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How photovoltaics can contribute to GHG emission reductions of 55% in the EU by 2030

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ABSTRACT

The new European Commission plans to raise the greenhouse gas (GHG) emissions reduction target from 40% towards 55% by 2030 and make Europe the first climate-neutral continent by 2050. Achieving this will require accelerated energy efficiency measures, deeper electrification of sectors currently consuming conventional fuels and the deployment of more renewables, faster. This opinion article looks specifically at the role of photovoltaics (PV), based on scenarios from the Commission's 2018 long-term strategy (LTS) for energy and climate. To reach a 55% GHG emissions reduction, the cumulative PV capacity in the EU and the UK would need to surge to 455–605 GW, depending on the strategic policy scenario. This implies a compound annual growth rate between 12 and 15% in the timeframe 2020–203 to increase the annual PV market from approximately 16.5 GW in 2019 to 50–80 GW by 2030. Such a volume can provide the basis for reviving the European solar manufacturing industry as well as creating more than 100 000 jobs along the value chain.

1. Introduction

Solar PV power generation is one of the pillars of the plans to decarbonise the EU's power supply and its role is highlighted in the European Commission Communication "A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" [1]. Recent technology progress positions PV among the most cost-effective electricity generation technologies [2]. PV plants with storage are currently being built to operate without subsidies throughout Europe e.g. Ref. [3]. Soon, residential PV systems coupled with storage may provide electricity at costs below retail prices [2].

The 2018 recast of the Renewable Energy Directive [4] already set a 2030 target of 40% reduction in GHG emissions, together with 32% share of renewable energy in gross final energy consumption. In the 2020 European Green Deal [5], the new European Commission 2019–2024 declared its aim "to increase the EU's greenhouse gas emission reductions target for 2030 to at least 50% and towards 55% compared with 1990 levels in a responsible way" by mid-2020, and to achieve climate neutrality by 2050. The proposed European Climate Law [6] sets out a legal framework for this.

Plans for future GHG emission cuts align with the vision set out in 2018 in an EC Communication [1]. The accompanying in-depth analysis outlines pathways to realise the net-zero long-term strategy (LTS) based on the analysis of different scenarios [7]. A dedicated energy modelling exercise analysed nine cases i.e. a baseline and eight alternative scenarios, each with a different technology focus [8]. All scenarios build upon increased deployments of renewable energy sources (RES) and energy efficiency (EE). This article extends these officially endorsed results to explore the implications for an enlarged role for solar PV by 2030.

It is noted that 100% renewable electricity and even 100% renewable energy scenarios are also now being proposed. Descriptions of such energy transition pathways for Europe can be found in articles by Refs. [9–12]. These simulations are far more ambitious than the Commission's LTS pathways and all highlight the importance and value of PV to the energy transition.

Between 2010 and 2019 solar PV electricity generation capacity in the EU increased from 1.9 GW to over 133 GW (Fig. 1), exceeding previous expectations. In 2019 new PV capacity of 16.5 GW was installed and further market growth is expected for 2020 [13].

The installed PV power capacity in the EU and UK at the end of 2019 could generate around 150 TWh of electricity or about 5.2% of the final electricity demand. At first glance, this development appears to be a success. However, by looking at the annual installations over the last ten

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years, it becomes obvious that between 2011 and 2017 Europe's market share was declining not only in relation to the growing global market, but also in terms of actual installation figures (Fig. 2). This trend was finally reversed in 2018, when the EU PV market rebounded to about 9 GW, thanks to increased demand in Germany, the Netherlands, France, and Hungary.

2. Methodology

What can PV contribute to achieving a 55% GHG reduction target by 2030 in the EU? As the base year is 1990 and given that the EU achieved a GHG reduction of 23% up to 2018, a further 32% reduction would be needed by 2030 [15]. To answer this question, the paper analyses the 9 different scenarios that form the analytic basis for the 2018 Commission Communication "A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" [7]. The focus here is not a review of the existing literature about this topic, rather an analysis of what the Commission's 9 LTS scenarios for the EU – with all their possible shortcomings – would require PV to deliver for a 55% GHG reduction by 2030.

2.1. EU long-term strategy options for emissions and energy

The 9 scenarios describe the long-term strategy (LTS) options for 2050, with possible pathways to reduce the GHG emissions from 61% in the baseline scenario to more than 90% (net-zero GHG emissions) in the 1.5° scenarios by 2050 as compared to 1990 (Table 1).[2] GHG reductions of 80% by 2050, excluding the carbon sink effects from land use, land-use change and forestry (LULUCF) sector, are consistent with the temperature change objectives defined in the Paris Agreement [7].

The baseline scenario reflects the current climate and energy policies but is not consistent with the longer-term climate targets. For this, the nine LTS explore different sectoral options, namely broad electrification of all sectors (ELEC), extensive hydrogen use (H2), the use of e-fuels (P2X), deep energy efficiency measures (EE) and increased resource efficiency in terms of a circular economy (CIRC). A combination of these options provides an additional scenario (COMBO) that achieves higher GHG reductions. Finally, the full decarbonisation pathways (1.5TECH, 1.5LIFE) achieve net-zero GHG emissions subject to two main assumptions:

a) Introduction of significant capacities of carbon removal technologies from 2035 onwards.
b) Lifestyle changes from 2030 onwards.

2.2. Scenarios for 55% greenhouse gas emission reduction by 2030

Up to 2030 all scenarios assume the same pathway with moderate growth in electricity use by 13–14% compared to 2015 (the reference year for the modelling) and achieve a 46% reduction of the GHG emissions (higher than the current policy for a 40% reduction). The foreseen solar capacity is 320.5 GW_{AC} and we assume that this is realised with PV systems with a nominal power of 400 GW_{DC} (concentrated solar power may also play a minor role but this is not considered here). This is slightly higher than the estimated 360 GW_{DC} [16,17] needed to achieve the present 32% RES target in the recast Renewable Energy Directive [4].

To assess the implications of a 55% reduction in GHG emissions in the energy system, a linear interpolation is made of the scenario results for 2030 and 2050, taking account of the final level of GHG reduction achieved in each scenario. In most cases, the 55% GHG reduction level is reached 3–5 years after 2030. Only the baseline scenario trajectory needs until 2042 to reach this level. A similar interpolation is used to estimate the breakdown of power generation capacities and production corresponding to a −55% GHG reduction.

The final step is to postulate that the 55% GHG reduction scenarios are accelerated in time to 2030. This allows to calculate the compound annual growth rate of power generation capacities for 2020–2030,

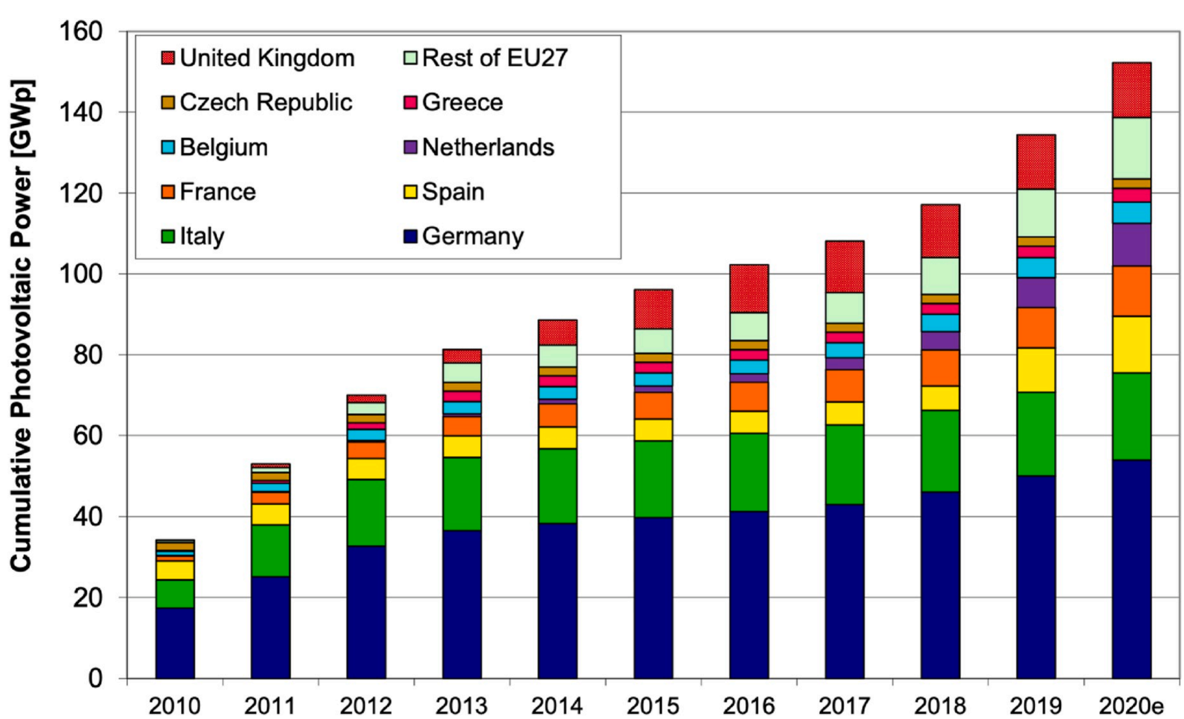

Fig. 1. Grid-connected PV capacity in EU and the United Kingdom, including JRC estimates for 2020 [13,14].

[2] The LTS analyses were made for the EU as it was in 2018, so including the UK.

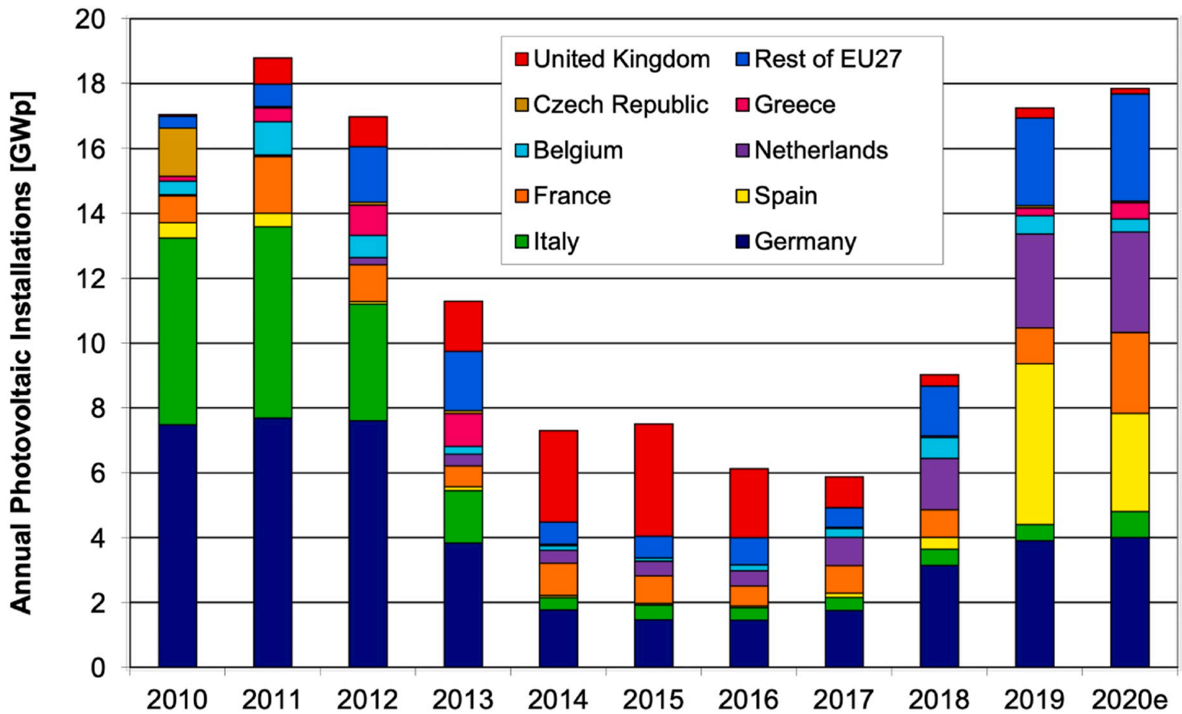

Fig. 2. Annual photovoltaic installations in EU and the UK from 2010 to 2020. Values for 2020 are based on authors' estimations [13,14].

Table 1
GHG reductions according to the LTS scenarios (excl. LULUCF) [7], showing also the interpolated value of model year to reach −55% GHG emissions.

		well below 2 °C					1.5–2 °C	1.5 °C	
Model year	Baseline	ELEC	H2	P2X	EE	CIRC	COMBO	1.5TECH	1.5LIFE
2030	−46%	−46%	−46%	−46%	−46%	−46%	−46%	−46%	−46%
2033							−55%	−55%	−55%
2034						−55%			
2035		−55%	−55%	−55%	−55%				
2042	−55%								
2050	−61%	−82%	−82%	−82%	−82%	−83%	−85%	−94%	−91%

assuming a starting value of 150 GW_{DC} in 2020.

3. Results

Table 2 summarises the estimates for solar PV capacity additions for 55% GHG reduction scenarios derived according to the methodology outlined above. A factor of 1.25 is used to convert the model value of AC power to the DC capacity, as is typical for sizing PV systems. However, given the fact that AC to DC ratio for utility-scale projects has increased by almost 50% between 2009 and 2019 to maximise the time systems operate at their rated AC power, a higher conversion factor between 1.3 and 1.5 might have to be applied in the future [17]. The cumulative PV power capacity additions range between 455 and 605 GW_{DC} Fig. 3 illustrates the growth needed for the 2020 to 2030 period. The 2030 values are higher than the current ambition (400 GW_{DC} in 2030) by 55–205 GW_{DC}. A maximum compound annual growth rate (CAGR) of 15% is needed compared to 10.3% for the 46% GHG reduction target. Depending on the chosen pathway, a three to fivefold increase in the annual EU market would be necessary.

It is worth mentioning that values in the same range were already published by the European Photovoltaic Industry Association (EPIA) in 2008 [18]. At that time it was assumed that the Solar Europe Industry Initiative (SEII), which was launched under the European Union's Strategic Energy Technology Plan (SET Plan), would enable the European PV industry to become fully cost-competitive by 2020 [19]. The discussion at that time focused on the topic of where, when and under which conditions PV electricity could achieve grid parity [20–22].

The trend for higher DC to AC ratios in utility PV plants, as mentioned above, could further raise PV capacity as could the possible repowering of existing solar photovoltaic plants (although this is considered to be only about 10 GW until 2030 [7,13]).

Table 2
Calculated PV capacities for 55% GHG reduction in the LTS model scenarios.

	Base-line	ELEC	H2	P2X	EE	CIRC	COMBO	1.5-TECH	1.5LIFE
Model year to reach -55% GHG	2042	2035	2035	2035	2035	2034	2033	2033	2033
Solar capacity for -55% GHG [GW_{AC}]	393	364	377	412	443	484	438	439	395
Corresponding PV capacity [GW_{DC})]	491	455	471	515	554	605	548	549	494
Δ PV capacity from 2020 [GW_{DC}]	361	325	341	385	424	475	418	419	364
Compound Annual Growth Rate 2020–2030	11%	10%	10%	11%	13%	14%	12%	12%	11%

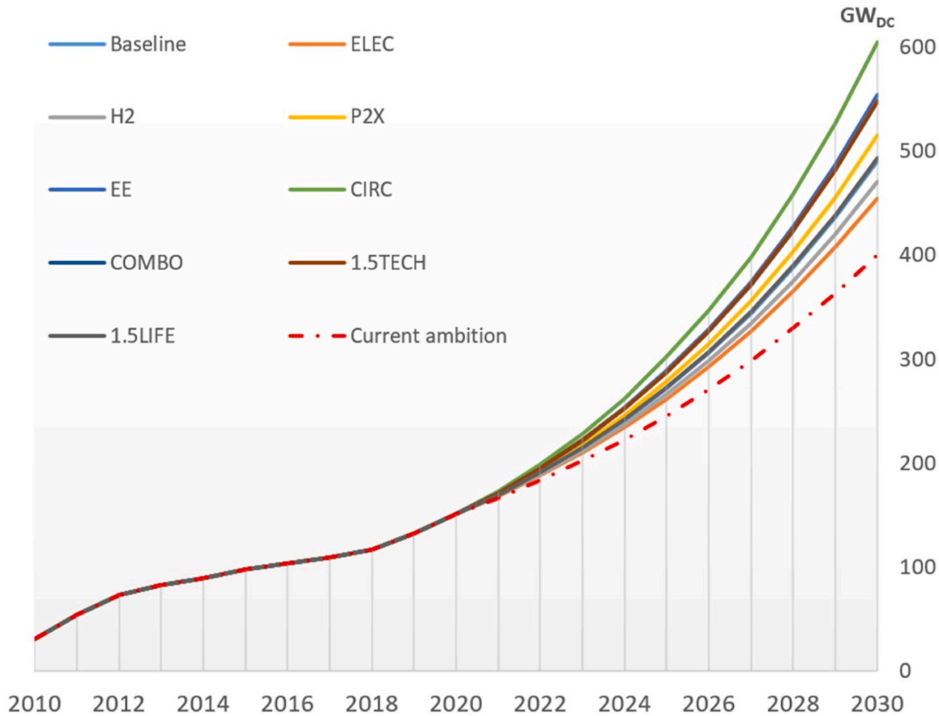

Fig. 3. Solar PV capacity projections in the EU to achieve −55% GHG in 2030 under the LTS scenarios. Current ambition results in 46% GHG reductions [7].

4. Discussion

4.1. Uncertainties related to electricity demand

To reach the −55% GHG emissions level, the LTS scenarios anticipate a moderate increase in electricity demand of 13% by 2030 compared to the Eurostat data for 2018. However, there is a risk that the LTS assumptions may not fully capture the structural changes to electricity consumption that can occur over the coming decade and are likely to increase demand, as outlined below.

All LTS scenarios assume a decarbonisation of the residential and tertiary sectors by 55% and 65% in 2030 and 2035, respectively. Given the fact that these two sectors are currently responsible for about 57% of the final electricity demand [23] and their demand is assumed to grow by 27% and 14% respectively, a higher level of electricity demand is likely [24]. Besides, LTS projections consider electrification as a no-regret option when cost-effective [8].

Another open question is how the transport sector will achieve GHG emission reductions by 20% (2030) and 28–42% (2035) as the LTS scenarios anticipate. This includes only a 10% increase in biofuel consumption until 2030, as it is uncertain when advanced biofuels will enter mass production. Therefore, achieving the 55% GHG reduction by 2030 requires mass electrification for transport and/or additional electricity for power-to-gas/liquid. Again, this would require a higher production capacity of low-carbon electricity sources, mainly solar and wind, to cover the additional needs.

The main driver of the decarbonisation of the power sector in the 9 LTS scenarios until 2030/35 is the substitution of coal-fired power stations with gas-fired ones [7]. However, despite the lower carbon footprint of gas-fired power plants, it still represents a carbon lock-in for any new gas-fired power stations built in the next decade. The only carbon-neutral option for the post-2030 operation of these new power stations would be biogas and synthetic gas generated from RES (syngas), which would itself have consequences. Due to the conversion losses in syngas production, to be competitive syngas production needs to utilise the surplus electricity from variable RES sources already supplying the grid [8]. Adding this need for syngas with those in the transport and industrial sectors, such a pathway could eventually increase the demand for electricity substantially.

Given the above factors, there may be a need for additional electric power generation by 2030 that the LTS projections do not capture at the −55% GHG level, although they do play a significant role as decarbonisation deepens towards −80% GHG. The implication for the PV sector can be dramatic. With the assumption that the electricity supply ratio from wind and solar photovoltaics does not change over the next decade, an additional 10% increase of the electricity demand on top of the 13% projected by the 9 LTS scenarios would effectively double the required PV capacity additions in the EU as shown in Fig. 4, reaching the Terawatt scale. To achieve this, PV's CAGR would need to increase from 10% for business as usual up to 23%.

4.2. Markets and investments

A significant expansion of renewable power capacity presents challenges for the power market and for realising the investments needed in new generating capacities and grid infrastructure. It is widely acknowledged that the current wholesale market arrangements in many EU countries do not spontaneously generate the needed investments [25,26]. Indeed for PV and other renewables, the experience of the last 15 years has been one of a policy-driven market environment and as such highly sensitive to policy changes at the national level. The resulting series of market expansions and contractions is evident in Fig. 2. Going forward it is critical to create and implement stable plans for market reform, as foreseen in the overall framework of the recast EC Market Directive [27]. This can give confidence to investors but specific financial instruments may be also needed, for instance to ensure uniform access to low credit risk financing for renewables projects in all member states. Parallel to that, an enhanced role for the Emission Trading Scheme (ETS) supported by the recently introduced Market Stability Reserve can accelerate decarbonisation efforts and favour RES deployment and investments in low-carbon enabling technologies (e.g. storage) [28].

At prosumer level, increased efforts are needed to make the rooftop PV installation market more cost competitive and reduce administrative

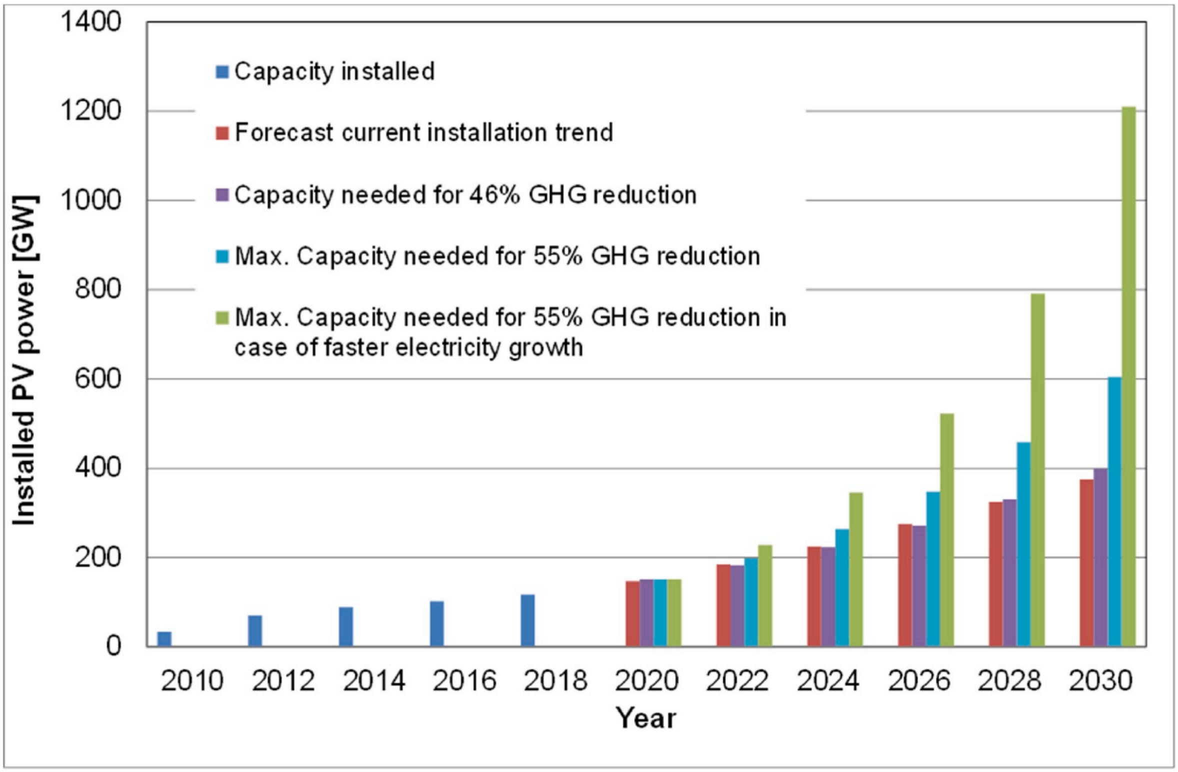

Fig. 4. Actual and projected photovoltaic installations from 2010 to 2030 [7 and own estimates].

and other soft costs. For instance, a stable, cross-border PV market within the EU can enhance competition for installers and promote efficient market-mechanisms [29]. Policy implementation guidance at EU level could also help push down costs in individual jurisdictions. Similarly, the possibilities for renewable energy communities [4] and citizen energy communities [27] envisaged in recent EU directives can scale-up installation. Such interventions need to be transposed into effective legal measures at national level to support a proliferation of smaller installations funded by private investors.

4.3. Opportunities for a renaissance in PV manufacturing capacity

The current production capacities for solar cells and modules in the EU are just 1 GW and 3 GW respectively. From a security of supply point of view, the projected massive increase of installations (from 16.5 GW_{DC} in 2019 to >50 GW_{DC} in 2030) should be matched by an EU regional manufacturing to ensure supply and avoid disruptions.

Recent rapid cost reductions in PV manufacturing coupled with a large increase in module demand could bring PV factories back to Europe. Indeed CAPEX costs for polysilicon, solar cell and module manufacturing plants have decreased by 75 and 90% between 2010 and 2018 [30,31].

Applying Manufacturing 4.0 methods can also contribute. The often-cited obstacle of high labour costs in Europe could be compensated by utilising cutting-edge automation solutions. Evidence of such an approach already exists: Tongwai Solar has started the operation of a 2 GW solar cell facility in Shuangliu, China, and claims that it manufactures 1 GW of solar cells with 300 people compared to 3000 in 2011 [32]. On the solar module side, Hanwah Q-Cells reported the opening of their latest module factory in Dalton, GA, USA, where 650 staff manufacture 1.7 GW of modules, annually [33]. Similarly, First Solar claims that its new CdTe-thin film factory in Lake Towship, OH, USA, has an annual manufacturing capacity of 1.3 GW and a staff of 500 [34]. Economies of scale are critical and a recent study has shown that a European manufacturing chain could be competitive with solar PV factories with an annual production volume between 5 and 10 GW [35].

As far as raw materials are concerned, the EU hosts one of the leading polysilicon manufacturers (Wacker Polysilicon AG) with total annual productivity of 80 000 MT (60 000 in Germany and 20, 000 in USA). With an average material consumption of 4 g/W this production alone is sufficient for manufacturing 20 GW of solar cells. A significant part of the polysilicon manufactured in Europe is currently exported to China. However, the increase of Chinese cell manufacturing capacity exceeding the overall market growth led to a significant decrease in sales and profits for Wacker in 2018.

4.4. Job impacts of decarbonising the power sector

The European Green Deal offers an opportunity to expand sustainable and job-intensive activities in the areas of low-emission technologies, thus compensating for the reductions in employment in the fossil fuel sector and in carbon-intensive processes. Again here the PV sector can play an important role.

As described above, a revival of the EU PV industry that follows the *Manufacturing 4.0* paradigm would create about 6000–8000 permanent jobs for manufacturing 20 GW of solar cells annually. On top of that is the increased need for operation and maintenance (O&M) of the installed systems. According to the USA Solar Census, about 0.17 full-time work equivalents (FTE) per MW and year of installed PV systems were needed for O&M in 2018 [36] with a decreasing tendency due to continuously improving automation and digitalisation of O&M activities. Large-scale PV system installations require about 3.5 FTE per MW but this could fall as well. The number of FTE for rooftop installations will remain somewhat higher than that of utility-scale systems.

The additional PV capacity of about 325–475 GW_{DC} (Table 2) would be split between large-scale power plants and rooftop installations. At the end of 2018, about 19% of the installations in Europe were on rooftops, about 37% were commercial and industrial systems and about 34% were of utility-scale [37]. The installation of 150–300 GW_{DC} of large scale PV power capacity could create an increasing number of new construction jobs and could reach 60 000 to 150 000 by 2030. Even if the O&M FTE per MW were to halve over the next 10 years, this sector could add up to 30 000 jobs. Additional jobs could come from the installation and services for rooftop systems. In this case, however, quantification is more difficult as these jobs are more dependent on local regulations and building codes. Taking the large system FTE per MW as a lower bound benchmark, the installation and maintenance of new rooftop systems could add another 60 000 to 75 000 jobs by 2030. The above numbers refer to direct net employment and are in line with detailed studies that recognise the solar PV sector's importance as job creator [38].

4.5. Land-use challenges and opportunities

Solar PV system installations on the scale described above may face certain obstacles related to land availability and policies on the use of land, in addition to those regarding the integration of variable power sources in the electricity systems.

Rooftop PV systems do not capture productive land and their integration is relatively easier due to proximity to consumption points. The estimated solar photovoltaic potential of EU rooftops is about 560 GW and could generate 680 TWh of electricity every year [39]. Even a modest utilisation of this untapped potential could allow the addition of a few hundred GW of PV. In the EU and UK at present about 60% of the total PV system capacity is installed on rooftops [40]. Many of these systems were financed by citizens individually for their own houses. With the phase out of guaranteed feed-in tariffs, the use of PV electricity systems for self-consumption with and without local storage [41] and in multi-apartment buildings or building complexes [42] is gaining increasing attention.

An additional opportunity lies in utilising closed mines and their surrounding degraded land. Such an approach has several advantages and allows for integrated brownfield redevelopment solutions [43]. The need to decarbonise the EU power sector has far-reaching consequences for those European regions where coal and lignite are still mined (42 regions across 12 EU countries) and used in thermal power plants. Coal mining is still ongoing and accounts for significant economic activity [44]. A recent study by the authors [45], assessed the technical potential for solar photovoltaic electricity generation in CRiT regions and estimated it at 730 GW (mines and surrounding areas). Even a moderate utilisation of this potential could allow for the deployment of the required capacities with minimum land use conflicts, since the estimated potential excludes land dedicated to productive uses. Such installations could also benefit from dedicated financial instruments, including the Just Transition Fund [46].

4.6. How to integrate PV in power systems

The variable nature of PV will require some adaptation in the power sector in order to ensure grid stability and security of supply. Technological breakthroughs and significant R&D, including combinations of PV with demand management, storage or sector coupling, for example via power-to-gas, can help balance demand and supply. Nonetheless, some measures that facilitate the integration of large-scale PV [47] already exist, for instance grid codes for support voltage control that allow PV system inverters to provide reactive power [48].

Additional options lie in integrated system design and management, since wind and PV daily power output profiles are in many cases complementary [49], while design options increase can time complementarity between solar and run-of-river hydroelectric stations, with negligible additional costs [50]. The biggest opportunity lies probably in the electrification of the transport sector, which can be synergistic with PV [51]. Building-applied or building-integrated PV systems that power electric vehicles offer a set-up that aligns with the EU's system operators' proposal for direct consumption of RES electricity, where feasible [52].

Such interventions are particularly important in the short term as hydrogen storage and power-to-fuel solutions (LTS scenarios H2 and P2X) may not upscale until after 2030. Parallel to that, energy storage will play an important role. The LTS anticipates an increase of pumped storage capacities by 2030 (+8%). This requires enabling market conditions that remunerate storage services, thereby encouraging investments and high utilisation rates [53]. Battery storage is compatible with PV systems of different scales [doi.org/10.3390/en13020488]. Further cost reductions of batteries will make rooftop systems with storage the norm. Additional storage near consumption points (e.g. electric vehicles) can allow the integration of larger quantities of PV, mitigate grid congestion and minimise curtailments [41,54].

4.7. A no-regret option

Solar photovoltaic electricity generation is a readily available technology to bridge the identified gap in a short timeframe. Along with wind energy, they are the only technologically mature renewable options that the EU can deploy in large quantities, as hydropower and biomass face limited resource availability. Accelerating the annual PV installation rate compared to the current value is a no-regret option since all the LTS scenarios require PV capacity to at least double in size by 2030. Indeed, as explained above, solar PV module demand for the EU and UK would increase from 16.5 GW_{DC} in 2019 to 50 GW_{DC} in 2030.

Reaching the climate targets requires carbon-neutral electricity supply produced by 83% from RES [24]. In case there are insufficient solar PV installations to provide the required amounts of clean electricity, other RES technologies will have to fill the gap, mainly onshore/offshore wind. However, the envisaged wind installations are already significant (350 GW in 2030 [24]) and any further increase would be challenging. Given the limited options for hydropower and biomass expansion, moderate PV deployment would perforce increase power imports. Besides, emerging RES (e.g. ocean), power to gas, and carbon capture and storage (CCS) may not be ready to scale up by 2030. A higher increase in the final electricity demand than the expected 13–14% could even drive up the annual module demand to 200 GW_{DC} in 2030.

Continuous cost reductions of solar modules [13,55], as well as improving financing conditions in the EU [56] have rendered PV electricity highly competitive with conventional electricity generation technologies. Solar PV systems are, thus, cost-effective both presently and under the future LTS scenarios and since they do not involve trade-offs with other policy objectives, they represent a win-win option.

5. Conclusions

The European Union is currently following a pathway to reach 46% of GHG reduction by 2030. In order to increase the ambition towards 55% GHG reduction by 2030, the pathways in different long-term scenarios (as published in 2018) would have to be brought forward by between 3 and 12 years.

As some of the technological options in the different decarbonisation scenarios might not be mature enough within the next ten years, proven technologies like wind and solar photovoltaics will have to bridge the gap. This is a "no regrets" choice as both are already among the lowest cost electricity generation technologies.

In this paper, we only analysed the need for additional PV power capacity, but realising this will need accompanying measures such as additional electricity storage, power demand and supply management, as well as complementing renewable electricity generation capacities from wind or biomass.

The different decarbonisation scenarios to reach a 55% GHG reduction require installation of new PV capacity of between 325 and 375 GW_{DC} in the timeframe 2020 to 2030. The PV market volume in the EU would have to grow between three to five times compared to the 2019 level to achieve this goal. However, these values could almost double if the electricity demand rises faster than currently projected.

The focus of this expert view is on the analysis of the pathways for a 55% GHG reduction in the EU as published by the Commission in 2018. Nevertheless, to reach a climate neutral economy by 2050, a rapid decarbonisation of our energy supply in the next decade is crucial. Delays now can make future actions more costly and increase the probability to reach the climate tipping point, after which limiting the temperature increase to below 1.5 °C would no longer be possible in this century.

Policy implementation needs to support the legal framework set up with the EU Clean Energy Package, for instance with appropriate measures on electricity market design and instruments to provide uniform low credit risk for project financing in all member states.

The prospect of an invigorated EU PV market strengthens the case for a development strategy for the full PV value chain, supported by research and innovation. This should include new cell and module manufacturing in the EU. The development of the PV market needs a just transition dimension by ensuring a significant share of decentralised PV to provide local jobs and ensure citizen participation.

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