A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

REPowerEU: Feasibility of Fast Renewable Energy Growth under a Crisis

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June, 2023

Vienna

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfilment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean, Central European University, Lund University and the University of Manchester (United Kingdom).

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ABSTRACT OF THESIS submitted by:

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for the degree of Master of Science and entitled: REPowerEU: Feasibility of Fast Renewable Energy Growth under a Crisis

Month and Year of submission: June, 2023.

The European Union (EU) proposed the REPowerEU Plan in May 2022 to reduce its dependency on Russian fossil fuels following the start of Russo-Ukrainian war. One of the key pillars of this plan is to quickly expand wind and solar energy, which will be instrumental in achieving both climate targets and energy independence. Given the ambitious target of total 1.1 terawatt wind and solar photovoltaic (PV) capacity by 2030, feasibility of achieving it is an important question. This study evaluates the feasibility of REPowerEU targets through a variety of approaches: sufficiency of national targets of the major electricity producers, comparative assessment of recent trends and historical precedents of fast energy transitions, as well as the forecasts from international reports. It was found that the current national targets are insufficient and should be raised to deliver on collective EU targets. The envisioned growth of wind and solar was found to share similarities with the historical growth of nuclear power in 1980s. Historically, a few Member States have achieved fast adoption rates of solar PV and onshore wind, that will need to be replicated at EU-27 scale to reach REPowerEU targets. The offshore wind ambition is considerably higher than its historical trends and its successful implementation at EU-scale will be more difficult. Overall, solar power can be expected to exceed its target, while the envisioned wind installations will require extensive efforts for speed-up of permitting procedures, upgrade of grid infrastructure, and close cooperation between the Member States.

Keywords: REPowerEU, energy transition, renewable energy, solar, wind, energy security, decarbonisation

Acknowledgements

Firstly, I would like to thank my thesis supervisor Professor Aleh Cherp, for his extensive guidance during all stages of this research, as well as throughout the two years of MESPOM. I would also like to thank Anastasia Pavlenko, for her valuable inputs and support in the writing process of this thesis.

I am sincerely grateful to the staff and faculty of the MESPOM programme for their support, mentorship and guidance during my studies.

I would also like to extend special thanks to my parents, family, and friends, who have been constant source of motivation and strength for me and played a part in my journey.

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1. Introduction

1.1 Background

Climate change is a change of climate attributed to human activities altering the composition of atmosphere through release of greenhouse gases (GHGs) (UNFCCC n.d.). The largest share of CO_2 emissions comes from burning of fossil fuels for energy and industrial needs, and it soared to an all-time high amount of over 14 gigatonnes of CO_2 in 2022 (IEA 2023a). On the other hand, global electricity demand has been on a rise, increasing by 30% between 2011 and 2021. This demand may increase even faster in the future with electrification of transport, heating and industry (IEA 2021a). Thus, meeting the growing electricity needs of the society while reducing the use of fossil fuels is crucial to ensure sustainable development combined with limiting the global warming. This calls for drastic measures to replace fossil fuels with low-carbon sources of electricity within the next 2-3 decades (IEA 2021a).

The central role of low-carbon electricity generation technologies in climate mitigation is widely recognised, as reflected in climate stabilisation scenarios or pathways reported by the Intergovernmental Panel on Climate Change (IPCC) (Shukla et al. 2022). While the largest sectoral increase of global CO_2 emissions in 2022 was from electricity and heat generation sector, wind and solar photovoltaic (PV) were the leading technologies resulting in avoided CO_2 emissions (IEA 2023a). In addition to climate benefits, replacing fossil fuel consumption, especially coal and oil, with low-carbon electricity, brings further benefits such as reduction of air pollution and consequences of air pollution to human health and wildlife (Jacobson 2009). Creation of more long-term jobs, reduction of energy costs and overall social cost of energy (private cost + health costs) are also among the long-term positive ramifications of low-carbon energy systems (Jacobson et al. 2022). Yet, despite the recent rapid expansion of low-carbon electricity generation, the global deployment rates are far behind on the way to achieving 100% by 2050 (Shukla et al. 2022; Cherp et al. 2021).

With regard to historical energy transitions in terms of fuel substitution, the most rapid ones were triggered by crises affecting energy security. The 1970s' oil shock triggered by the embargo of oil-producing countries led the industrialised import-dependent nations to replace oil with coal, nuclear or gas. It should be underlined that this timeframe (1970-1990) also corresponds to a period of high electricity demand growth in those industrialised nations (Vinichenko, Cherp, and Jewell 2021). Similarly, growth in demand is expected in the EU for the upcoming decades, due to increased electrification of heating, industry, transport and other sectors. Such examples of past transitions at national level electricity mixes can provide insight into how fast and under which policy tools/triggers energy transition have already happened and can inform feasibility outlooks for future transitions to low-carbon electricity (Sovacool 2016).

The European Union (EU) has been at the forefront of climate mitigation and energy transition policy: the EU has fulfilled its 2020 goal with 22% share of renewable sources in total final energy consumption (European Commission 2020a); created the world's first and the largest Emissions Trading System (ETS); introduced the European Green Deal to tackle air pollution and promote low-carbon technology adoption (European Commission 2019; Eyl-Mazzega and Mathieu 2020). "Fit for 55", a package adopted in July 2021, sets out 2030 targets for reduction of net GHG emissions in the EU by 55% from reference year 1990. This plan includes extension of sectors covered by ETS system, greater efforts for tackling maritime and air transport emissions, as well as addressing the issue of "carbon leakage" to non-EU countries by introducing Carbon Border Adjustment Mechanism (CBAM), i.e. carbon pricing for carbon-intensive imported goods to EU from international producers (European Commission 2021b). Besides these measures, the package includes the target for 40% renewables in the energy mix by 2030, aiming for fast expansion of wind and solar to ~1000 GW total installed capacity (469 GW wind + 530 GW solar) (ibid.).

Whilst these recent advances in EU energy policy were primarily motivated by climate ambitions, 2022 saw the emergence of a major threat to energy security with Russia's war on Ukraine. The conflict highlighted the dependence of EU's energy systems on fossil fuel imports and susceptibility to disruptions by external players. The share of Russian gas in EU's gas demand had dropped to 39% in 2021, linked to Russian state company Gazprom's artificial reduction of supplies (IEA 2023c). With the start of Russian invasion in February 2022, this trend evolved further, resulting in: cancellation of Nord Stream 2 pipeline by Germany on 22nd February 2022; complete cuts of gas supply in Nord Stream 1 pipeline by September 2022, Yamal-Europe by May 2022 (IEA 2022a). As a consequence of these events, share of Russian gas in EU's demand dropped to 23% in 2022 (IEA 2023c).

Combined decisions from either sides – cuts of supplies from Russian end and the EU's intentions to reduce and sanction Russian fossil fuels have been driving a reshape of EU's energy policies with a stronger focus on energy security/independence (Kuzemko et al. 2022). By 3rd of March 2022, IEA released a ten-point plan to rapidly reduce dependence of the EU on Russian gas: proposed measures entail finding alternative suppliers, ramping up LNG imports, accelerating deployment of solar and wind energy, delaying nuclear phase-out, fuel-switching to biomethane and coal, as well as demand-side energy-saving measures (IEA 2022b).

Following this, the REPowerEU plan was adopted by the Commission in May 2022 (European Commission 2022c).

REPowerEU plan

REPowerEU plan outlines measures to reduce and eventually fully phase out Russian fossil fuels through a combination of measures. These measures include diversification of supplies, enhanced electrification of end-use sectors, accelerated deployment of renewables (European Commission 2022c).

The plan builds upon “Fit for 55” package: the European Commission envisions 69% share of renewables in electricity generation, achieved largely by expanding installed capacities for solar PV to 592 GW and wind energy to 510 GW by 2030 (European Commission 2022b). These 2030 targets are an increase of ambition by 62 GW for solar PV and 41 GW for wind, compared to those of “Fit for 55”.

While these EU-level policy changes are crucial for mobilisation of resources and joint efforts by Member States, realisation of the REPowerEU targets relies heavily on how these are translated into national policies and actions. Each Member State have distinct features in this regard, in terms of solar and wind resources availability, extent of dependence on Russian fossil fuel imports, and future vision for other low-carbon electricity sources such as nuclear and hydropower.

1.2 Research questions

Given the ambitious nature of the REPowerEU plan for solar and wind energy, the feasibility of reaching its targets becomes an important question. Feasibility of a goal can be defined as the presence of a path for an agent or a group of agents to achieve this goal (Jewell and Cherp 2020). In our case, the main actors in achieving the REPowerEU targets are the Member States. Many of the Member States have adopted renewed national targets in 2022 and 2023. But are these targets sufficiently ambitious and realistic to enable the achievement of the EU-wide goals? Guided by this overarching question, this thesis asks the following research questions:

1. *Ambitiousness*: How do the revised targets compare to historical trends of for wind and solar energy?

Given the short-term timeframe of REPowerEU until 2030, comparative analysis of historical deployment rates holds valuable insights into how the deployment of solar and wind technologies occurred in the past, against the required/projected outlooks.

2. *National targets*: How do the current national targets of the Member States for solar and wind energy deployment align with the EU-level targets set by the REPowerEU plan?

Addressing this question helps clarify how REPowerEU is translated to national plans and measures, and whether combined ambitions of major electricity producers add up to what REPowerEU envisions at the EU level.

3. *Feasibility*: Do the growth of wind/solar under REPowerEU plan's vision have historical precedents and do they match near-term projections?

A comparison of the historical growth of nuclear power in the 1970s-1980s, in times of another energy security crisis, and the envisioned rates of solar/wind for 2030 aims to benchmark the REPowerEU's ambition to the fastest energy security-driven transitions in a similar socio-political context. Another angle on feasibility is verifying whether the REPowerEU targets are in line with near-term projections of IEA that take into account the firm plans for energy infrastructure development (IEA 2022d).

1.3 Aims and objectives

The aim of this thesis is to analyse the feasibility of REPowerEU plan's solar and wind power targets for EU-27, by focusing on the largest electricity producers of EU-27. The objectives of this thesis are to:

- Compare the solar and wind deployment rates envisioned by REPowerEU to those achieved in the most recent decade;
- Compare the solar and wind deployment rates envisioned by REPowerEU to the recent projections by the IEA, based on the expected policy changes, market dynamics, reductions in cost of technology.
- Review the change in solar and wind deployment targets after the start of war, focusing on the largest electricity producers within EU-27 (Germany, France, Spain, Italy, Poland, Sweden, Netherlands and Belgium), to analyse whether these combined ambitions add up to the REPowerEU targets.
- Compare projected solar and wind deployment rates with the fastest growth of nuclear power in Europe in the 1970s-1980s, to explore the contextual differences and the similarities between the speed and the context of these two transitions.

1.4 Thesis structure

The thesis entails six chapters. Chapter 1 gives background information and defines the research problem, aim and objectives. Chapter 2 provides literature review on past energy transitions, their drivers, the role of energy security in driving policy changes and energy transitions. Chapter 3 outlines the analytical framework for comparing historical trends for the assessment of future projections, and the methodology for data collection and processing (indicators, data sources) used in the study. Chapter 4 presents the findings of the analysis, whilst Chapter 5 discusses different approaches taken for evaluation of feasibility, key takeaways and limitations of the study. Lastly, Chapter 6 provides a summary of the research and its limitations.

2. Literature review

2.1 The drivers and the speed of energy transitions

Energy transitions have historically been driven by a variety of factors, including technological advancement, shifts in end-use, availability of fuels/resources, energy market prices. There is an ongoing debate about which of these factors have more impact on determining speed of transitions. A three-perspective approach proposed by Cherp et al. (2018) provides a framework to combine techno-economic, socio-technical and political perspectives of energy transitions for identifying underlying drivers and other factors affecting energy transitions. The techno-economic perspective focuses on energy flows and markets, and changes in them as components of energy transitions. This includes availability of energy resources, carriers and technologies (fossil fuel reserves, as well as uranium, sunlight, wind etc.), and the supply-demand balance disruptions in energy markets (ibid.). The socio-technical perspective acknowledges the role of societal norms, knowledge and interests that influence energy systems. In this view, social legitimacy of a technology is regarded as one of the key enablers of the rapid adoption of it (Wilson et al. 2020). Social legitimacy is the combined societal benefits of a technology such as job creation, increased access to modern energy, lower energy bills (ibid.). On these indicators, more-granular (decentralised, with low unit-size) technologies – such as solar PV have an advantage over lumpy alternatives (such as nuclear power plants), and thus have more potential for a rapid transition.

Lastly, the political perspective recognises the impact governments and institutional players have on energy transitions: regulations, policies and incentives that target changes in energy generation/consumption. National governments play a central role ensuring energy demand is sufficiently met and supply is secured, import dependency is minimised, as well as the societal benefits - industrial competitiveness and employment of the sector are functioning well (Cherp et al. 2018). Accordingly, national energy policies are designed to serve these needs. Besides this, the political perspective acknowledges the influence of ‘special interests’ of the political structure of a country: governments are inclined to serve the interests of the community actors (such as industrial lobbies, social movements) in making energy-related decisions (ibid.).

Depending on the context, certain drivers can be more influential: for example in Asia in 2000s, economic boom and population growth were the primary drivers for demand growth, whereas for early phase-out of nuclear power in Germany, socio-technical factors were more decisive (Cherp et al. 2018).

A key highlight from the historical energy transitions is that security crises, especially the oil shock of the 1970s, have led to large and rapid changes in national energy mixes (Vinichenko, Cherp, and Jewell 2021; Cherp et al. 2017). This crisis occurred simultaneously with high demand growth in many Western industrialised countries, which was an additional pressure for the governments (Ikenberry 1986). As a consequence, the majority of historical large-scale fuel switching episodes in electricity generation (transition from oil to gas, coal or nuclear power) correspond to this crisis and the following decades of 1970s/80s/90s (Vinichenko, Cherp, and Jewell 2021).

There are similarities in current energy crisis and the 1970s’ oil shock: the 1973 oil embargo had been named as “oil weapon”, i.e. a political tool for exporting countries, just as the REPowerEU Plan mentioning Russian fossil fuels as “economic and political weapon” (European Commission 2022c). Oil shock also triggered large scale response measures in energy policies, promoting diversification of suppliers, switch to alternatives such as nuclear and gas, energy efficiency improvements (Ikenberry 1986). While ensuring security of supplies was the ultimate common goal during the oil shock, the governmental policy responses were divergent in terms of government spendings, incentives and control of energy markets (ibid.).

On the other hand, the current energy transition to low-carbon technologies is distinct from historical transitions of industrial revolution and oil boom, where transitions were motivated by fuel abundance, higher energy density, ease of transport and low cost (Fischer-Kowalski and Schaffartzik 2015; Krausmann, Weisz, and Eisenmenger 2016). Hence, the role of political factors is considered a crucial component in the current transition. Considering climate mitigation and further positive impacts of transition to a low-carbon system, the benefits and those who pay for it are displaced in space and time, stressing the importance of political interventions (Roberts et al. 2018). These interventions include pricing, financial and tax incentives such as power purchase agreements, auctions, pre-set tariffs/premiums, tradeable certificates (IRENA, IEA, and REN21 2018). Such mechanisms help translate national/ high-level renewable energy targets to a more binding form to drive expansion of renewables. With help of such interventions, as well as technological developments, the levelized cost of energy of solar and wind have been steadily declining in the past decade (2010-21): the global averages for new commissioned solar PV plants by 88%; onshore wind by 68% and offshore wind by 60% (IRENA 2022). These low costs have rendered these technologies within fossil fuel cost range (ibid.). On the other hand, fossil fuel prices are considered lower than their 'actual' price (actual – if the negative externalities would have been factored in) (White et al. 2013).

Sensitivity of renewable energy deployment to government policy changes was observed in different contexts, such as *reduction* of feed-in tariff for solar and wind in Ontario, Canada and *postponement* of tax exemption for biofuel producers in Norway: in both cases, investments in respective industries (solar PV plants and biodiesel) slowed down (White et al. 2013).

2.2 Assessing feasible speed of energy transitions

In addition to driving forces, scholars have been intensely debating another key aspect of energy transitions, their timescales, given the urgency to reduce emissions and limit the global warming, and also *"phase out Europe's dependency on Russian energy imports as soon as* *possible"*, as the REPowerEU plan stated (European Commission 2022c). A study by Vinichenko et al. (2021) on historical transitions away from fossil fuel usage in power sector shows that they have been slower than the rates required to meet high or no overshoot of 1.5 degree climate mitigation scenarios. In another study by Cherp et al. (2021), it was concluded that the growth rates of solar and wind energy for meeting 1.5-degree or 2-degree scenarios are required to increase twofold/threefold, and feasibility of such a fast transition is a concern. Gielen et al.'s study analysing International Renewable Energy Agency's (IRENA) Renewable Energy Roadmap (2019) found that a six-fold acceleration of global renewable energy growth (from a business-as-usual case) is needed to stay within Paris Agreement goals. The current slow pace is pointed out by scholars regarding the overall concept of sustainable energy transitions: such transitions bring "*little immediate adoption benefits*" other than reduction of social/environmental externalities, and thus take longer (often decades) to implement (Grubler, Wilson, and Nemet 2016).

Scholars have used different approaches to assess the feasibility of rapid energy transitions. The term 'feasible' is often used in different contexts, in the meanings of probability, plausibility of something being done/achieved. In the climate context, it is termed by the IPCC as 'the potential for a mitigation or adaptation option to be implemented' (Shukla et al. 2022; Jewell and Cherp 2023).

Analyses of feasibility of a climate scenario (or an energy transition pathway) can be broken down to three generic types: causal reasoning, comparative assessment and reflexive consideration of agency (ibid.):

Causal reasoning: this analysis focuses on external and internal factors that can influence the implementation of a climate solution. Feasibility is assessed through analysis of whether causal links of actors and events can lead to or prevent a future scenario.

Comparative assessment: this analysis, in contrast to the causal reasoning, uses quantitative or semi-qualitative techniques to compare a future scenario to a threshold or benchmark. This approach primarily relies on choice of appropriate indicators for comparative analysis of across different systems (countries, technologies, time periods etc.).

Reflexive consideration of agency: this type of feasibility assessments is centred on certain actors (usually policymakers). The analysis comprises of distinguishing between which elements of a climate option can be influenced by the actor, and which are beyond control. Accordingly, the degree of control is what determines whether implementation of a certain climate action is feasible.

With regard to energy transition, and in particular for power generation, the feasibility of low-carbon technology adoption and fossil fuel declines envisioned in scenarios have increasingly been the focus of scholars (Grubler, Wilson, and Nemet 2016; Vinichenko, Cherp, and Jewell 2021). The analyses of historical precedents can give valuable insight into how fast and under which circumstances transitions have occurred, and how historical rates compare to what is required for the future. Nevertheless, this approach is criticised since the forces that caused historical transitions have little relevance for future scenarios (Jewell and Cherp 2023; Kern and Rogge 2016).

Jewell and Cherp (2023) also introduce another way to distinguish the approaches of feasibility assessments: inside and outside views. In inside view, the assessment focuses on particular (unique) characteristics of a system, to answer the question of whether a transition pathway/target is achievable. This is achieved through energy system modelling, plans/strategies and incorporation of other contextual characteristics. Outside view, on the other hand, takes a broader look at the case, identifying similarities with historical reference cases and different contexts to judge the degree of feasibility outcomes. The latter view, therefore, is rather empirical and uses generalisations to decide what features of systems are chosen for comparisons. Despite such features of the outside view, it still provides a more realistic outlook for evaluation of future transitions (Jewell and Cherp 2023). It is worth noting that, ideally, energy transition feasibility studies should integrate both the 'inside view' and the 'outside view', and focusing on only one of these can lead to biased conclusions.

Examples of 'inside view' studies can be energy system modelling based on technical factors such as cost, transmission, storage needs (such as Child et al. 2019; European Commission 2018a), stakeholder perspectives and social attitudes towards on energy transition scenarios (such as Xexakis and Trutnevyte 2021; Xexakis et al. 2020), models based on socio-political feasibility (such as Freeman 2021).

Examples for 'outside view' studies can be comparisons of energy transition cases with historical analogies of fossil fuel phase-out and renewables deployment (such as Vinichenko et al. 2021, 2023; Cherp et al. 2021), investment needs for the energy transition (such as van Sluisveld et al. 2015).

2.3 Energy transition in the EU

In the EU countries, renewable energy policies, such as Germany's first feed-in law of 1990, government financing for pilot projects in 1990s are examples of successful promotion of renewable energy through policy (Cherp et al. 2017). Easier access to loans for renewable energy investors, research and development funding, among other factors, supported the participation of different actors in the expansion of renewables as an industry, making Germany the leading Member State in number of patents in solar/wind energy, number of people employed in renewable energy sector (Ćetković and Buzogány 2016), as well as increasing the combined share of wind and solar in electricity generation from 1.6% in 2000 to 32% in 2022. The EU is leading the global renewables market shares in several renewable energy technologies, in particular wind, geothermal and hydropower, according to 2018 market analysis by the Commission (2021a). This is also true for innovation in the sector, with largest share of global high-value patents in clean technologies (36% in 2016) (ibid.).

Despite the EU-level policies and success examples of Germany, Sweden and Denmark, the adoption rates of renewables vary greatly across the Member States. Especially in new Member States such as Czechia, Hungary, Poland and Slovakia, the annual capacity additions for wind and solar have been remarkably low (for instance, total average solar PV additions in these four states in 2015-2022 were only 2 GW/year). The unstable and low adoption in such countries are largely explained by strong state influence in power sector, low civic participation and decentralised projects, inconsistent and unstable political support for renewables (Ćetković and Buzogány 2016).

In 2009, the Renewable Energy Directive was introduced, as a part of Climate and Energy package (20-20-20 for 2020) of 2008, setting EU's climate targets for 2020: 20% share of renewables in total final energy consumption, 20% reduction of GHG emissions from 1990 levels and 20% improvement of energy efficiency (European Commission 2009). This package entailed a variety of policy instruments, introduction of ETS, binding national renewable energy and emission reduction targets and financing mechanisms for development of certain clean technologies (ibid.). By 2020, the RE share in EU's final energy consumption was 22%, with only France underachieving its national target (European Commission 2020a).

The 2030 target for this indicator was initially agreed as 27% in November 2016 by the Commission (2016), to be revised in 2023. This target has since undergone several upward revisions, to 32% (2018b), to 40% under "Fit for 55" package (2021b), and to 42.5% under the REPowerEU Plan (2022c).

2.3.1 Fit for 55 package

Introduced on 14 July 2021, the package proposes areas of action by the EU to reduce EU's net GHG emissions by 55% by 2030, from 1990 baseline level (European Commission 2021b). Similar to 20-20-20 package, energy is one of the three core areas of this package, besides industrial transformation and cleaner mobility areas. The 2030 target under "Fit for 55" for share of renewable energy in total energy consumption was set to 40% (European Commission 2021c), to be achieved through a combination of measures, including energy efficiency improvements, electrification and accelerated deployment of renewable electricity. The revised Renewable Energy Directive promotes acceleration of administrative processes through a unified online platform, to save time and effort for permitting procedures (European Commission 2021c). Financial support to small and medium businesses for power purchase agreements, obligation for cooperation between Member States on renewable energy projects, in particular offshore wind and industrial product labelling "made from renewable energy" are among the amendments to the directive, identified in the impact assessment study by the Commission as "cost-effective way to the Union's 2030 climate ambition" (European Commission 2021c).

2.3.2 Energy security crisis

While the previous climate and energy plans had decarbonisation at its core, this situation started to shift towards security of supplies and energy sovereignty. The current energy crunch due to dependence on Russian gas imports started in 2021, when gas supplies by Gazprom to the EU was reduced, interpreted as artificial reduction – a move by Russia to accelerate the certification process of Nord Stream 2 pipeline connecting Russia directly to Germany (IEA 2023c; Balmaceda 2021). However, this is not an entirely new issue in EU-Russia relations regarding energy, with IEA's earlier warnings of the EU's overreliance on Russian fossil fuels dating back to 2004, and supply cuts in 2006 (EUobserver 2006; IEA 2023c).

As a result of the artificial reduction, the share of Russian gas in the EU's demand dropped from 47% (pre-pandemic level of 2019) to 39% in 2021 (IEA 2023c). With the start of Russia's invasion of Ukraine on 24 February 2022, and the following cuts of supplies, this figure reached 23% in 2022 (ibid.). Shortly after the start of the war, the Member States resorted to a variety of measures to accommodate the reduction of gas consumption across end-use sectors as well as replacing it with other sources/fuels in electricity generation.

The short-term response measures included increases in coal-fired generation (+27.9 TWh in 2022 compared to 2021), which was also in response to drops in nuclear (-16%) and hydropower (-19%) generation, both of which saw the lowest generation at least since 2000. Combined share of solar and wind energy rose to 22.3% of EU's electricity mix, overtaking gas-fired generation (19.9%) for the first time in history. Overall, these changes resulted in increase of GHG intensity of electricity generation in EU to 255 gCO2e/kWh, above 2019 levels (Ember 2023b). Demand-side measures also resulted in a drop of -79 TWh of electricity demand in the EU between 2021-22 (see Figure 1). The gap between electricity demand and domestic generation almost doubled in 2022 compared to 2021, reaching 14 TWh of net imports.

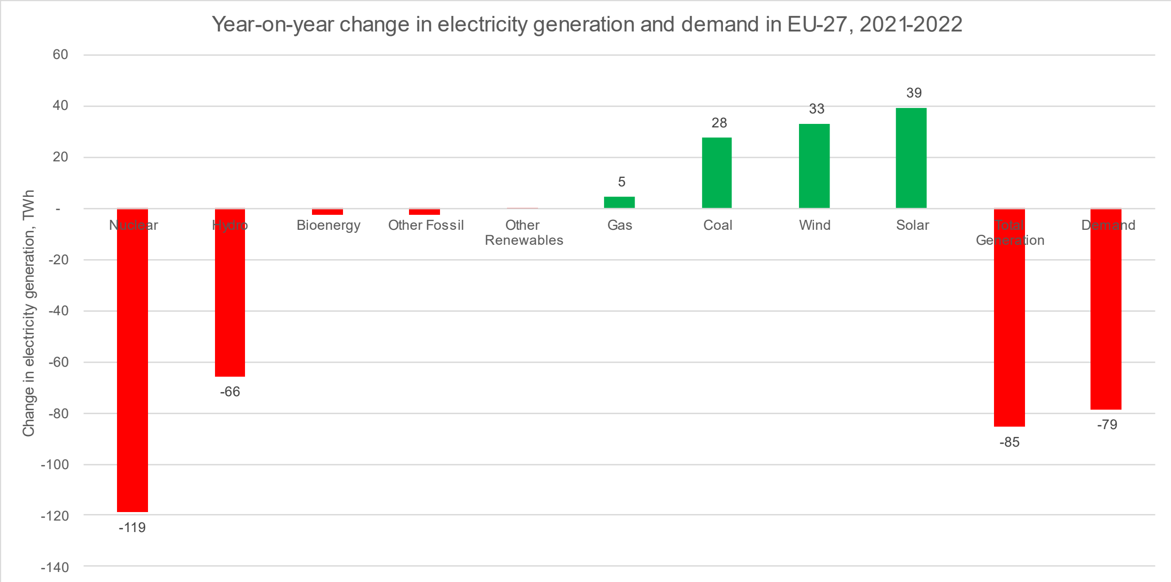


Figure 1. Absolute year-on-year changes in electricity generation and demand in the EU between 2021 and 2022.

Another change in energy policies was about nuclear power. Nuclear has been a source of controversy due to divided opinions across Member States about its role in energy transition of the EU. Comprising 25% of EU's total electricity generation in 2021, nuclear had long been the largest source of low-carbon electricity generation, until only 2022 - when 26 of 56 nuclear plants in France were shut for maintenance and repair reasons. Whilst European Parliament's approval of taxonomy labelling nuclear and gas as "environmentally sustainable economic activities" indicates some EU-level favouring of nuclear, it is largely down to national level decisions determining phase-out/ delay of phase-out or vision for construction of future plants.

Germany's exit of nuclear by end of 2022 was delayed, keeping the last three reactors running until April 2023 (DW.com 2022). Belgium, likewise, reconsidered the nuclear exit by 2025, deciding to continue using nuclear power for another decade (DW.com 2023). However, for new plants, nuclear power's long permitting and construction phases, high upfront capital costs against dropping costs of solar and wind render it unattractive for the long term. Thus, of 13 countries with nuclear power in EU-27, only two – France and Slovakia have currently (as of

February 2023) nuclear reactors under construction and Hungary planning to start construction of new units (World Nuclear Association 2023).

On the long term, political views around renewable energy have been strengthened to frame it as “the energy of freedom”, “sovereignty” (Osička and Černoch 2022). A shift in views of political leaderships of Poland and Czechia is being witnessed, where commitment to energy transition had been traditionally weak (ibid.). In Germany, more ambitious renewable energy targets (80% renewables in electricity mix by 2030) and policies supporting renewable deployment have been announced, such as Onshore Wind Power Act, where 2% of the country’s land area is to be designated for wind installations by 2032 (Clean Energy Wire 2023; Germany Federal Ministry for Economic Affairs and Climate Action 2022). Similar to Germany, Belgium, France and Denmark have announced accelerated deployment of renewables as the main strategy to secure domestic energy (Kuzemko et al. 2022).

Nevertheless, the combination of urgency of climate mitigation, energy security threats triggered by Russia’s war on Ukraine, as well as impacts of resulting high energy prices on cost of living and industrial slowdown have engendered a unique and unprecedented case for the EU.

2.3.3 REPowerEU Plan

The REPowerEU Plan, released as a response plan focusing on reduction and phase-out of Russian fossil fuels from EU's energy supply, builds upon ambitions of "Fit for 55" (European Commission 2022c). The plan consists of four core areas of action:

- *Energy efficiency/ savings:* This includes demand side behavioural measures and investments for heat pumps, retrofitting buildings, enhancing energy efficiency of industrial processes.

- *Gas supply diversification:* This includes increasing pipeline and non-pipeline imports from non-Russian suppliers and addressing infrastructure needs for ramping up liquefied natural gas (LNG) imports and storage, boosting EU's biomethane production capacities.

- *Acceleration of the transition to clean energy sources:* This includes increasing share of renewable energy in total final energy consumption of EU to 42.5% by 2030, up from the "Fit for 55" target of 40%. Since this target covers final energy consumption (not only electricity generation), the measures to achieve this entail solutions such as biomethane for transport and industry, accelerated deployment of solar PV and wind energy, accelerated electrification of end-use in transport and industrial sectors, higher production and import amounts of hydrogen.

- *Smarter investment mechanisms to support the transition:* Investment needs for the above-mentioned measures, and additional requirements such as upgrades to grids, gas interconnections are estimated at 210 billion EUR in addition to implementation of "Fit for 55", between 2022 and 2027.

With the release of this plan by the Commission, a number of additional documents, such as "EU Solar Energy Strategy" have been released to accompany the actions set out in REPowerEU (European Commission 2022a). This Strategy includes four initiatives to support the ramp-up of solar PV deployment in the EU:

1. *European Solar Rooftops Initiative:* Member States should create support frameworks for rooftop solar installations with energy storage, speed up and ensure that its deployment is integrated smoothly to rooftop renovations. Mandatory solar installations on new and existing rooftops are also part of this initiative.
2. *Simplified permits:* to overcome delays/barriers to scale-up of utility-scale solar PV installations, renewable go-to areas should be defined, where environmental impact is estimated to be minimal, and the permit-granting periods for such installations should be limited.
3. *EU large-scale skills partnership for renewable energy:* to meet the labour demand associated with expansion of solar PV, expected doubling of need for workforce by 2030 should be fulfilled by development of training and vocational education programmes by Member States.
4. *European Solar PV Industry Alliance:* the alliance, launched on 9 December 2022, aims to localise supply chains and attract investments for domestic manufacturing of solar PV technologies. With a target of 30 GW manufacturing capacity by 2025, coordinated action by various stakeholders of the industry and funding by relevant EU programmes are expected to generate additional 400,000 jobs and generate additional 60 billion EUR GDP per annum by 2025 (European Commission 2022a).

Commission Recommendation "On Speeding up Permit-granting Procedures" also addresses one of the key barriers to deployment of renewable energy: administrative barriers in applications for and approval of installations (European Commission 2022d). Under this recommendation, Member States should map out renewable go-to areas designated for fast and simplified environmental impact assessment (areas with low risk to environment). For project proposals in these areas, permit-granting processes may not exceed *one* year for onshore and *two* years for offshore projects (ibid.):

Table 1. Maximum time limits for permit granting procedures, Source: (European Commission 2022d)

Project type	Maximum period for permits (possible extension)	
	Go-to areas	**Outside go-to areas**
Onshore renewable Capacity < 150 kW*	6 months (+3 months)	1 year (+6 months)
Offshore renewable Capacity < 150 kW*	1 year (+6 months)	2 year (+6 months)
Onshore renewable	1 year (+6 months)	2 year (+6 months)
Offshore renewable	2 year (+6 months)	3 year (+6 months)

*plants with capacity up to 150 kW, their energy storage and grid connection

In exceptional circumstances, these periods may be extended for up to six months.

Import dependency of the EU on these technologies is perceived as a threat to supply chains, especially due to China's dominance in solar PV, fuel cells and EVs. Accordingly, more regulations and proposals have recently been produced, such as "A Green Deal Industrial Plan for the Net-Zero Age" on 1st February 2023, a proposal for electricity market design reform and a proposal for "Net Zero Industry Act" on 16th March 2023 (European Commission 2023a; 2023i; 2023h). These policy changes aim to boost EU's domestic manufacturing capabilities and increase investor confidence for key clean technologies, including but not limited to solar and wind power, batteries, hydrogen production, electric vehicles (EVs), heat pumps.

As REPowerEU Plan calls for furthering expansion of renewables, especially wind and solar energy, Member States increasingly revise their targets for the deployment of these technologies. Some of the updates are already reflected in official documents and plans of respective energy/environmental ministries of Member States, whilst for others, it will be reflected in the updated national energy and climate plans (NECPs) that are to be submitted to the Commission by 30 June 2023 (European Commission 2023b).

3. Analytical framework and methodology

This chapter presents the underlying theoretical framework, data sources and data analysis procedures for addressing the research questions. It also outlines justifications where assumptions are taken for future projections.

3.1 Historical transitions and feasibility of future energy transitions

The focus of this thesis is the comparative assessment of feasibility in the case of solar and wind energy targets of EU, comparing it to the respective technology's deployment trends in the recent decade. In addition to this, the comparative assessment also looks at the historical growth of nuclear power following the oil shock of 1970s, due to the following contextual similarities:

Table 2. Contextual factors affecting the three periods of energy transitions in Europe, 1970-2040

Perspective*/dimension	1970-1990	2000-2020	2020-2040
Techno-economic and political (demand growth)	High (because of economic growth)	Low	Medium-High (because of electrification)
Political (security of supplies)	Threatened (Arab oil embargoes)	Stable	Threatened (Russia's invasion of Ukraine)
Socio-technical (available non-fossil technologies)	Nuclear	Renewables	Renewables

* 'Perspective' here refers to three-perspectives of the meta-theoretical framework proposed by Cherp et al. (2018)

As summarised in Table 2, both the 1970-1990 and the current period are characterised by two drivers: threat of supplies and growth in demand; and both require(d) rapid switch to non-fossil alternative source (nuclear and renewables).

The choice of appropriate indicators for the growth of low-carbon sources is key to comparison (Grubler, Wilson, and Nemet 2016). Nuclear power plants typically operate with stable supply at a high capacity factor of ~90%, whereas wind and solar PV are intermittent with lower capacity factors of ~25-35%, ~10-15% respectively. For a like-for-like comparison of evolution of the technologies, the key data points are *amount of electricity generated* instead of *installed capacity*.

Another issue with comparability is the variation in the scales – how large the electricity grids are/were across countries and across periods. Larger countries are naturally expected to deploy larger low-carbon capacities than smaller ones. Furthermore, the size of the electricity system now is significantly larger than it was in the past. This is accounted for through normalisation by total electricity generation in each system. It should be noted that, however, the scale still remains an important metric, since transitions take longer time in complex heterogeneous systems and the EU-wide scale of the shift to low-carbon electricity adds up to the complexity of the transition.

3.2 Methodology and data sources

This research entails historical data collection and analysis for nuclear, wind, solar generation capacity, as well as review of future targets of wind and solar energy deployment envisioned by the EU/national strategies.

The following data sources have been used in the analysis:

3.2.1 Historical data

Table 3. Data sources used in the study

Indicator and units	**Source**	**Time period coverage of dataset**
Electricity generation by source/by country, TWh	Ember* (2023a); IRENA** (2023); IEA (2023b)	2000-2022 (Ember) 2000-2020 (IRENA) 1971-2020 (IEA)
Electricity demand by country, TWh	Ember (2023a)	2000-2022
Renewable electricity generation capacity (solar, offshore and onshore wind, MWe)	IRENA (2023)	2000-2022

*Ember uses European Network of Transmission Systems Operators for Electricity (ENTSO-E) and Eurostat as data sources for electricity generation and demand for EU countries. For non-EU countries, such as United Kingdom and China, national statistics are used.
**IRENA data used for disaggregation of wind energy generation by offshore and onshore technologies

All of the data on above indicators have been taken as annual aggregates. Unless otherwise stated/cited, the graphs depicting historical electricity generation and/or capacity are constructed by the author on these data sources.

3.2.2 Renewable energy deployment targets and projections

For offshore wind, the Ostend Declaration of 24 April 2023, and the non-binding agreements of priority offshore grid zones of 19 January 2023 (see (European Commission 2023f; 2023e; 2023d; 2023g; 2023c; NSEC 2023) provide the most recent and EU-wide breakdown of deployment targets.

For solar and onshore wind, the latest available plans/strategies disclosed by each Member State's governing bodies have been used, since the NECPs are undergoing revision, due June 2023 (not updated since 2019). This research focuses on the top eight electricity producers in the EU that countries generated 80% of EU-27's electricity in 2022: Germany, France, Spain, Italy, Poland, Sweden, Netherlands and Belgium.

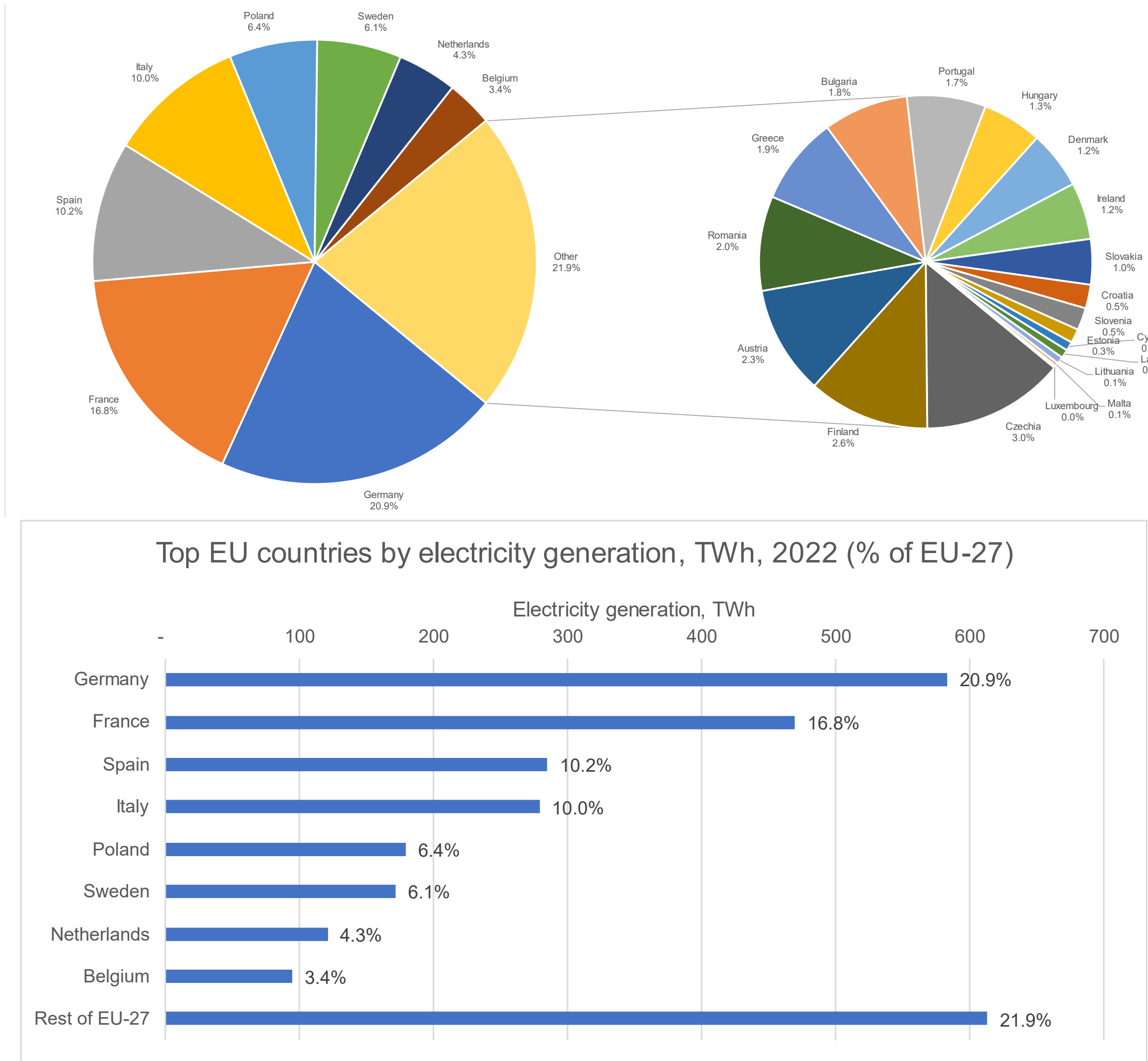


Figure 2. Breakdown of total electricity generation in 2022 by Member States, TWh. These 8 countries are responsible for about 80% of electricity generation in EU-27.

3.2.3 Considerations for future projections

REPowerEU targets: whereby installed capacity targets are needed, 592 GW of solar PV, 510 GW of total wind capacity by 2030 have been taken, as defined by the accompanying document of REPowerEU plan (European Commission 2022b). For the breakdown of wind capacity by offshore and onshore, the non-binding agreements on priority offshore grid zones were taken as primary reference, which total to 117 GW offshore wind capacity by 2030 (this target initially summed to 112 GW, further adjusted with increased target by the Netherlands in April 2023, in the Ostend meeting of the North Seas Energy Cooperation countries (NSEC 2023)). This leaves 393 GW of the REPowerEU target for onshore wind.

Future system sizes (Total electricity generation in a country/region): For EU-27 and Member States, IEA’s total generation projection for 2030 under announced pledges scenario (APS) is taken, from the World Energy Outlook 2022 report (IEA 2022c). All countries are assumed to undergo same growth as EU-27 and grow linearly within 2022-2030 timeframe.

For the UK, the 2030 total generation projection in the reference scenario outlined by the HM Government has been taken (Department for Business, Energy and Industrial Strategy, UK 2022b)**.**

Conversion from capacity target/projection to generated electricity: For comparative analysis between historical expansion of nuclear energy and solar/wind, the installed capacity targets for wind/solar technology should be converted to electricity generation. The latest available IRENA data (2020) has been used to estimate capacity factors, which are then used for conversion. These figures are expected to increase in the future, thanks to technological advancements in offshore and onshore wind turbines, as already reported in the statistics of the newly installed wind farms (EnergyNumbers.info 2022). To accommodate the increased efficiency of new wind turbines in calculations, the projected growth rates are estimated using the three cases, as in Table 4:

Table 4. Latest (2020) and future capacity factors for the EU-27 and the United Kingdom.

	EU-27			**United Kingdom**		
Technology	**2020**	**medium**	**high**	**2020**	**medium**	**high**
Offshore wind	34%	38%	45%	45%		
Onshore wind	25%	30%	35%	28%	30%	35%
Solar PV	12%			11%		

The latest (2020) figures were chosen as lower bound and 45% (offshore)/35% (onshore) as upper bound for the projections.

IEA projections and national targets: For national level targets and IEA projections for the EU, where available, 2030 projections are taken. Where the targets are specified for different timeframes (e.g. 2027, 2028, 2050), the target is linearly interpolated/extrapolated to 2030 (with the assumption of constant annual capacity additions between 2023 and target year). The IEA projections for solar PV and wind capacity additions have been taken from the Renewables 2022 report (IEA 2022d). For offshore and onshore breakdown of the IEA projections, the same ratio of capacity additions as in REPowerEU plan is assumed (~30% of the total wind additions offshore and ~70% onshore).

3.2.4 Normalisation and comparative analysis

With respect to like-for-like comparison of temporal dynamics in transitions, the following features of energy systems (at national and larger scales (EU/group of countries)) are taken into account:

- **Time period**: Since the REPowerEU plan is to be fulfilled by 2030, the remaining time period is 8 years (2023-2030, both years inclusive). This time-window size is kept consistent throughout the comparisons in the study, to better reflect growth of technologies over a limited and consistent timeframe.
- **System size**: Comparisons of different time periods correspond to different electricity system sizes, and the comparative assessment largely entails growth of demand (motivated by increase in population, electrification, industrial growth etc.). Additionally, for relative comparison of technologies/deployment rates across different countries, normalisation of the system size is required. This is carried out through choosing a mid-point in the respective time period, and normalising figures to the total electricity generation in the system.
- **Nuclear versus wind/solar comparisons:** To eliminate technology differences (capacity factor, delay between construction and connection to the grid) across nuclear

and wind/solar, and to consistently reflect their growth in electricity systems, **change in generated electricity by source** is taken, rather than installed capacity. This also allows for summation of growth rates across technologies (to combine wind+solar).

Taking these into account, the growth rate ***G*** is formulated as below:

$$G_{Y-8\ to\ Y}^{tech} = \frac{8 - year\ change\ in\ generation}{System\ size\ in\ midpoint\ year}$$

$$G_{Y-8\ to\ Y}^{tech} = \frac{(El.gen_{tech}\ in\ year\ Y) - (El.gen_{tech}\ in\ year\ Y - 8)}{El.gen_{total}\ in\ year\ Y - 4}$$

In terms of respective units, this becomes:

$$G_{Y-8\ to\ Y}^{tech} = \frac{[Change\ in\ TWh]}{[System\ size, TWh]} = [\%]$$

An example calculation for onshore wind for total EU-27 in 2012-20 period:

$$G_{2012\_20}^{ONW} = \frac{Onshore\ wind\ gen.in\ 2020 - Onshore\ wind\ gen.in\ 2012}{Total\ generation\ in\ 2016}$$

$$= \frac{354.33 - 181.03\ (TWh)}{2894.87\ (TWh)} = 5.99\%$$

- **Change in system sizes over the time period:** since this research explores 8-year time windows, the use of total system sizes is not only needed for normalisation purposes, but also for reflecting how much total growth has happened within the period. The growth of system size is a key contextual feature of energy transitions, as highlighted by Vinichenko et al. (2021). In particular for nuclear, the pursuit of nuclear power by countries was motivated by high growth in electricity consumption, alongside with the motivation to replace existing capacities (Jewell 2011). Thus, the relative growth of system sizes should be incorporated in the comparative analysis, through mapping the growth rates against the relative growths of system sizes.

- **Cross-country deployment rate comparisons:** for deployment rate comparisons on an installed capacity-basis, average annual capacity additions (MW) and mid-point system size (TWh) are taken. Taking average annual capacity additions allows for comparisons across different lengths of time windows.

In this case, normalised capacity addition rate ***C*** takes the following form:

$$C^{tech}_{Y\_1\ to\ Y\_2} = \frac{average\ annual\ capacity\ additions}{System\ size\ in\ midpoint\ year}$$

$$C^{tech}_{Y\_1\ to\ Y\_2} = \frac{((cap_{tech}\ in\ year\ Y_2) - (cap_{tech}\ in\ year\ Y_1))/(Y_2 - Y_1)}{El.gen_{total}\ in\ year\ (Y_1 + Y_2)/2}$$

In terms of respective units, this becomes:

$$C^{tech}_{Y\_1\ to\ Y\_2} = \frac{[MWe/year]}{[System\ size, TWh]} = [\frac{MWe/year}{TWh}]$$

An example calculation for onshore wind for total EU-27 in 2012-20 period:

$$C^{ONW}_{2012-20} = \frac{(Onshore\ wind\ cap.in\ 2020 - Onshore\ wind\ cap.in\ 2012)/(2020 - 2012)}{Total\ generation\ in\ 2016}$$

$$= \frac{\frac{162{,}508 - 95{,}126\ (MWe)}{8\ (years)}}{2894.87\ (TWh)} = 2.91 \frac{MWe/year}{TWh}$$

4. Results

This section provides outcomes of the data collection of national targets, as well as the comparative analysis of solar and wind capacity additions in the envisioned/projected scenarios versus the recent trends and the historical expansion of nuclear power.

4.1 Overview of wind and solar energy in the EU

Total electricity generation in 2022 was 2,795 TWh, with nuclear energy (22%) as the largest source, followed by gas (20%) and coal (16%).

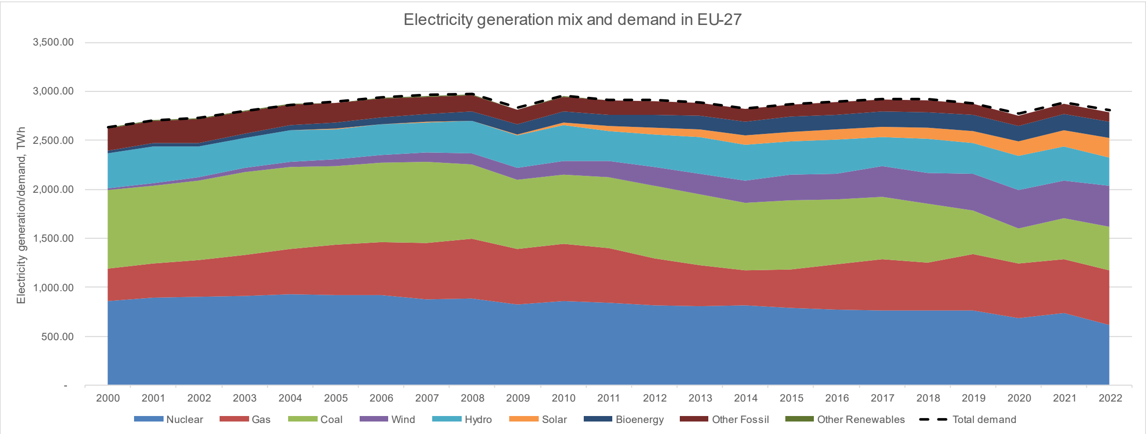


Figure 3. Electricity generation mix and demand in EU-27 in 2000-2022.

Solar PV: with a record annual addition of 35.9 GW, the total capacity reached 198 GW in 2022. The annual capacity additions for solar PV have been steadily rising since 2016, unlike onshore and offshore wind, where annual additions have fluctuated in the past 8-year period.

Onshore wind: also with the record annual addition (14 GW), the total capacity reached 187 GW in 2022. Onshore wind is the 4th largest source of electricity in the EU (13%).

Offshore wind: being a less mature/more expensive technology, also due to long environmental permitting and construction procedures, the offshore wind capacity additions have not been steady in the recent years. The installed capacity of offshore wind rose by 1.6 GW in 2022 to 16.7 GW, recovering after the additions in 2021 plummeted to a low of 0.5 GW.

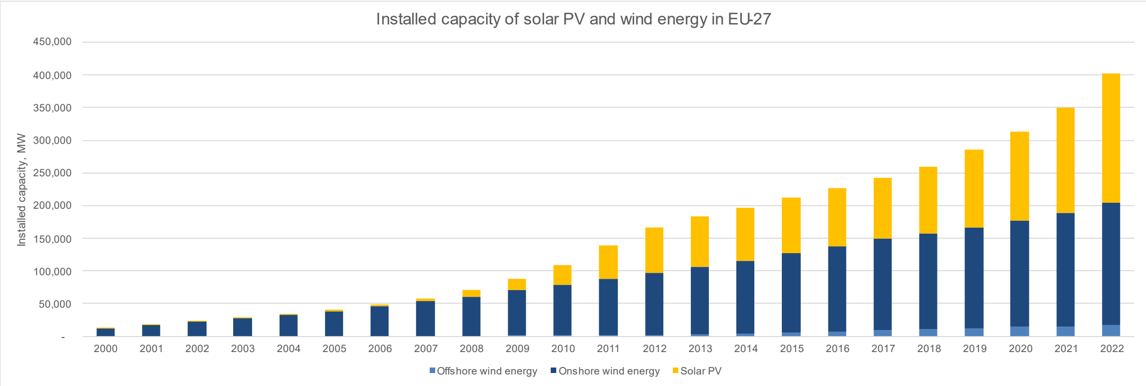
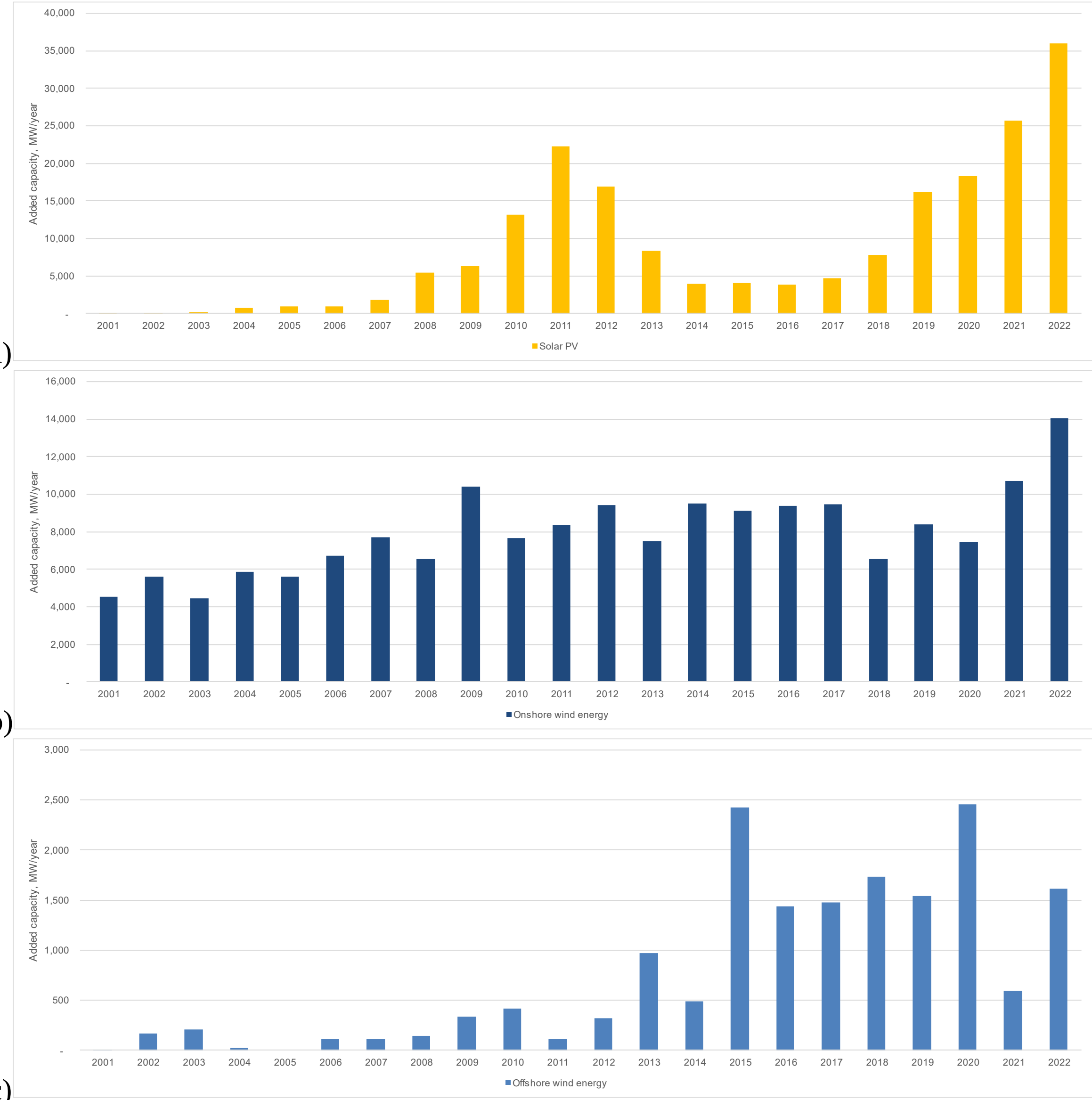


Figure 4. Total installed capacities of wind and solar PV energy in EU-27 in 2000-2022.



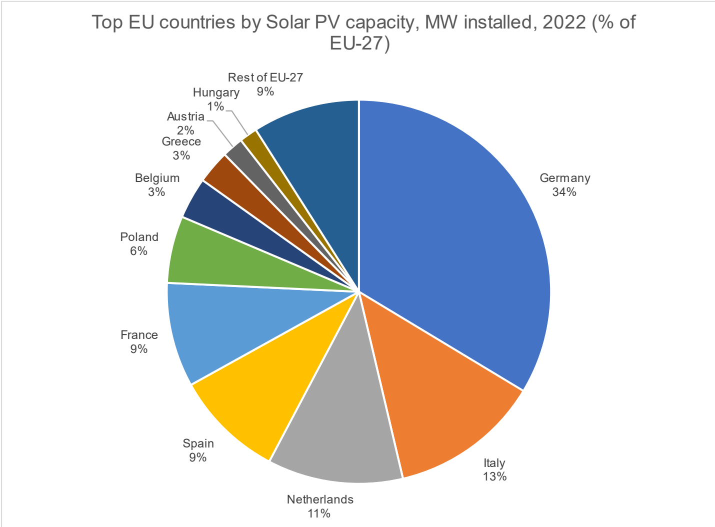
a)

b)

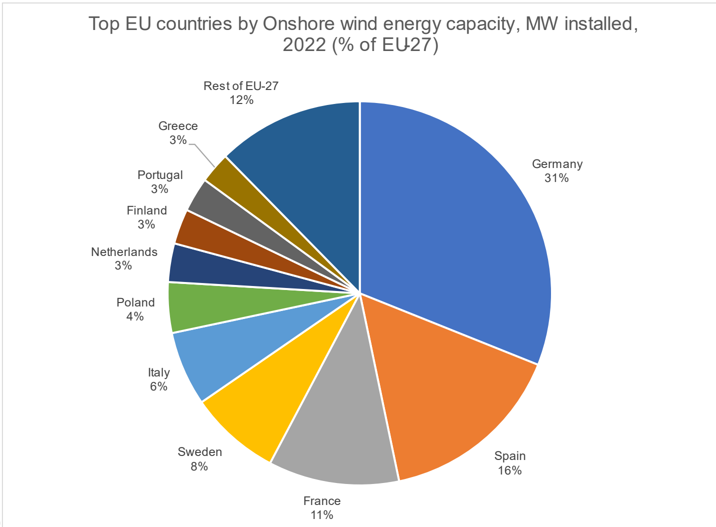
c)

Figure 5. Annual capacity additions (MW/year) of a) solar PV; b) onshore wind; c) offshore wind energy in EU-27 in 2001-2022.

As outlined in the Methodology section, this analysis focuses on the national targets of the major electricity producers of the EU – Germany, France, Spain, Italy, Poland, Sweden, the Netherlands and Belgium – the largest 8 countries that account for 80% of total electricity generation in 2022. For wind and solar energy as well, these countries are the leading Member States: 86% of the offshore wind, 86% of the solar PV, 81% of the onshore wind capacities (total installed, MWe basis) are concentrated in these 'largest 8', see Figure 6:



a)



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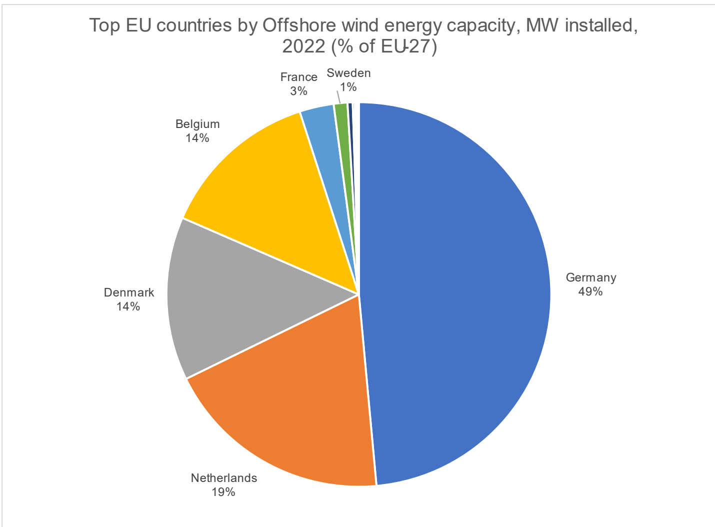
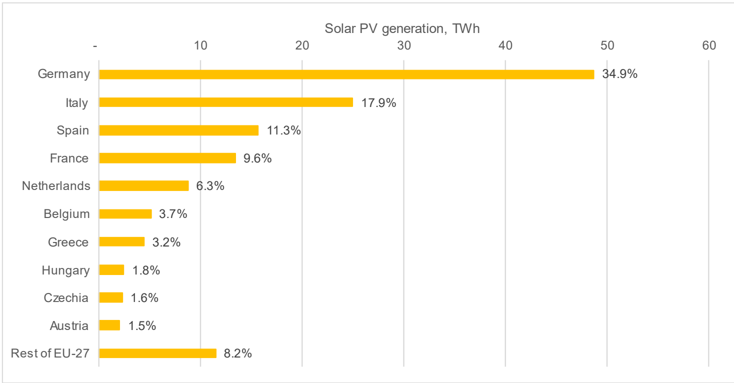


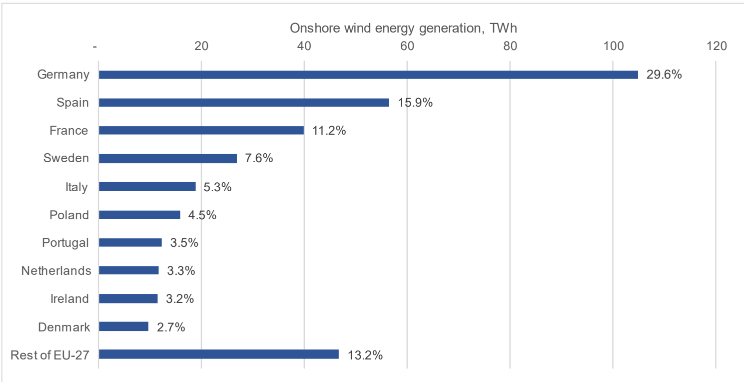
c)

Figure 6. Breakdown of total installed capacity of a) solar PV (197 GW); b) onshore wind (187 GW); c) offshore wind (16.7 GW) by Member State in EU-27 (2022).

A breakdown of wind and solar electricity generation in the EU is given in the Figure 7:



a)



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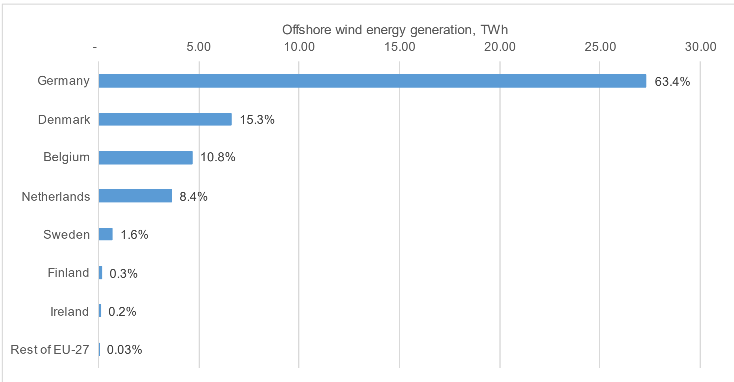

c)

Figure 7. Breakdown of total electricity generation from a) solar PV (139 TWh); b) onshore wind (354 TWh); c) offshore wind (43 TWh) by Member State in EU-27 (2022).

4.2 Offshore wind energy

Offshore wind, unlike onshore wind or solar PV, requires higher level of coordination between Member States to build necessary transmission infrastructure in seas for joint and hybrid projects, as emphasised in the joint statement of North Seas Countries and the European Commission (NSEC 2020). The potential and key role of offshore wind was highlighted by the Commission earlier as well, mentioned as "mature, large-scale technology" in "Offshore Renewable Energy" strategy introduced back in 2020 (European Commission 2020b). That strategy envisioned 60 GW installed capacity by 2030 and 300 GW by 2050 for offshore wind.

In January 2023, these targets were revised in five non-binding agreements for offshore wind deployment goals signed by the countries of priority offshore grid zones. Table 4 presents the revised targets for 2050, with intermediate near-term targets for 2030 and 2040 (European Commission 2023f; 2023e; 2023d; 2023g; 2023c):

Table 5. Priority offshore grid corridors and offshore wind deployment targets

Priority offshore grid corridor	**Member States**	**Targets (installed capacity, GW)**		
		2030	**2040**	**2050**
Atlantic	Ireland, Spain, France, Portugal	12.74-14.26	21.74-26.06	29.74-43.06
South and West (SW)	Greece, Spain, France, Italy, Malta, Portugal	5.15-6.15	6.7-12.6	6.7-20.1
Baltic Energy Market Interconnection Plan (BEMIP)	Denmark, Germany, Estonia, Latvia, Lithuania, Poland, Finland, Sweden.	22.4	34.6	46.8
Northern Seas Offshore Grids (NSOG)	Belgium, Denmark, Germany, Ireland, France, Luxembourg, Netherlands, Sweden	60.3	134.9-158.3	171.6-218
South and East (SE)	Bulgaria, Croatia, Greece, Italy, Cyprus, Romania, Slovenia	8.81	16.8	25.9
Total	**20 Member States**	**109.4-111.92**	**214.74-248.36**	**280.74-353.86**

4.2.1 Summary of national targets

For some Member States, the targets have not been finalised, and may be subject to change in the revision process of NECPs, thus noted as ranges, see Annex A. At national level, the targets are as follows, (with comparisons to targets in NECPs for 2021-30 (finalised in 2019), where available):

Table 6. Offshore wind deployment targets for 2030: NECPs (2019) and non-binding agreements (2023)

Member State	**NECP (2019) target for 2030, MWe**	**Note on NECP target**	**Revised target (2023) for 2030, MWe**
Germany	15,000 (2019)	North Seas Energy Cooperation (NSEC) meeting on 20 June 2019	30,500
Netherlands	11,000 (2019)	NSEC meeting on 20 June 2019	16,000**- 21,000
Denmark	5,000 (2019)	NSEC meeting on 20 June 2019	13,200
Portugal	300 (2019)	100 MW by 2025	10,000
Italy	-		8,500
Belgium	4,000 (2019)	NSEC meeting on 20 June 2019	6,000
Poland	3,815 (2019)	725 MW by 2025	5,900
Ireland	3,500 (2019)	NSEC meeting on 20 June 2019	5,500
France	5,200-6,200 (2019)	2,400 MW by 2023, 5,200-6,200 MW by 2028	***4,400***
Spain	50,330* (2019)	Total wind capacity target, no specific target for offshore	3,060
Greece	Not available		2,700
Lithuania	700 (2019)		1,400
Estonia	Not available		1,000
Finland	5,500* (2019)	Total wind capacity target, no specific target for offshore	1,000
Romania	5,255* (2019)	Total wind capacity target, no specific target for offshore	1,000
Sweden	Not available		700
Croatia	1,184* (2019)	Total wind capacity target, no specific target for offshore	510
Latvia	Not available		400
Cyprus	Not available		100
Malta	Not available		50

* Target for total wind capacity only, offshore wind not specified
**The Netherlands have revised their 2030 target from 16,000 MW (19 January 2023) to 21,000 MW on 24 April 2023, announced at the meeting of North Sea countries in Ostend, Belgium (NSEC 2023).

Overall, all of the countries listed either had no or lower previous offshore wind deployment target, prior to the revision in January 2023, with the exception of France. The French Multi-annual Energy Program (2019-23/2024-28) introduced back in 2015 had a vision of 2,400 MW offshore wind capacity by 2023, to be expanded to 5,200-6,200 MW by 2028 (Ministry for the

Ecological Transition - France 2020), with their 2019 version of NECP also outlining same targets (Ministry for the Ecological Transition - France 2019). However, by the end of 2022, France only managed to install one offshore wind farm with a total capacity of 480 MW. Thus, their offshore wind target was reduced in the non-binding agreements to 4,400 MW by 2030.

At EU level, the total of national targets in NECPs were in the range of 49 to 60 GW, and the 2020 EU Strategy to harness the potential of offshore renewable energy also had set an EU target of 60 GW by 2030; 300 GW by 2050 (European Commission 2020b).

The revised targets add up to 117 GW by 2030, 90% of which is projected to be concentrated in 10 countries (Germany, Netherlands, Denmark, Portugal, Belgium, Ireland, Finland, Italy, Poland, France), (Figure 8).

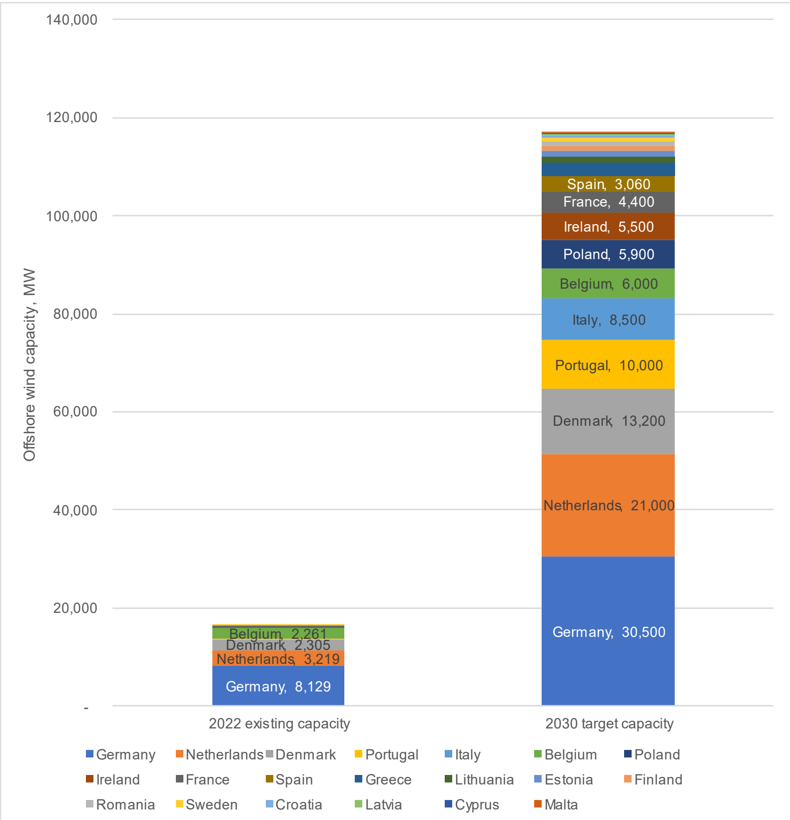

Figure 8. Offshore wind capacity in the EU: installed capacity in 2022 and 2030 targets

4.2.2 Comparisons with the recent deployment rates and across countries

As with the overall increase in ambitions from previous targets, the deployment rates envisioned to meet the new 2030 targets require considerable increase in comparison to that of recent years. To visualise this, normalised capacity addition rate ***C*** has been calculated for 8-year periods of 2014-22 and 2023-30, for each Member State and EU-27 as an aggregate. For comparison, China and the UK have been selected: majority of the worldwide offshore wind capacity additions took place in China recently, with over 70% (6.8 GW out of 9.4 GW) of global new installations of 2022 (WindEurope 2023). On the other hand, the United Kingdom alone had more new installations than the EU-27 as a whole in 2021 and 2022. The UK government has also recently announced ambitious targets to expand offshore wind capacity to 50 GW by 2030, per British Energy Security Strategy of 7 April 2022 (Department for Business, Energy and Industrial Strategy, UK 2022a).

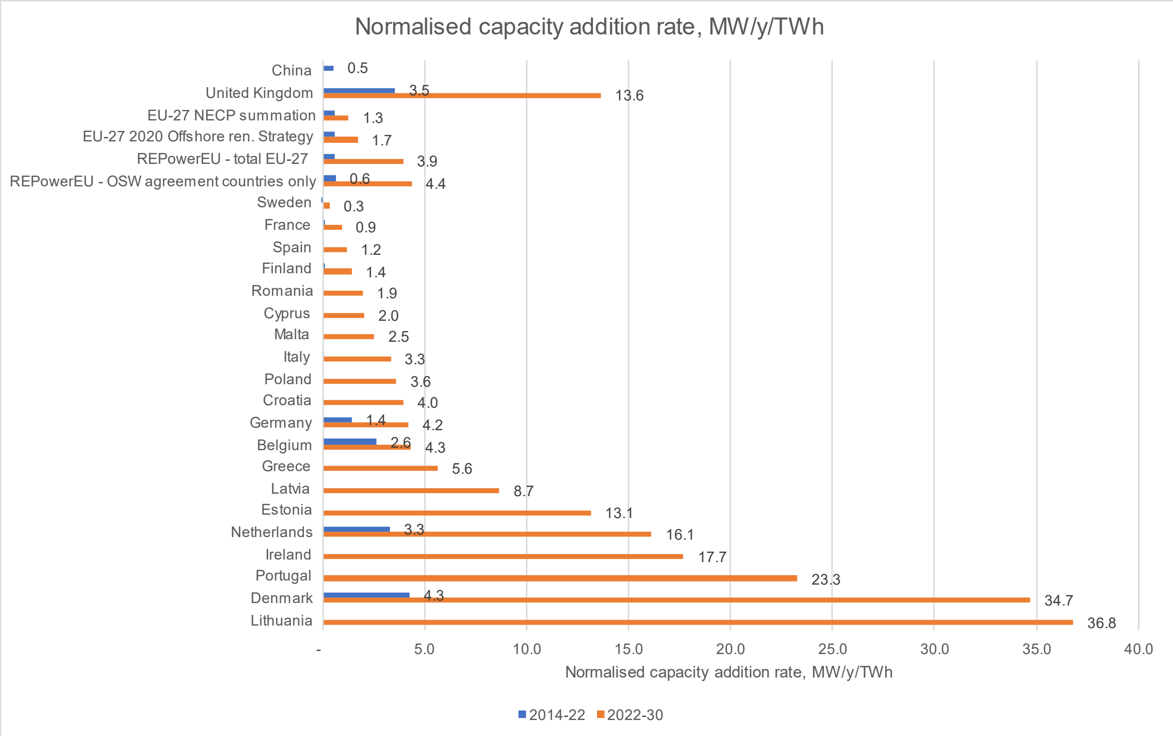

Figure 9. Normalised deployment rates of offshore wind capacity in the UK, China and EU-27 countries for 2014-22 period and 2022-2030 targets.

Notes about targets:
***UK**: 50 GW by 2030;*
***China** has not set a capacity target at national level;*
***EU-27 offshore renewable energy strategy** – 60 GW by 2030, as envisioned in offshore renewable energy strategy.*
***EU-27 NECP summation** - 49 GW by 2030– summation of available offshore wind targets in NECPs submitted in 2019.*
*For REPowerEU target of 117 GW by 2030, two approaches were considered: taking whole total **EU-27's** system size (3189 TWh) and **REPowerEU – OSW agreement countries** - by adding up the non-binding agreements' signatory countries only - 20 Member States (2870 TWh).*

In the 2014-22 period, the highest observed ***C*** was in Denmark with 4.3 MW/y/TWh, followed by the UK (3.5), the Netherlands (3.3), and Germany (1.4). As for China, due to its huge system size of 7,120 TWh, the normalised ***C*** was 0.5 MW/y/TWh.

With respect to envisioned targets for the 2023-30 period, the highest ***C*** values are in the Netherlands (16.1 MW/y/TWh: ~5 times greater than the 2014-22 value) and the UK (13.6 MW/y/TWh: ~4 times greater than the 2014-22 value) among the large countries. For Germany and Denmark as well, the aimed deployment rates are ~3 times and ~8 times higher than their 2014-22 values, respectively.

In addition to the 2014-22 8-year period, the highest normalised deployment rates in other 8-year periods are also of interest for comparisons. The leading countries in this indicator were Denmark, the Netherlands and Belgium, with the highest value of 4.3 MW/y/TWh in Denmark 2014-22 period. For these countries, the historical rates are visualised in the Figure 10 below:

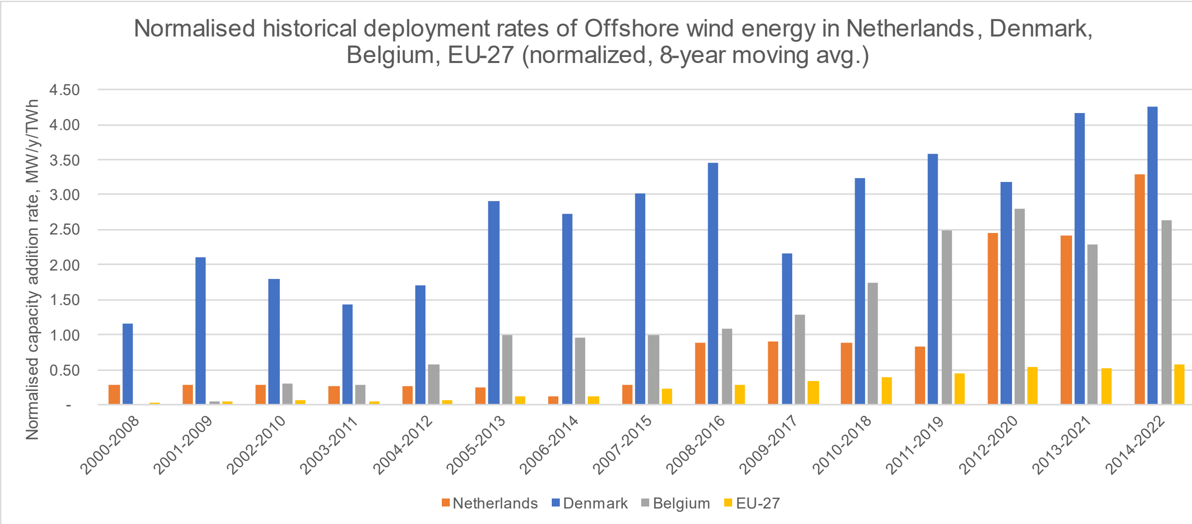

Figure 10. Normalised historical deployment rates of offshore wind capacity in the Netherlands, Denmark, Belgium and EU-27 countries for 8-year periods from 2000-2022.

The fact that highest ever deployment rates correspond to the most recent periods is an indication of acceleration, however, it should be noted that the overall 117 GW target agreed by the 20 Member States is equivalent to ***C***=4.4 MW/y/TWh, higher than the highest-ever precedented figure for any Member State.

Another key aspect of analysing the capacity additions is the distribution of new installations among the Member States. For this comparison, division of EU-27 countries by “the largest 8” (representing the 80% of EU) and “Rest of EU” (12 Member States) has been done:

Table 7. Breakdown of offshore wind capacity additions in EU-27 by grouping the Member States.

"The largest 8" refers to Germany, France, Spain, Italy, Poland, Sweden, Netherlands, Belgium, "Rest of EU" refers to Denmark, Portugal, Ireland, Finland, Greece, Lithuania, Estonia, Romania, Croatia, Latvia, Cyprus, Malta.

	Annual avg. capacity additions (MW/y)		**Normalised capacity addition rate (MW/y/TWh)**	
	2014-22	**REPowerEU 2022-30**	**2014-22**	**REPowerEU 2022-30**
The largest 8	1,522 (92%)	8,218 (66%)	0.7	3.3
Rest of EU	137 (8%)	4,304 (34%)	0.4	11.2
EU	1,660	12,522	0.6	4.4

While the past offshore wind installations were heavily concentrated in the "largest 8", accounting for 92%, the distribution is expected to change dramatically, reducing this figure to 66%. Looking at the normalised capacity addition rate ***C***, this discrepancy is more evident: even after normalisation, the 2014-22 value was higher (0.7 MW/y/TWh) for "largest 8", whilst the target rate for the Rest of EU (11.2 MW/y/TWh) is considerably faster than the "largest 8" (3.3 MW/y/TWh).

4.3 Onshore wind energy

4.3.1 Summary of national targets

The data for national onshore wind energy targets were taken from the latest projections from the respective ministries' documents, or from the respective NECPs dating back to 2019. The following table summarises the latest available targets set by the "largest 8" Member States:

Table 8. Onshore wind energy in the "largest 8" Member States of EU-27: existing capacity and the latest national targets for 2030.

Member State	Onshore wind capacity, 2022, MWe	Onshore wind capacity target for 2030, MWe	Source and notes on target:
Germany	58,186	115,000	Renewable Energy Act (Germany Federal Ministry for Economic Affairs and Climate Action 2022)
France	20,637	39,388	NECP (2019), the higher target for 2028 was taken and extrapolated to 2030
Spain	29,302	47,333	NECP (2019), only total wind capacity target (50.3 GW) is specified, from which the offshore wind target (3 GW) has been subtracted.
Italy	11,749	18,400	NECP (2019)
Poland	7,987	15,999	The Polish National Recovery Plan (Ministry of Development Funds and Regional Policy - Poland 2021), estimated 6-10 GW additions from 2021
Sweden	14,364	28,900	Swedish Energy Agency (2023)
Netherlands	6,089	7,778	Netherlands Organisation for Applied Scientific Research (TNO) (2022), 12 GW by 2050 projection was taken and interpolated to 2030
Belgium	2,989	4,200	NECP (2019)

4.3.2 Comparisons with the recent deployment rates and across countries

The normalised capacity addition rates for these countries, as well as the United Kingdom were calculated, given in the Figure 11 below.

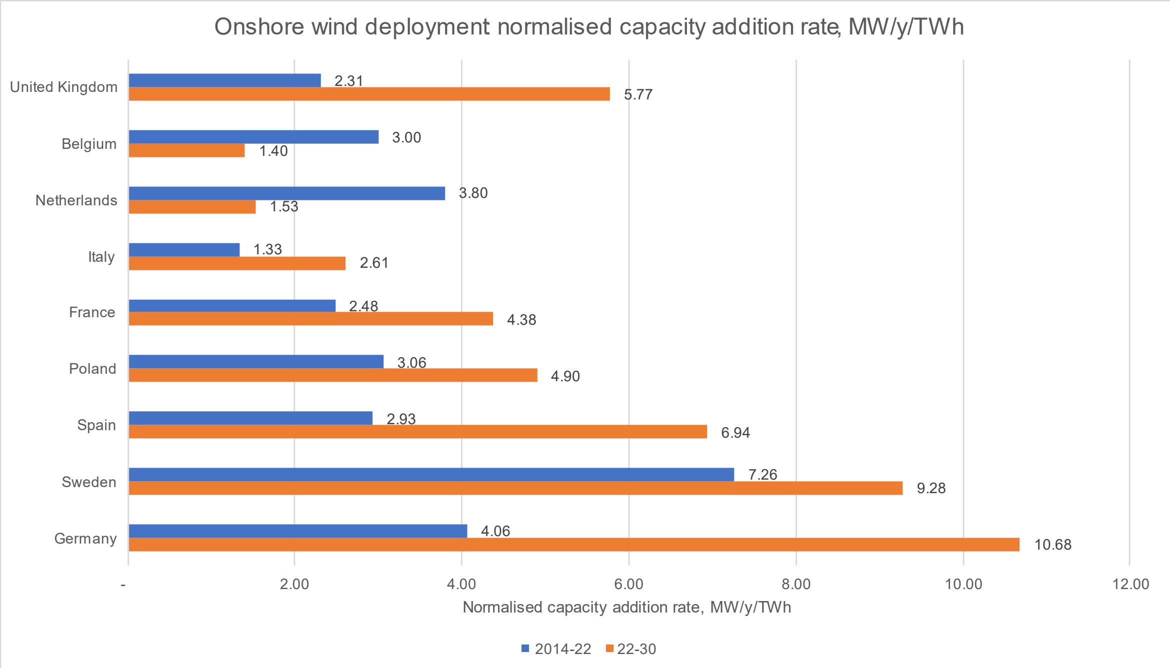

Figure 11. Normalised deployment rates of onshore wind capacity in the UK, and the "largest 8" of EU-27 for 2014-22 period and current national 2022-2030 targets.
Notes about targets:
***UK**: 30 GW by 2030*

Excluding Belgium and the Netherlands, the target capacity addition rates are higher than the respective recorded for 2014-22. Of these, the most ambitious increase in onshore wind capacity addition rates are for Germany (from 4.1 MW/y/TWh to 10.7 MW/y/TWh) and the UK (from 2.3 MW/y/TWh to 5.8 MW/y/TWh), from their 2014-22 values.

Looking at the historical normalised capacity addition rates from the largest countries of EU, it can be seen that the highest rates observed were around 7 MW/y/TWh. Among smaller countries, the capacity addition rates observed of Ireland stand out, with a maximum value of 11.3 MW/y/TWh.

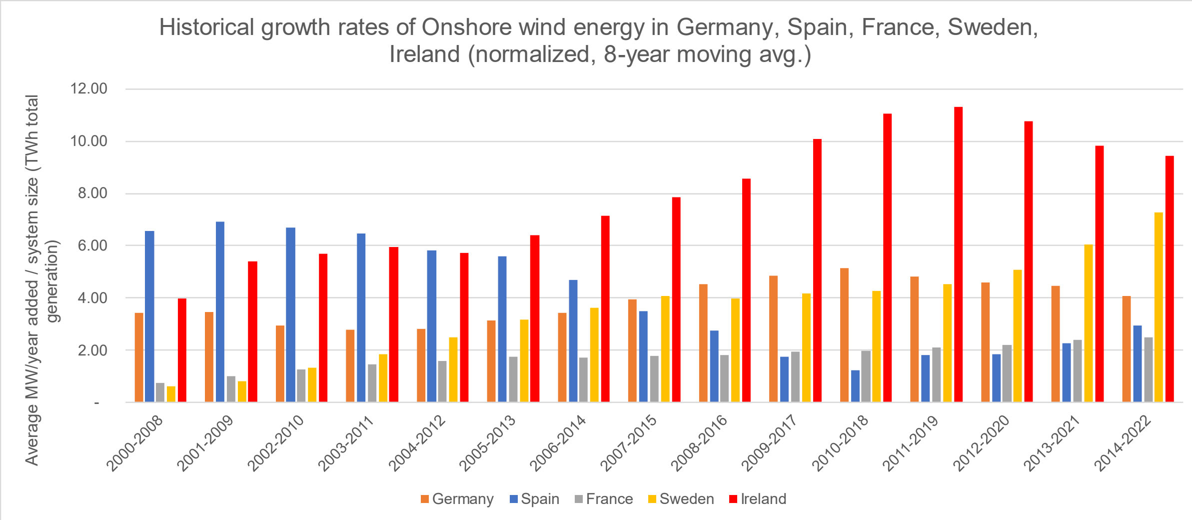

Figure 12. Normalised historical deployment rates of onshore wind capacity in Germany, Spain, France, Sweden and Ireland for 8-year periods from 2000-2022.

To illustrate the insufficiency of the national onshore wind targets of the "largest 8", the distribution of new installations among the Member States is used. The aggregated target capacity additions of the "largest 8" is 15.7 GW/year out of 25.7 GW/year total for REPowerEU plan, leaving a 10 GW/year gap for the remaining Member States. This would correspond to a significant shift in where the new onshore wind installations take place, reducing the share of the "largest 8" from 80% to 61%. After normalisation, the contrast is more evident, requiring "Rest of EU" countries to deploy at a rate >2x of the "largest 8", whereas the 2014-22 rate for the Rest of EU was behind the "largest 8".

Table 9. Breakdown of onshore wind capacity additions in EU-27 by grouping the Member States.

"The largest 8" refers to Germany, France, Spain, Italy, Poland, Sweden, Netherlands, Belgium, "Rest of EU" refers to the remaining 19 Member States.

	Annual avg. capacity additions (MW/y)		**Normalised capacity addition rate (MW/y/TWh)**	
	2014-22	**2022-30**	**2014-22**	**2022-30**
The largest 8	7,538 (80%)	15,712 (61%)	3.3	6.3
Rest of EU*	1,854 (20%)	*10,013 (39%)**	3.0	*14.3**
REPowerEU	9,392	25,725	3.2	8.1

*This rate corresponds to remaining additions needed to fulfil REPowerEU plan, under current targets of the "largest 8".

4.4 Solar energy

4.4.1 Summary of national targets

The data for national solar PV deployment targets were taken from the latest projections from the respective ministries' documents, or from the respective NECPs dating back to 2019. The following table summarises the latest available targets set by the "largest 8" Member States:

Table 10. Solar energy in the "largest 8" Member States of EU-27: existing capacity and the latest national targets for 2030.

Member State	Solar PV capacity, 2022, MWe	Solar PV capacity target for 2030, MWe	Source and notes on target:
Germany	66,552	215,000	Renewable Energy Act (Germany Federal Ministry for Economic Affairs and Climate Action 2022)
France	17,409	52,864	NECP (2019), the higher target for 2028 was taken and extrapolated to 2030
Spain	18,212	39,181	NECP (2019), target scenario
Italy	25,076	52,000	NECP (2019)
Poland	11,166	41,174	No target available: the most ambitious target of 7 GW by 2030 from NECP (2019) was already surpassed in 2021. Annual additions of 2022 were extrapolated to 2030 (+3.7 GW/y).
Sweden	2,606	9,500	Swedish Energy Agency (2023)
Netherlands	22,589	53,849	Netherlands Organisation for Applied Scientific Research (TNO) (2022), 132 GW by 2050 projection was taken and interpolated to 2030
Belgium	6,898	8,000	NECP (2019)

4.4.2 Comparisons with the recent deployment rates and across countries

The normalised capacity addition rates for these countries, as well as the United Kingdom were calculated, given in Figure 13.

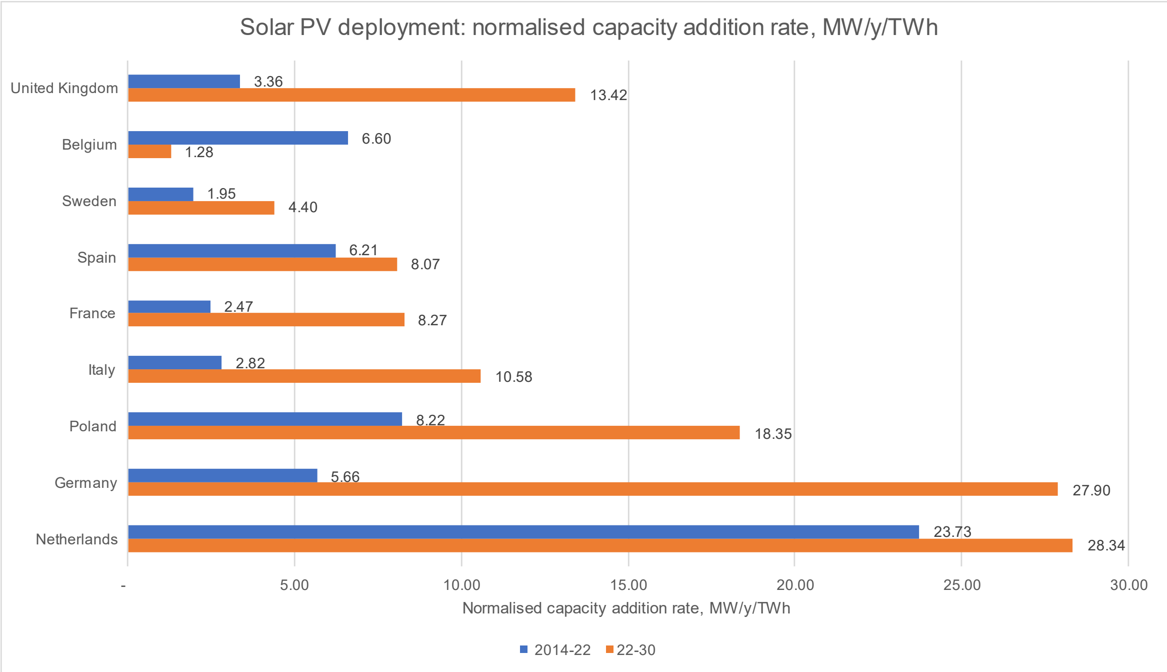

Figure 13. Normalised deployment rates of solar PV capacity in the UK, and the "largest 8" of EU-27 for 2014-22 period and current national 2022-2030 targets.
Notes about targets:
***UK**: 50 GW by 2030*

Excluding Belgium, the target capacity addition rates are higher than the respective recorded value for 2014-22. Of these, Germany and the UK have the most ambitious increase in solar PV capacity addition rates, (from 5.7 MW/y/TWh to 27.9 MW/y/TWh) and (from 3.4 MW/y/TWh to 13.4 MW/y/TWh) from their 2014-22 values.

Looking at the historical normalised capacity addition rates from the largest countries of EU, the highest rates observed were ~7-8 MW/y/TWh until 2011-19 period. Since then, this rate for the Netherlands have shoot up, reaching 23.7 MW/y/TWh in 2014-22 period. The envisioned rates of Germany and the Netherlands exceed this highest precedented rate. Among smaller countries, the capacity addition rates observed of Hungary stand out, with a maximum value of 11.4 MW/y/TWh.

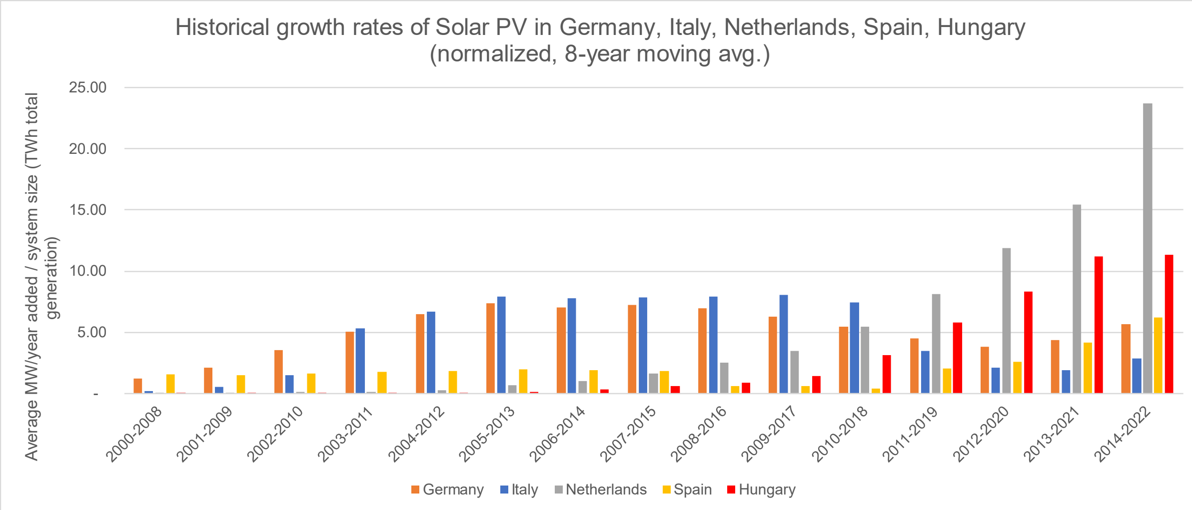

Figure 14. Normalised historical deployment rates of solar PV capacity in Germany, Italy, Netherlands, Spain and Hungary for 8-year periods from 2000-2022.

To illustrate the insufficiency of the national onshore wind targets of the "largest 8", the distribution of new installations among the Member States is used. The aggregated target capacity additions of the "largest 8" is 38 GW/year out of 49 GW/year total for REPowerEU plan, leaving a 11 GW/year gap for the remaining Member States. Similarly to onshore wind, this would correspond to a significant shift in where the new solar installations take place, reducing the share of the "largest 8" from 85% to 76%. After normalisation, the contrast is more evident, requiring "Rest of EU" countries to deploy solar at a higher rate than the "largest 8", whereas historically, the Rest of EU were behind the "largest 8".

Table 11. Breakdown of solar PV capacity additions in EU-27 by grouping the Member States.

"The largest 8" refers to Germany, France, Spain, Italy, Poland, Sweden, Netherlands, Belgium, "Rest of EU" refers to the remaining 19 Member States.

	Annual avg. capacity additions (MW/y)		**Normalised capacity addition rate (MW/y/TWh)**	
	2014-22	**2022-30**	**2014-22**	**2022-30**
The largest 8	12,397 (85%)	37,632 (76%)	5.4	15.1
Rest of EU*	2,169 (15%)	*11,638 (24%)**	3.5	*16.6**
REPowerEU	14,566	49,271	5.0	15.4

*This rate corresponds to remaining additions needed to fulfil REPowerEU plan, under current targets of the "largest 8".

4.5 REPowerEU and IEA projections

To compare the deployment rates required for REPowerEU and the IEA projections, the latest projections available in IEA's "Renewables 2022: Analysis and forecast to 2027" (2022d) were taken and normalised (with extrapolation to 2030). There are two scenarios: the main case, expecting 39 GW/year solar PV and 17 GW/year wind capacity additions, and the accelerated case, expecting 52 GW/year solar PV and 21 GW/year wind capacity additions. The offshore-onshore allocation of these capacity addition figures has not been provided by the IEA, thus, it is assumed to be 30% offshore / 70% onshore, to reflect the same ratio of additions required to reach REPowerEU's targets (117 GW offshore + 393 GW onshore).

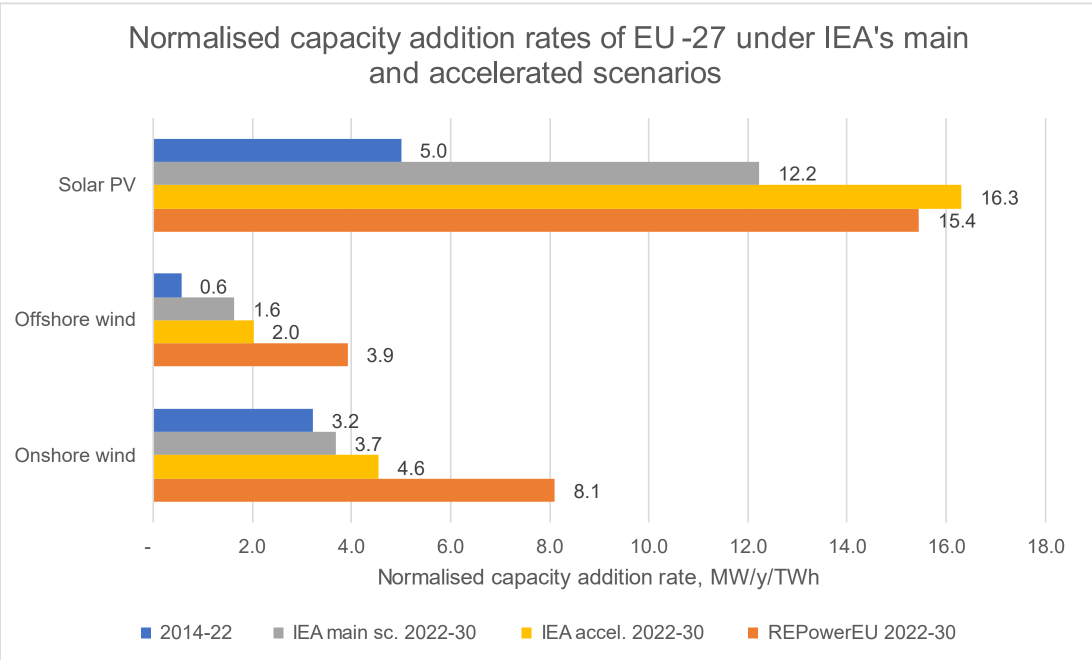

Figure 15. Normalised deployment rates of solar PV, offshore and onshore wind in EU-27 under IEA's main and accelerated scenarios and under REPowerEU plan.

Notes about projections:
***IEA main**: 39 GW/year solar, 17 GW/year wind, reaching **59 GW** offshore wind, **281 GW** onshore wind and **510 GW** solar by 2030.*
***IEA accelerated**: 52 GW/year solar, 21 GW/year wind, reaching **68 GW** offshore wind, **303 GW** onshore wind and **613 GW** solar by 2030.*

As depicted in the Figure 15, under both scenarios, wind capacity in 2030 fall considerably short of REPowerEU targets, with offshore wind capacity reaching only 59 GW by 2030, which is same as EU's 2020 offshore renewable energy strategy target and half of the envisioned 117

GW. For solar capacity, however, the accelerated case predicts annual additions of 52 GW, more than REPowerEU's 49 GW/year requirement. When compared to the recent numbers (2014-22), the IEA's solar PV projections are over 2x and 3x more than the last 8 years' rates (main and accel. case, respectively), while for wind, the expected increase is only up to 73% (from 3.8 MW/y/TWh to 6.6 MW/y/TWh under accel. case).

4.6 REPowerEU and historical expansion of nuclear energy

As described in the methodology section, cross-technology comparison of the historical rise of nuclear power during the 1980s' energy crisis with the projected rise of the solar and wind power requires the use of growth rate **G** which uses [TWh change in gen./TWh system size] units. These figures were directly computed for the historical cases, while the future growths of wind and solar for the EU-27 and the United Kingdom required additional inputs of capacity factors, taken as three scenarios for offshore and onshore wind power. These scenarios were plotted as vertical error bars. These growth rates were mapped on a scatter plot against the change in system size in respective time windows, shown in the Figure 16:

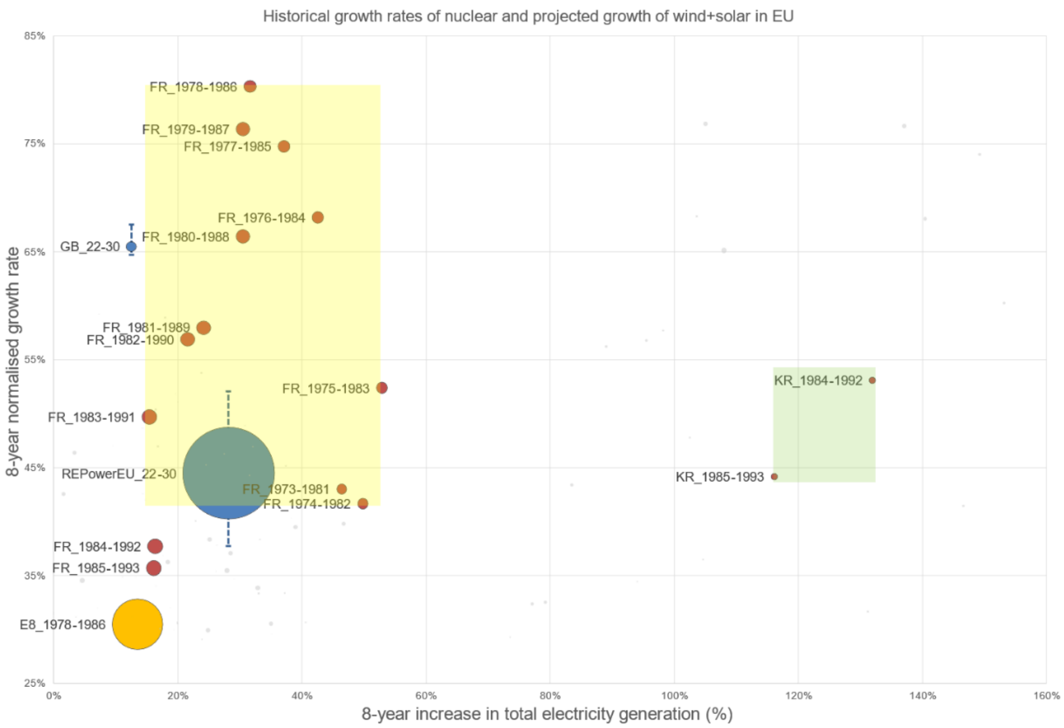

Figure 16. Normalised growth rates of nuclear in large countries/regions and projected wind+solar, mapped against change in total system size within the respective 8-year periods.

Notes about data points:
Blue (GB_22-30; REPowerEU_22-30) – projected combined growth rate of wind+solar
The vertical bars reflect the possible range of growth rate under different capacity factor assumptions
Red: historical growth rate of nuclear power in large countries (system size>200 TWh)
Orange (E8_1978-86): historical growth rate of nuclear power in the "largest 8" of EU-27
Grey: historical growth rate of nuclear power in small countries (system size<200 TWh)
Notes about zones:
Green: (high system size change>100%) only historical precedents in South Korea
Yellow: (high growth rate>42%) only historical precedents in France

There are only two large (system size>200 TWh) countries where the 8-year normalised growth rate of nuclear power was over 42%: South Korea (KR) and France (FR). These two systems are distinct in their system size growth:

South Korea saw huge system size (demand) growth in these 8-year periods (132%), linked to the country's rapid economic boom starting in mid-80s, expansion of demand through creation of electronics, steel, petrochemicals and other industries (Council on Foreign Relations (CFR) n.d.).

On the other hand, France is the only large country where normalised growth rates of over 42% have been observed for nuclear power, and no other large country falls in this yellow zone.

The growth of nuclear power in the "largest 8" countries (*E8_1978-86*) had a peak of 31%, with a total system size increase of 14% within same timeframe. REPowerEU's (*REPowerEU_22-30*) combined wind+solar growth is aimed to reach ~38-52%, and a system size increase of 28%. For the UK, (*GB_22-30*) combined wind+solar growth ***G*** is aimed to reach ~65-67.5%, with a marginal system size change of 12%.

Overall, transitions that entail low system size change and high growth of low-carbon generation are more complex, in contrast to high system size change and lower growth of low-carbon generation. In the former case, the growth of the low-carbon generation primarily replaces other existing sources, while in the latter case, it is merely an addition to the existing system. Considering this, the points that fall in the left-top corner (*GB_22-30*) of the scatter plot require higher effort than that of bottom-right corner (*South Korea*).

5. Discussion

Guided by the research questions of the study, this section tries to address the issue of feasibility of REPowerEU Plan's solar and wind visions in the light of comparative analyses conducted: via a bottom-up approach (from national targets to EU targets), historical trends and precedents and from projections of IEA and other available reports.

5.1 Feasibility insights based on national targets

Presence of sufficient national level targets is a foremost step for strategy and policy developments around them, especially in the case of wind power, where the influence of governments in speeding up (or slowing down) the investments, construction and connection of the power plant to the grid is higher. This is regarded as a special feature of the current energy transition – 'consciously governed' transition, as opposed to emergent ones, which was driven primarily by availability of resources (coal, oil) and technological development around those resources (Kern and Rogge 2016).

For offshore wind targets in the EU, the non-binding agreements of priority offshore grids give a more comprehensive picture of effort-sharing between the Member States. Except for France, all other 19 Member States have increased their 2030 ambitions in comparison to targets set in NECPs of 2019, collectively doubling the previous EU target from 60 GW to 117 GW.

As of 2022, only 5 of these 20 signatory countries (Germany, the Netherlands, Denmark, Belgium, and France) have large offshore wind farms (>0.5 GW). The normalised capacity addition rates required to reach national offshore wind targets are particularly higher for Member States with smaller system sizes (such as Lithuania, Estonia, Portugal, Ireland). If reached by 2030, such large offshore wind capacities would constitute >50% of these countries' electricity generation mix. Accordingly, it will require grid infrastructure upgrades, strengthening of the interconnections with neighbouring countries, as well as integration with energy storage and green hydrogen production. Such fast deployment of the offshore wind farms in newcomer countries will require extra efforts in addition to the installation of the offshore wind farms, such as upskilling of local workforce for operation and maintenance of the wind farms and upgrade of existing seaport infrastructure to handle large turbine parts.

The analysis of the distribution of target capacity installations gave the largest change for offshore wind: In the last 8 years, the vast majority (92%) of the deployments were in the "largest 8" Member States, as opposed to 66% of the target installations (until 2030).

This is also true for the onshore wind and solar PV targets of the "largest 8": summation of their current national targets suggests that greater efforts by the smaller countries of the EU are needed, to collectively reach the REPowerEU plan's goals. Especially for smaller countries, this is expected to be difficult, due to the issue of grid congestion. Grid congestion is a general issue for transmission systems with high shares of intermittent renewables, seen in large countries such as China, United States, too. For instance, Germany's offshore wind generation in the North Sea and demand hotspots (industrial centres) which are located in the south of the country require a highly flexible grid for load management, as emphasised by the grid operators (Jesberger 2023). Upgrade of grids and expansion of interconnections will require significant investments and it will be crucial to bring offshore wind energy from Baltic and North seas to inland countries like Hungary and Czechia, as reported by energy modelling studies (Ember 2023c; Child et al. 2019; del Granado et al. 2020).

Therefore, as emphasised in the official communications by the European Commission and ministers of Member States, coordination between the Member States will be the key to the ramp-up of the deployment of offshore wind farms and associated supporting infrastructure. This is also an aspect where the EU is powerful and unique: an enabling environment for the

Member States to cooperate and benefit from smooth knowledge transfer, cross-border infrastructure build-up, integrated electricity markets and financial support mechanisms.

Along the supply chain, manufacturing capacity of the wind turbines in the EU is a recognised issue. The "Net Zero Industry Act" proposed on 16 March 2023 by the Commission addresses this, setting a target of 36 GW manufacturing capacity for wind turbines by 2030.

The insufficiency of national targets of the "largest 8" and the shift of historical deployment from large countries to small countries is another area of concern for both solar and wind: rapid expansion of variable renewable energy and its impact on national grids, allocation of resources (financial, labour) would put pressure on the smaller countries, as opposed to the distribution of past installations across the EU, when the large countries were taking the lead with higher capacity addition rates.

5.2 Feasibility insights based on historical trends and precedents

Comparing the target capacity addition rates to that of recent decade, all three technologies require accelerated deployment to reach EU-level targets, with the largest jump of capacity additions (~6-fold increase) needed for offshore wind energy, this means the normalised offshore wind capacity additions of Denmark (i.e. the highest rate observed in any Member State) must be replicated at EU-wide scale. Considering Denmark's small system size (1.4% of offshore wind-committed Member States), the level of ambition becomes more evident. On the other hand, since offshore wind is a newer technology than onshore wind and solar PV, it is still at the acceleration phase of technology diffusion: the recent auctions held by the Member States point to consistent reductions of bid prices, while the technological developments are also underway with more efficient turbine designs (WindEurope 2023). Thus, there is a room for an optimistic outlook – expecting historically unprecedented rates of capacity additions.

For solar PV, there are numerous historical precedents among the Member States that exceed the addition rates required for REPowerEU target, and these cases were observed in both large and small Member States. Comparing the NECP (2019) targets and actual solar PV capacities, several Member States have reached their 2030 targets in or before 2022. Thus, solar PV is the most promising of the three technologies: for example, SolarPower Europe have framed REPowerEU scenario as the “low scenario” in their latest outlook report (SolarPower Europe 2022).

For onshore wind, unlike solar and offshore wind, the recent capacity addition rates have been fluctuating in the EU-27 and the large countries such as Germany, Spain, France, Sweden. Although the REPowerEU’s target capacity additions were exceeded in several countries historically, only 9 out of 27 Member States have seen consistent upward trend in annual capacity additions in the last three years. The wind turbine orders have declined in 2022, compared to the first quarter of 2021 (Balkan Green Energy News 2022). This issue is largely linked to long permitting procedures, land availability and local opposition aspects of onshore wind. Ember’s analysis of permitting times for wind projects revealed that, in most Member States take significantly longer than the 2-year ‘deadline’ suggested by the Commission (Ember 2022). Considering such recent developments, a huge leap in onshore wind deployments (almost doubling the annual deployment of 2022 and maintaining it at that level through the next eight years) would be largely unlikely.

At national level, only for two Member States of the “largest 8” (Belgium (onshore wind and solar PV) and Netherlands (onshore wind)), the envisioned 2023-30 deployments are less ambitious than the respective country’s installations in 2014-2022. For Belgium, they have not revised their targets since NECP (2019). The Netherlands, similarly, have already reached their 2030 target onshore wind capacity by 2022, and their latest projections do not foresee large expansion of onshore wind capacities (12 GW target for 2050).

Comparing the historical energy security crisis and the fastest growth of nuclear power in Europe, the envisioned growth of solar+wind under REPowerEU plan and the growth of nuclear in "largest 8" (1978-86) are quite similar: although solar+wind under REPowerEU plan have a higher growth rate than the historical growth of nuclear, the increase of total system size for the REPowerEU plan is also higher. Higher increase of the total system size indicates that the growth does not necessitate large infrastructure changes to replace other sources, thus is easier to implement. On the other hand, the scale of REPowerEU is much larger than the historical reference case. This explanation should be accompanied with the contextual similarities and differences between these periods and technologies: both cases correspond to a growth in total system size and energy security crisis triggered by import dependency. The REPowerEU plan is a more controlled energy transition target by the EU and follows a top-down approach to national levels, whilst the 1980s' "oil shock" transition was dealt by the national governments with varying response measures and policies (Ikenberry 1986). This increases the feasibility of the growth envisioned under REPowerEU, which is at a considerably larger scale than the historical reference case.

The primary difference between nuclear and wind/solar technologies is that the solar and wind are more granular technologies, can be deployed at scales of several megawatts, whilst conventional nuclear reactors are "lumpy" at gigawatt scales with high upfront costs. Granular technologies have advantages in the current energy transition, in the EU's liberal energy market while promoting decentralisation. Accordingly, the historical growth of nuclear is more centred around state funding and state-owned energy generation, while the current transition is towards a more privatised and decentralised system with the participation of more actors and investors along supply chains. From governance perspective, this means that the Member States can expect to achieve more growth of granular technologies with fewer direct interventions by the governments. Furthermore, granular technologies are more favoured by the citizens and face less barriers in terms of social acceptance, which is a key criterion for the acceleration of deployment (Wilson et al. 2020; Xexakis and Trutnevyte 2021).

With these contextual and technological differences, it can be concluded that the envisioned growth of solar+wind under REPowerEU had a comparable historical precedent of a fast transition in a comparable system in 1980s.

5.3 Feasibility insights based on projections

Since IEA's projections take a multitude of factors into account, contrasting those to that of REPowerEU targets can give valuable insight into feasibility analysis. There are two scenarios in IEA's forecasts, main case, which assumes continuation of current market conditions, policies and technology advancements, and the accelerated case, with stronger ambitions and more investments expected. In IEA's "Renewables 2021" report (released in December 2021, before the start of Russo-Ukrainian war), the forecasts were optimistic about meeting and exceeding targets of NECPs (IEA 2021b). The latest "Renewables 2022" report sees an increase of the renewables deployment projections by one third from the previous report (IEA 2022d).

The three key barriers to achieving the REPowerEU target rates identified by the IEA are as follows: 1) insufficient policy support with limited number of auctions; 2) permitting complexities and delays; 3) grid congestion (IEA 2022d).

Regarding permitting challenges, which is a huge barrier for the acceleration of onshore wind deployment, the Renewables 2022 forecast report by the IEA only mentions Germany and Spain as the Member States which have implemented "*substantial legislative changes*" (IEA 2022d, p. 121), and the need for a widespread change so that other Member States would follow. This again underscores the leading role of the "largest 8" countries, and how important their actions are in terms of setting and delivering on high solar and wind ambitions. The WindEurope outlook report analysis shows that around 80 GW of wind projects are ‘stuck’ at various stages of permitting procedure, and ¾ of these projects are onshore (WindEurope 2023).

Numerically, both the main and the accelerated scenarios for wind installations foresee missing REPowerEU targets by large margins. The annual additions for the next five years in IEA’s “Renewables 2022” are about the same as WindEurope’s outlook for 2027, with similar barriers noted by both reports (IEA 2022d; WindEurope 2023). For solar, the main scenario foresees insufficient capacity additions for the REPowerEU plan’s 592 GW target, however, it is set to reach 613 GW and exceed the target in the accelerated case. SolarPower Europe’s outlook report (2022) is much more optimistic and frames the REPowerEU target as the ‘low’ scenario, envisioning 736 GW and 950 GW under ‘medium’ and ‘high’ scenarios, respectively. Although both of these forecasts anticipate going beyond REPowerEU plan, the differences between their projections are huge.

The large difference (+30%) between the main and accelerated scenarios of IEA underlines how stronger ambitions and support policies have the potential to steer up the acceleration of deployment.

5.4 Limitations of the study and future research directions

While this study attempted to review and analyse the feasibility of wind and solar energy deployment targets of the REPowerEU plan and EU countries via a consistent comparative approach, there are limitations tied to data collection and availability, as well as assumptions used throughout the study.

With regard to data collection and availability, NECPs are at the heart of national energy targets for Member States, and thus, a clearer and more comprehensive overall picture of the national targets will be available only after the 2023 revisions to the NECPs are submitted to the European Commission (due 30 June 2023).

With regard to the assumptions taken for the future projections, one aspect is about the linear growth of total generation (system sizes) in EU-27 and Member States, at the same rate for the period 2023-30. While the EU-27's system size is taken from the latest (December 2022) IEA projection under the Announced Pledges Scenario, the rate of growth may vary across Member States, especially for small countries that have set high offshore wind ambitions (Lithuania, Latvia, Estonia, Ireland, Denmark).

Another assumption of pivotal importance is the capacity factors chosen for the nuclear versus wind+solar growth comparisons. For the electricity generated from offshore wind and onshore wind, technological advancements are expected to raise the capacity factors, as already observed in the newest offshore wind farms of the UK, Hywind Scotland, Hornsea 1 farms reaching as high as 46-49% CF according to the 2022 figures (EnergyNumbers.info 2022). Likewise, WindEurope's 2023-27 outlook report also takes the optimistic view on capacity factors, mentioning even 45% offshore and 35% onshore capacity factors as "conservative" for EU, and estimating that 440 GW of wind capacity, instead of the REPowerEU plan's 510 GW, can be enough to hit EU's 42.5% share of RES target by 2030 (WindEurope 2023).

Lastly, solar PV deployment projections and thus, making conclusions about the feasibility of the proposed targets are the primary sources of uncertainty for the future. Historically, IEA's predictions published in their annual World Energy Outlook reports have significantly underestimated the growth potential of solar PV (Zenmo.com 2019). Besides IEA, many Member States' 2019 NECP targets for solar PV also demonstrate this underestimation: for instance, Sweden, Poland, Estonia, Lithuania have already hit their 2030 solar PV targets in 2022 or earlier (Ministry of Environment and Climate - Sweden 2019; Ministry of Climate and Environment - Poland 2019; Ministry of Economic Affairs and Communications - Estonia 2019; Ministry of Energy - Lithuania 2019).

Regarding the solar and wind targets of the EU, a more in-depth review of national targets after the revision of the NECPs, as well as incorporating the capacities of pipeline projects of the Member States would further improve upon the conclusions of this study.

Beyond solar and wind technologies' deployment, it would be essential to extend the scope of the study beyond electricity generation, towards two main directions: 1) green hydrogen targets at the EU and Member State levels; 2) interconnectivity and energy storage capabilities. This is especially of interest for small system size countries, such as Denmark, Ireland and Lithuania, where realisation of offshore wind targets would pose challenges of managing high shares (over >70% of total generation mix) of intermittent sources.

6. Conclusion

Speed-up of the transition to wind and solar energy is crucial area of action for the EU's ambitious climate targets and this was further emphasised by the energy security crisis triggered by the Russo-Ukrainian war started in 2022. Introduced shortly after the start of the war, the REPowerEU plan saw upward revision of the 2030 solar and wind capacity targets. The short timeline of the plan and high ambitions set at the EU level raise questions about feasibility of reaching those targets.

This thesis aimed to address these questions using a variety of approaches, in the light of national level targets of the Member States, recent renewables deployment rates and projections. In addition, historical precedents of the fastest nuclear energy growth in Europe were compared to the envisioned transition in the REPowerEU context. The normalised comparisons across countries and different time periods helped to judge the ambition levels of the targets.

The main findings of this study are as follows: reaching REPowerEU Plan's wind and solar targets will require corresponding upward revisions at Member State level, which are currently insufficient. Looking at the trends in the recent decade, the deployment rates of all three technologies (onshore and offshore wind, solar PV) has to be ramped up and maintained until 2030. For offshore wind especially, fulfilment of the EU-wide target will require replication of highest ever normalised capacity addition rate observed in any Member State. For onshore wind and solar, the envisioned capacity addition rates have several historical precedents across the Member States, that should be replicated at EU-wide scale. Comparative assessment of the growth of nuclear following the "oil shock" crisis and the current crisis driven by the dependency on Russian fossil fuels revealed numerous similarities between the two, both contextually and numerically, indicating that an analogously fast transition has occurred in Europe.

Regarding the projections by the IEA for the REPowerEU Plan, there are several barriers that hold back the accelerated deployment of renewables, in particular for onshore and offshore wind, which are expected to miss the REPowerEU targets. For solar PV, however, the overall outlook by the IEA and other projections are quite optimistic to exceed the targets.

Overall, the EU is a strong global leader in climate mitigation through innovation, introduction and implementation of first-of-its-kind policies. Furthermore, the EU provides an enabling framework that enables cooperation between the Member States and harmonisation of policies regarding deployment of renewables and supporting infrastructure such as energy storage, hydrogen and interconnections. Nevertheless, the realisation of the REPowerEU Plan's targets for solar and wind energy will require substantial efforts at national level, in terms of legislative changes, investments, expansion of domestic manufacturing capacities, upskilling labour force, etc. The time limitation (until 2030) of the plan is the key issue here: making these changes fast enough to see its effect in implementation will be challenging. This is especially true for wind energy, where the projects typically take years from design to construction phases.

There are several limitations in this thesis that could be improved in further studies. A more up-to-date picture of national 2030 commitments will be available by the end of 2023, and those targets would clarify the sufficiency of national contributions to the collective REPowerEU goal. Other limitations are regarding the estimation assumptions for future electricity generation (capacity factors and linear extrapolation for system sizes, annual capacity additions). Extending this study beyond renewable electricity, analysis of the national/EU-level green hydrogen production commitments and planned expansion of interconnection capacities would inform feasibility of the EU's energy system with high share of variable renewable electricity.

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Annex A. Notes on national offshore wind deployment targets

Member State	Note
Denmark	The estimate is based on the Danish forecast describing the development within the energy sector including offshore renewable energy development. The forecast is prepared by the Danish Energy Agency and is updated each year. The estimate is based on the latest published forecast (2022). The span of the forecast goes to 2050. The Danish TSO (Energinet) uses these forecasts to plan the Danish grid.
Estonia	For the time being Estonia does not have any non-binding or legally binding goals for offshore capacity for 2040 and 2050. The Estonian Maritime Spatial Plan indicates its potential to be up to 7GW.
Finland	Non-binding goals are preliminary. National targets will be reviewed during the updating process of NECP.
France	The upper bandwith for 2040 and 2050 is based on the average of the upper bandwith of scenarios N1 and N2 of the "Futurs énergétiques 2050" study by RTE for the Nord Atlantique-Manche Ouest and Sud Atlantique maritime zones. In 2023 and 2024, France's MSP documents and multiannual energy program will be revised after a public consultation, potentially modifying substantially the provided targets.
Germany	In its Offshore Wind Act 2022 Germany has established deployment goals for offshore wind of at least 30 GW in 2030, 40 GW in 2035 and 70 GW in 2045. The development goal in 2035 will probably be exceeded by 10 GW. These are overall targets covering both North Sea and Baltic Sea.
Greece	Targets are according to initial calculations as included in Greece's initial draft revised NECP of January 2023
Ireland	The 2030 target does not include a government objective of developing 2 GW of offshore renewable wind dedicated to production of green hydrogen by 2030, due to uncertainty regarding the location of this capacity
Lithuania	Goals to be defined exactly after review of the Lithuanian National Energy Strategy, therefore figures are preliminary.
Luxembourg	While Luxembourg, having no national maritime space, does not participate through specific offshore renewable target contributions, Luxembourg plans to contribute significantly through cooperation on cross-border projects, especially through contributing via the Renewable Energy Financing Mechanism in exchange of statistical transfers.
Netherlands	In the Netherlands, preparations are made for the upper bandwidth of these targets (50 GW in 2040 and 70 GW in 2050), whilst continuously reviewing and researching whether these ambitions are correct and feasible in reality
Portugal	Portugal's goals for offshore renewable generation are allocated entirely to the Atlantic Offshore Grid Corridor
Spain	Target to be determined
Sweden	For the time being Sweden does not have any non-binding or legally binding goals for offshore capacity to be deployed by 2040 and 2050. The Swedish Maritime Spatial Plans by 2022 consider 20 to 30 TWh offshore wind power. At the same time the relevant authorities were given a supplementary assignment that aims to investigate additional areas for energy production, which can enable an additional 90 TWh offshore wind power.