each extra kWp installed between 7 kWp-20 kWp, €200/kWp for each extra kWp installed between 21 kWp - 200 kWp and €150 per kWp for each extra kWp installed between 201 kWp -1000 kWp. This means that non-domestic installation of 1 MWp could be eligible for a grant of up to €162,600. These policies collectively contribute to Ireland's efforts to expand solar energy adoption and meet renewable energy targets (Government of Ireland, 2023).

Ireland is introducing solar mandates in line with the EU Energy Performance of Buildings Directive. All new commercial and public buildings with a useful floor area exceeding 250m² will have solar PV installed from 2026. A similar measure will apply to existing commercial and public buildings with a useful floor area exceeding 250m² within the third carbon budget period (2031-2035). Installation of solar PV in schools up to 6 kWp is now directly supported by the Climate Action Fund. New measures introduced in Budget 2024 include an increase in the Clean Energy Guarantee tax disregard to €400. Innovative approaches to micro and small-scale solar PV have emerged in other EU member nations. France's regulatory framework mandates the incorporation of solar panels within sprawling parking complexes, like Australia's introduction of a Solar Panel Car Parking measure.

5.2 Areas for further policy development

There has been a strong focus on the design and implementation of solar PV policy in Ireland in recent years as demonstrated in Section 5.1. Measures are in place (or soon will be) covering PV installations of all sizes from self-consumers to large utility-scale projects integrated into wholesale electricity markets. Are there policy gaps? One way to answer this question is from the survey of policy measures adopted in other countries (Section 3) and to consider their suitability for Ireland. Some of the more promising possibilities suggested by this process are listed below.

1. Access to solar PV for low-Income Households

The issues of equity and fairness cannot be separated from climate action. Solar PV can help to alleviate energy poverty, but there is evidence that low to moderate-income households face higher barriers to adoption compared to their higher-income counterparts due to economic constraints and situational factors (Wolske, K.S. 2020). Australia's "Solar for Low-Income Households Program" gives eligible households in the Australian Capital Territory (ACT) the opportunity to invest in rooftop solar panels, thereby mitigating their energy expenses. Through this initiative, qualifying participants can access a substantial subsidy of up to 50% of the total solar system cost.

The potential vulnerabilities of low-income households during the energy transition are well-known, along with the necessity of tailored approaches to safeguard their interests (Feng, K., et al., 2023). Solar incentive policies may specifically target economically challenged households who are unable to afford other advanced technologies or who lack the necessary knowledge. This serves a dual purpose as a tool to alleviate fuel poverty as well as reduce GHG emissions (Best, R., et al., 2019b).

2. Rooftop solar PV for apartment buildings

Encouraging the use of rooftop space for shared solar systems in apartment complexes may be a fruitful area for policy. For example, Estonia's Ministry of Economic Affairs and Communications allocated EUR 5 million earmarked for solar panel subsidies for apartment associations. This highlights the potential of a shared energy microgrid (Syed et al. 2020). Australia's deployment of photovoltaic systems on multi-occupancy residential buildings is motivated by the relationship between lower investment costs, optimal system size, and augmented bill savings (Fina et al., 2021). These examples reveal that shared microgrid systems can offer a lower cost threshold for battery storage compared to individual households, leading to cost savings and a greater sense of self-sufficiency (Roberts et al., 2019).

Ireland has a growing apartment stock with 239k households living in apartments according to the 2022 Census (CSO, 2023). The potential of these roofs has not been quantified but is likely to be significant.

3. Landlord-tenant scheme

Split incentives to investment in energy retrofits and clean energy technology are pervasive in the residential sector (Petrov and Ryan, 2021). This implies that landlords, the property owners, have little incentive to invest in solar energy PV systems or other energy saving technologies, as they do not generally pay the energy bills in the property. The tenant also does not have an incentive to invest in solar PV, as they do not own the property and most tenants do not remain long-term in the same house. Landlords are eligible for the same grants for solar PV installation as homeowners; since they do not capture the energy bill savings, perhaps the grant should be higher for them. Galvin (2023) showed that landlords/landladies who retrofit apartments then rent them out, the rental premiums due to higher energy efficiency are nowhere near sufficient to compensate for the retrofit costs. This should be considered in the context of the potential for higher rent for housing with a higher BER, for which there is significant evidence there is a small rental premium for more energy-efficient properties. Another study by Carroll. et al. (2020) also supports the fact that energy efficient properties sell faster and have higher demand. A consideration could be also to allow landlords to share in any revenue earned through export of electricity generated by the solar PV system to the grid. In Germany, the landlord-to-tenant electricity scheme introduced in 2019, could also be of interest whereby the landlord is considered to be the generator of the solar PV electricity and sells it to the tenant and can make a profit. This has been quite complicated to implement and therefore take-up has been lower than hoped.[8]

There were 192k households renting in the private sector in 2022 (CSO, 2023). Assuming that the split-incentive barrier can be overcome, the potential from this sector is estimated to be ≈0.3 GW in 2030 assuming the uptake rate found in the base scenario of Section 4.3 for owner-occupiers.

[8] https://www.en-former.com/en/landlord-to-tenant-electricity/

4. Local authority housing

Local authorities own a large stock of housing. According to the 2022 Census (CSO, 2023), 153k households rented from local authorities, with a further 30k renting from voluntary housing bodies. Solar PV mandates that required local authorities to install appropriate PV-BESS systems in their properties could be used to reach a specific 2030 capacity target.

A significant share of local authority housing is in the form of detached, semi-detached and particularly terraced housing. If 50% of this housing stock or 70k houses (CSO, 2023) had PV systems installed by 2030, it is estimated that this could add another ≈0.3 GW of additional rooftop solar PV capacity. Some further capacity could be available from local authority or voluntary body owned apartment buildings.

5. Solar PV for parking spaces and depots

Rooftop solar PV is unique in that it can allows agents to exploit their existing infrastructure for energy generation in a relatively unobtrusive way. France (The Guardian, 2022) has mandated solar panels to cover larger car parks. A 2.4 MW solar car park (Dezeen, 2021) has been activated in Melbourne as part of a 10 MW rooftop installation. Solar car parks have demonstrated robust performance to date with substantial annual electricity output with a relatively short payback period of 7 years (Mongkoldhumrongkul, 2023). Integration of solar PV into car parks, potentially on roadsides, and bus depots can also directly support the charging of electric cars and buses, an important step towards sustainable urban transport. (Vespasiano et al., 2023).

6. Extended Solar Policy for Commercial & Public Spaces

Residential solar is the largest category of the small scale (< 1MW) solar installation in Ireland (ISEA, 2023). There is an opportunity to further develop the rooftop solar paradigm to commercial and public spaces in the 10 kWp - 1 MWp capacity range. The emphasis should be on self-consumers. To date, the rollout of rooftop solar initiatives in this area have remained limited, with the except of planning permission exemptions and the "Rooftop Revolution" aimed at schools introduced in 2022.

Deeper integration of photovoltaics and battery storage into the core of urban infrastructure is becoming more feasible. Policy intervention at the design stage of buildings could enhance the prospects of PV integration within commercial structures (Ghaleb, B., & Asif, M. (2022). Solar energy policies for rooftops underpin the surge in solar power generation to a significant extent (Al-Sharafi, E.A. et al., 2023).

7. Support for Home Solar batteries:

Incentivizing the installation of a battery storage element in new or existing PV systems can help achieve renewable energy and emissions reduction targets (Best et al., 2023). The choice of incentive for solar PV may also significantly affect the level of battery storage installed (Section 4). Government subsidies can help to encourage battery adoption directly, especially in scenarios where the technology's affordability is a barrier (Al Khafaf et al., 2022). A grant for battery storage was removed in Ireland at the beginning of 2022. Australia's 2018 Solar Homes Program provides rebates for solar water heaters and rebates and interest-free loans for solar PV systems with batteries, including special assistance for rental properties. Policymakers can consider strengthening incentives for residential energy storage systems, to complement their rooftop solar installations. This may promote energy self-consumption (Section 4) and may offer advantages to the wider distribution grid, particularly as the penetration of Distributed Energy Resources (DERs) and potential grid congestion issues increase.

Batteries can provide an attractive avenue for individuals facing potential usage issues such as solar export curtailment, enabling them to store excess solar power for personal use (Esplin & Nelson 2022). Apart from this, by redirecting feed-in tariff payments towards residential battery storage, the potential arises to lower overall system costs, enhancing the financial feasibility of energy storage solutions and contributing to a more sustainable energy landscape (Esplin & Nelson, 2022). Low solar feed-in tariffs have shown a positive impact on battery adoption rates, yielding significant policy and capital effects, showcasing the interconnected nature of incentives and broader policy dynamics (Best et al., 2021., & see modelling Section 4). With an uncertain short-term outlook for energy storage costs, government subsidies could play a crucial role in bridging the gap and motivating users to invest in battery technologies (Al Khafaf et al., 2022).

8. Long-term evolution of solar PV incentives

Consideration should be given to the longer-term evolution of residential solar PV subsidies. California provides an example of how solar PV incentives need to evolve, as the market becomes more mature and the number of installed increases. California established itself as an early leader in solar energy, driven by robust pro-solar policies that have included feed-in tariffs and net metering. A significant turning point in this journey has been reached as the state's Public Utilities Commission contemplates the removal of existing incentives. In effect, this represents a pivot towards self-consumption and energy storage. Energy storage aligns with the growing need for grid stability and facilitates the integration of intermittent renewable sources such as solar PV. This strategic evolution aims to ensure the sustainability of the grid and to usher in a new era of energy autonomy for consumers. This is an example of dynamic policy evolution, where the focus transitions from mere solar generation to a more comprehensive approach to efficient energy consumption and management. As other regions contemplate their solar policy trajectories, the Californian model provides a thought-provoking blueprint that recognizes the evolving dynamics of the energy ecosystem and champions strategies that promote both individual empowerment and the broader sustainability of energy systems.

6. Conclusion

Ireland has witnessed an upsurge in installed solar photovoltaic (PV) capacity in recent years, which is a welcome contribution to the energy transition and decarbonisation. This rapid growth can be attributed to a combination of photovoltaic panel price falls, high electricity prices and government supports in place for utility-scale and micro-PV generation. Quantitative modelling of uptake by owner-occupier households indicates that the potential for rooftop solar PV adoption is far from saturated and will continue to grow through 2030. A successful extension of solar PV policy to tenants, apartment building residents, low-income households, local authority housing and to larger installations on public and commercial infrastructure has the potential to reshape Ireland's energy landscape at distribution level. A social benefit-cost analysis is needed to analyse the individual policies before implementation. Strengthened incentives for battery storage to promote increased self-consumption are also recommended.

7. References

Abreu, J., et al. (2019). New trends in solar: A comparative study assessing the attitudes towards the adoption of rooftop PV. Energy Policy, 128, 347–363. Available at: https://doi:10.1016/j.enpol.2018.12.038

Agdas, D., & Barooah, P. (2023). On the economics of rooftop solar PV adoption. Energy Policy, 178(113611). Available at: https://doi.org/10.1016/j.enpol.2023.113611

Alipour, M., Salim, H., Stewart, R.A., & Sahin, O. (2021). Residential solar photovoltaic adoption behaviour: End-to-end review of theories, methods and approaches. Renewable Energy, 170, 471-486. Available at: https://doi:10.1016/j.renene.2021.01.128

Al Khafaf, N., Asgharian Rezaei, A., Moradi Amani, A., Jalili, M., McGrath, B., Meegahapola, L., & Vahidnia, A. (2022). Impact of battery storage on residential energy consumption: An Australian case study based on smart meter data. Renewable Energy, 182, 390-400. ISSN 0960-1481. Available at: https://doi.org/10.1016/j.renene.2021.10.005.

Alrawi, O.F. and Al-Ghamdi, S.G. (2023). Residential Rooftop Photovoltaic Adoption Using a Sequential Mixed Methods Approach in Qatar. Sustainability, 15(7353). Available at: https://doi.org/10.3390/su15097353

Al-Sharafi, E.A. et al. (2023). Rooftop Solar PV Policy Assessment of Global Best Practices and Lessons Learned for the Kingdom of Saudi Arabia. Sustainability, 15(12). Available at: https://www.mdpi.com/2071-1050/15/12/9630

Bertsch, V., Geldermann, J., & Lühn, T. (2017). What drives the profitability of household PV investments, self-consumption and self-sufficiency? Applied Energy, 204, 1-15. ISSN 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2017.06.055

Best, R., et al. (2019a). Factors contributing to energy-related financial stress in Australia. Economic Record. Available at: https://onlinelibrary.wiley.com/doi/full/10.1111/1475-4932.12504

Best, R., et al. (2019b). Understanding the determinants of rooftop solar installation: evidence from household surveys in Australia. Australian Journal of Agricultural and Resource Economics, 63, 922–939. Available at: https://doi.org/10.1111/1467-8489.12319

Best, R., Li, H., Trück, S., & Truong, C. (2021). Actual uptake of home batteries: The key roles of capital and policy. Energy Policy, 151, 112186. ISSN 0301-4215. Available at: https://doi.org/10.1016/j.enpol.2021.112186

Best, R., Kent, D., & Lee, M. (2023). Solar battery rebates for Victorian homes: Eligibility and impacts. Energy Policy, 178, 113594. ISSN 0301-4215. Available at: https://doi.org/10.1016/j.enpol.2023.113594.

Bódis, K., et al. (2019). A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. Renewable and Sustainable Energy Reviews, 114(109309). Available at: https://doi:10.1016/j.rser.2019.109309

Campoccia, A., et al. (2014). Solar Energy. An analysis of feed-in tariffs for solar PV in six representative countries of the European Union, 107, 530 – 542. Available at: https://doi.org/10.1016/j.solener.2014.05.047

Carroll, J. Denny, E. and Lyons, R.C. (2020). Better energy cost information changes household property investment decisions: Evidence from a nationwide experiment. Retrieved from https://www.tcd.ie/Economics/TEP/2020/tep1520.pdf

Castaneda, M., Zapata, S., Cherni, J., Aristizabal, A. J., & Dyner, I. (2020). The long-term effects of cautious feed-in tariff reductions on photovoltaic generation in the UK residential sector. Renewable Energy, 155, 1432-1443. ISSN 0960-1481. Available at: DOI: 10.1016/j.renene.2020.04.051

CSO. (2016). Retrieved from https://www.cso.ie/en/releasesandpublications/ep/p-cp1hii/cp1hii/od/

CSO. (2023). Retrieved from https://www.cso.ie/en/statistics/population/censusofpopulation2022/

Climate Action Plan (CAP). (2022). Retrieved from https://www.gov.ie/en/publication/7bd8c-climate-action-plan-2023/

Cuenca, J.J., et al. (2023). Sharing the grid: The key to equitable access for small-scale energy generation. Applied Energy, 349(121641). Available at: https://doi:10.1016/j.apenergy.2023.121641

Danielis, R., et al. (2023). Simulating the Diffusion of Residential Rooftop Photovoltaic, Battery Storage Systems and Electric Cars in Italy: An Exploratory Study Combining a Discrete Choice and Agent-Based Modelling Approach. Energies, 16(557). Available at: https://www.mdpi.com/1996-1073/16/1/557

Department of the Environment, Climate and Communications. (2023). Retrieved from https://www.gov.ie/en/organisation/department-of-the-environment-climate-and-communications/

DECC. (2022). DECC Climate Action Plan. Retrieved from https://www.gov.ie/en/publication/7bd8c-climateaction-plan-2023/.%202022

Department of Agriculture, Food and the Marine. (2023). Retrieved from https://www.gov.ie/en/organisation/department-of-agriculture-food-and-the-marine/

Dezeen. (2021). Retrieved from https://www.dezeen.com/2021/08/27/wilton-sydney-dark-roofs-climate-change/

Dubey, S., Sarvaiya, J. N., & Seshadri, B. (2013). Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world–a review. *Energy procedia*, *33*, 311-321.

EirGrid. (2023a). Retrieved from https://www.eirgridgroup.com/how-the-grid-works/renewables/

EirGrid (2023b). System and Renewable Data Summary Report. Renewable Energy webpage. Available at: https://www.eirgridgroup.com/site-files/library/EirGrid/System-and-Renewable-Data-Summary-Report.xlsx

EnergyD. (2020a). Ireland's trusted solar panel experts. Are Solar Panels Worth It In Ireland? (Costs vs Savings). Retrieved from https://energyd.ie/are-solar-panels-worth-it-in-ireland/

EnergyD. (2020b). Ireland's trusted solar panel experts - Solar Panels Cost Guide For Houses in Ireland. Retrieved from http://energyd.ie/solar-panels-cost-ireland/

Esplin, R., & Nelson, T. (2022). Redirecting solar feed-in tariffs to residential battery storage: Would it be worth it? Economic Analysis and Policy, 73, 373-389. ISSN 0313-5926. Available at: https://doi.org/10.1016/j.eap.2021.12.008

EU Directive. (2018). DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

European Commission (2009) Renewable Energy Directive (2009/28/EC). Retrieved from https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

EU Solar Energy Strategy. (2022). Retrieved from https://energy.ec.europa.eu/topics/renewable-energy/solar-energy_en

EU Solar Energy Strategy (2023). Retrieved from https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13338-EU-solar-energy-strategy_en

Fraunhofer Institute for Solar Energy Systems. (2023). Photovoltaics Report 2023. Retrieved from https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

Feng, K., et al. (2023). Low-Income and Elderly with Feed-in Tariffs Drive Solar Installation Rates for Energy Equity. Available at: https://doi.org/10.21203/rs.3.rs-2815646/v1

Fina, B. et al. (2021). Exogenous influences on deployment and profitability of photovoltaics for self-consumption in multi-apartment buildings in Australia and Austria. Applied Energy, 283(116309). Available at: https://doi.org/10.1016/j.apenergy.2020.116309

Galvin, R. (2023). Do housing rental and sales markets incentivise energy-efficient retrofitting of western Germany's post-war apartments? Challenges for property owners, tenants, and policymakers. Energy Efficiency, 16:25. Available at https://doi.org/10.1007/s12053-023-10102-y

Gernaat, D.E.H.J., et al. (2020). The role of residential rooftop photovoltaic in long-term energy and climate scenarios. Applied Energy, 279(115705). Available at: https://doi.org/10.1016/j.apenergy.2020.115705

Ghaleb, B., & Asif, M. (2022). Assessment of solar PV potential in commercial buildings. Renewable Energy, 187, 618-630. https://doi.org/10.1016/j.renene.2022.01.013

Government of Ireland. (2023). Solar PV Scheme. Government of Ireland. Retrieved from https://www.gov.ie/en/press-release/b40ad-ministers-ryan-and-coveney-announce-enhanced-supports-for-business-through-solar-pv-scheme/

Grafstrom, J., & Poudineh, R. (2023). No evidence of counteracting policy effects on European solar power invention and diffusion. Energy Policy, 172(113319). Available at https://doi:10.1016/j.enpol.2022.113319

Hu, H.J.J., & Popiolek, N. (2014). A comparative study on the consequence and impact of public policies in favor of solar photovoltaic (PV) development. International Energy Policy & Programme Evaluation Conference. Available at: https://energy-evaluation.org/wp-content/uploads/2019/06/2014-berlin-julie-hyun-jin-yu.pdf

Hyvonen, J., et al. (2023). Possible bottlenecks in clean energy transitions: Overview and modelled effects – Case Finland. Journal of Cleaner Production, 410(137317). Available at: https://doi:10.1016/j.jclepro.2023.137317

IEA (2020). Retrieved from https://www.iea.org/data-and-statistics/charts/evolution-of-solar-pv-module-cost-by-data-source-1970-2020

IEA. (2022a). Retrieved from https://www.iea.org/energy-system/renewables/solar-pv

IEA (2022b) Solar PV Global Supply Chains – Analysis, International Energy Agency. Retrieved from https://www.iea.org/reports/solar-pv-global-supply-chains.

IEA. (2023). Retrieved from https://www.iea.org/policies?technology%5B0%5D=Solar%20PV&region%5B0%5D=Europe#

IEA-PVPS. (2023). Retrieved from https://iea-pvps.org/wp-content/uploads/2023/04/IEA_PVPS_Snapshot_2023.pdf

IPCC. (2023). Retrieved from https://www.ipcc.ch

IRENA. (2017). Retrieved from https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

IRENA. (2018). Retrieved from https://www.irena.org

IRENA. (2019). Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Nov/IRENA_Future_of_Solar_PV_summary_2019.pdf

IRENA. (2022). Off-grid for Energy Access. Policies and Benefits. Retrieved from https://www.irena.org/Energy-Transition/Policy/Off-grid-for-Energy-Access/Policies-and-Benefits

IRENA. (2023a). Retrieved from https://www.irena.org/Energy-Transition/Technology/Solar-energy

IRENA. (2023b). The cost of financing for renewable power. IRENA. Retrieved from https://www.irena.org/Publications/2023/May/The-cost-of-financing-for-renewable-power

ISEA. (2023). Retrieved from https://www.irishsolarenergy.org/news-1/ireland%27s-solar-revolution

ISSDA | Commission for Energy Regulation (CER). (2012). University College Dublin. Retrieved from https://www.ucd.ie/issda/data/commissionforenergyregulationcer/

Joshi, S., & Deane, P. (2022). Quantifying the Potential for Rooftop Solar Photovoltaic in Ireland. MaREI. Available at: https://www.marei.ie/wp-content/uploads/2022/07/Quantifying-the-Potential-for-Rooftop-Solar-Photovoltaic-in-Ireland.pdf

Kılıç, U., & Kekezoğlu, B. (2022). A review of solar photovoltaic incentives and policy: Selected countries and Turkey. Ain Shams Engineering Journal, 13(5), 101669. ISSN 2090-4479. Available at: https://doi.org/10.1016/j.asej.2021.101669

La Monaca, S., & Ryan, L. (2017). Solar PV where the sun doesn't shine: Estimating the economic impacts of support schemes for residential PV with detailed net demand profiling. Energy Policy, 108, 731-741. ISSN 0301-4215. Available at: https://doi.org/10.1016/j.enpol.2017.05.052

Lan, H., et al. (2020). An evaluation of feed-in tariffs for promoting household solar energy adoption in Southeast Queensland, Australia. Sustainable Cities and Society, 53. Available at: https://doi.org/10.1016/j.scs.2019.101942

Meles, T. H., Ryan, L., & Mukherjee, S. C. (2022). Heterogeneity in preferences for renewable home heating systems among Irish households. Applied Energy, 307, 118219. ISSN 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2021.118219

Mongkoldhumrongkul, K. (2023). Techno-economic analysis of photovoltaic rooftop system on car parking area in Rayong, Thailand. Energy Reports, 9, 202–212. Available at: https://doi:10.1016/j.egyr.2022.10.421

Mountain, B., & Szuster, P. (2015). Solar, Solar Everywhere. IEEE Power & Energy Magazine. Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7131647

Murphy, F., & McDonnell, K. (2017). A Feasibility Assessment of Photovoltaic Power Systems in Ireland; a Case Study for the Dublin Region. Sustainability, 9(2), 302. Available at: https://www.mdpi.com/2071-1050/9/2/302

O'Shaughnessy, E. (2023). Rooftop solar deployment, what's next? Next Energy, 1(100002). Available at: https://doi:10.1016/j.nxener.2023.100002

Petrov, I and Ryan, L. (2018). Information Asymmetry, Split Incentives and Energy Efficiency in the Residential Rental Market.

Photovoltaics - Science Direct. (2023). Retrieved from https://www.sciencedirect.com/topics/engineering/photovoltaics

Public Utility Commission - Science Direct. (2023). Retrieved from https://www.sciencedirect.com/topics/engineering/public-utility-commission

Quitzow, R. (2015). Assessing policy strategies for the promotion of environmental technologies: A review of India's National Solar Mission. Research Policy, 44(1), 233-243. ISSN 0048-7333. Available at: https://doi.org/10.1016/j.respol.2014.09.003

Rengasamy, M., et al. (2020). The Motivation for Incorporation of Microgrid Technology in Rooftop Solar Photovoltaic Deployment to Enhance Energy Economics. Sustainability, 12(24), 10365. Available at: https://www.mdpi.com/2071-1050/12/24/10365

Roberts, M.B., Bruce, A., & MacGill, I. (2019). Impact of shared battery energy storage systems on photovoltaic self-consumption and electricity bills in apartment buildings. Applied Energy, 245, 78-95. Available at: https://doi:10.1016/j.apenergy.2019.04.001

Rode, J., & Weber, A. (2016). Does localized imitation drive technology adoption? A case study on rooftop photovoltaic systems in Germany. Journal of Environmental Economics and Management, 78, 38–48. Available at: https://doi:10.1016/j.jeem.2016.02.001

Ruokamo, E., et al. (2023). Innovators, followers and laggards in home solar PV: Factors driving diffusion in Finland. Energy Research & Social Science, 102(103183). Available at: https://doi:10.1016/j.erss.2023.103183

Schardt, J., & te Heesen, H. (2020). Performance of roof-top PV systems in selected European countries from 2012 to 2019. Solar Energy, 217, 235–244. Available at: https://doi:10.1016/j.solener.2021.02.001

SEAI. (2017). Ireland's Solar Value Chain Opportunity. Retrieved from https://www.seai.ie/publications/Solar-Chain-Opportunity-report.pdf

SEAI Building Energy Ratings. (2022a). Retrieved from https ://ndber.seai.ie/BERResearchTool/ber/search.aspx

SEAI. (2022b). Policy options to support the up-take of Small-scale Renewable Electricity Generation in Ireland. Retrieved from https://assets.gov.ie/232068/fefeb1e3-5028-4cca-b86b-2b87b201b176.pdf

SEAI. (2023a). Solar Electricity PV Grants | Home Energy Grants. SEAI. Retrieved from https://www.seai.ie/grants/home-energy-grants/solar-electricity-grant/

SEAI (2023b). Promoting retrofitting among homeowners in Ireland through a behavioural lens. Retrieved from https://www.seai.ie/publications/Promoting-retrofitting-among-homeowners-in-Ireland-through-a-behavioural-lens.pdf

SEAI Solar Atlas. (2023). Retrieved from https://www.seai.ie/technologies/seai-maps/solar-map/

Solar Panel Grant Ireland | A Bittersweet Update From The Sustainable Energy Authority Of Ireland. (2022). SolarShare. Retrieved from https://solarshare.ie/articles/seai-grants-solar-pv-update-february-2022/

Solar Share. (2022). SEAI Grants 2022: Solar Panel Grant Ireland | A Bittersweet Update From The Sustainable Energy Authority Of Ireland. SolarShare. Retrieved from https://solarshare.ie/articles/seai-grants-solar-pv-update-february-2022/

Sundaram, A., Goncalves, J., Ghorbani, A., & Verma, T. (2023). Designing Policies for Equitable Adoption of Rooftop Solar PV. Available at SSRN: https://ssrn.com/abstract=4403544 or http://dx.doi.org/10.2139/ssrn.4403544

Syed, M. M., Hansen, P., & Morrison, G. M. (2020). Performance of a shared solar and battery storage system in an Australian apartment building. Energy and Buildings, 225, 110321. ISSN 0378-7788. Available at: https://doi.org/10.1016/j.enbuild.2020.110321

The Guardian. (2022). Retrieved from https://www.theguardian.com/world/2022/nov/09/france-to-require-all-large-car-parks-to-be-covered-by-solar-panels

UNFCCC. (2015). ADOPTION OF THE PARIS AGREEMENT. United Nations. UNFCCC. Retrieved from https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Vespasiano, F., Vespasiano, D., Troiani, C., Nardecchia, F., & Pompei, L. (2023). Towards smart communities: Evaluation of solar photovoltaic panels on a parking depot. In 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Madrid, Spain, pp. 1-5. Available at: https://doi: 10.1109/EEEIC/ICPSEurope57605.2023.10194896

Wolske, K.S., Stern, P.C., & Dietz, T. (2017). Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. Energy Research & Social Science, 25, 134-151. Available at https://doi:10.1016/j.erss.2016.12.023

Wolske, K.S. (2020). More alike than different: Profiles of high-income and low-income rooftop solar adopters in the United States. Energy Research & Social Science, 63(101399). Available at: https://doi:10.1016/j.erss.2019.101399

World Bank. (2023). Global Solar Atlas. Global Solar Atlas. Retrieved from https://globalsolaratlas.info/global-pv-potential-study

Yan, G., & Han, L. (2023). The impact of rooftop solar on wholesale electricity demand in the Australian National Electricity Market. Frontiers in Energy Research, 11. Available at: https://www.frontiersin.org/articles/10.3389/fenrg.2023.1197504/full

Yu, H.J.J., & Geoffron, P. (2020). Chapter 13 - Solar PV market and policies. In S. Gorjian & A. Shukla (Eds.), Photovoltaic Solar Energy Conversion (pp. 413-437). Academic Press. ISBN 9780128196106. Available at: https://doi:10.1016/B978-0-12-819610-6.00013-2

Zander, K.K., Simpson, G., Mathew, S., Nepal, R., & Garnett, S.T. (2019). Preferences for and potential impacts of financial incentives to install residential rooftop solar photovoltaic systems in Australia. Journal of Cleaner Production, 230, 328-338. Available at: https://doi:10.1016/j.jclepro.2019.05.133

Zhan, S., Dong, B., & Chong, A. (2023). Improving energy flexibility and PV self-consumption for a tropical net-zero energy office building. Energy & Buildings, 278(112606). Available at: https://doi.org/10.1016/j.enbuild.2022.112606

Zhang, Y., Chang, R., Zuo, J., Shabunko, V., & Zheng, X. (2023). Regional disparity of residential solar panel diffusion in Australia: The roles of socio-economic factors. Renewable Energy, 206, 808-819. ISSN 0960-1481. Available at: https://doi.org/10.1016/j.renene.2023.02.111.