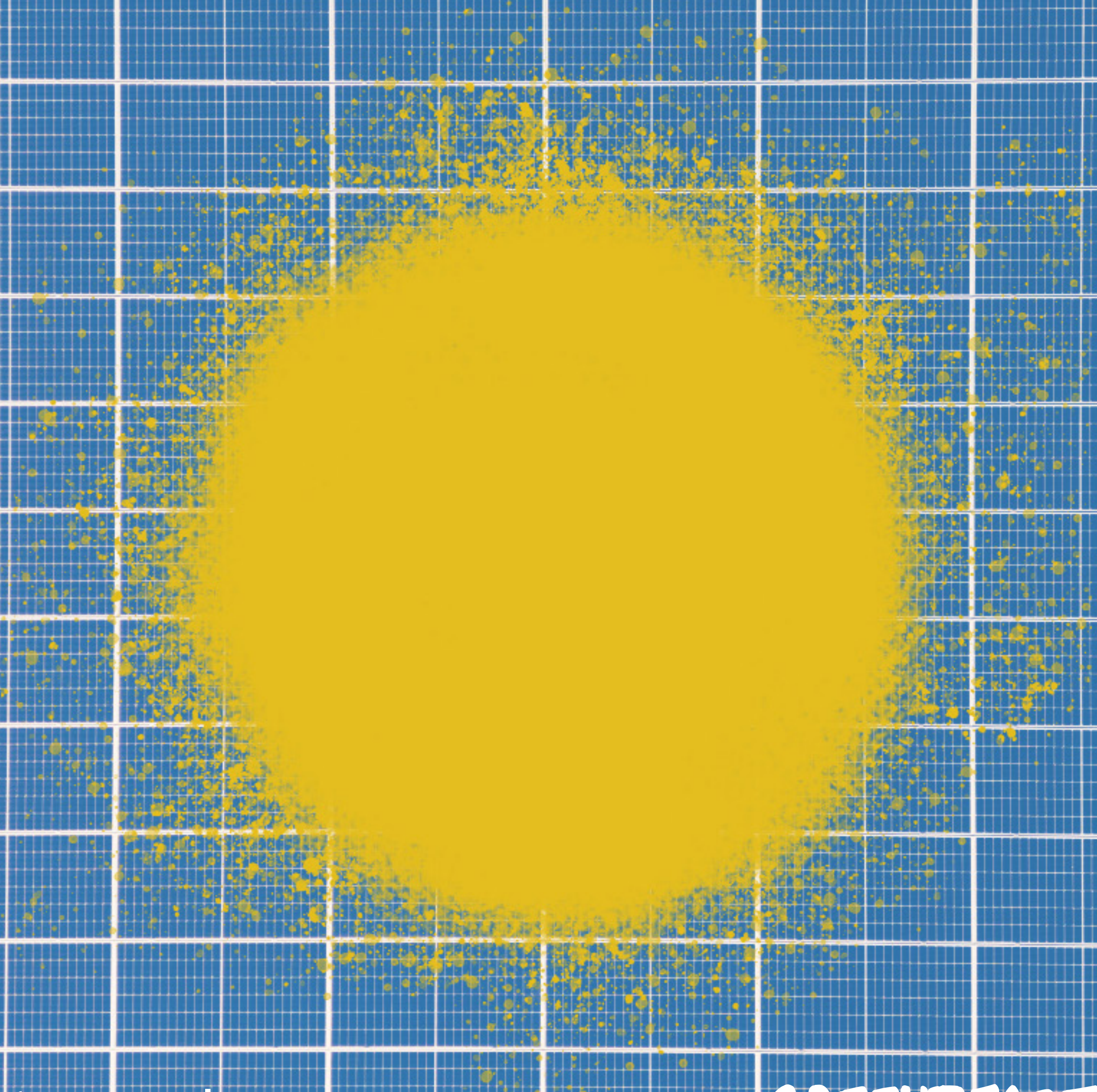
A SOLAR MARSHALL PLAN FOR UKRAINE

Empowering Ukraine's brighter future: bottlenecks and key policy reforms needed to boost solar PV deployment



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POLICY PAPER

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Executive summary

Solar PV holds significant potential for the reconstruction of Ukraine's electricity system. The Ukrainian solar PV sector has experienced rapid growth in the late 2010s, growing almost three-fold from 2.0 GW to 5.9 GW in 2018 alone, reaching a total of 8.06 GW by early 2022. Nonetheless, just as all segments of Ukraine's economy, the sector has been heavily impacted by Russia's invasion. Roughly 30% of all solar PV capacity has been affected as of mid-2024, much of which is temporarily unavailable, as it is either located in occupied territories or its status is unknown. Solar PV has however been fundamental to keeping the lights on in Ukraine, especially due to its highly decentralised nature. Both existing utility-scale solar PV, and the accelerated installation of small-scale distributed solar PV in the residential sector and public buildings (most notably schools and hospitals) have significantly increased system resilience, providing clean, reliable electricity even as large stationary fossil-fuel plants have been disabled. While the deployment of solar PV has been progressing even during the war, the recently adopted Ukraine Plan foresees total additions of only 0.7 GW by 2027, well short of Ukraine's significant technical potential. It is also unclear how such small additions square with more significant ambitions by 2030.

As such, this policy paper assesses the potential integration of larger amounts of solar PV into Ukraine's electricity system by 2027 and 2030, using a techno-economic modelling approach to determine a cost-optimal, adequate energy system. The findings show that by 2027, a total of 9.2 GW of total solar PV can be integrated into the system, meaning a 3.6 GW increase compared to today's levels: more than a five-fold increase compared to the additions envisioned in the Ukraine Plan. Additionally, 14 GW total, or an 8.4 GW increase compared to today's levels is possible by 2030, requiring a total of EUR 4.39 bn in investments. These targets represent the lower bound of possible installations based on estimates of Ukraine's future electricity demand, but given the cost competitiveness of solar PV, larger amounts of installed capacity of solar PV may be needed if the reconstruction progresses more rapidly and if more end sectors are electrified.

While these estimates hold significant promise for the greening of Ukraine's electricity system, the rest of this policy brief assesses the obstacles to the larger deployment of solar PV, focusing on both technical and market aspects and providing possible solutions. In terms of technical obstacles, balancing and grid stability, especially since the most recent attacks pose a challenge to the integration of variable renewable generation, but damaged and inadequate transmission infrastructure may lead to grid congestion and curtailment as well. Concurrently, to ensure an adequate and balanced electricity system, additional investments in storage and highly maneuverable power-generating technologies will be required to complement the roll-out of solar PV. In addition, labour availability and supply chain delays are also fundamental issues which must be considered.

Nonetheless, the market and economic obstacles are even more significant. The current structure of the wholesale market, including price caps, high levels of debt across the electricity system, including those on the renewable and balancing markets, inadequate incentives for investors and trust issues are a fundamental barrier to the further market-based development of solar PV. At the same time, the very high cost of capital, as well as regulatory aspects related to the sector further decrease attractiveness. As such, significant steps have to be made towards market liberalization, while considering social support mechanisms for vulnerable consumers. The paper concludes by providing policy recommendations to both Ukrainian decision-makers as well as international partners on how to catalyse Ukraine's solar PV sector, focusing, among others, on:

- Investments in grid stability and transmission infrastructure
- Decreasing financing costs and provision of capital and equipment
- Reforming and liberalising Ukraine's energy markets
- Strengthening public finance for renewables
- Facilitating the status of active consumers

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1. Introduction

Ukraine's energy system has been one of the most prominent sectors since Russia's invasion of the country in early 2022, showcasing remarkable levels of resilience despite significant levels of damage and destruction. As Ukraine battles to keep the lights on, the future of Ukraine's energy mix is however undergoing significant debate, although a strong consensus exists on the importance of the progressive roll-out of both small- and large-scale decentralised generation capacities.

Ukraine boasts significant renewable energy potential for both solar PV and wind power, and long-term strategies and plans foresee a significant role for both in any future energy mix. At the moment, the decentralised nature of solar PV also provides an optimal solution during the ongoing war, and low levelized costs of electricity and environmental benefits make it the ideal electricity source for Ukraine. Concurrently, a gap exists between less ambitious short-term plans for renewable roll-out and the country's significant RES potential and its ability to quickly install large quantities of solar PV capacity, as proven in 2018 where installed capacity nearly tripled from 2 to 5.9 GW. This paper assesses this dilemma specifically for the solar PV sector, examining the increased potential for solar PV roll-out by 2027 and 2030 vis-à-vis plans presented in the Ukraine Plan, which underpins the EU's Ukraine Facility. Assessing both existing plans and forecasts, and using a custom techno-economic modelling analysis, this policy brief presents a possible pathway for a more ambitious solar PV roll-out, including assessments of the financial requirements, but also the other technologies needed to ensure a balanced electricity system.

Nonetheless, significant obstacles to solar PV roll-out in the Ukrainian context exist, posing a threat to the future of a greener Ukrainian energy system. As such, the bulk of the analysis in this policy brief thereafter focuses on the technical, economic, and regulatory bottlenecks, presenting both the current state of play as well as possible remedies needed to unlock Ukraine's true solar PV potential.

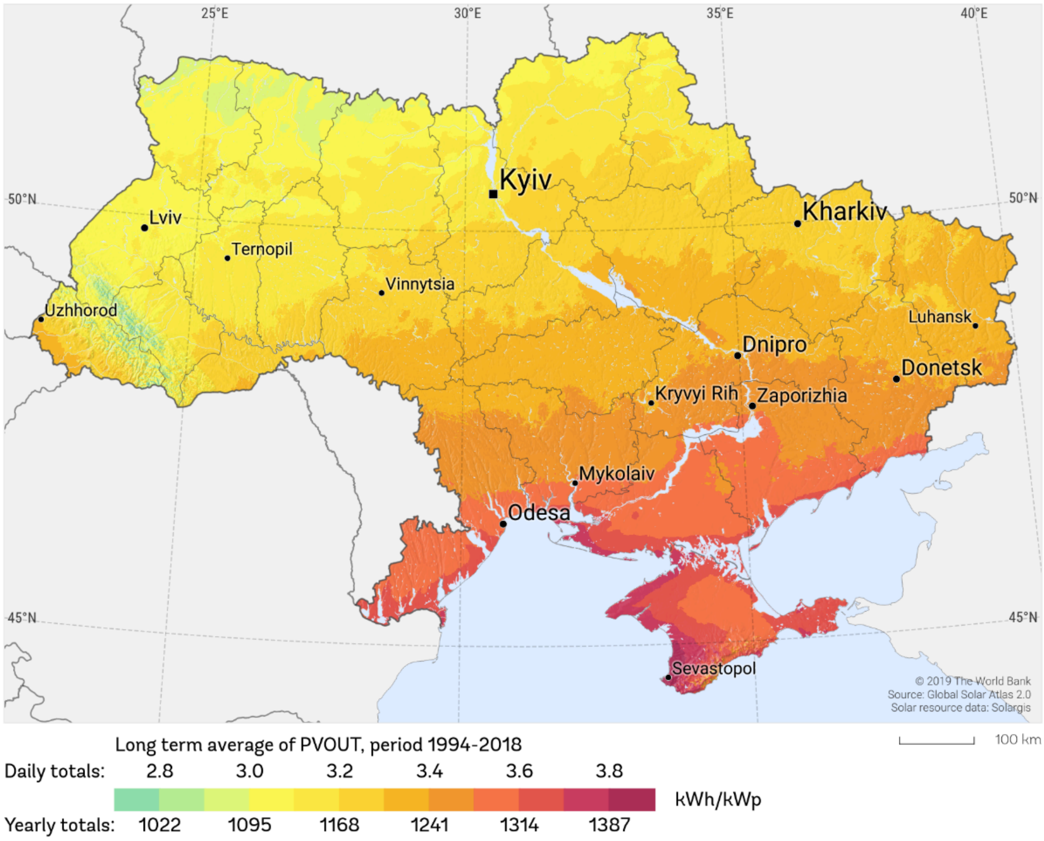
2. Current state of play of Ukrainian solar PV

In order to assess the potential for increasing solar PV deployment in Ukraine, the following sections survey the country's technical potential, but also the development of the industry so far, the current state of the energy system, and key market dynamics.

2.1 Technical potential

Ukraine boasts some of the most significant renewable energy potential in Europe, with great resources for both wind and solar PV generation. Several of the country's regions, including Crimea, Kherson, Mykolaiv and Odessa exceed 2400 hours of sunshine per year, with annual solar radiance levels around 1200kWh/m^2. The relatively flat topography of the solar-rich regions further facilitates the theoretical technical potential of building out significant solar PV capacity.

Figure 1: Solar photovoltaic power potential of Ukraine



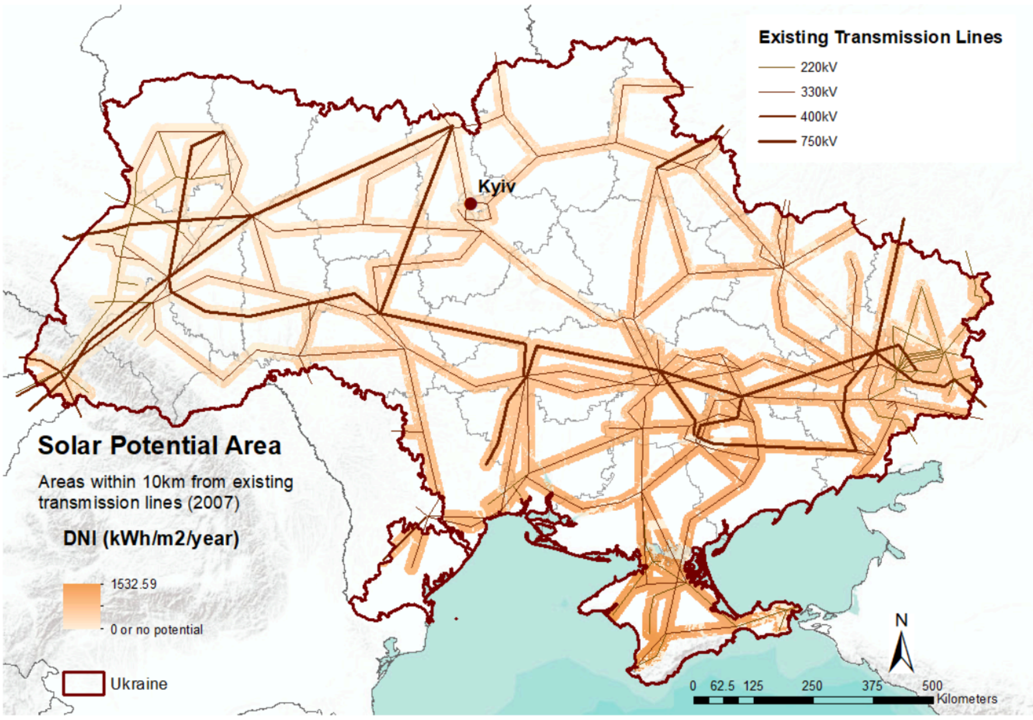
Source: The World Bank, Global Solar Atlas 2.0, Solar resource data: Solargis (2020)

A recent report commissioned by Greenpeace finds that the upper-bound solar PV capacity, taking into consideration available land under certain surface constraints[1] and proximity to high voltage power lines, exceeds 5000 GW with a possible annual output of over 5300 TWh of electricity, which dwarves Ukraine's pre-war electricity consumption of 125 TWh.[2]

[1] Surface constraints concern land cover, slope steepness, area protection, and solar irradiance.

[2] Greenpeace 2024, *Ukraine: Mapping the Energy Opportunities – Solar and Wind Energy Assessment*. Link

Figure 2: Ukraine's technical solar PV potential



Source: Greenpeace (2024)

Assessing other technical estimates which take additional factors like cost-competitiveness, population density, and system performance into account, an upper bound of 83 GW estimated by the Institute of Renewable Energy Sources of National Academy of Sciences of Ukraine is reached.[3] Computations conducted by IRENA yield a lower potential of 70.6 GW[4] and estimates of roughly 57 GW are found by the Energy Community.[5] However, independent of the underlying assumptions taken for quantifying solar PV potential, it is clear that the pre-war installed capacity of just over 8 GW represents a significant under-utilisation of the country's solar potential.

2.2 Installed generation capacities and damages

Over the course of the last decade, Ukraine has significantly bolstered its effort in increasing the renewable energy share within the electricity mix. While progress was slow until the late 2010s, Solar PV generation capacity almost tripled within a year from 2 GW in 2018 to 5.9 GW in 2019, and until 2021, the installed capacity grew further to reach a final total of 8.09 GW with no significant additional installations until 2022. During this period, solar PV experienced the most significant comparative rise in installed capacity vis-à-vis all the other generation capacities making up for 14% of the 57.4 GW total

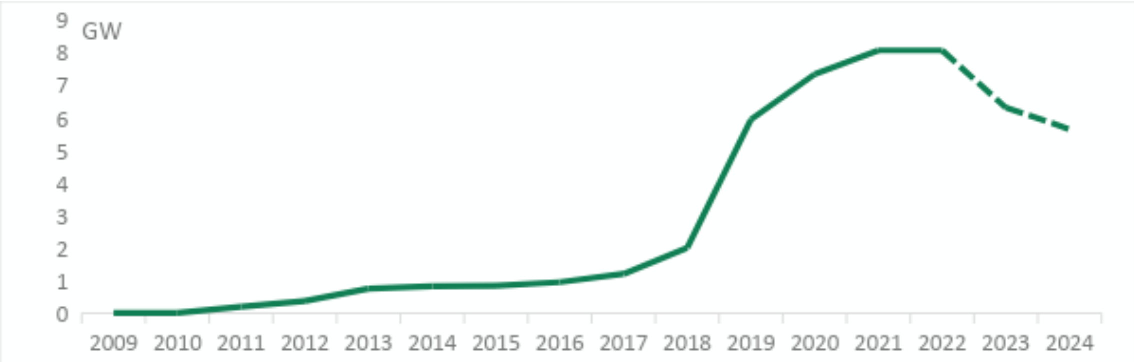
[3] IRE (2020). Атлас Енергетичного Потенціалу Відновлюваних Джерел Енергії України. Link

[4] IRENA (2017). *Cost-competitive renewable Power generation: Potential across South East Europe.* Link

[5] Energy Community Secretariat (2024). *Post War Development of the Renewable Energy Sector in Ukraine*. Link

installed capacity. Of the installed solar PV capacity in 2021, only 16% (~1.3 GW) was mounted as residential solar capacity, but the segment experienced the strongest annual growth at 54.7%. In comparison, utility scale, as well as commercial and public rooftop solar generation capacity constituted the remaining 84% (~6.8 GW) but additional deployment in 2021 was only 5%.[6]

Figure 2: Ukrainian solar PV capacity



Source: EMBER (2024), UNDP (2023), Ministry of Energy (2024). Values for 2023 and 2024 are estimations based on damages.

Ukraine's large installed generation capacity helped the country withstand Russia's direct attacks against the power infrastructure from late 2022 onwards, with remarkable system stability. However, the most recent attacks in early 2024 have led to massive damages to generation, transmission, and balancing capacity. DTEK, Ukraine's largest private electricity company, has lost over 80% of its electricity generation capacity and Centrenergo, the state-owned power generator, has seen its entire power plant fleet disabled due to either destruction or occupation.

As of May 2024, following the devastating strikes in March and April 2024, over 85% of generation capacity from thermal power plants and 50% from hydroelectric power plants has been lost and almost 45% of nuclear capacity cannot be used due to the occupation of Zaporizhzhia NPP. [7] With regards to renewable energy sources, approximately 30% of all solar PV and up to 90% of wind capacity has been occupied, damaged or destroyed.[8] This leads to an estimated available solar PV capacity of only 5.6 GW in 2024 and a total of available generation capacity ranging approximately between 17 and 19 GW.[9] As the system struggles with large reductions in capacity, the situation may be further worsened due to the required annual maintenance on Ukraine's nuclear power plants. While Ukraine is able to import up to 1.7 GW of electricity, it is estimated that there will be a significant electricity deficit already this summer. This has already materialised in mid-May, with planned electricity outages, with the situation expected to only deteriorate in the winter

[6] Energy Community Secretariat (2024). *Post War Development of the Renewable Energy Sector in Ukraine*. Link

EMBER (2024). Yearly electricity data. Link

[7] Matuszak, S. (2024). *Russia's new large-scale attacks on Ukraine's energy infrastructure: losses and challenges.* Analysis: Centre for Eastern Studies. Link

[8] Limb, L. (2024). *Ukraine's Green Fightback: Wind farms, solar schools and counting the cost of destroying nature, Euronews.Green.* Link:

[9] Matuszak, S. (2024). *Russia's new large-scale attacks on Ukraine's energy infrastructure: losses and challenges.* Analysis: Centre for Eastern Studies. Link

months.[10,11] The large-scale destruction of Ukraine's energy sector, especially the country's thermal power plants and hydropower also threaten the ability to adequately balance the electricity system.

At the same time, it is key to note that Ukraine's electricity demand has also witnessed a significant decrease given the destruction to both the residential sector, but also electricity-intensive industrial assets.

2.3 Current Solar PV market

The overwhelming majority of currently installed solar PV capacities has been constructed under the feed-in tariff support scheme, commonly known as the "Green Tariff" in Ukraine. The Green Tariff provides a fixed payment per generated unit of energy. For small-scale producers (without a commercial licence) this tariff is paid by the electricity supplier, while for commercial solar PV operators, it is paid by a central purchasing entity, the publicly owned enterprise Guaranteed Buyer (GB). The GB (or supplier) purchases the generated electricity from eligible producers, sells it on the wholesale market and bears responsibility for imbalances between forecasted and actual generation. From 2019 until recently, the level of the Green Tariff to be paid to solar PV producers has been set very generously, providing attractive conditions for solar PV investors, which has led to the observed boom in solar PV construction in 2019-2021. The payments to renewable energy (RE) producers under the Green Tariff are financed by the supplier/GB's revenues from selling the electricity on the wholesale market, as well as via an additional subsidy from a share of the transmission tariff collected by the Transmission System Operator (TSO) Ukrenergo and passed on to the supplier/GB.

Nonetheless, the inadequate level of the transmission tariff, as well as payment arrears from Ukrenergo to the GB, have led to a situation where the latter was unable to fulfil its payment obligations to RE producers. Ukrenergo, in turn, is suffering from payment arrears by other market participants in different market segments, in particular for the settlement of imbalances. In 2020, Ukraine's Parliament approved a retroactive cut to the Green Tariff, reducing the payment obligations to solar PV producers by up to 15% and introduced a stepwise reduction of Green Tariff payments for future installations. Despite the retroactive tariff cuts, the GB's payment arrears have persisted, with the GB only paying out ca. 55% of the Green Tariff in 2022/2023 (plus some additional deferred payments in late 2023 and early 2024).[12] Cumulatively, this has led to a net debt position which currently amounts to over UAH 20 bn (approx. EUR 500 m) from the GB to RES producers. Primarily, this is due to persistent payment arrears from Ukrenergo to the GB. With the full-scale Russian invasion of Ukraine and the targeted attacks on Ukraine's civilian energy infrastructure, Ukrenergo's finances have come under additional strains, adding to payment arrears to the GB. The retroactive payment cuts in 2020 and especially the payment arrears by the GB have created considerable uncertainty for solar PV investors since it is unclear when and whether the arrears will be resolved, and investors will be paid in full. The arrears also create liquidity risks for solar PV investors since the

[10] See: https://visitukraine.today/blog/3946/it-was-a-matter-of-time-why-are-the-power-cuts-in-ukraine-happening-again-and-are-there-any-schedules

[11] Matuszak, S. (2024). *Russia's new large-scale attacks on Ukraine's energy infrastructure: losses and challenges.* Analysis: Centre for Eastern Studies. Link

[12] https://dlf.ua/en/renewable-energy-in-ukraine-current-state-of-affairs/

irregular and incomplete payments by the GB make it difficult for investors to pay back bank loans and honour other payment obligations, which has strongly affected the investment climate for additional solar PV installations.

Another option for utility-scale solar PV investors, besides the Green Tariff, is selling electricity directly to the wholesale market. Some solar PV operators have recently used this option and left the Green Tariff scheme altogether. However, this is fraught with another set of problems. Selling into the wholesale market usually means either selling on the bilateral market for longer procurement periods or selling into the short-term market segments (day-ahead market, intraday market, balancing market). The bilateral market is relatively illiquid and highly concentrated in Ukraine. It also lacks suitable products with delivery periods suitable for solar PV producers. The short-term markets, especially the day-ahead market (DAM), are more liquid, even though they are also affected by considerable market concentration. However, the short-term markets are tightly regulated with price caps and price floors, affecting price formation and proper market functioning. As such, there are no adequate price spreads to incentivise market-driven investments in flexible generation and storage capacities. The lack of flexibility and storage providers reduces the ability of the system to integrate additional variable RE generation, in particular solar PV, and leads to very low prices during periods of high renewable potential (e.g. very sunny hours) on short-term markets, thus reducing the attractiveness for solar PV producers of directly selling into wholesale markets. Additionally, leaving the balancing group of the GB means that solar PV producers operating on the open wholesale market are themselves responsible for any imbalances between forecasted and actual generation. This has financial implications, since balancing volumes need to be procured on the balancing market, which is itself affected by payment arrears. Finally, there is anecdotal evidence that solar PV installations operating directly on the wholesale market are curtailed more often than those covered by the Green Tariff.

Another option for small-scale, in particular rooftop, solar PV producers, besides the Green Tariff, is the recently introduced net billing scheme for active consumers, also called prosumers. According to the net billing scheme, introduced as part of the Law 3220-IX on the Restoration and Green Transformation of the Energy System of Ukraine, active consumers can reduce their energy bills by consuming self-produced electricity and injecting surplus electricity into the grid, which is compensated at hourly wholesale DAM prices. The net billing scheme is particularly attractive to businesses and other entities facing cost-reflective market prices for electricity, where it has the potential to significantly reduce electricity bills, leading to relatively short payback periods for investments in solar PV installations. For residential prosumers, payback periods under the net billing scheme are still relatively long and unattractive due to the low opportunity cost of subsidised electricity provision from universal service suppliers.[13]

3. Modelling techno-economically optimal pathways for Ukraine's solar PV roll-out

While technical potential is fundamental to understand the amount of solar PV that can be built in Ukraine, techno-economic modelling must be conducted to ensure that the levels

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[13] See also Low Carbon Ukraine (2023). *Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Restoration and Green Transformation of the Energy System of Ukraine" n° 9011-d: Assessing the economics of prosumer provisions for residential rooftop PV*. Link

of deployed solar PV can be integrated into the system, and that both the technical and economic feasibility is ensured. The following section first surveys the different long-term energy system assessments conducted by various governmental and non-governmental stakeholder, and provides an additional assessment modelled by the authors of this study.

3.1 Comparison of existing studies and plans

As described in the previous section, Ukraine boasts a high technical potential for solar PV but utilises currently only a fraction of it. Ambitions to increase this value are set in the Ukraine Plan developed within the framework of the EU's Ukraine Facility. This plan pledges an expansion of solar PV capacity of only 0.7 GW, reaching approximately 6.3 GW in total, by 2027, using the conservative baseline of 5.6 GW of available capacity. After regaining temporarily occupied territory this value potentially increases, although it is yet to be fully assessed how much capacity will be destroyed. Nevertheless, the envisaged expansion presents only a modest increase given the natural potential and low levelised costs of electricity that solar PV can provide.

In order to ensure that the electricity system is balanced, the Plan also envisions an extra storage capacity by 2027 of 0.5 GW of grid-scale lithium-ion batteries. Furthermore, the development of additional long-term storage capacity using hydroelectric and hydro-accumulating power plants is targeted to reach 2.4 GW by 2027. Flexible peaking generation is planned to reach 0.96 GW by 2027 using highly flexible open-cycle gas turbines (OCGT). Comparing these targets to other modelling results, the Ukraine Plan demonstrates renewable ambitions below Ukraine's technical and economic potential.

While the Ukrainian Energy Strategy 2050 is not yet published in its entirety, some of the envisioned capacities are cited in Ukraine's draft NECP, presenting a more ambitious vision for the deployment of solar PV. The NECP adopts these numbers, forecasting a total solar power plant capacity of 12.6 GW targeted by 2032.[14] An adjusted assessment developed by the Energy Community that considers additional bottlenecks, business climate and a broader technological outlook envisions a similar value of 12 GW of installed solar PV capacity for 2032. With regards to planned balancing capacities, the draft NECP cites Ukrenergo estimates for 2030, which state that the expansion of solar PV should be accompanied by the provision of highly manoeuvrable power units that ramp up within 10 to 15 minutes from zero to nominal power with a capacity between 1.7 GW and 2.0 GW depending on the level of accepted curtailment. In addition, electricity storage capacity with a capacity of at between 0.8 GW and 2.0 GW should be available. [15]

[14] Ministry of Economy of Ukraine (2024). *Draft National Energy and Climate Plan (NECP)*

[15] Ministry of Economy of Ukraine (2024). *Draft National Energy and Climate Plan (NECP)*

Table 1: Overview of solar PV and balancing capacity additions by 2030

Source	Solar capacity	Balancing capacity
Ukraine Plan	2027: ~ 6.3 GW[16]	2024-2027: 0.5 GW (battery storage); additional 2.4 GW (hydro storage); additional 0.96 GW (highly flexible fast ramping-up capacity)[17]
Draft NECP	2032: 12.6 GW (Reference scenario)[18]	2030: 1.7-2 GW (highly flexible fast ramping-up capacity), 0.8-2 GW (storage)[19]
Energy Community 2024	2032: 12 GW (Technical scenario)	/
Dixi NZ RES 2050	2030: 16 GW (NZ RES scenario)	2030: 1.4 GW (upward), 0.7 GW (downward)
Clean Energy Roadmap	2030: ~ 17 GW (NZ scenario)	/

Another techno-economic modelling exercise which assessed possible Net Zero scenarios envisions Ukraine building 16 GW of solar PV by 2030 accompanied by 1.4 GW of upward and 0.7 GW of downward reserve capacity to balance the grid's frequency.[20] The Clean Energy Roadmap, commissioned by the Ukrainian Ministry of Energy, reaches similar modelling results for the Net Zero scenario and targets approximately an installed capacity of 17 GW of solar PV by 2030.[21] As such, every modelled techno-economic assessment envisions ambitious targets for 2030 and onwards. It is therefore questionable whether an addition of only 0.7 GW by 2027, as envisioned by the Ukraine Plan, would be sufficient to then reach a much more ambitious goal by 2030 as envisioned by the Energy Strategy 2050 and by other modelling assessments.

3.2 Modelling approach, assumptions and data

For the purpose of this analysis, the Ukrainian electricity system was assessed in "island mode", i.e. with no interconnections to other countries to assess what a fully independent system would look like. Nonetheless, it is important to note that this applies only to electricity generation, and Ukraine would still be dependent, to varying extents, on the import of natural gas, oil products and nuclear fuel. Ukraine currently has an interconnection capacity of 1.7 GW with neighbouring countries, with a possibility to

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[16] The Ukraine Plan envisages that 0.7 GW additional capacity is built between 2024 and 2027. With a currently available capacity of approximately 5.6 GW this conservatively sums up to 6.3 GW in 2027. However, after regaining the temporarily occupied territory the available baseline solar PV capacity could be higher than 5.6 GW.

[17] Ukraine Plan cites the soon to be published Energy Strategy Ukraine 2050.

[18] Draft NECP cites the soon to be published Energy Strategy Ukraine 2050.

[19] Draft NECP cites the Generation Capacity Adequacy Assessment Report by Ukrenergo, published after martial law is terminated or lifted.

[20] REKK et al. (2024). *Long-term decarbonization pathways for Ukraine's power sector*. Link

[21] Net Zero World et al. (2023). *Clean energy roadmap: from reconstruction to decarbonization in Ukraine*

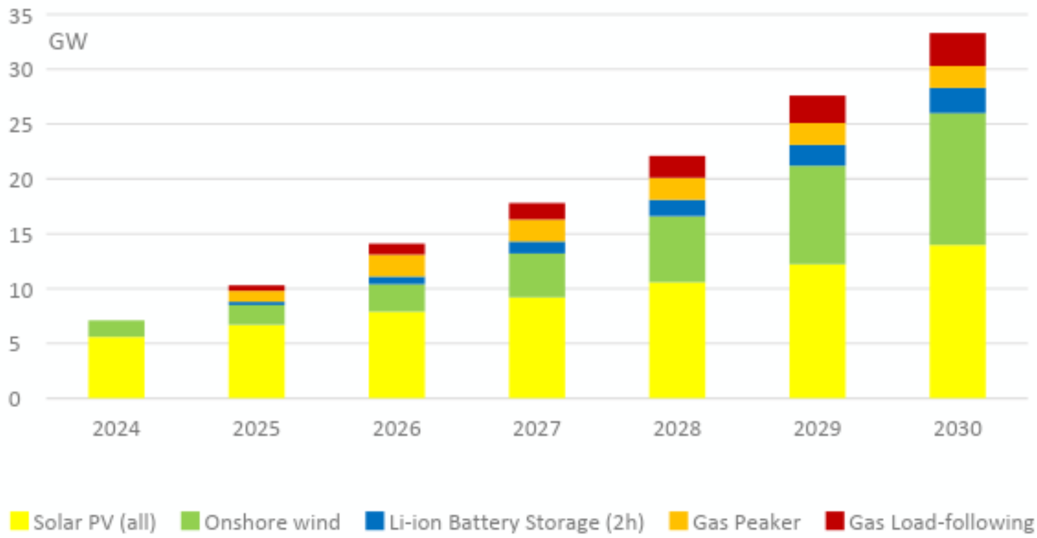
further increase this value in the medium- and long-term. While this interconnection capacity can be used to import in times of deficit and export excess generation, this analysis aims to provide a robust idea of domestic generation adequacy without reliance on imports.

The analysis is conducted in a custom-built techno-economic dispatch and capacity expansion optimisation model based on the open-source energy systems modelling framework Calliope.[22] The model jointly optimises installed generation and storage capacities and hourly dispatch for all 8760 hours within one year. A feasible pathway for capacity expansion until 2030, based on the modelling results, is provided in the results section below.[23]

3.3 Modelling results and discussion

The results of the techno-economic assessment show that a higher installed capacity of renewables by 2030 is not only possible, but highly economically desirable, as the cost-optimal system includes roughly 14 GW of solar PV and 12 GW of onshore wind. For utility-scale solar PV, the increase from 5.6 GW available in 2024 to 14 GW in 2030 means that deployment should be spread out more evenly over the period to ensure the simultaneous build-up of balancing and reserve technologies such as grid-scale lithium-ion batteries, but also highly manoeuvrable gas-fired power generation.[24]

Figure 3: Installed capacities for selected technologies



Source: Modelling results, author's own elaboration

[22] Pfenninger, S., & Pickering, B. (2018). Calliope: a multi-scale energy systems modelling framework. *Journal of Open Source Software, 3*(29), 825

[23] The techno-economic model optimises the energy system for the year 2030, assessing the cost-optimal solution for that year. As such, the model itself does not automatically create a build-out pathway for how much of each technology is built between 2024 to 2030. Rather, the build-out pathway is created manually by an expert assessment which takes into consideration the optimal build-out based on increasing demand, but also the need to maintain sufficient system flexibility through more solar PV, manoeuvrable capacity and storage technologies.

[24] This can include the firing of natural gas, but also biogas, biomethane or even green hydrogen.

In terms of the deployment of solar PV, 1.1 GW is added in 2025, 1.2 GW in 2026, and 1.3 GW and 2027 with subsequent additions increasing by 200 MW annually. As such, 1.4 GW is added in 2028, 1.6 GW in 2029 and 1.8 GW in 2030. While an increase from nearly 5.6 GW to 14 GW until 2030 seems ambitious, it is important to recall that Ukraine added almost 4 GW between 2018 and 2019 alone, over three-fold more than any year expected in the techno-economic modelling. The results demonstrate that a much more ambitious deployment than that envisaged in the Ukraine Plan is possible. In the conducted modelling and additional 3.6 GW of solar PV can be installed by 2027 (as opposed to the 0.7 GW proposed), representing a more than five-fold increase as opposed to the Ukraine Plan. These additions are highly significant, as they mean an additional 6.7 TWh is produced by solar PV by 2027, compared to the Ukraine Plan forecasts.

On the financial side, the installation of large amounts of solar PV presents the most cost-optimal solution for Ukraine. Given the significant technological cost decreases in the last few decades, and the continuously decreasing costs of RES and especially solar PV, the cost of installing 3.6 GW by 2027 is estimated at EUR 1.88 bn, while the 8.4 GW to be built by 2030 is cumulatively assessed at EUR 4.39 bn. While this means an installed cost per kW of roughly EUR 522, which trumps most other technologies, it is still key to consider the additional costs that will need to be spent on grids, as well as storage and balancing capacities to ensure the full integration of the solar PV.

Importantly, the amount of solar PV integrated is also subject to physical constraints. In parallel to deploying new solar PV, balancing and storage technologies need to be installed to ensure the stability of the system and to limit the curtailment of renewable energies (discussed further in 4.1.1 and 4.1.2). This is critical as not doing so has the potential to significantly slow down solar PV deployment. The cost-optimal system by 2030 therefore envisages 2.3 GW (4.6 GWh) of lithium-ion battery storage, but also 2 GW of highly manoeuvrable turbines and/or pistons which act as peaking plants and backup reserve, as well as 3 GW of load-following plants, such as combined-cycle turbines. From a cost-optimal perspective these balancing technologies are best operated on natural gas, however fuelling them with green hydrogen, biomethane or biogas could be a viable option, if these are commercially available. The pace of integration also must consider key environmental and social frameworks and strategic impact assessments, as well as overall lead times, especially as technologies have to be rolled out progressively but jointly to maintain system stability.

The results of the modelling must however also be placed in a broader context. While an installed capacity of 9.2 GW of solar PV by 2027 and 14 GW by 2030 may not seem too high in absolute terms, especially given Ukraine's current energy crisis, these additions would be extremely significant when considering the overall size of Ukraine's overall power plant park and technical constraints.

Prior to the war, the total installed capacity of all technologies was around 59 GW, with the modelled 14 GW of solar PV and 12 GW of wind power therefore representing a significant increase in RES as a share of total generation. This number is however even more impressive when considering the significant overcapacity and number of mothballed projects. In 2021, the peak load for the whole year was 24.7 GW[25], meaning that under perfect solar conditions, the modelled 14 GW of solar PV could cover close to 57% of Ukraine's peak electricity demand. These capacity additions are also key when comparing

[25] UNDP, (2023), Towards a Green Transition of the Energy Sector in Ukraine, Update to the Energy Damage Assessment, Link

Ukraine's electricity demand to other countries in Europe[26], but also when considering reductions in demand since the start of the war. Ukraine's annual electricity demand decreased from 158 TWh in 2021 to roughly 107 TWh in 2022[27] due to several factors, chief among which have been the destruction of significant parts of Ukraine's industrial economy, reductions in population, but also the further destruction in electricity infrastructure. As such, the pace of Ukraine's reconstruction will be key at determining the levels of electricity demand, and therefore also the need to install additional generation capacity. Thus, the modelled solar PV capacity can be interpreted as the minimum level of optimal additional capacity. Given that solar PV is one of the cheapest possible energy sources and given Ukraine's technical potential, it can be assumed that in a more rapid recovery scenario, additions of solar PV could be much higher. As shown, Ukraine was able to integrate close to 4 GW of new solar PV in 2018, which can be replicated if key factors (discuss further in following sections) align. As Ukraine progresses further in terms of its EU accession process and towards meeting long-term environmental goals, speeding up the rate of electrification of end-sectors will also mean additional electricity demand, which can then lead to further solar PV deployment.

4. Bottlenecks to greater solar PV integration and preliminary solutions

While the techno-economic conducted in this study as well as the other recent assessments demonstrate that the integration of greater amounts of solar PV are possible and economically desirable, in tandem with other generation and grid investments, serious barriers exist in Ukraine that pose problems for the greater expansion of renewable energy sources. The following sections highlight the key problems and provide preliminary ways to begin overcoming these challenges to enable increased solar PV deployment.

4.1 Technical obstacles

The first set of challenges relate primarily to both physical constraints in Ukraine's energy system including balancing and transmission constraints, but also broader issues related to the skills needed for renewable energy deployment and the procurement of key technologies.

4.1.1 Balancing and grid stability

Ukraine's transmission, distribution, and generation capacities have been one of the primary targets of Russian attacks from October 2022 onwards, with the most significant attacks coming in the winter of 2022 and the spring of 2024, both leading to significant planned and unplanned electricity outages. The most recent attacks however pose a more significant challenge, as damage to, or destruction of, effectively all of Ukraine's thermal power plants and significant amounts of large hydropower leave almost only the largely inflexible nuclear power plants left operating, threatening the ability to balance the

[26] For example, Germany's electricity demand in 2021 was roughly 4 times as large as Ukraine's hence requiring a significantly larger power plant park.

[27] Laffitte, T. & Moshenets, I., (2023), Synchronized: The impact of the War on Ukraine's Energy Landscape, Link

electricity system. While Ukraine's power system was already short in flexible balancing capacities before the most recent attacks, the lack of manoeuvrable capacities is now very critical.

Within the context of electricity, balancing supply and demand involves ensuring that the amount of electricity consumed is equal to the amount of electricity produced at all times. This involves forecasting by the Transmission System Operator (TSO) and coordination with power producers ahead of time, but also requires the existence of highly flexible power generating assets, which can ramp up and down quickly to meet demand, as well as ancillary services including frequency and voltage control and reserves to quickly dispatch electricity to smooth any spikes or drops in demand or supply. With the larger integration of renewable energy sources into electricity systems, the capacity of more flexible and reserve assets increases due to the intermittency of solar radiation and wind.

Within the context of Ukraine, the destruction of large amounts of balancing and reserve capacity poses serious issues for grid stability in the short-term, but also significant problems for the roll-out of renewables, including solar PV. As the modelling results demonstrate, large amounts of batteries (2.3 GW) and flexible gas-power (2 GW) capacity is needed to integrate larger amounts of solar PV and preventing curtailment, but besides the technical challenges associated with constructing these assets during wartime, the market conditions are a major barrier (see sections 2.3 and 4.2.1).

4.1.2 Transmission infrastructure

Ukraine's electricity transmission and distribution networks, much like the generation capacities, have been heavily affected by Russia's attacks, with significant repairs and up-keep required in order to keep the system running. Most prominent examples of damages to transmission infrastructure include the downed power lines near the Zaporizhzhia Nuclear Power Plant, which posed a significant risk to the safe operations of the plant.

Nonetheless, even in its pre-war state, the electricity grid suffered from persistent under-investment due to a lack of cost-covering tariffs across the energy system (see sections 2.3 and 4.2.1 for further discussion), characterised by aging equipment and technology that has not been adequately updated or maintained. This has resulted in inefficiencies and vulnerabilities in the system, including high transmission losses and power outages even prior to the war.

In addition, several obstacles exist to the integration of large amounts of variable renewable energy sources. Integrating large quantities of solar PV will also require the significant expansion of distribution grids, including speeding up interconnection requests (now a primary obstacle to the integration of new solar in the US and other countries).[28] The large-scale roll-out of small-scale and household solar PV will necessitate better planning and distribution of new transmission capacity, but also the transition to smarter grids that can accommodate elevated demand in light of the growing electrification of various end-uses, including heat pumps and electromobility.

[28] See, for example: https://emp.lbl.gov/news/grid-connection-backlog-grows-30-2023-dominated-requests-solar-wind-and-energy-storage

Additionally, transmission capacities between Ukraine's various electricity regions may pose constraints and lead to grid congestion. As the most renewable-rich regions are found primarily in the Southern regions of Ukraine, the deployment of renewable energy sources there must be accompanied not only with the build-out of local interconnections and transmission networks, but also regional transmission to ensure that "green" electricity can be transmitted to parts of the country with less renewable potential and larger demand centres. Lastly, increasing interconnections with Ukraine's ENTSO-E neighbours, as well as regional interconnection of the Western regions with the rest of the country, will be important for the expansions of transmission capacity which would be used for imports and grid balancing, but also for exports of RES electricity in the future.

All these steps are fundamental to ensuring that the deployment or renewable energy and solar PV specifically can proceed un-interrupted, but also that curtailment of renewable energy is minimised as much as possible, especially when capacity factors are high. As a starting point, the transmission system needs significant investment volumes for modernisation and expansion, financed in the very short-term through emergency assistance to ensure stability, including through in-kind donations of equipment. Nonetheless, the longer-term sustainability of system will be needed, with further investments financed through a move to more cost-covering transmission tariffs charged by Ukrenergo (see 4.2.1). This also means reforming and enhancing the state-owned enterprise to enable the securing of commercial capital, rather than relying on subsidies and cross-subsidies and creating robust and reliable market conditions and regulatory frameworks to ensure larger private sector participation.

4.1.3 Skills and labour availability

Another obstacle to larger solar PV roll-out is the skills gap when it comes to renewable energy companies, as well as the installation and maintenance of both household and utility-scale renewable energy sources. An OECD-World Bank Skills Gap Survey from 2014 identified significant skills gaps in the renewable energies space, especially for high-skilled workers, with a critical shortage of electrical engineers and mechanical engineering technicians.[29] A more recent survey from 2020 conducted by the European-Ukrainian Energy Association that surveyed 27 Ukrainian companies found that 89.2% of companies noted a shortage, and 67.6% considered this shortage critical to operations.[30] While there has been a noted increase in the number of personnel in the renewable energies space, the current military duty obligations of a large part of the (primarily) male working-age population presents a fundamental issue for many businesses. While anecdotal, conversations conducted with stakeholders in Kyiv in late March 2024 point to an understanding of the problem by companies, business associations, international partners and the Ukrainian government.

The skills shortage may pose a significant barrier to the speed of solar deployment, especially at the more labour-intensive small-scale level, which has already seen significant increases. In the aforementioned survey conducted by EUEA, businesses were seen as the

[29] OECD (2015). *Identifying and addressing skills gaps in Ukraine*.- Link

[30] Kalinina, S., Lyndiuk, O., Buchyk, V. (2020). The development of renewable energy in Ukraine in the context of ensuring public employment. *Polityka Energetyczna – Energy Policy Journal*, 23(4), 141-154. DOI: 10.33223/epj/130319

primary actor in the renewables training and capacity development space[31], but more support may be required from the government and international donors in terms of expanding technical, vocational education and training (TVET) more broadly, and expanding technical training for renewables, energy efficiency and solar PV more concretely. Additionally, given the military service duties of the (primarily) male working age population, programmes focusing on the training of women (as well as veterans) may be prioritised.

4.1.4 Equipment availability and supply chain issues

While supply chains and logistics had initially been severely disrupted by the war, both land and seaborne routes have largely re-opened, providing an important avenue for both the import and export of vital goods. Nonetheless, global supply chain shortages for key energy equipment are currently posing a major problem to countries' energy transitions more broadly, and to Ukraine's recovery of the energy sector more concretely. The issue is most visible in the transformers segment, where lead times have increased to 120 weeks, with large transformers (both substation power and generator step-up) currently between 80-210 weeks, but still with ever-increasing prices.[32] Elevated demand for other equipment, such as solar PV panels and batteries is also showing some signs of delays as global demand skyrockets.

Some support mechanisms and possible pathways forward do exist. The Energy Community's Ukraine Energy Support Fund has disbursed close to EUR 400 m by April 2024[33], and USAID's ESP programme has contributed USD 250 m.[34] Various bilateral initiatives and in-kind donations have also been fundamental, such as the German-Ukrainian Energy Partnership, through which 30 German energy companies sent equipment in 2023. The German Federal Ministry of Economic Affairs and Climate Action, in co-operation with the Ukrainian Ministry of Energy is supporting the energy sector through both a donation and procurement campaign.[35]

While these efforts have been fundamental to keeping Ukraine's energy system afloat, more long-term efforts will require the deepening of relations directly with equipment manufacturers in producer countries. This will entail both the Ukrainian state as well as private sector participants looking to construct projects to further build up relations and business connections themselves, but also to integrate lead times into any project or grid planning.

4.2 Market dimension

While technical factors are fundamental, the largest problem in the Ukrainian context has always been primarily related to the market dimension, where flaws in the wholesale

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[31] Kalinina, S., Lyndiuk, O., Buchyk, V. (2020). The development of renewable energy in Ukraine in the context of ensuring public employment. Polityka Energetyczna – Energy Policy Journal, 23(4), 141-154. DOI: 10.33223/epj/130319

[32] See: https://www.woodmac.com/news/opinion/supply-shortages-and-an-inflexible-market-give-rise-to-high-power-transformer-lead-times/

[33] See: https://www.energy-community.org/Ukraine/Fund.html

[34] See: https://energysecurityua.org/

[35] See: https://www.energypartnership-ukraine.org/tr/energy-institutions-in-ukraine-initiative/

market design, issues related to government support and high costs of financing provide a strained case for increasing solar PV investment and deployment.

4.2.1 Wholesale market design and market functioning

As described in Chapter 2.3, there are several fundamental issues affecting the proper functioning of Ukraine's electricity wholesale market segments. Most importantly, price caps and price floors in the short-term markets (day-ahead, intraday, balancing) are negatively affecting the price formation in electricity markets. Due to the price caps and floors, there are no adequate price spreads to incentivise market-driven investments in flexible generation and storage capacities. Additional market segments that could help incentivise investments in flexible balancing capacities, such as auxiliary service markets for frequency containment (FCR) and frequency restoration (aFRR, mFRR) are not well developed and lack adequate products with multi-year delivery periods, which could provide long-term revenues to stimulate investments.

The resulting lack of flexibility and storage providers, aggravated by the recent attacks on thermal and hydro power plants, reduces the ability of the system to integrate additional variable renewable energy generation, in particular solar PV. The lack of balancing and storage, as well as the dominant share of relatively inflexible generation (nuclear, combined heat-and-power plants, thermal power plants) leads to very low prices during high renewable generation, i.e. during sunny hours, on short-term markets, reducing the attractiveness of wholesale market prices to solar PV investors. This situation, also known as the price cannibalisation of renewables, would deteriorate further with any solar PV plants added to the system unless flexible balancing capacities are integrated in tandem. However, market-driven integration of balancing capacities is not feasible under the current market design.

In order to achieve a properly functioning wholesale market, price caps and price floors should be removed. Potentially, this would need to be accompanied with measures tackling excessive market concentration, such as compulsory divestment of price-setting power plants, energy release programmes, and/or a diversification of asset ownership for newly constructed balancing and storage capacities, especially if constructed with public support during wartime.[36] Ukrenergo's debt on the balancing market needs to be cleared, together with the accumulated debt on other market segments, including in the Green Tariff scheme (see section 4.2.2 below) and cost-reflective tariffs for all market segments, including transmission tariffs, should be introduced. Debt collection needs to be improved significantly, with streamlined procedures and adequate automatic penalties that reduce the need for financially and time-consuming lawsuits. Finally, adequate products for ancillary services (such as frequency containment and frequency restoration reserves) with multi-year delivery periods should be introduced on the ancillary services market to bolster suitable business models for highly manoeuvrable balancing and storage plants across different market segments.

It is however imperative to note that any steps taken towards price liberalisation will have to be accompanied with adequate social compensation policies to prevent the exacerbation of energy poverty. This is especially the case given the currently low energy tariffs, with a relatively large and possibly rapid increase in prices expected as convergence to cost-covering prices occurs. The move to cost-covering tariffs may also have an even more pronounced effect on consumers under the current conditions, as the ongoing war

[36] See Low Carbon Ukraine (2022). *Policy reforms supporting Ukraine's green reconstruction*. Link

has led to a significant deterioration in customers' budgets due to worsened economic conditions. As such, ensuring that a well-designed social transfer programme is in place to protect vulnerable consumers is fundamental. This can be done through either introducing more targeted, consumption-independent subsidies for vulnerable consumers, or through broad-based social transfers.

If focusing on targeted subsidies, vulnerability criteria have to be updated to reflect the current realities, which would however require significant data collection to understand the most up-to-date, relevant consumer information. This would present the more fiscally beneficial approach but may be more challenging given the significant structural and regional changes and continuously evolving situation. On the other hand, a broad-based transfer approach could be rolled out in tandem with price liberalisation, which could also make the process more politically feasible. If fiscally possible, well-calibrated broad-based transfers might be preferrable in the context of a post-war reconstruction.

Ultimately, the decision between targeted transfers and broad-based transfers remains a strategic decision that needs to be taken on a political level.

4.2.2 Adequate public finance for RES support

Another major challenge connected to providing a reliable and adequate stream of revenues for investors and to de-risk investments into solar PV is the incomplete and delayed payment of public support for renewable energy payments via the Green Tariff. There are two issues here that merit further discussion:

One issue is the accumulated legacy debt for Green Tariff payments described in section 2.3. The accumulated debt threatens the financial liquidity of existing solar PV operators and needs to be repaid eventually. Commitment of public funds, possibly including donor support, will be necessary to clear the accumulated debt. The debt accumulation, as well as the retroactive tariff cut, has heavily damaged investor confidence in the Green Tariff and Ukraine's RES support schemes more broadly, extending to potential future support schemes. As a result, investors started to opt out of planned solar PV projects, lawsuits are pending and trust in the system is highly damaged. Clearing legacy debt will have to be one of the steps required to restore investor confidence.

The second issue, while connected to the first, goes beyond the issue of legacy debt. There are several proposals circulating for how to reform the financial mechanism to fund the Green Tariff, including a proposal to disentangle Green Tariff financing from the transmission tariff, which is highly criticised by market participants on the grounds of potentially aggravating the problem of payment discipline. Most reform proposals entail some sort of debt restructuring and reshuffling but fail to address the underlying problem – along the value chain, there are several regulated tariffs that do not reflect the true cost of the service provided. This includes the electricity tariff for household and small non-household consumers, the transmission tariff, but also tariffs for other services such as water supply and district heating. The low tariffs for water supply and district heating leads to deficits of municipally owned utility companies, many of which are the main debtors to Universal Service Suppliers, i.e. electricity suppliers, some of which in turn are the main debtors to Ukrenergo.[37] Securing adequate financing for the Green Tariff and

[37] Another important debtor to Ukrenergo is the state-owned nuclear company Energoatom, who accumulated payment arrears for its special obligations to finance the household Public Service Obligation (PSO), i.e. the subsidised household (and small non-household) electricity tariffs.

future RES support schemes therefore has to entail either the introduction of cost-reflective tariffs for all utility services (electricity, water, district heating) and a clearance of accumulated debt across all market participants, and/or a commitment for adequate public financial support to finance RES support schemes from the public budget, possibly with donor support. As long as the Guaranteed Buyer is not equipped with adequate financial resources, through whichever mechanism, to pay renewable energy generators in the future, it is largely irrelevant whether the Green Tariff is replaced by a more sophisticated support scheme. Thus, the successful implementation of competitive auctions for feed-in premiums (FiP), foreseen in law no. 3220-IX, requires a broader reform to ensure adequate public finance for RES support, so that FiP can be paid out and new debt accumulation is avoided.

4.2.3 High financing costs as a barrier to investments

While significantly exacerbated by Russia's invasion of Ukraine, the high weighted average cost of capital (WACC) has been a significant barrier to renewable investment even prior to the war. Very high WACC rates, such as those found in pre-war Ukraine significantly decrease the attractiveness of investments due to the high cost of borrowing and larger repayments needed. Out of an assessment of 45 countries globally, IRENA found that the cost of capital of utility-scale solar PV projects between 2019-2021 was the absolute highest in Ukraine at 12.2%. For comparison, Germany's WACC was 2.2%, with Western Europe 7.7% and Eastern Europe (incl. Ukraine) 8.7%.[38] In 2020, Trypolska and Ryabchin reported the WACC in Ukraine to be in the range of 15%-16%, posing a significant obstacle to a competitive renewable energy build-up.[39] The situation has understandably worsened since the start of the full-scale invasion, as the added risk brought on by the war, coupled with the targeting of Ukraine's energy infrastructure has raised the risk premium, with some consumer loans exceeding 20% in early 2024.

As a high WACC (among other things mentioned previously) decreases the attractiveness of new solar PV investments (among other investments), de-risking loans and providing access to more affordable financing is fundamental to the growth of Ukraine's solar PV sector. This is fundamental for both domestic firms looking to enter the segment, as well as foreign investors.

On the domestic front, the Ukrainian National Bank together with the Ministry of Economy is currently working on an investment risk insurance scheme against destruction caused by military aggression, which may play an important role in attracting investments. For SMEs, an existing and highly adopted measure to de-risk investments is the 5-7-9 loan subsidy programme, which provides interest rate subsidies for loans used for projects that function as a multiplier for the Ukrainian economy, e. g. through generating employment. While the current programme is also open to large companies, the IMF is making their phasing out a condition for payment disbursements.

In terms of the provision of protection to foreign investors, the US International Development Finance Corporation (DFC) and the Multilateral Investment Guarantee Agency (MIGA) cover various investments in Ukraine. At the bilateral level, the German government, through its Investment Guarantee Scheme, is providing protection to German investors in Ukraine against war and other related risks in order to encourage investments.

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[38] IRENA (2023). *The cost of financing renewable power.* Link

[39] Trypolska, G. & Ryabchin, O. (2021). Experience and Prospects of Financing Renewable Energy Projects in Ukraine. DOI: https://doi.org/10.32479/ijeep.11999

However, this does not have any implications on decreasing financing costs, which are still high even for foreign investors.[40] It is nonetheless fundamental to expand the scope and size of the covered investments to further de-risk finance and to incentivise foreign private companies to enter the Ukrainian solar PV segment to add much needed generation capacities, and to also help increase competition of the market by increasing the number of participants.

4.3 Other regulatory aspects

Other legislative aspects which may support the successful roll-out of solar PV concern the active consumers, also called prosumers. These are entities that produce energy for sale as well as consume it as final customers. The role of a prosumer can be taken by private households, companies as well as municipal owned enterprises (MOE) like hospitals, schools, kindergartens or water supply companies which have significant roof space for building solar PV.

To help MOEs become large scale prosumers, decrease energy expenditure and increase green energy production, a set of measures can be implemented. For one, communities could be supported by targeted funding programs for installing solar PV. Another channel to receive the necessary financial resources is through establishing a register of possible solar PV locations for interested investors and to perform open tenders. A third channel is the introduction of additional incentives and support schemes like the reimbursement of interest payments on loans for purchasing and installing power generation systems for households and firms. These are foreseen in Law no. 3220-IX but still need to be established by the Cabinet of Ministers. Furthermore, it is vital that MOEs can sell the surplus of produced power to the respective power supplier for a successful implementation.[41]

In order to generate and consume electricity efficiently, the entity should participate in balancing supply and demand for which the municipality has to establish parties responsible for the balance (PRB) that take care of balancing demand and supply within the community and procure power for the communities' entities in periods of low production either directly or indirectly through a central purchasing organisation (CPO). Consequentially, the PRBs should have the right to sell power to the communities' MOEs through a procurement mechanism. Additionally, the establishment of CPOs needs to be facilitated and the threshold needs to be lowered to establish a CPO for a community which is currently only allowed for cities with a population larger than one million. Alternatively, smaller communities could be allowed to establish joint CPOs to surpass the threshold. These changes lie in the responsibility of the Verkhovna Rada of Ukraine. For establishing PRBs there are no regulatory changes necessary. However, to optimise balancing schedules it should be made possible for small PRBs to join larger groups and act as one entity within this group.[42]

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[40] See, for example: https://eba.com.ua/en/nimetskyj-uryad-nadaye-garantiyi-dlya-novyh-nimetskyh-investytsij-v-ukrayinu/

[41] Vizir, O. (2023). *Small Distributed Generation: A window of opportunity for Ukraine: focus on communities.* LibMod Policy Paper. Link

[42] Vizir, O. (2023). *Small Distributed Generation: A window of opportunity for Ukraine: focus on communities*. LibMod Policy Paper. Link

A further regulatory adjustment necessary for a successful increase in solar PV is improving the independence of the Ukrainian regulator National Energy and Utilities Regulatory Commission (NEURC) to ensure an efficient generation and allocation of electricity independent of individual interests of single market participants. One fundamental measure is ensuring that the appointment of staff can be conducted without the approval of external bodies and enabling the NEURC to manage its own budget. Further suggestions on enhancing the independence of NEURC proposed by the Energy Community should be implemented.[43] On a positive side note, increasing the independence of NEURC and aligning it with the Energy Community acquis helps integrating with the European energy markets and increasing the confidence of private investors as well as public donors.

5. Conclusion and policy recommendations

Over the last two years, Ukraine's energy infrastructure has been significantly affected by Russia's war of aggression. While the system has been remarkably resilient, it has also exposed the pitfalls of over-relying on highly centralised, fossil-fuel based generation. A broad consensus exists among stakeholders that the future of Ukraine's energy system lies in distributed generation and large-scale increases in renewable energy sources. Nonetheless, while Ukraine's technical potential for renewables, and especially solar PV is strong, the Ukraine Plan foresees only meagre additions to solar PV capacities until 2027.

Through a review of other studies, and techno-economic modelling conducted for this policy paper, the conclusions are that a viable pathway towards a significantly enhanced solar PV roll-out is possible. Ukraine could significantly exceed the modest targets set under current plans, with a possible 2.5-fold increase from the 5.6 GW of solar PV installed today to 14 GW by 2030, and more than a five-fold increase by 2027 compared to the additions envisioned in the Ukraine Plan.

Nonetheless, significant barriers to increasing solar PV deployment exist, which will require fundamental reforms. At the technical level, balancing and reserves technologies must be built-up in tandem with solar PV to ensure grid stability, but transmission and distribution grids must also be modernised and expanded significantly. Supply chain shortages may affect the availability of equipment, but domestic skills have also been identified as an issue in the renewables sector.

The most significant challenges however relate to market and regulatory factors. The wholesale market and existence of price caps distorts price signals, with little attractiveness of market-based storage and balancing capacities, but other (often connected) issues, such as the high levels of debt across the renewable and balancing markets and non-payment of feed-in tariffs to renewable producers decreases investor confidence. Due to both war-related and other factors, the financing rates for projects are extremely high, which further detracts investment, and changes to regulations governing prosumers are necessary to increase adoption. The latter especially is key, as the build-up of solar PV in Ukraine from current levels to 14 GW by 2030 will require over EUR 4.39 bn, which will necessitate significant financing from both private actors as well as international

[43] Energy Community Secretariat (2023). *The National Energy Regulatory Authority of Ukraine Governance and Independence.* Link

partners. As such, several key priority areas emerge, which must be addressed in order to spur Ukraine's solar PV sector:

To both **Ukrainian** and **International Stakeholders:**

- **Invest in grid stability and transmission**: To accommodate the rapid expansion of solar PV, significant investment is needed in grid modernisation and expansion. This includes enhancing transmission capacities and adopting smart grid technologies to ensure that the increased generation from decentralised sources can be efficiently managed and distributed.

- **Decrease financing costs**: Implement measures to de-risk investments, particularly for small and medium enterprises (SMEs) and foreign investors. This can include loan guarantees, interest subsidies, and insurance schemes against risks like military aggression. Such measures will help reduce the high capital costs currently hindering the growth of Ukraine's solar PV sector.

To the **Government of Ukraine:**

- **Reform and liberalise electricity markets**: Revise the current wholesale market design to remove price caps and floors, reducing market distortions and encouraging investment in flexible generation and storage capacities. This should be complemented by the development of ancillary service markets to provide long-term revenue streams to support investments in system flexibility.

- **Strengthen public finance mechanisms for renewables**: Address the payment arrears and financial liabilities in the Green Tariff system to restore investor confidence. New mechanisms such as feed-in premiums should be supported by reliable and consistent public financial backing, ensuring that renewable energy producers receive timely and full payment for their contributions to the energy grid. Consider also support to the build-up of technical skills and capacity development through state financing to fill market gaps, with a specific target also on women and veterans.

- **Facilitate the status of active consumers**: Implementing targeted funding programs and consider reimbursements on interest payments on small-scale solar PV investments. Allow small parties responsible for balancing to join larger ones, and enable smaller communities to establish central purchasing organisations.

To **International Partners:**

- **Provision of capital to facilitate investments**: Capital allocation by international donors for preferential loans and grants help scale investments into solar PV but also essential balancing technologies like battery storage or flexible power generation. Relevant actors able to do so are financial institutions (World Bank, EBRD, EIB) as well as European Governments.

- **Continue support and collection campaigns**: Helping mobilise in-kind assistance and donations of energy equipment by various governments and organisations has been pivotal to ensuring the rapid repair and sustenance of the Ukrainian energy system. Continuing and expanding this process, with a focus on clean technologies can be fundamental to helping overcome supply chain issues and speed up adoption.

To **Civil Society**:

- **Maintain focus on green reconstruction:** the role of Ukrainian civil society, think-tank and NGOs has been fundamental in mainstreaming the narrative of the green reconstruction of Ukraine's energy sector, but also in facilitating the deployment of concrete green projects. Alongside international partners and think-tanks, the voice of civil society must continue to be heard, to ensure that the greening of the energy system continues to remain the primary future pathway.

6. Annex: Modelling assumptions and results

Table 2: Overnight capital cost and efficiency for selected technologies (2025-2030)

	Overnight capital cost (EUR/kW)	Electrical Efficiency (%)
Solar PV (utility-scale)	522.58	100%
Solar PV (commercial rooftop)	800.55	100%
Solar PV (residential rooftop)	1,156.35	100%
Onshore wind	1,312.01	100%
Li-ion Battery Storage (2h)	958.69	85% (roundtrip)
Gas peaker	555.70	41%
Gas load-following	1,064.10	58%
Coal (steam turbine)	2,427.20	33%

Sources: Danish Energy Agency, EU Joint Research Centre, NREL, authors' own calculations

Table 2: Assumed fuel costs, carbon content and carbon price by 2030

	Fuel price (EUR/MWh)	Carbon content (tCO_2/MWh)
Natural gas	27.86	0.20
Crude oil	32.27	0.28
Hard coal	12.06	0.34
Nuclear fuel	2.78	-
Biomass*	27.18	-
Carbon price (EUR/tCO_2)	120.98	

**Note: Assuming sustainably sourced biomass with net-zero GHG emissions (e.g. agricultural residues)*
Sources: World Bank, IMF, Umweltbundesamt, WISE Uranium Project, EWI Köln, authors' own calculations

Table 3: Assumed minimum installed capacities by 2030 (before capacity expansion)

	Min. installed capacity by 2030 (MW)
Solar PV (all)	5,600
Onshore wind	1,500
Biomass/Biogas	244
Small Hydropower (run-of-river)	256
Large Hydropower (reservoir)	5,990
Pumped-Storage Plants	1,515
Nuclear	12,794
Coal (steam turbine)	1,300
Li-ion Battery Storage (2h)	-
Gas peaker	-
Gas load-following	-

Sources: Ukrenergo (pre-war installed capacities), authors' own assumptions and calculations

Table 4: Installed capacity for selected technologies by year in MW (rounded)

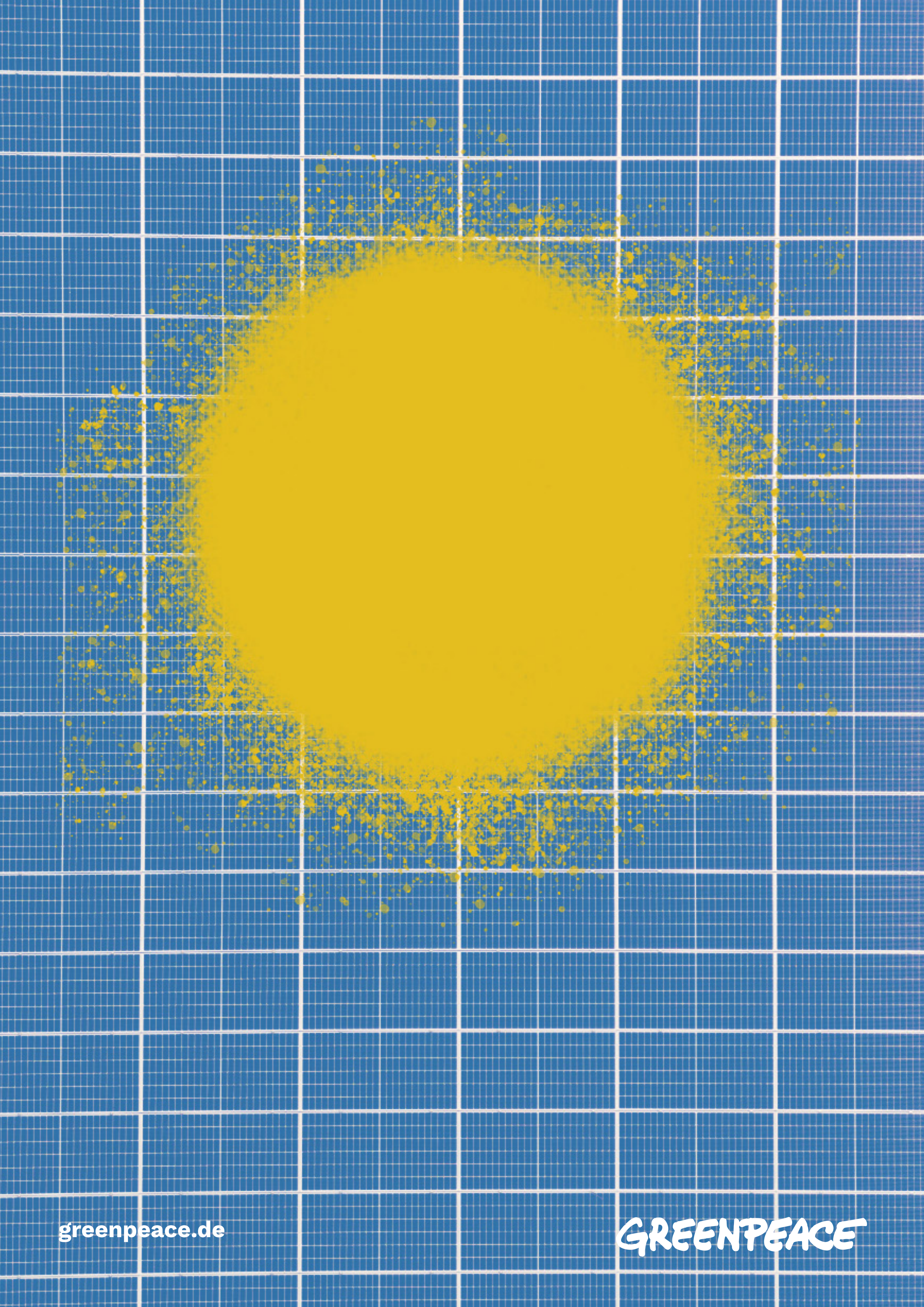
	2024	2025	2026	2027	2028	2029	2030
Solar PV (all)	5,600	6,700	7,900	9,200	10,600	12,200	14,000
Onshore wind	1,500	1,800	2,500	4,000	6,000	9,000	12,000
Li-ion Battery Storage (2h)	-	300	700	1,100	1,500	1,900	2,300
Gas Peaker	-	1,000	2,000	2,000	2,000	2,000	2,000
Gas Load-following	-	500	1,000	1,500	2,000	2,500	3,000

Sources: Authors' modelling results, calculations and assumptions

Table 5: Annual capacity additions for selected technologies by year in MW (rounded)

	2025	2026	2027	2028	2029	2030
Solar PV (all)	1,100	1,200	1,300	1,400	1,600	1,800
Onshore wind	300	700	1,500	2,000	3,000	3,000
Li-ion Battery Storage (2h)	300	400	400	400	400	400
Gas Peaker	1,000	1,000	-	-	-	-
Gas Load-following	500	500	500	500	500	500

Sources: Authors' modelling results, calculations and assumptions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