When is it feasible for policies to accelerate energy transitions? The case of REPowerEU

Anastasia Pavlenko (Central European University (CEU) Austria) and Aleh Cherp (CEU and Lund University, Sweden)[1]

Abstract

To mitigate climate change, transition to clean energy should proceed faster than in the last three decades. Can policies overcome economic, technological and social inertia to achieve the required acceleration, and if so, under what conditions? The 2022 REPowerEU plan is an excellent case to investigate these questions because it responds to a profound energy security threat (Russia's invasion of Ukraine) in advanced economies that are already the global leaders in decarbonisation. Here we analyse to which extent REPowerEU and related policies aim to accelerate energy transitions, what has enabled the ambitious targets, and whether these are feasible. Considering policy-technology co-evolution involving multiple feedbacks and non-linear growth, we define policy-driven acceleration as a significant deviation of feasible policy goals from the S-curve of technology diffusion reflecting empirical trends, near-term projections and analogies.

We show that REPowerEU sets unprecedented targets implying acceleration of all renewables and a radical deviation from the onshore wind growth trajectory. At the same time, REPowerEU is not an isolated crisis response, but a continuation of a policy shift that started around 2018 and included the European Green Deal (2019), the 'Fit for 55' package (2021), and related plans. Before 2018, policy targets extended historical trends and did not become more ambitious over time. Although motivated by climate concerns, they were only weakly linked to long-term climate goals but strongly shaped by technological uncertainties and economic costs. Energy security was seen as protection from short-term shocks through resilient infrastructure and did not directly shape the goals for renewables. In contrast, post-2018 policies decisively link the net-zero vision for 2050 and the 2030 renewable targets. In 2022, these climate-derived targets were securitised through directly linking them to energy independence from Russian oil and gas, now viewed as a long-term security concern. Both net-zero and energy independence goals were inspired by the declining costs of renewables and by the emerging technological opportunities of substituting fossil fuels in transport, industry and heating through low-carbon electrification.

We analyse whether the new targets are feasible using the 'inside' and the 'outside' view of feasibility by Jewell and Cherp (2023). We argue that the main barriers for onshore wind are conflicting land uses, for offshore wind - uncertainties around the infrastructure and complementary technologies, and for solar power - grid integration. We show that the required growth of each renewable technology is similar to the growth of nuclear in Western Europe in the 1960s-1980s. The similarities between the two contexts, including the presence of an energy security crisis, give hope that the planned growth is feasible. However, the combined growth of solar and wind is entirely unprecedented, although on a smaller scale, a similarly fast growth of nuclear occurred in France and Sweden. Our findings indicate that policy-driven acceleration of energy transitions might be possible but requires a unique constellation of motivations and capacities. Historical analogies provide useful benchmarks for the attainable speed of transition, but more research is needed on the applicability of policy lessons across different low-carbon technologies.

[1] The authors are grateful to Vadim Vinichenko of Chalmers University of Technology and Ismayil Aliyev for providing figures, calculations and data used in this paper.

Table of Contents

1 Introduction

Rapid transition towards low-carbon energy is crucial for mitigating climate change, yet whether such transition is feasible is widely debated. Some scholars believe that switching to new energy sources always takes many decades (Smil 2010; Fouquet and Pearson 2012; Grubler and Wilson 2013), while others argue that future transitions can be faster if they are accelerated by deliberate policies (Kern and Rogge 2016; Sovacool 2016; Sovacool and Geels 2016). At the same time, the evidence on whether and if so under what conditions policies accelerate energy transitions remains inconclusive.

On the one hand, there are good reasons to believe that policies can drive energy transitions as in industrialized countries responding to the oil crises of the 1970s (Ikenberry 1986) or in Germany pursuing 'Energiewende' in the 2000s (Hake et al. 2015). Moreover, policies could potentially get stronger over time or 'ratcheted up' if they create supportive coalitions or institutional learning (Meckling, Sterner, and Wagner 2017; Pahle et al. 2018; Leipprand, Flachsland, and Pahle 2020). On the other hand, policy ambitions may be constrained by insufficient capacities (EC Directorate-General for Energy et al. 2023; Ember 2023) and policy feedbacks may not only increase stringency but also lead to the lock-in of existing structures or to growing resistance to change (Kontogianni et al. 2014; Breetz, Mildenberger, and Stokes 2018; Schumacher et al. 2019). Empirically, Vinichenko et al. (2023) show that the rates of coal phase-out envisioned in existing plans are not faster than historical, Suzuki, Jewell, and Cherp (2023) argue that the growth of low-carbon energy in the Group of Seven (G7) has not been accelerated by numerous climate policies, and Lægreid et al. (2023) demonstrate that countries commit to phase out coal after, not before, they reach the peak of coal use.

This paper empirically contributes to the debate on whether and under what conditions policies can accelerate energy transitions. As a case study we use the EU's renewable energy policies, which were strongly impacted by the 2022 Russia's invasion of Ukraine in 2022, providing an excellent case to test whether policies can accelerate energy transitions under such extreme circumstances. In its 2022 Renewable Energy report, the International Energy Agency (IEA 2022b) called the war in Ukraine "a turning point for renewables in Europe", referring to the REPowerEU plan (EC 2022e) published in Spring 2022. Focusing on this plan and the related policies we ask the following questions:

1. **Are the recent EU policies, especially REPowerEU, accelerating transition to renewables?** To address the methodological challenge of detecting policy-driven acceleration, we develop a framework that considers co-evolution of socio-technical and policy action systems. We show that the recent EU policies, especially REPowerEU, aim for unprecedented acceleration of wind power, on par with the growth of nuclear power in Western Europe in the 1960-80s, but that large part of this growth was planned under climate policies before the war.
2. **What caused the recent policy shift towards the acceleration of energy transitions?** We show that this policy change was driven by several mechanisms including shifting policy paradigm on long- vs. near-term climate mitigation, elevated security risks accompanied by bold securitization moves, and perceived technological opportunities associated with cost declines and decarbonisation of industry, transport and heating. We argue that none of these mechanisms would enable policy change in isolation from others.
3. **Is acceleration envisioned by the new policies feasible?** Even the most ambitious policies will not accelerate energy transitions if they stay on paper and are not implemented in the real world. To assess the feasibility of implementing the new policies, we review the challenges, compare the EU-wide targets with the existing national plans, and benchmark these targets to the growth of nuclear power in Western Europe in the 1960s-1980s, identifying similarities and differences with that historical analogy. We highlight that the existing barriers are likely to

hinder the growth of onshore wind on the local level and that overcoming these challenges while adhering to democratic principles may be difficult.

This paper starts with outlining its theoretical premises and analytical approach. Subsequently, we report the results structured by the three research questions and followed by Discussion and Conclusions.

2 Theoretical premises and analytical approach

2.1 Defining policy-driven acceleration in the context of policy-technology co-evolution

There are three main challenges of detecting and measuring policy-driven acceleration of energy transitions. First, transitions are driven not only by policies but also by other factors, such as technology diffusion and market dynamics. Any observed acceleration may be due to these factors rather than to policies. Second, technologies and policies regularly interact. For example, policies may support innovation, provide subsidies, or restrict competing technologies, while technological development may reduce policy costs and thus enable (seemingly) more stringent policies. Such integration makes it difficult to establish a causal dependence that would allow arguing for policies accelerating transition. Finally, due to these feedbacks, energy transition trajectories are normally non-linear, which makes it difficult to measure their 'regular' vs. 'accelerated' speed.

The concept of co-evolution of socio-technical and policy action systems proposed by Cherp et al. (2018) helps to address these challenges. Co-evolution means that policies and technologies experience periods of autonomous development intercepted by periods of strong mutual interaction. In words of Christopher Freeman:

> 'It is … essential to study both the relatively independent development of each stream of history and their interdependencies, their loss of integration, and their reintegration.' (Freeman and Louçã 2001).

From the perspective of co-evolution, there is obviously no policy-driven acceleration when policies and technologies develop autonomously without impacting each other. However, full integration of policies and technologies also make it impossible to meaningfully speak of policy-driven acceleration. This is because the multitude of two-way feedbacks between policies and technologies in tightly coupled systems makes it impossible to trace causal dependencies or even to draw a clear boundary between political and socio-technical systems (making some of the scholars speak of a single 'seamless web' encompassing technologies, regulations, and political goals (Bijker 1997; Hughes 1986)).

In contrast, the pattern of co-evolution, signifying a policy-driven acceleration, logically includes two necessary elements:

1) **Loss of integration between policies and technologies**: when the policy action system autonomously develops goals for acceleration through changing the course of transition;
2) **Reintegration of policies and technologies**: when these policy goals are implemented, they drive a change in socio-technical systems that results in acceleration of transition.

Within this framework, detecting policy-driven acceleration implies two elements: (1) proving the 'loss of integration', i.e., demonstrating that policy goals are set autonomously from socio-technical systems and aim intervene and (2) establishing that the implementation of these policy goals is feasible given the realities of socio-technical systems which they aim to change.

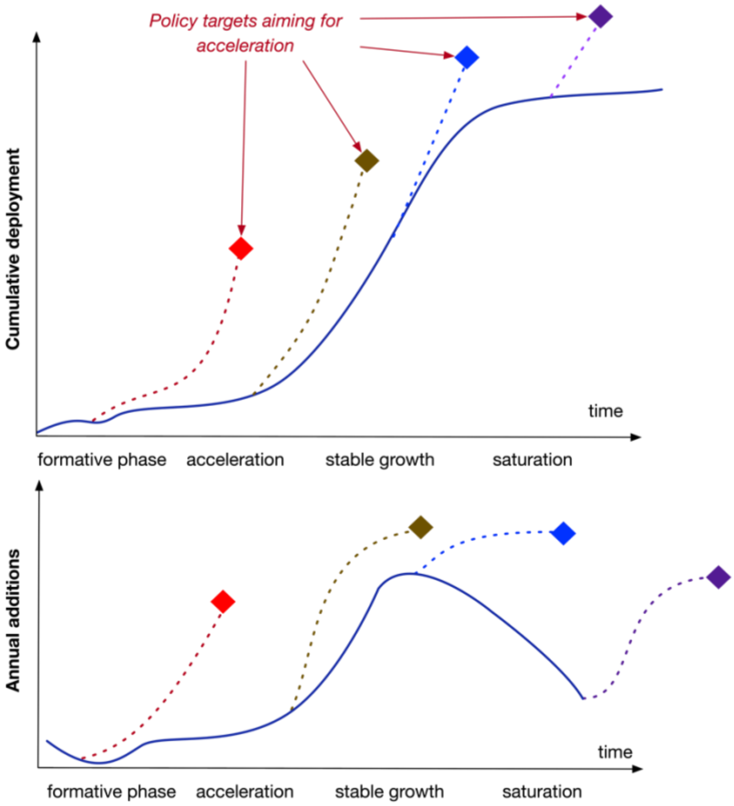
2.1.1 How to measure acceleration of energy transitions?

To establish that a particular policy aims to accelerate energy transitions it is important to understand how a technology would have evolved in the absence of the policy. This can be done by depicting the baseline or regular technology deployment by an S-curve with four distinct phases (Figure 1) according to technology diffusion theories.

1) The first **formative** phase[2] of a new technology is "*an extended period of experimentation during which the technology is tested, refined and adapted to market conditions*" (Grubler, Wilson, and Nemet 2016). At this phase, the growth is erratic due to experimentation, failures, and rapid learning. Policies aim to create favourable conditions for new technologies (Markard 2018) and may include direct subsidies to pilot and demonstration projects as well as support to research and innovation.
   - Policy-driven acceleration at the formative phase is signalled by targets which drive the technology beyond the formative phase, especially if it is faster than in similar technologies.
2) In the second, **acceleration**, phase, growth is nearly exponential (with a constant year-on-year growth rate) because annual additions increase from one year to another due of positive feedback loops or 'increasing returns' in economic, technological and policy spheres. At this stage, policies focus on ensuring that technology remains profitable and does not run into barriers.
   - Policy-driven acceleration at this phase is signalled by targets aiming to increase year-on-year growth rates, especially beyond what was observed in other contexts or for similar technologies historically.
3) In the third, **stable growth**, phase, countervailing forces (such as more complex grid integration, decreasing land availability, increasing social opposition, and political resistance (Kontogianni et al. 2014; Breetz, Mildenberger, and Stokes 2018; Schumacher et al. 2019) start balancing the 'increasing returns' and the growth no longer accelerates. In other words, annual additions of new technology reach their maximum and stop increasing from year to year: the growth becomes quasi-linear. At this stage, policies focus on reducing countervailing barriers, e.g., through ensuring grid integration, streamlining permitting procedures, or compensating the affected communities (Markard 2018).
   - Policy-driven acceleration at the stable growth phase is signalled by targets aiming to increase annual additions, i.e., the rate of linear growth, especially faster than the rate observed in similar polities or for similar technologies historically.
4) In the final, **slow-down** phase, growth eventually stops as technology reaches its final market share. Policy-driven acceleration would be signalled by resumption of growth. This phase has not been achieved by renewables and therefore not analysed in this paper.

[2] Recent literature defines the threshold for the formative phase of energy technologies of providing 0.5-1.0% of total electricity (Cherp et al. 2021; Vinichenko, Jewell, et al. 2023; Jakhmola et al. 2023).

Figure 1. Policy targets aiming for acceleration of transition compared to a regular S-curve of technology diffusion for cumulative (top) and the growth rate (bottom) of deployment at four different stages



Criteria for detecting policy-driven acceleration are summarized in Table 1. To detect reliable policy acceleration all or several of these criteria should be met.

Table 1. Criteria for detecting policy-driven acceleration of energy transitions

Phase	Criteria of policy-driven acceleration
All phases	Policy goals become more ambitious or stringent over time
Formative	Policy targets exceed the take-off threshold with growth trajectories comparable or faster for similar successful technologies at similar stage
Acceleration	Policy targets require an increase in the *year-on-year growth rates* especially beyond near-term projections and those observed in similar countries or technologies
Stable growth	Policy targets require an increase in the *linear growth rate* (yearly additions) especially beyond near-term projections and those observed in similar countries or technologies
Slow-down	Policies aim for the resumption of growth or increase in yearly additions

2.1.2 Feasibility of implementing policy goals

For policy-driven acceleration, policy goals should be formulated autonomously from technological trends, but subsequently be implemented (or, in terms of co-evolution, 'reintegrated') in real-life socio-technical systems. This is not automatically guaranteed. Historically, energy transition plans often fail as was the case of rooftop solar and wind power in India (Mercom India 2023) and CCS in Europe and North America (Reiner 2016; Wang, Akimoto, and Nemet 2021) This may happen because policy goals fail to properly account for or address real-life challenges. To assess the feasibility (defined by the IPCC as the "likelihood of climate mitigation options to be implemented" (IPCC 2022b, footnote 72)) of accelerating energy transitions Jewell and Cherp (2023) highlight two approaches: the 'inside' and the 'outside' views.

The 'inside view' identifies barriers, risks and strategies to overcome these. For the implementation of EU-wide policies one challenge is translating them into national legislation, for which we review national plans of EU member states and check whether these add up to the EU-wide goals. We also identify other barriers to renewable growth, measures that have been proposed to overcome these barriers and potential second-order effects of these measures.

The 'outside view' identifies reference cases of similar transitions in history or in other contexts and compares the context and the outcome of these cases to the planned transitions. Here we use the reference case of nuclear power in Western Europe, which was a case of rapid growth of advanced capital-intensive technology in industrialised countries exposed to energy security risks. We also use reference cases from other technologies and contexts to benchmark the proposed acceleration and assess its feasibility.

2.2 Explaining change in policy goals

Our paper aims not only to detect policy-driven acceleration, but also to explain how the relevant policy change came about. Cherp et al. (2018) point to three top-level variables potentially explaining energy transition policies: state goals, institutions, and political interests. The interaction of these factors involves discursive elements such as policy paradigms and securitization and features positive and negative feedbacks, eventually resulting in non-linear policy change (Kingdon 2014).

Among **state goals**, energy security has historically been the most visible (Jewell and Brutschin 2019; Helm 2002). For example, oil crises of the 1970s motivated expansion of nuclear power in France and natural gas in the Netherlands (Sovacool 2016), phasing out oil from the power sector (Vinichenko, Cherp, and Jewell 2021), as well as industrial restructuring in Germany, Japan, France and the US (Ikenberry 1986). The literature argues that articulating and prioritizing specific energy security concerns involves political judgement as much as objective analysis of material realities. For example, Cherp and Jewell (2014), who define energy security as '*low vulnerability of vital energy systems*', recognize that both 'vital systems' and their 'vulnerabilities' may be objectively delineated in different ways, may differ across countries and time periods, and may also be viewed differently by different actors. Energy security is important for our analysis because it was used among the main arguments supporting ambitious energy goals in the REPowerEU plan.

Another state goal affecting renewable energy policies is climate change mitigation**.** Over the last three decades, it has been enshrined in global treaties such as the United Nations Framework Convention on Climate Change (UN 1992) and its Kyoto Protocol (UNFCCC 1997) and Paris Agreement (UNFCCC 2015) as well as in hundreds of energy-related national climate policies (NewClimate Institute 2023). However, translating the global temperature goals into specific national energy policies has not been straightforward. In addition to scientific uncertainties, it involves political judgement about the distribution of mitigation costs and efforts across regions and countries and over time as well as choosing mitigation options which can range from forcing lifestyle changes to capturing carbon dioxide from the atmosphere. In its Sixth Assessment Report (AR6), IPCC has published over 200 different scenarios (climate mitigation pathways) compatible with the 1.5°C target, each envisioning its own mix of measures to reduce the concentration of greenhouse gases in the atmosphere (IPCC 2022a). As we will show, understanding how these choices were made is important for explaining the evolution of renewable energy policies in the EU, since until 2022 their main rationale was climate change mitigation.

Explaining policies in terms of state goals is 'state-centric': it views the state as an autonomous actor capable of formulating and pursuing its own goals (Cherp et al. 2018). In contrast, 'state-structured', 'neo-pluralist', approaches view the state as lacking its own agenda but instead aggregating **interests** of different actors such as voters, businesses, and social movements (Cherp et al. 2018). For example, policies supporting coal and renewables in Germany as well as nuclear power in Japan were adopted under a strong influence of vested interests (Cherp et al. 2017). Whether the state pursues its own goals or aggregates diverse interests, it operates through **institutions**. The structure and capacity of institutions have been used to explain energy policy and policy change starting from the seminal Ikenberry's paper (1986) discussing how different institutions led to different responses to oil crises in Germany, France, Japan and the US, to more recent literature showing how institutions affect energy transitions in the EU (Ćetković and Buzogány 2020) that states with stronger institutional capacity often experience earlier and faster energy transitions (Brutschin and Andrijevic 2022), including the introduction of nuclear power (Brutschin, Cherp, and Jewell 2021) and renewables (Cherp et al. 2021) as well as phase-out of coal (Jewell et al. 2019; Brutschin et al. 2022; Lægreid, Cherp, and Jewell 2023).

Thus, an explanation of policy-driven acceleration of energy transitions should consider state goals, special interests and institutions as well as factors that are 'external' to political systems such as technological development, economic change, and geopolitical dynamics. For example, economic downturn or hostile actions of energy suppliers may re-order state priorities and new technologies may empower certain interests or enable certain institutions. In addition to this dynamics, policy change literature stresses three concepts: discursive elements, policy feedbacks and non-linearities.

The dominant discourse about policy goals, priorities and instruments is conceptualized as *policy paradigm* (Hall 1993). Hall argues that a policy paradigm shift occurs when the state and other actors agree on a new problem definition or solution, emphasizing the role of learning. Kern et al. (2014) apply Hall's theory to explain the shift in UK energy policies in the 2000s from self-regulated markets to state intervention, attributing it to changes in 'crisis narratives' (Widmaier, Blyth, and Seabrooke 2007).

Another concept explaining discursive shifts is 'securitization': presenting a policy problem as an existential threat. As originally formulated by the Copenhagen School (Buzan 1983; Buzan and Wæver 2003; Buzan, Wæver, and Wilde 1998), securitization is a twofold discursive move, which, first, presents a referent object (e.g. energy supply in case of energy security or food production in case of climate change) as being under the existential threat and, second, legitimizes urgent and exceptional measures aimed at the elimination of the threat and securing the referent object. In its ultimate form, securitization may justify disruption of normal democratic procedures, because dealing with a threat in extreme situation typically involves a centralized, top-down approach to decision-making and requires sacrifices from society that would not be accepted in other circumstances (Delina and Diesendorf 2013; Kester and Sovacool 2017; Delina and Diesendorf 2018). Securitization does not necessarily mean accelerating green energy transition, it could also trigger securing energy supplies from alternative sources, military protection of critical infrastructure (Jewell et al. 2016) or other security-related measures. Although energy security threats often trigger changes in energy systems, securitization may remain a 'figure of speech', what Heinrich and Szulecki (2017) call 'security jargon'. This happens if security language is used only to gain political weight or media attention instead of taking prompt action. Moreover, securitization of energy may also be used by politicians as an element of 'state encroachment' (Szulecki 2020) on energy systems. Finally, securitization of energy issues may not be sufficient to facilitate long-term green transitions as it is vulnerable to other shocks competing for public attention (Kester and Sovacool 2017).

Policy feedbacks involve how the implementation of one policy influences conditions for future policies, resulting in a non-linear and path-dependent process (Knill and Tosun 2012). Pierson (2000) highlights 'increasing returns' as a policy benefits specific recipients, leading to their support and reinforcement of the policy, thus amplifying its impact. Jacobsson and Lauber (2006) demonstrate this cycle with the case of Germany's renewable electricity policies from the 1990s, where initial modest policies empowered beneficiaries who then advocated for policy retention and expansion in the 2000s (also observed in (Cherp et al. 2017)). Creating such 'winning coalitions' (Meckling et al. 2015; Meckling, Sterner, and Wagner 2017) as well as fostering institutional learning and increase in expertise (Pahle et al. 2018) would make it possible to develop more stringent policies overtime. This theory is behind the policy sequencing framework based on the hypothesis that "each stage [of policy development – AP] is conducive to achieving the subsequent, more stringent one" (Pahle et al. 2018). Literature shows how stepwise policy development with a shift in interests and coalitions of policy actors leads to the ratcheting-up of climate policies in the EU (Pahle et al. 2018; Leipprand, Flachsland, and Pahle 2020; Meckling, Sterner, and Wagner 2017). On the other hand, increasing returns may lead to policy path dependence (Pierson 2000) and lock-in as is generally the case with fossil fuel subsidies, which, once enacted, are very difficult to withdraw due to their multiple beneficiaries (Inchauste and Victor 2017).

Moreover, not all policy feedbacks are positive, i.e., reinforcing the existing policies, because policies produce both winners and losers with the latter likely to oppose their strengthening. The number of losers often increase with stronger policies or, in our case, increasing the use of renewables. For example, even among the public who supports renewables in general, there is less support for specific projects at the local level as (Schumacher et al. 2019) show. Moreover, the acceptance of renewable infrastructure further decreases among the public who already has experience with renewables (Donald et al. 2022; Kontogianni et al. 2014). Politicians who support renewables responding to national opinion polls pay locally with electoral losses (Stokes 2016). The growth of renewables is therefore slowed down by socio-political resistance that may weaken the accelerating effect of technological learning (Breetz, Mildenberger, and Stokes 2018) and ratcheting-up of a given policy.

The presence of both positive and negative feedbacks makes policy evolution highly uneven and non-linear, when periods of relative stagnation are intercepted by brief periods of rapid change as articulated in the concept of punctuated equilibrium (Baumgartner and Jones 2002) and accounted for in the Multiple Streams Theory (Kingdon 2014) arguing that for policy change to occur many factors should coincide in time such as external circumstances, interests, and institutional capacity. Similarly, the Advocacy Coalition Framework (ACF) (Sabatier and Weible 2007) explains policy change as a result of conflicts between competing advocacy coalitions with different beliefs and interests on a policy issue. Policy change can be triggered by external shocks, prompting coalitions to adapt through policy-oriented learning (Knill and Tosun 2012). The implementation of new policies may generate feedback effects, influencing subsequent policy decisions and contributing to the overall policy change process.

In summary, to account for conditions when policy goals aim to accelerate transitions we consider state goals, interests, institutions, discursive elements such as policy paradigms and securitization, and the process by which all these factors interact with each other.

3 Results

3.1 Renewable energy growth and the evolution of policy goals in the EU

Plans and policies targeting renewable energy in the EU date back to the early 2000s when the first Renewable Energy Directive 2001/77/EC ('RED 0') (EC 2001) was published. Subsequently, the updated REDs were published in 2009 ('RED I', Directive 2009/28/EC) (EC 2009a) and in 2018 ('RED II', Directive 2018/2001/EU) (EC 2018b). In July 2021, a proposal amending RED II was released with regard to the 'Fit for 55' package (EC 2021b). In less than a year, in May 2022, the Commission released the REPowerEU plan[3] (EC 2022e) together with five Communications related to its implementation (EC 2022b). In order to reach the REPowerEU objectives, the Commission has also proposed to update, among other things, RED II (EC 2022f). After discussion, in spring 2023, the European Parliament and the Council reached a provisional agreement on the Commission's proposal (EC 2023). The final draft of the updated Renewable Energy Directive ('RED III') will be considered in the European Parliament in September 2023 (European Parliament 2023). Throughout the paper, we refer to all the documents released together or amended with regard to the REPowerEU plan as to '*REPowerEU and related policies*'. In this section we analyse the relationship between the growth of renewable energy (overall

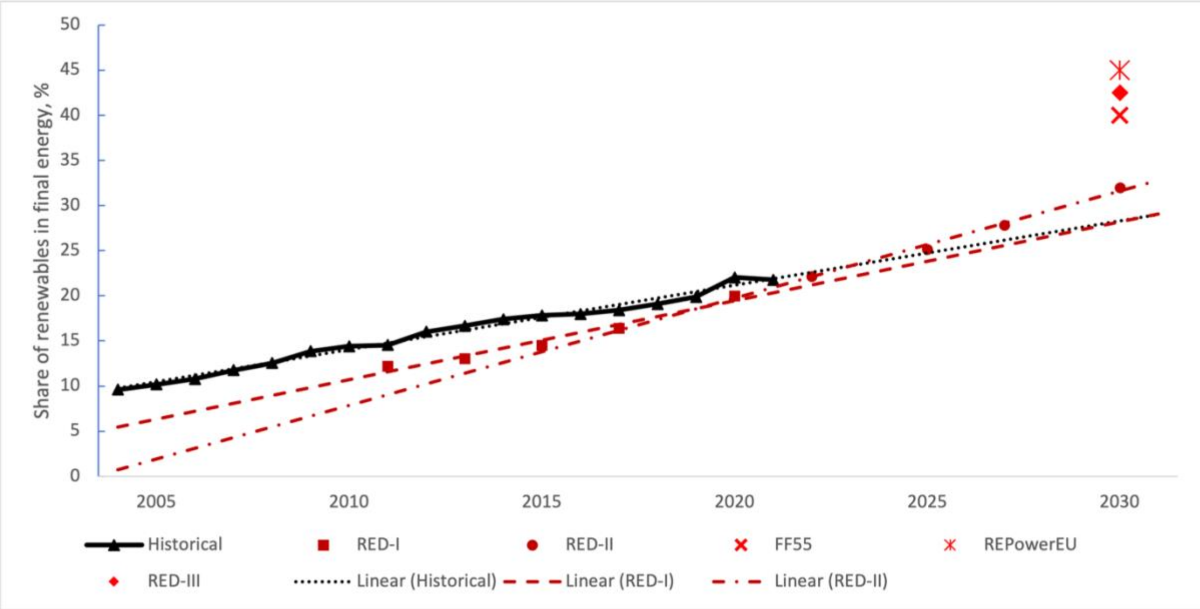
[3] Note that a draft proposal of the REPowerEU plan was resealed even earlier, in March 2022 (EC 2022a).

as well as specifically solar and wind power) and EU policy goals. Subsequently we use the criteria from Table 1 to reason whether there is evidence that the policies aim to accelerate the transitions.

3.1.1 Share of renewables in final energy

Comparisons of renewable energy targets set in REDs from different years and the actual trends in renewable energy are shown in **Table 2**, **Figure 2, and Figure 3**). Approximated with linear trend, the average historical rate in 2004-2021 is close to 0.7 percentage points (pp). In these terms, RED I targeted a slightly faster growth of 0.9pp and RED II still faster growth of 1.2pp, whereas REPowerEU is way more ambitious, almost tripling this rate to 2.6pp ('Fit for 55' package – 2.1pp and RED III[4] – 2.3pp).

Figure 2. Historical trends (linear) and policy targets for the share of renewable energy in final energy consumption in the EU



However, both the actual growth of renewables and the indicative trajectories in RED I and RED II are not linear (Figure 3). The actual growth slightly *slows down* between 2004-2019 and then experiences a boost in 2020-2021 (which may be partially attributed to COVID-19 (EC 2022c)). In contrast, the indicative trajectories in both RED I and RED II envision *accelerated growth* of renewables. RED I envisions acceleration with a higher year-on-year rate (about 5.7%) than has happened historical, but RED II envisions acceleration with exactly the historical rate (4.7%). In this sense RED II is less stringent than RED I but is closer to historical data. The proposal for RED II made in 2014 envisioned an even slower rate under 3%. The 'Fit for 55' package and the REPowerEU related policies are more ambitious also in terms of exponential growth: 'Fit for 55' envisions 7.0% year-on-year growth, REPowerEU – 8.4%, and RED III – 7.6% (Figure 3, Table 2).

[4] The REPowerEU plan's proposal amending RED II (EC 2022f) envisioned to raise a 2030 target for the share of renewable energy in final energy consumption in the EU up to 45% – from 32% set in the 2018 RED II. In spring 2023, the European Parliament and the Council agreed on raising the 2018 RED II target to 42.5% (EC 2023). Throughout the paper, we refer to the former as to 'REPowerEU' target and to the latter as to 'RED III'.

Figure 3. Historical trends (exponential) and policy targets for the share of renewable energy in final energy consumption in the EU, log-scale

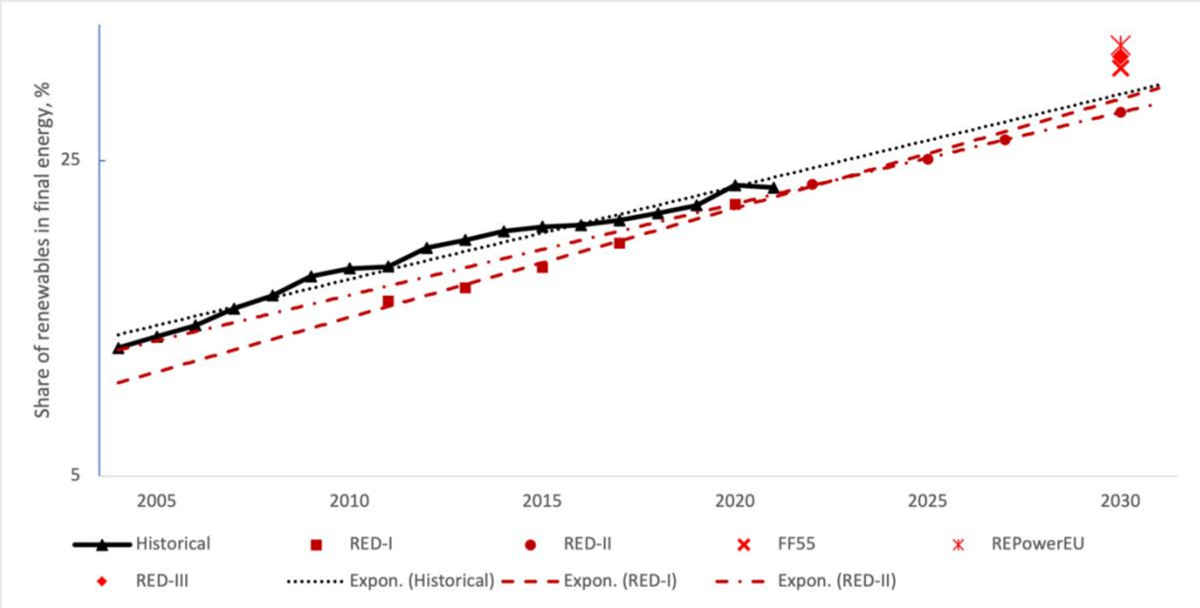


Table 2. Historical and current trends and plans concerning renewable energy share in FEC*

Policy and year of adoption	Policy Target	Linear growth (percentage points of TES)	Compound annual growth rate (CAGR)
Historical 2004-2008		7.5 pp	6.9%
RED I, 2009	20% by 2020	0.6 pp	5.7%
Historical 2004-2014		0.78 pp	6.1%
Proposal for RED II, 2014	27% by 2030	0.6 pp	2.8%
Historical 2004-2018		0.7 pp	5.0%
RED II, 2018	32% by 2030	1.1 pp	4.7%
Historical 2004-2021		0.7 pp	4.9%
'Fit for 55', 2021	40% by 2030	2.1 pp	7.0%
REPowerEU, 2022	45% by 2030	2.6 pp	8.4%
Provisional agreement on RED III, 2023	42.5% by 2030	2.3 pp	7.6%

*FEC - Final energy consumption

3.1.2 Electricity from solar and wind power

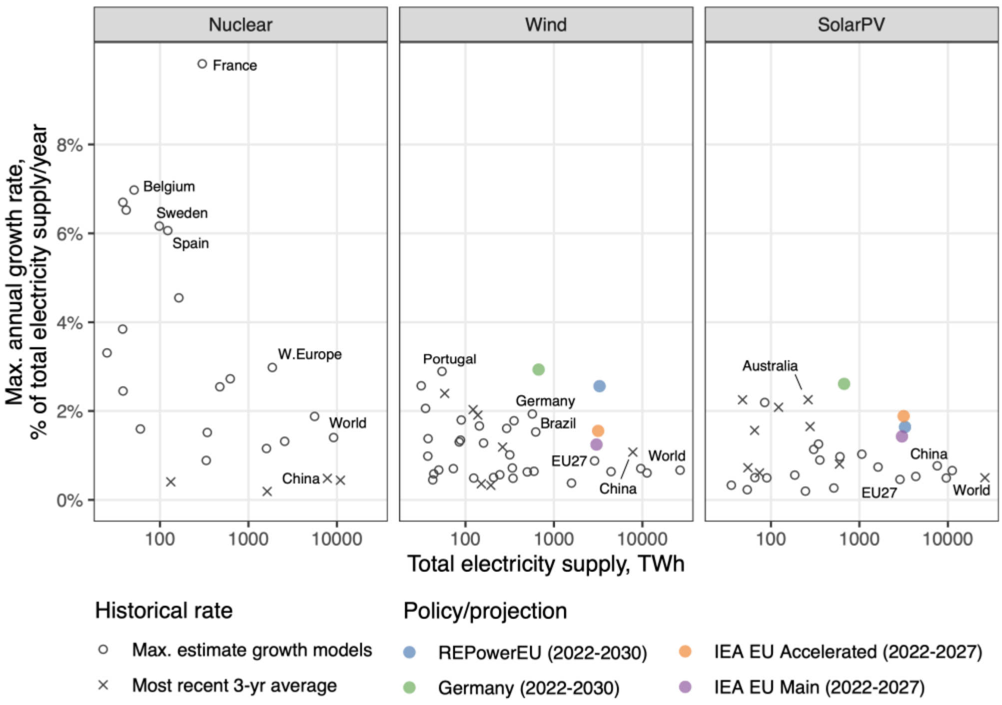
The total share of renewables in the final energy consumption (FEC) is a very aggregate indicator, encompassing many different sectors (buildings, transport, industry, power) and technologies (hydro, biomass, heat pumps, electric vehicles, wind power), which do not develop in a synchronized manner. It is possible that policies seek to accelerate the growth of some of these technologies more than others. We therefore examine EU's policy goals specifically for renewable electricity. Renewable electricity is needed not only to decarbonise the power sector, but also for reducing emissions of transport, heating, and industry. Solar and wind power are posed to generate almost of all low-carbon electricity growth by 2030.

REPowerEU envisions about 3.4 times faster growth of renewables in electricity in 2022-2030 than in 2014-2022, increasing the speed of onshore wind and solar PV deployment by about 3 times and offshore wind by almost 8 times (Table 3). This unprecedented growth is faster than any historical growth in similar size countries (Figure 4) and can be compared to the growth of nuclear in Western Europe (Figure 11). In the next section we focus on the three main renewable electricity technologies: onshore and offshore wind and solar power.

Table 3. Capacity addition rates of main renewable electricity technologies: historical for 2014-2022 and as envisioned in REPowerEU, GW/year

	Historical (2014-2022)	REPowerEU (2022-2030)
Onshore wind	9.4	26
Offshore wind	1.7	13
Solar PV	15	49
Total	**26**	**88**

Figure 4. Maximum growth rate of low carbon technologies in countries and regions of different sizes. Historical: hollow circles (for stable and stagnating growth) and crosses (for accelerating growth). EU and Germany plans and near-term projections: color circles. *Replicated with permission from* Vinichenko, Jewell, et al. (2023).



3.1.3 Onshore wind

Onshore wind emerged as a commercial technology first in Denmark in the 1980s and then towards the end of the 1990s in Germany and Spain followed by other European countries (Cherp et al. 2021). Its rate of growth accelerated until about 2010 subsequently stabilising at ca 9-10 GW/year between 2010-2021 (Figure 5) despite continuous cost decline. The year-on-year growth rate of 21% observed in 2000-2009 dropped to under 7% in 2014-2022. This means that onshore wind is currently at the *stable growth* phase of the S-curve (Figure 1), when the driving and countervailing forces such as conflicting land uses are balanced out. According to technology diffusion theories, it would be natural to expect future growth with either the existing rate or possibly even slowing down.

In contrast, both 'Fit for 55' and REPowerEU require much faster growth at ca 25 GW/year[5] or with CGAR of 10% between 2022 and 2030. This growth would be much faster than what is projected in both the main and the accelerated cases by the IEA (IEA 2022b).To achieve their goals, the policies would need not only to significantly accelerate the current pace of onshore wind deployment but also to change its entire growth trajectory (Figure 5).

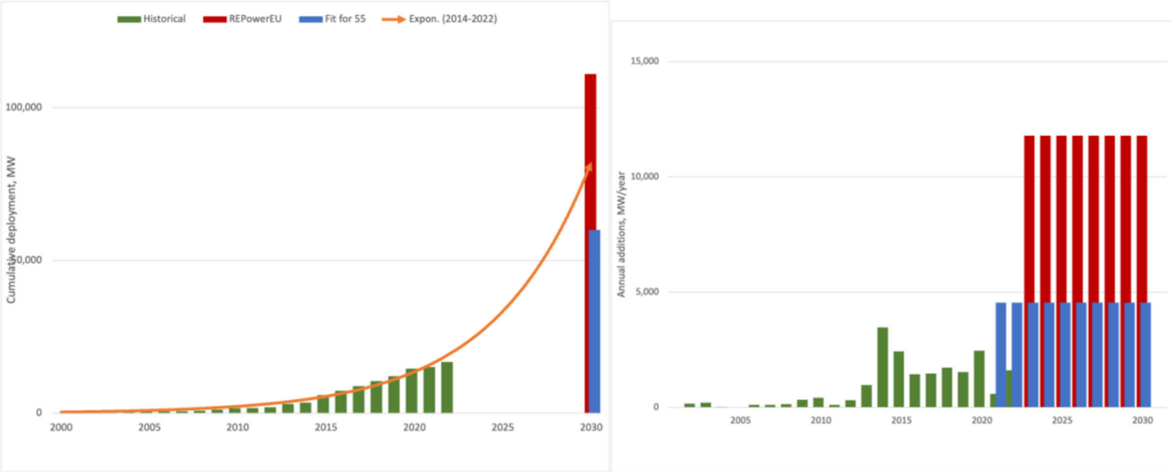
Figure 5. Cumulative (left) and annual additions (right) capacity of onshore wind power in the EU in 2001-2023 vs. the growth envisioned in 'Fit for 55' and REPowerEU by 2030 and projected in the IEA main and accelerated cases

3.1.4 Offshore wind

In comparison to onshore wind, offshore wind power is a newer and more complex technology, which still plays a relatively minor role in renewable electricity supply. The use of offshore wind in the EU is dominated by four countries: Denmark, Germany, the Netherlands and Belgium (Cherp et al. 2021), and its overall growth is uneven. In 2009, the European Energy Programme for Recovery (EC 2009b) allocated almost €600 m to offshore wind energy projects which could have caused a boost of deployment around 2014-2015 but the subsequent rate of additions did not increase (Figure 6). 'Fit for 55', based on the EU strategy on offshore renewable energy (EC 2020b), aims to almost quadruple offshore wind capacity by 2030 and the REPowerEU roughly doubles this ambition[5] (Figure 6). This accelerates the historical trends and is generally comparable to the growth of nuclear power in Western Europe in the 1960s (Figure 9).

[5] 'Fit for 55' envisioned 469 GW of total wind of which 60-70 offshore and 400-410 – onshore. REPowerEU envisioned 510 GW of total wind of which 111 GW offshore (EC Directorate-General for Energy 2023), and 399 GW onshore. Subtracting the 2021 capacity (173 GW) and dividing the result by 9 we get 25 GW/year of expected additions.

Figure 6. Cumulative capacity (left) and annual capacity additions (right) of offshore wind in the EU vs. the growth envisioned by REPowerEU and the 'Fit for 55' package

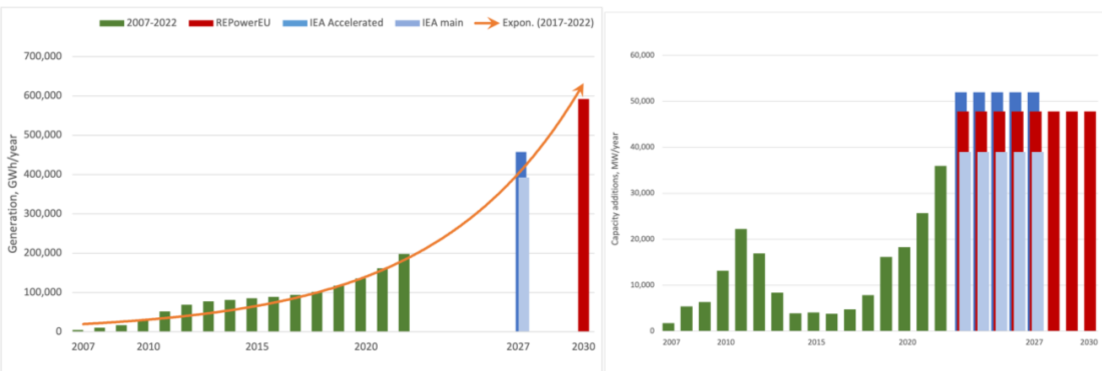


3.1.5 Solar PV

Solar power took off about one decade later than onshore wind and its initial growth in the EU was uneven. There was a boost in additions around 2009-2012 which followed subsidies provided as part of the European Economic Recovery Plan (EC 2008a), a response to the financial crisis of 2008-2009. At the peak in 2011, additions of solar power reached over 20 GW/year. In subsequent years most of the subsidies were stopped (Vinichenko 2018) and the additions decreased to much lower levels of 5-6 GW/year in 2013-2018. However, due to the rapidly declining costs of solar power it started re-acceleration to the level exceeding the growth in the early 2010s (Figure 7). After 2017, the additions started to steadily increase reaching almost 36 GW in 2022 as a result of decreasing costs of solar (IRENA 2022) (Figure 7). The IEA main case (IEA 2022b) projects a continuation of these additions until 2027 with approximately the same pace, while the accelerated case envisions their increase to about 52 GW/year.

REPowerEU aims to modestly accelerate the rate of recent additions to about 48 GW/year, which is more than in the IEA main case, but less than in the IEA accelerated case. The CAGR of solar power in the EU in 2017-2022 was 16%, whereas REPowerEU envisions 15% in 2022-2030, which means that exponentially extrapolating the growth from 2017-2022 to 2030 would result in approximately the same capacity as REPowerEU (Figure 7). The envisioned growth of solar power is faster than past growth of wind but comparable to the early growth of nuclear (Figure 10).

Figure 7 Cumulative (left) and annual capacity additions (right) of solar power in the EU vs. the growth envisioned by REPowerEU and projected in the IEA main and accelerated cases



3.1.6 Summary

The relationship between the growth of renewables and policy goals can be divided into two distinct periods. In the first period extending approximately to 2018, renewable technologies followed the trends that could be expected from technology diffusion theories and policy goals were generally in line or even more modest than these trends. Policy goals also did not become more ambitious over time, though temporary policy interventions around the financial crisis led to short growth spurs of solar and offshore wind.

In contrast, post-2018 policies aim to substantially accelerate both the growth in the overall share of renewable energy and the uptake of solar and wind power. The increased ambition is evident not only in REPowerEU but also in the 'Fit for 55' package and other Green deal (EC 2019) related policies (e.g., 'Climate Target Plan' (EC 2020c), EU strategy on offshore renewable energy (EC 2020b), and the proposal to amend RED II (EC 2021b)). The acceleration was most obvious with respect to wind power, where the onshore wind entered the stable growth phase already in 2010s but is presumed to be accelerated by up to 3 times and much faster than the near-term projections which clearly means finding new growth mechanisms and offshore wind witnessed doubling the already very high ambitions between the 'Fit for 55' package and REPowerEU.

3.2 Policy stability and change: pre- and post-2018

The previous section shows that the EU renewable policy goals in the pre-2018 period both followed the historical technology trends and were relatively constant over time, while the post-2018 goals deviated from the historical trends and became decidedly more ambitious. This section discusses the mechanisms that could explain this different policy dynamics. For each period, we consider policy goals and paradigms related to climate and decarbonisation, energy security, economic growth, and perceived technological opportunities while also accounting for institutional capacities and interests.

3.2.1 Pre-2018: renewable targets are motivated by climate concerns but only weakly linked to long-term climate goals

During this period, renewable energy policies were primarily driven by **climate change** concerns, that were present in the EU policies already since mid-1990s (EC 1996). However, translating these concerns to specific renewable targets was complicated by scientific, technological, and political uncertainties. In setting the indicative objective in the White Paper "Energy for the future" in 1997 (EC 1997), the European Commission remarked:

> *"Given the overall importance of significantly increasing the share of RES in the Union, this indicative objective is considered as an important minimum objective to maintain, whatever the precise binding commitments for CO2 emission reduction may finally be."*

The first European Renewable Energy Directive ('RED 0') (EC 2001) was released in 2001 based on the White Paper and reflecting the climate commitments arising from the Kyoto Protocol (UNFCCC 1997). The goal of RED 0 was to promote renewable energy, contributing to environmental protection, social cohesion, and security of energy supply (EC 2001). Limiting the scope only to electricity generation, RED 0 set an indicative target of 22% renewables in the EU electricity consumption by 2010, in line with the White Paper's indicative target of 12 % of renewables in energy consumption by 2010 (ibid.). The first target was under-achieved (the EU produced 19.6% of its electricity from renewables in 2010) while the second target was slightly over-achieved (12.5% of total consumption from renewables in 2010).

With entering into force of the Treaty of Lisbon in 2009, 'combatting climate change' became a specific EU goal (Kurrer and Lipcaneanu 2023). The first concrete climate targets by the European Union were aligned with the Kyoto Protocol (EU 2015). In the first commitment period in 2008-2012, the required emission reduction was 5% and the EU adopted 8% compared to the 1990s level. In the second commitment period (2013-2020) the required reduction was 18%, and the EU committed to 20% in its "20 20 by 2020" package (EC 2008b). The target for renewable share in energy consumption at 20% by 2020 was later stipulated in the Renewable Energy Directive 2009/28/EC ('RED I') (EC 2009a), also part of the package (EC 2008b).

In 2011, the Commission proposed a 'Roadmap for moving towards competitive low-carbon economy' (EC 2011) with 80% reduction of emissions by 2050, which was widely believed to be necessary to keep the temperature increase below 2°C as well as intermediate targets of 40% by 2030 and 60% by 2040, (retaining the 20% by 2020 target). In 2010, at the request of the Council of the European Union (2009), the Commission assessed an option to increase the 2020 target from 20% to 30%. However, the Commission argued that achieving the proposed target would to be too costly, especially in light of the recent financial crisis and given the failure of the 2009 COP in Copenhagen (EC 2010a). A similar analysis conducted in 2012 (EC 2012) concluded that even increasing the 2020 target to 25% would be too expensive (by an extra €18 bln/year). In 2014, the goal to reduce emissions by 40% by 2030 was finally enacted in the policy framework for climate and energy for 2020-2030 (EC 2014), which also set a goal of renewable share at 32% by 2030. While the emission reductions target already exceeded Kyoto Protocol's commitments, the target for renewables has continued the historical trajectory (Figure 2). Eventually, the RE share target of 32% by 2030 was enacted in the revised Renewable Energy Directive 2018/2001/EU ('RED II') (EC 2018b) in 2018.

Concerns about **energy security** were present in European energy policy at least since the 1980s (see e.g. (The Council of the European Communities 1986). Yet, in contrast to climate, EU energy policy was specifically incorporated into the EU Treaty only in 2009 (EU 2015). The specific concerns about security of hydrocarbon supplies from Russia first emerged in the early 2000s due to Russia's 'resurgent resource nationalism' (Kuzemko 2013) and a series of gas supply crises (in 2006, 2009) to Europe through Ukraine (Stern 2006; Pirani, Stern, and Yafimava 2009). However, despite the mention of energy security in both 2001 and 2009 Renewable Energy Directive (EC 2009a), no specific linkage between renewable targets and energy security were articulated. After the 2009 crisis when 18 EU countries experienced gas disruption in the middle of the winter (Reuters 2009) the EC proposed "A strategy for competitive, sustainable and secure energy" (EC 2010b) that defined the EU's energy security objective as insuring "the uninterrupted physical availability of energy products and services on the market, at a price which is affordable for all consumers (private and industrial), while contributing to the EU's wider social and climate goals". Overall, the 2010 Strategy (EC 2010b) primarily focused on creating critical infrastructure to increase the systems resilience and protect against supply shocks rather than accelerating the uptake of renewables.

After 2014, concerns about energy supplies from Russia have intensified as, on the one hand, Russia annexed Crimea and got involved in the armed conflict over Donbas and, on the other hand, the dependence of the EU on natural gas supplies from Russia increased (EIA 2022). In light of the potential risks, the EC proposed a new European Energy Security Strategy (EC 2014) that outlined eight steps aimed to increase the EU energy security, including diversification of energy supplies through establishing new gas routes and expansion of the infrastructure, moderation of energy demand, increase in energy production inside the EU, and improvements of interconnectivity between the Member States. Energy security policies rarely mentioned increasing supply of renewable electricity as a means reducing dependence on Russian fossils. This was to a certain extent logical: the increase in intermittent renewable electricity and simultaneous phase-out of coal and nuclear power was bound to increase rather than decrease dependence on imported gas.

The connection between economic considerations and renewable energy policies in this period was highlighted in the aftermath of the financial crisis of 2008 which led to a slow-down of most European economies. To support economic recovery, the European Union introduced the European Economic Recovery Plan (EC 2008a), with specific provisions to stimulate green energy technologies, including offshore wind power. Some of the member states provided additional subsidies to solar power, which have led to its temporary growth spur (Figure 6, Figure 7, (Cherp et al. 2021)). It was also around this time that Germany subsidised and expanded manufacturing of solar panels, which significantly contributed to their cost decline[6].

In summary, in this period renewable energy goals were mostly driven by climate change concerns, however, the climate goals themselves were a relatively conservative response to the modest global targets. Moreover, translating these goals into renewable energy targets was first hindered by considerable uncertainty over technology potential and subsequently by concerns over the costs. Thus, long-term climate targets were translated into more even more cautious near-term renewable targets for renewables essentially continuing their historical trends. Exceptions to these policies were temporary responses to the 2008 financial crises with the purpose to stimulate the economy through public spending, when both EU and national subsidies resulted in growth spurs of solar and offshore wind. The dominant energy security concern at that time was supply shocks and the protective measures focused on increasing short-term system's resilience without much effect on renewable policies. Finally, institutional capacity for understanding and promoting renewable growth has been gradually strengthened including through the evolution of epistemic communities linking policy makers to energy modellers, other scientists, think tanks and advocacy groups, that laid the foundation for formulating more ambitious targets in the 2nd period.

3.2.2 Post-2018: near-term renewable targets are derived from net-zero for 2050 vision

Towards the second half of the 2010s, the global climate governance has changed. The Paris agreement (UNFCCC 2015) set a political goal of limiting global warming to 1.5°C (Cointe and Guillemot 2023). This goal was linked to the 'net zero emissions' by mid-century aspiration (Rogelj et al. 2021) and the related concept of 'net zero energy by 2050' (IEA 2021). In 2018 the European Commission endorsed the goal of achieving net zero emissions by 2050 (EC 2018a). In 2019, the adoption of the European Green Deal marked a resetting of the Commission's commitment to solving climate and environmental problems with an aim to:

> *"transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use"*(EC 2019).

This was still far too distant a goal to dictate concrete near-term strategies. Following the adoption of the Green Deal, the EC investigated what would the 2050 goal mean for 2030 emissions reduction target, which was still set at 40% as in the 2011 Roadmap. The EC's Impact Assessment (EC 2020a) argued that achieving net zero emissions by 2050 would require increasing the 2030 target as well, because otherwise it will lead to unrealistically high rate of decarbonisation in 2030-2050. Thus, the 2030 emission reduction target was recommended to be set at 55%, a massive ramping up meaning nearly doubling the speed of the previously planned emission reduction. Subsequently, energy and emission scenarios based on cost-optimisation models derived the required speed of renewables introduction (EC 2020a), which formed the bases of the 'Climate target plan' (EC 2020c), 'EU offshore wind strategy 2020' (EC 2020b) and the 'Fit for 55' package (EC 2021a). Increased ambition with regard to emissions reduction target has also led to the revision of the 2030 renewables share target, that was set at 40% in the proposal amending Renewable Energy Directive (EC 2021b) – up from 32% in the 2018 RED II. Reaching climate neutrality by 2050 was eventually enacted into the first 'European Climate Law' (Regulation (EU) 2021/1119) in 2021.

Expansion of renewables was eventually linked not only to climate targets but also to ensuring EU's energy independence, where long-term dependence on Russia rather than short-term supply shocks have emerged as the primary concern. At first, although the relationships between the EU and Russia continued to deteriorate, energy security remained a marginal consideration in the 'Climate Target Plan' (EC 2020c) and the Green Deal (EC 2019). For example, the 2021 'Fit for 55' package (EC 2021a)

[6] Though the manufacturing was subsequently shifted to China, the cost decline continued eventually enabling the possibility of solar growth almost a decade later.

mentions security only once and that is not energy, but food security. However, with Russia's full-scale invasion of Ukraine in February 2022, Europe's dependence on Russia's gas was immediately casted as an existential security problem. The winter and spring of 2022 featured intense media discussion on how to reduce this dependence (Pavlenko 2022). In March 2022, the IEA came up with a 10-point plan to reduce the European reliance on *Russian* (emphasis added) natural gas (IEA 2022a), which included expansion of renewables and maximization of electricity generation from nuclear in the EU. Same time, "to make Europe independent from Russian fossil fuels well before 2030, starting with gas" (EC 2022d), the Commission proposed an outline of the REPowerEU plan (EC 2022a). The final version of the plan as well as other accompanying documents were presented in May 2022 (EC 2022b). In contrast to previous policies, REPowerEU features a very strong energy security language, claiming that renewables increase the EU's energy independence and improve security of supply. While the 'Fit for 55' package (EC 2021a) did not mention energy security, the REPowerEU plan (EC 2022e) mentions security of energy supply over 20 times. It Is also noteworthy that 'Fit for 55' package clearly calls for action 'to fight against climate change', whereas the REPowerEU plan (EC 2022e) does not mention 'climate change', not even once. Yet, paradoxically, despite this radically different rhetoric, REPowerEU does not dramatically alter the 'Fit for 55' goals for renewables.

Linking near-term renewables targets to long-term climate goals as well as energy independence was possible, among other things, by perceived technological opportunities. First, the net zero targets signalled the need to decarbonise not only electricity but also industry, heating and transport, which among other things would mean a much larger market for renewable power. Second, decarbonising these sectors would also be a plausible strategy to reduce the dependence on Russian oil and gas (which could never be achieved by decarbonising electricity alone). Third, advances in decarbonising non-electricity sectors held a promise of maintaining or expanding EU leadership in low-carbon technologies ranging from heat pumps to non-fossil steel and cement production and thus in worldwide economic competitiveness. These goals now seem not only desirable, but also feasible considering the declining costs of renewables (especially solar) as well as the explosive growth of batteries and electric vehicles and emerging visions and plans for production and use of hydrogen and other low-carbon fuels.

In summary, the post-2018 ramping up of renewable energy targets was due to several coinciding factors. The increased climate ambition linked to the net-zero by 2050 commitment implied rapid decarbonisation of non-electricity sectors, thus promising larger markets and requiring faster growth of renewable power. In a paradigmatic shift, the European Commission linked these long-term goals to near-term targets through the 'Fit for 55' package. In parallel, the dependence on Russian oil and gas was securitised as a result of the war in Ukraine and also linked to the rapid expansion of renewables, following, somewhat paradoxically, the targets derived from long-term climate goals. This fusion of climate and energy security goals to support massive expansion of renewables was made possible on the one hand by perceived technological opportunities especially cost decline and advances in electrification and on the other hand by the strengthened EU bureaucracy and weakening of economic interests linked to the import of Russian gas as well as the use of coal and nuclear power[7].

3.3 Challenges and feasibility of achieving renewable energy goals

Due to the high ambition of recent policies, the feasibility of their implementation has been questioned, as, for example, during the discussion of the recently proposed revision of the Renewable Energy Directive (EC 2022f) in May-June 2023 (see, e.g., Abnett 2023). In this section we discuss this concern with respect to offshore and onshore wind and solar power. For each technology we compare its

[7] Germany completed phase out of the 2nd largest nuclear power fleet in Europe by early 2023. The production and use of coal in the European Union has declined under the 2010s, with most countries pledging to phase out coal use (Jewell et al. 2019; Vinichenko, Vetier, et al. 2023).

projected EU-wide deployment with the existing national plans, with historic development of nuclear power, and discuss potential barriers for its implementation.

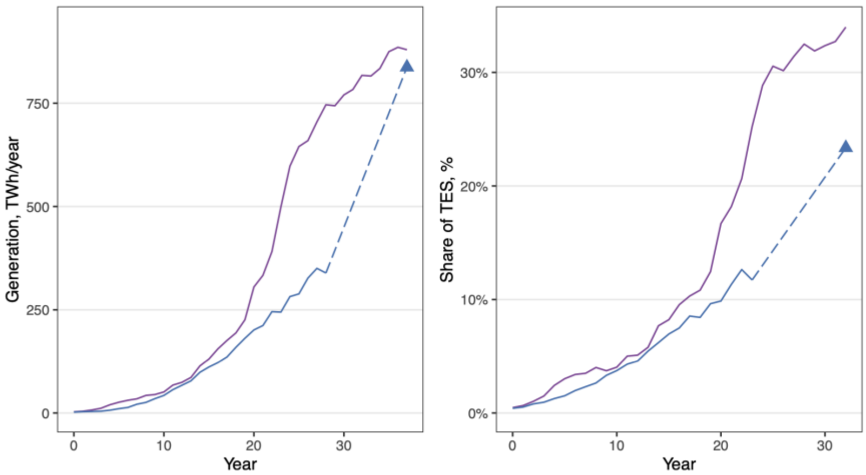
3.3.1 Onshore wind

Onshore wind is the most mature and largest source of renewable electricity in the EU and globally and it is also posed to contribute most to the REPowerEU goals. As we explain in section 3.1.3, these goals would need to alter its historical trajectory of steady quasi-linear growth in the last decade. This means that re-accelerating growth would need to eliminate the barriers that have prevented acceleration over the last decade. One of the most important barriers is broadly understood land availability which manifests itself in complicated permitting and wider social opposition. Onshore wind required more land than solar and offshore wind and good sites are becoming increasingly scarce (McKinsey 2023). In its report "Land: a critical resource for energy transitions", McKinsey argues "beyond the technical suitability of the land, which is a hard limiting factor, a significant amount of land in Europe is unavailable for development because of strict regulations". The report finds that in Germany, the rules about distance from settlements and infrastructure as well as other technical, regulatory, and environmental constraints reduce available land by 82 percent in comparison with what is technically available. Competing land uses result in lengthy permitting procedures and permits for onshore wind and other renewable projects being frequently denied. For example, about 80% of applications for onshore wind power in Sweden were refused in 2021 (SVT 2022). There is significant pressure to 'streamline', 'shorten' and 'simplify' the permitting procedures, but these also run risk on infringing on normal democratic processes and may result in backlash and more resistance over time (Kester and Sovacool 2017; Bavarian Ministry of Economic Affairs, Energy and Technology 2022).

Currently, 80% of onshore wind power in the EU is deployed in 8 countries: Germany, France, Spain, Italy, Poland, Sweden, the Netherlands, and Belgium. These are the largest countries, predominately located in Northern Europe and on the Atlantic with best wind conditions, and historically characterized by strong motivation and capacity to develop wind power. There is therefore no reason to expect that the distribution of wind power across the member states will drastically change. These eight countries plan to install about 276 GW of onshore wind by 2030, which scaled up to the whole EU will add to 345 GW or some 50GW (10-15%) less than the REPowerEU target of ca 400 GW. REPowerEU would also require 25-30% faster additions than in the current national plans.

Onshore wind power has historically grown slower than nuclear power and even faster growth in REPowerEU would still be slower than nuclear (Figure 8). However, drawing lessons from the nuclear growth would be problematic because nuclear power was never in a situation when stable growth was re-accelerated by policies, and it never had to overcome the barrier of competing land-uses.

Figure 8. Historical generation from onshore wind power in the EU (blue solid line) and FF5 and REPowerEU targets (blue triangles) compared to the historical growth of nuclear power in Western Europe (purple line). The left panel shows the electricity supply from each technology in absolute numbers (1993-2021 + 2030 for wind and 1961-1998 for nuclear) and the right panel – as percentage of total electricity supply each year (1997-2021 +2030 for wind and 1961-1994 for nuclear).



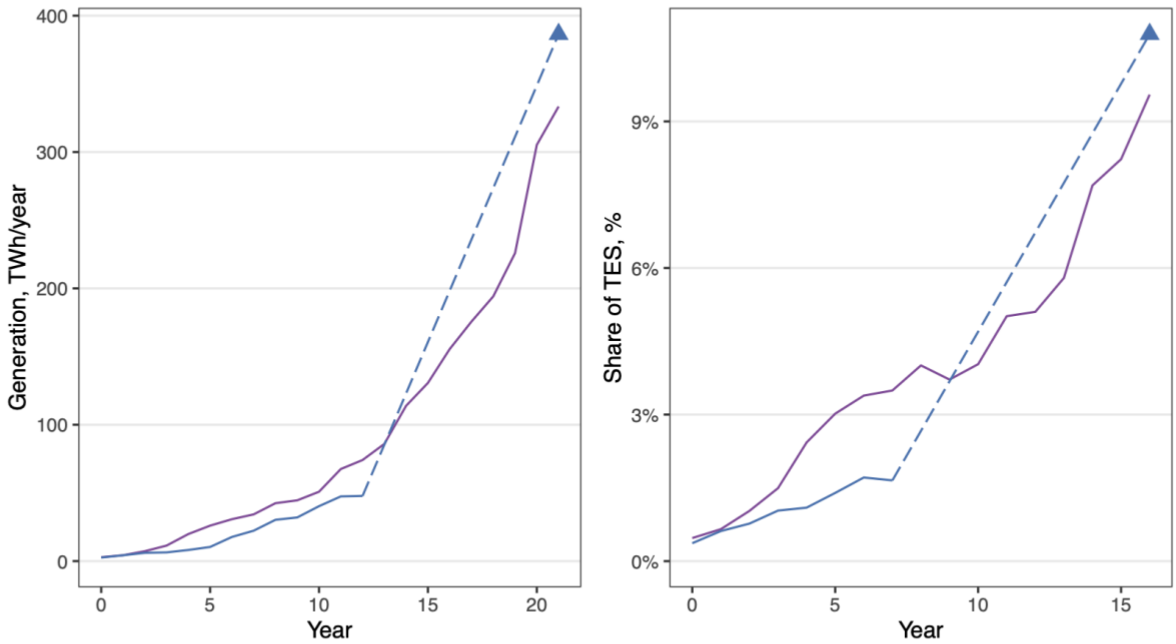
3.3.2 Offshore wind

Compared to onshore, offshore wind is a relatively new technology, where the EU is the global frontrunner, which has just cleared the formative phase and requires at least 8-fold upscaling to reach the REPowerEU targets. On the positive side, rapid deployment of offshore wind is in line with the voluntary national plans for offshore wind development set in the non-binding agreements (EC Directorate-General for Energy 2023). However, implementing these plans would require overcoming several barriers and risks, including securing the necessary investments, overcoming interest conflicts in using maritime areas, constructing the transmission infrastructure and ensuring that linked technologies such as hydrogen production do not fail to provide the necessary demand. Historically, development of offshore wind farms has been associated with long lead times and failures to implement the announced projects. To pursue an 8-fold increase in capacity within the 7 years would require immediately addressing these challenges.

Among renewable electricity technologies, offshore wind has most similarities to nuclear power, including technical complexity, large project size, and its concentration in a handful of countries that share necessary conditions. In contrast to nuclear power that relied on rapidly and 'naturally' growing domestic markets, offshore wind would need to be sold in international markets because many countries plan its production far beyond their own needs. Furthermore, it may need to be used in conjunction with other, even less mature, technologies, such as hydrogen production, that would also require massive state support to take off. Thus, development of offshore wind power would need massive state involvement, which also makes it similar to nuclear.

So far, the growth in offshore wind generation has been somewhat slower than the growth of nuclear power at early stages of its development (Figure 9). For example, the share of nuclear power in electricity in 1960-1967 increased by 8.5 times, but for offshore wind in the similar period (2014-2021) it increased by only 4.3 times. In contrast, REPowerEU envisions somewhat *faster* growth of offshore wind in 2022-2030 than the growth of nuclear in a comparable period (Figure 9).

Figure 9. Historical generation from offshore wind power in the EU (blue solid line) and the REPowerEU targets (blue triangles) compared to the historical growth in nuclear power generation in Western Europe (purple line). The left panel shows the electricity supply from each technology in absolute numbers (2009-2021 + 2030 for wind and 1961-1982 for nuclear) and the right panel – as percentage of total electricity supply each year (2014-2021 +2030 for wind and 1961-1977 for nuclear).



3.3.3 Solar PV

Solar power is a rapidly growing technology, which has achieved grid parity and is rapidly growing around the world including the EU. Its advantage are lower investment barriers and possibility of flexible deployment in diverse conditions. However, its growth also requires extensive policy support, for example protection from negative prices and price volatility when too much solar power is deployed (SolarPower Europe 2023). Other barriers include the near-term increase in costs due to raising costs of materials and bottlenecks in manufacturing. Isabel Schnabel of The European Central Bank (ECB) coins the term “Greenflation” (ECB 2022) identifying an “important paradox in the fight against climate change: the faster and more urgent the shift to a greener economy becomes, the more expensive it may get in the short run”. This is because solar requite large amounts of metals and minerals, such as copper, lithium, and cobalt. Demand for such materials rises faster than their supply because it typically takes five to ten years to develop new mines, and the constrained supply drives skyrocketing of the prices. Cost increases are important, because being extremely decentralised technology, solar power is very sensitive to costs, where any deterioration of economy immediately discourages multitude of actors to invest in new installations.

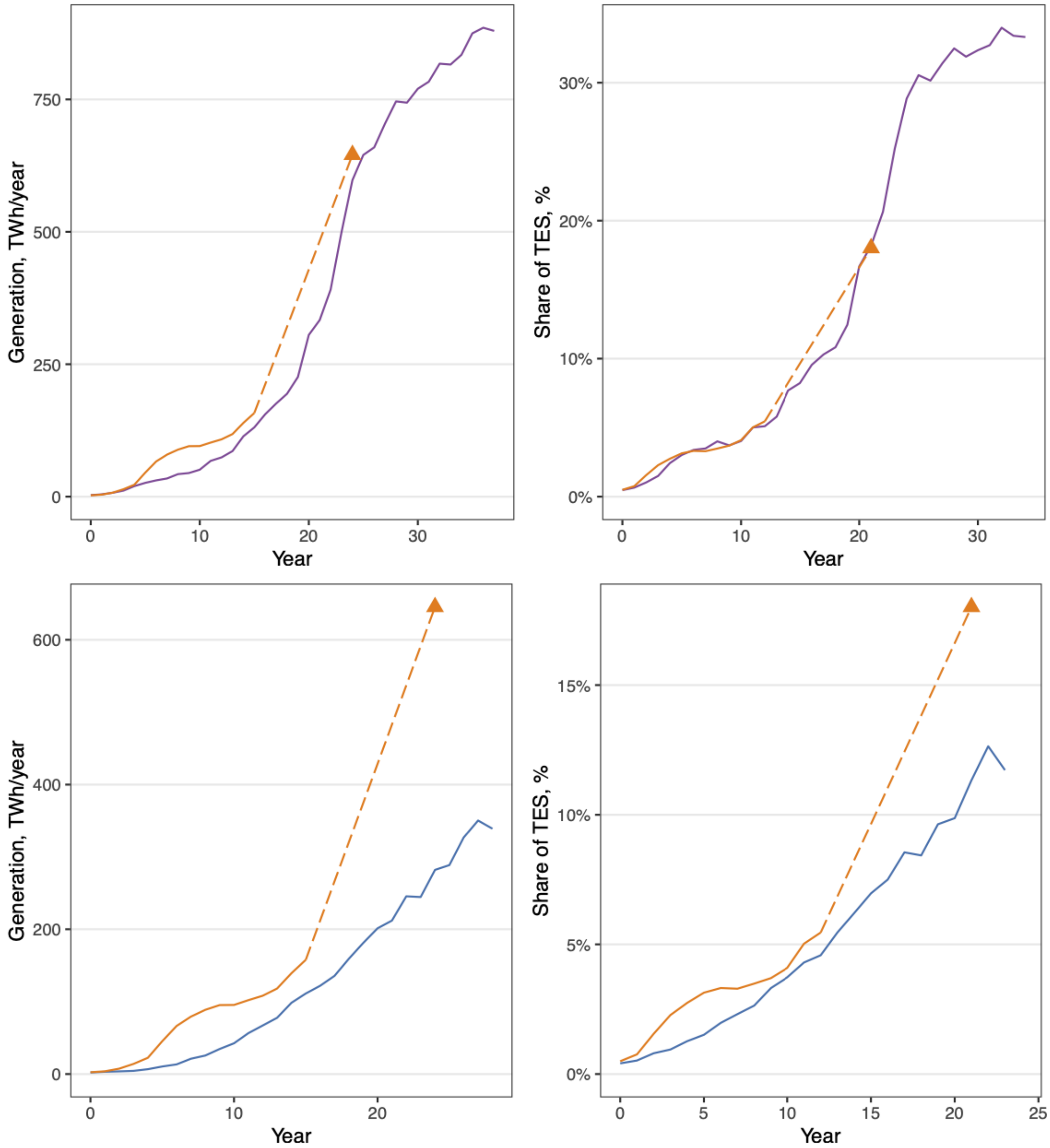
On the positive side, the eight countries which currently contribute 85% of solar power[8] currently plan additions in the range of 37-38 GW/year, which if upscaled to the whole of the EU will be 44-45 GW/year, close to the rate required by REPowerEU. Moreover, solar power is more likely to gain more share in Southern Europe, Central Europe and the Balkans than in the Northern Europe which make up the bulk of solar power deployment at the moment. Thus, the national plans can be realistically implemented leading to implementation of REPowerEU.

The generation from solar power was similar to nuclear in terms of the total volume (2006-2021 compared to 1960-1975) and the share in electricity supply (2009-2021 compared to 1960-1971). For

[8] These are the same eight countries as contributing 80% of wind power (Germany, France, Spain, Italy, Poland, Sweden, Netherlands and Belgium)

2021-2030, REPowerEU envisions growth comparable to the growth of nuclear in 1975-1984 (in terms of absolute generation) or 1971-1980 (in terms of the share in electricity supply) (Figure 10). This similarity signals the level of ambition for solar power in REPowerEU, but given that it is a very different technology, few lessons can be drawn from nuclear.

Figure 10. Historical generation from solar power in the EU (solid orange line) and the REPowerEU targets (orange triangles) compared to the historical growth of nuclear power in Western Europe (purple line) (top) and onshore wind in the EU (blue line) (bottom). Left panels: electricity supply in absolute numbers (2006-2021 + 2030 for solar; top: 1961-1997 for nuclear; bottom: 1993-2021 for wind) and the right panels – as percentage of total electricity supply each year (2009-2021 +2030 for solar; 1961-1997 for nuclear; bottom: 2006-2021 + 2030 for solar and 1998-2001 for wind).

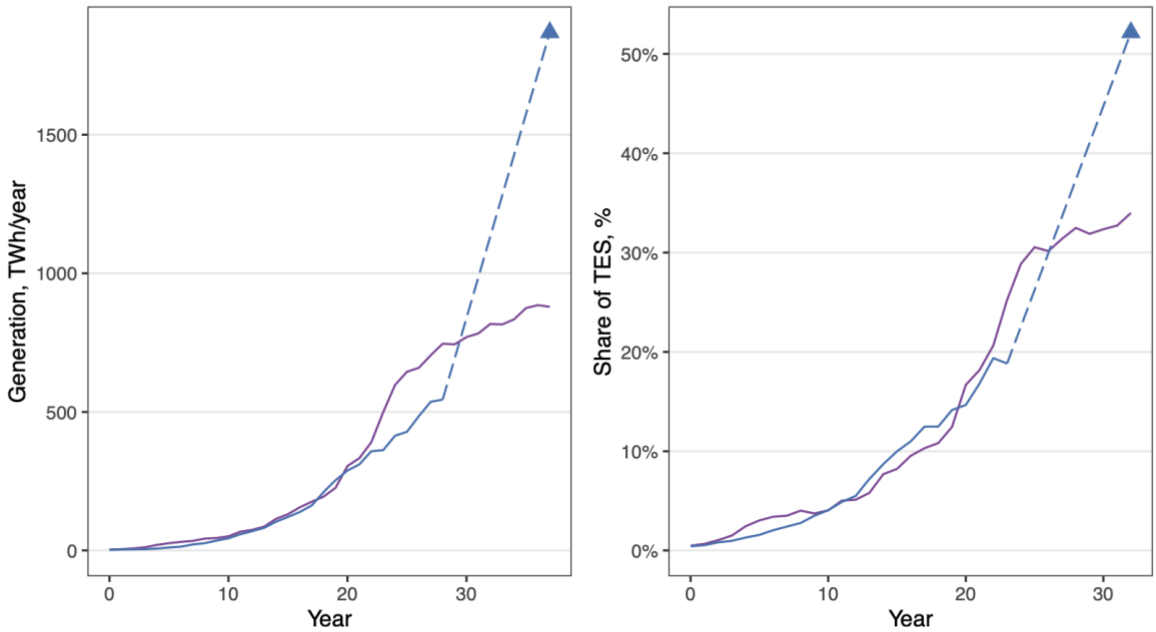


3.3.4 Combined growth of wind and solar

In addition to overcoming specific barriers for the development of on- and offshore wind and solar, European economies face a combined challenge of deploying all these three technologies simultaneously, which is historically unprecedented. The scale of this challenge is illustrated by comparing the combined generation from wind and solar power in the EU to the generation of nuclear in Western Europe (Figure 11).

While historically the growth of wind and solar power was initially similar and then slower than nuclear, REPowerEU envisions not only faster growth in 2022-2030, but also deployment to the higher eventual shares of electricity (which means that the growth of renewables would need to avoid the slowdown experienced by nuclear in the 1990s) (Figure 11). This will be an unprecedented policy challenge since all three renewable technologies (and the connected non-electricity technologies) would require policy support and resources.

Figure 11. Historical growth of solar and wind power in the EU (solid blue line) and the REPowerEU target (blue triangles) compared to the historical growth of nuclear power in Western Europe (purple line). The left panel shows the electricity supply from each technology in absolute numbers (1993-2021 + 2030 for solar and wind and 1961-1997 for nuclear) and the right panel – as percentage of total electricity supply each year (1998-2021 +2030 for solar and wind and 1961-1993 for nuclear).



4 Discussion

This paper contributes to the debate on whether and under what conditions policies can accelerate the transitions to low-carbon energy technologies. To address the challenge of two-way interaction between policies and technologies we address this question in terms of policy and technology co-evolution. Acceleration of technology growth can be attributed to policies when there is an 'autonomous' policy change which is subsequently re-integrated with technological realities. We subsequently argue that the post-2018 policy-technology interaction departs from the pre-2018 trends and may signal the beginning of policy-driven acceleration of transition.

Pre-2018, policy-technology coevolution was 'integrated'. Policies supported technology diffusion and reacted to emerging opportunities or barriers through incremental learning and adjustment. The empirical hallmarks of this pattern are smooth technology growth trajectories following S-curves, while policy goals are mostly tracing historical trends and do not become more stringent with time.

Supportive policies resulted in early adoption of renewable electricity throughout the EU (Cherp et al. 2021). At the same time the growth of these technologies was not especially fast, compared both to the growth required for reaching climate targets and to the past growth of nuclear (Cherp et al. 2021; Vinichenko, Jewell, et al. 2023). Although the renewable policies were guided by climate change concerns, the international climate targets were interpreted reactively and moderately. Even as long-term goals gradually became more stringent, their translation into near-term renewable targets was cautious and done with reference to economic costs and the global distribution of climate mitigation burden. In other words, the normative climate goals informed the direction rather than the speed of energy transitions.

Post-2018, renewable policies developed more autonomously, acquiring their own logic and aiming to achieve normative climate goals through disruptive interference in technological diffusion. The empirical hallmarks of this pattern are sudden changes in policy rhetoric, as well as policy goals which are not in line with historical trends (requiring deviation from S-curves) or past goals. Some of these hallmarks were observed around the late 2010s and early 2010s when large subsidies were distributed to solar and offshore wind power leading to temporary growth spurs. Yet, at that time there was neither sustained acceleration of technology diffusion nor a fundamental policy shift because policies reacted to a one-off disruption by the financial crisis of 2008 while socio-technical systems were not ready for acceleration due in part to high technology costs[9]. A more profound emergence of this pattern starts in 2018 when EU goals for renewables are set far beyond the historical trends (Figure 2) and a rapid simultaneous acceleration of renewable electricity (Figure 11), especially onshore (Figure 5) and offshore (Figure 6) wind is envisioned together with acceleration of hydrogen production and other technologies in the adjusted technology clusters.

Three simultaneously emerging policy discontinuities are likely to have contributed to the new pattern. The first was a paradigm shift in linking long-term climate goals, particularly the 'net zero' vision for 2050 to the near-term (2030) emission and renewable targets calculated through normative cost-optimisation scenarios. This can be contrasted to the previous mode of target-settings when the connection between long- and near-term targets was more tentative and balanced against technological and cost realities. This paradigm shift was the culmination of a long period of learning within the EU climate and energy bureaucracy and the closely linked epistemic communities of energy and climate modellers and researchers.

The second was securitization of renewables following Russia's invasion of Ukraine which brought attention to the dependence on Russian fossils to the media, public and politicians. Once again, the presence of actors capable of making the 'securitisation' move was critical. In the REPowerEU plan (EC 2022e), European Commission not only presented transition to renewables as a matter of avoiding an existential threat but also framed a proposal to promote renewables through declaring them a matter of national security that is 'overriding public interest' (EC 2023).

The third discontinuity was the perceived technological opportunities, especially reduction of costs of solar and offshore wind power, as well as the prospects of decarbonising transport, heating and industry through electrification and hydrogen production with help of renewables.

We argue that these factors could only work together, not in isolation. Climate concerns have inspired renewable energy policies over more than two decades but have not induced a disruptive change in technological trajectories, even when extreme urgency language was used in the UN and the media. While ambitious, the EU 'Fit for 55' package (EC 2021a) contained more modest targets for both offshore wind and solar power than the subsequently 'securitized' REPowerEU. Moreover, even with its extremely challenging onshore wind target, 'Fit for 55' did not contain a realistic strategy of achieving

[9] This effect on renewables can be compared with a similar failure with respect to carbon capture and storage (Reiner 2016; Abdulla et al. 2021).

it, it was the securitization mode that proposed to override the existing land use and social opposition concerns with casting renewables as a matter of public interest.

Likewise, energy dependence on Russia has been profound and increasing, but the main threat was seen as supply shocks, not a long-term vulnerability requiring a drastic expansion of renewables. Past energy security shocks led to build up of infrastructure and resilience including through supplier diversification whereas energy security was not even mentioned in policy rhetoric concerning renewables. Even after Russia's invasion of Ukraine there were still options to respond to the threat (e.g., increasing coal-fired and nuclear power generation, diversifying gas supplies, energy saving) without rapidly ramping up the renewable targets.

Finally, technological change on its own would also be unlikely to deliver the planned acceleration, except possibly for solar power. Onshore wind, where the cost of technology no longer declines has run into significant socio-technical barriers, particularly conflicting land uses, that stopped its acceleration. The rate of its steady growth over the last decade, although higher than for other renewables, has been far lower than policy aspirations. Offshore wind is a large-scale emerging technology which would only take-off with massive state involvement in the necessary infrastructure and related technologies such as hydrogen production.

While none of the three factors would work in isolation, it is their combination that is shifting the co-evolution pattern. The paradigm shift in climate policy allowed to formulate concrete near-term targets whereas securitization triggered by the war allowed to make these targets urgent and existential leading to their endorsement by policy-makers and stakeholders. Securitization was successful because the EU policy was primed in this direction by decades of previous, climate-motivated policies and the well elaborated 'Fit for 55' package and because the strong centralised bureaucracy was able to quickly make the securitisation move. Furthermore, dependence on Russia does not imply any *specific* renewable targets, so it was symptomatic, that REPowerEU mostly adopted the 'Fit for 55' climate targets that were never designed to address security concerns. In other words, normative and technocratic climate policy agenda was skilfully securitized by powerful bureaucracy. The perceived technological opportunities played an important role here because policy makers believed that implementing the ambitious targets would revive rather than slow down economies due to both lower costs and an opportunity to secure EU leadership in global clean tech markets. The observed dynamics resulting from this complex interaction exhibits the 'punctuated equilibrium' (Baumgartner and Jones 2002) pattern with stability periods intercepted by rapid change and is in line with the Multiple Streams Theory (Kingdon 2014).

Even given this unprecedented policy shift, it remains to be seen whether the renewable technology diffusion is going to be accelerated beyond the historically observed patterns. To do so, several major barriers should be removed. For onshore wind, the major barrier is competing land uses and resulting local opposition and complicated permitting. This is a barrier which should be overcome at the national rather than the EU level, and therefore it is a particularly strong warning sign that the current REPowerEU target is not aligned with national plans for this technology. Overcoming this barrier through 'streamlining' localisation of wind projects may infringe on democracy and trigger further backlash. For offshore wind, the main barrier is reducing long lead times and risks related to implementation of complementary technologies such as hydrogen production. Given technological similarities, certain lessons can probably be learned from nuclear power expansion in the 1960s and the 1970s. For solar power, the main risk may be near-term cost increases related to material availability.

The current conditions of an energy security shock may be conductive to overcoming some of these challenges. Once again, the parallel with nuclear may be useful, since nuclear expansion was also triggered by an existential threat to energy systems resulting from the oil embargoes of the 1970s. Some of the recent scholarly contributions to applying wartime mobilization models used during World War II to energy transition policies include, for example, Delina and Diesendorf (2013); Hanna et al.

(2021); Odenweller et al. (2022). A softer version of this is 'Mission Economy' proposed by Marianna Mazucato drawing parallels between clean energy transitions and the Appollo project. These analogies, while useful, may work better in overcoming barriers related to offshore wind with large projects, fewer interests and massive involvement of the states, while the challenges of wind and solar power are much more localised and thus would require different approaches. We also signal a specific challenge of developing all three technologies simultaneously, which would require a greater policy effort than for the development of nuclear power in Western Europe the 1960s-1980s, especially significant because so far renewables developed slower, not faster, than nuclear. In both cases this policy effort occurs in advanced industrialized democracies expecting boom in electricity demand and under an energy security crisis. However, there are also significant differences. European Union is more diverse than Western Europe with different conditions and capacities. This may create barriers in achieving universally fast growth but also an advantage because diverse conditions might enable applications of diverse technologies. It may also be hoped that the diversity of technologies will relax the barriers and thus enable their wider application (while nuclear was largely confined to larger countries and required rapid electricity demand growth, solar and wind can also be deployed in smaller countries with smaller demand growth). There are additional differences in the context (e.g. the degree of electricity market liberalisation and the stringency of environmental regulations) that would need to be addressed in future research.

5 Conclusions

The question we ask in the beginning: '*Can policies accelerate energy transitions*?' is less conceptually and methodologically straightforward than it seems, given the coevolution of policies and technologies. To answer this question, we first develop a definition of policy-driven acceleration as a process when policy goals on the one hand deviate from technology diffusion S-curves expected from empirical trends and near-term projections but on the other hand are feasible in given socio-technical institutional and economic realities.

When this definition is applied to the analysis of renewable energy targets in the EU, two distinct periods are easily identified: the pre-2018 with no policy driven acceleration and the post-2018 which is likely the beginning of an acceleration, especially in onshore and offshore wind. The contrast between the two periods is likely explained by three major and simultaneous shifts in the policy process and its context. The first was the shift from weakly to strongly coupled long-term climate and near-term renewable energy targets. This shift, closely connected to coining the net-zero for 2050 vision, occurred within a strong epistemic community of climate and energy modelers and policymakers, and required scientific advances and the institutional capacity to translate these into policies. The second was a shift from perceiving security as protection from short-term supply shocks to securitizing dependence on Russian oil and gas, triggered by Russia's war in Ukraine, and, as a consequence, renewable energy as a means to substantially reduce this dependence. The third was the shift of viewing renewable electricity as somewhat uncertain and potentially costly option to perceiving it as an opportunity to rapidly and cheaply decarbonize not only the power sector, but also transport, heating and industry thus achieving the net-zero climate goal and eliminating the dependence on Russia. In light of these findings, policy-driven acceleration is certainly possible but seems to be an exception rather than the rule.

Even though the new policies clearly aim to accelerate the transition, the feasibility of their implementation is not given. The 'inside view' signals profound barriers especially with respect to onshore wind power that has not been accelerating for the last decade and where a 3-fold acceleration is required. The 'outside view' points to a rather hopeful benchmark of nuclear power in Western Europe that historically could grow as fast as any of the three renewable technologies. Yet, the differences between the nuclear analogy and the planned growth of renewables are not trivial. Most importantly, nuclear power has not experienced the barrier of conflicting land uses and local opposition now faced by onshore wind. Furthermore, while nuclear growth can be matched to the targets for each of the three technologies (on- and offshore wind and solar), their combined simultaneous growth, especially coupled with the growth of complementary technologies in other sectors, is completely unprecedented. This poses a challenge for feasibility research that would need to combine the 'inside view' analysis with lessons carefully transferred from other technologies and contexts.

References

Abdulla, Ahmed, Ryan Hanna, Kristen R Schell, Oytun Babacan, and David G Victor. 2021. "Explaining Successful and Failed Investments in U.S. Carbon Capture and Storage Using Empirical and Expert Assessments." *Environmental Research Letters* 16, no. 1: 014036. https://doi.org/10.1088/1748-9326/abd19e.

Abnett, Kate. 2023. "EU Parliament Delays Renewable Energy Vote after Late Backlash | Reuters." May 22, 2023. https://www.reuters.com/world/europe/eu-parliament-delays-renewable-energy-vote-after-late-backlash-2023-05-22/.

Baumgartner, Frank R., and Bryan D. Jones. 2002. *Policy Dynamics*. Chicago: University of Chicago Press.

Bavarian Ministry of Economic Affairs, Energy and Technology. 2022. "Hearing of the Federal States and Associations on the Draft of the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Federal Ministry for Housing, Urban Development and Building (BMWSB) for a Formulation and Advice on the Onshore Wind Energy Act [Anhörung Der Länder u. Verbände Zum Entwurf Des BMWK Und BMWSB Für Eine Formulierungshilfe Für Ein Wind-an-Land-Gesetz]." 2022. https://www.bmwk.de/Redaktion/DE/Downloads/Stellungnahmen/Stellungnahmen-wind-an-land/bayern.pdf?__blob=publicationFile&;v=1.

Bijker, Wiebe E. 1997. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. The MIT Press.

Breetz, Hanna, Matto Mildenberger, and Leah Stokes. 2018. "The Political Logics of Clean Energy Transitions." *Business and Politics* 20, no. 4: 492–522. https://doi.org/10.1017/bap.2018.14.

Brutschin, Elina, and Marina Andrijevic. 2022. "Why Ambitious and Just Climate Mitigation Needs Political Science." *Politics and Governance* 10, no. 3: 167–70. https://doi.org/10.17645/pag.v10i3.6156.

Brutschin, Elina, Aleh Cherp, and Jessica Jewell. 2021. "Failing the Formative Phase: The Global Diffusion of Nuclear Power Is Limited by National Markets." *Energy Research & Social Science* 80: 102221. https://doi.org/10.1016/j.erss.2021.102221.

Brutschin, Elina, Felix Schenuit, Bas van Ruijven, and Keywan Riahi. 2022. "Exploring Enablers for an Ambitious Coal Phaseout." *Politics and Governance* 10, no. 3: 200–212. https://doi.org/10.17645/pag.v10i3.5535.

Buzan, Barry. 1983. *People, States, and Fear. The National Security Problem in International Relations*. Great Britain: WHEATSHEAF BOOKS LTD.

Buzan, Barry, and Ole Wæver. 2003. *Regions and Powers: The Structure of International Security*. Cambridge University Press.

Buzan, Barry, Ole Wæver, and Jaap de Wilde. 1998. *Security: A New Framework for Analysis*. Lynne Rienner Publishers, Inc.

Ćetković, Stefan, and Aron Buzogány. 2020. "Between Markets, Politics and Path-Dependence: Explaining the Growth of Solar and Wind Power in Six Central and Eastern European Countries." *Energy Policy* 139: 111325. https://doi.org/10.1016/j.enpol.2020.111325.

Cherp, Aleh, and Jewell Jewell. 2014. "The Concept of Energy Security: Beyond the Four As." *Energy Policy* 75, no. c (January): 415–21. https://doi.org/10.1016/j.enpol.2014.09.005.

Cherp, Aleh, Vadim Vinichenko, Jessica Jewell, Elina Brutschin, and Benjamin K Sovacool. 2018. "Integrating Techno-Economic, Socio-Technical and Political Perspectives on National Energy Transitions: A Meta-Theoretical Framework." *Energy Research & Social Science* 37: 175–90. https://doi.org/10.1016/j.erss.2017.09.015.

Cherp, Aleh, Vadim Vinichenko, Jessica Jewell, Masahiro Suzuki, and Miklos Antal. 2017. "Comparing Electricity Transitions: A Historical Analysis of Nuclear, Wind and Solar Power in Germany and Japan." *Energy Policy* 101, no. January (January): 612–28. https://doi.org/10.1016/j.enpol.2016.10.044.

Cherp, Aleh, Vadim Vinichenko, Jale Tosun, Joel A. Gordon, and Jessica Jewell. 2021. "National Growth Dynamics of Wind and Solar Power Compared to the Growth Required for Global Climate Targets." *Nature Energy* 6, no. 7: 742–54. https://doi.org/10.1038/s41560-021-00863-0.

Cointe, Béatrice, and Hélène Guillemot. 2023. "A History of the 1.5°C Target." *Wiley Interdisciplinary Reviews: Climate Change*. https://doi.org/10.1002/wcc.824.

Delina, Laurence L., and Mark Diesendorf. 2013. "Is Wartime Mobilisation a Suitable Policy Model for Rapid National Climate Mitigation?" *Energy Policy* 58: 371–80. https://doi.org/10.1016/j.enpol.2013.03.036.

———. 2018. "Critiquing the Use of War to Mobilise Peaceful Climate Action: A Response to Kester & Sovacool." *Energy Policy* 112: 1–3. https://doi.org/10.1016/j.enpol.2017.09.046.

Donald, James, Jonn Axsen, Karena Shaw, and Bryson Robertson. 2022. "Sun, Wind or Water? Public Support for Large-Scale Renewable Energy Development in Canada." *Journal of Environmental Policy & Planning* 24, no. 2: 175–93. https://doi.org/10.1080/1523908x.2021.2000375.

EC. 1996. "Communication from the Commission ENERGY FOR THE FUTURE: RENEWABLE SOURCES OF ENERGY Green Paper for a Community Strategy. COM/96/576 Final." https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=celex%3A51996DC0576.

———. 1997. "Communication from the Commission ENERGY FOR THE FUTURE: RENEWABLE SOURCES OF ENERGY White Paper for a Community Strategy and Action Plan. COM(97)599 Final of 26.11.1997." https://europa.eu/documents/comm/white_papers/pdf/com97_599_en.pdf.

———. 2001. "Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32001L0077.

———. 2008a. "Communication from the Commission to the European Council - A European Economic Recovery Plan. COM/2008/800 Final of 26.11.2008." https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52008DC0800.

———. 2008b. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 20 20 by 2020 - Europe's Climate Change Opportunity. COM (2008) 30 Final of 23.1.2008." 2008. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52008DC0030.

———. 2009a. "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA Relevance)." https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0028.

———. 2009b. "Regulation (EC) No 663/2009 of the European Parliament and of the Council of 13 July 2009 Establishing a Programme to Aid Economic Recovery by Granting Community Financial Assistance to Projects in the Field of Energy." https://eur-lex.europa.eu/eli/reg/2009/663/oj.

———. 2010a. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Analysis of Options to Move beyond 20% Greenhouse Gas Emission Reductions and Assessing the Risk of Carbon Leakage. COM(2010) 265 Final of 26.05.2010." https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0265.

———. 2010b. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Energy 2020 A Strategy for Competitive, Sustainable and Secure Energy. COM(2010) 639 Final of 10.11.2010." https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:En:PDF.

———. 2011. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A Roadmap for Moving to a Competitive Low Carbon Economy in 2050. COM(2011) 112 Final of 08.03.2011." https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:en:PDF.

———. 2012. "Commission Staff Working Document Analysis of Options to Move beyond 20% GHG Emission Reductions: Member States Results. SWD(2012)5 Final of 01.02.2012." https://climate.ec.europa.eu/system/files/2016-11/swd_2012_5_en.pdf.

———. 2014. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A Policy Framework for Climate and Energy in the Period from 2020 to 2030. COM(2014) 15 Final of 22.01.2014." https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2014:0015:FIN:EN:PDF.

———. 2018a. "Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy. COM(2018) 773 Final of 28.11.2018." https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773.

———. 2018b. "Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources (Recast) (Text with EEA Relevance.) PE/48/2018/REV/1." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001.

———. 2019. "Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions The European Green Deal. COM/2019/640 Final of 11.12.2019." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN.

———. 2020a. "Commission Staff Working Document IMPACT ASSESSMENT Accompanying the Document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Stepping up Europe's 2030 Climate Ambition Investing in a Climate-Neutral Future for the Benefit of Our People. SWD/2020/176 Final of 17.9.2020." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0176.

———. 2020b. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions An EU Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future. COM/2020/741 Final of 19.11.2020." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A741%3AFIN.

———. 2020c. “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Stepping up Europe’s 2030 Climate Ambition Investing in a Climate-Neutral Future for the Benefit of Our People. COM/2020/562 Final of 17.09.2020.” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0562.

———. 2021a. “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions ‘Fit for 55’: Delivering the EU’s 2030 Climate Target on the Way to Climate Neutrality. COM/2021/550 Final of 14.7.2021.” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550.

———. 2021b. “Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL Amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as Regards the Promotion of Energy from Renewable Sources, and Repealing Council Directive (EU) 2015/652. COM/2021/557 Final of 14.07.2021.” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0557.

———. 2022a. “Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU: Joint European Action for More Affordable, Secure and Sustainable Energy. COM(2022) 108 Final of 8.3.2022.” https://eur-lex.europa.eu/resource.html?uri=cellar:71767319-9f0a-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&;format=PDF.

———. 2022b. “Key Documents: REPowerEU.” 2022. https://commission.europa.eu/publications/key-documents-repowereu_en.

———. 2022c. “REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL 2022 Report on the Achievement of the 2020 Renewable Energy Targets. COM/2022/639 Final of 15.11.2022.” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0639&;qid=1669912949409.

———. 2022d. “REPowerEU: Joint European Action for More Affordable, Secure and Sustainable Energy.” Press release. March 8, 2022. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511.

———. 2022e. “Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU Plan. COM(2022) 230 Final of 18.05.2022.” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN.

———. 2022f. “Proposal for a Directive of the European Parliament and of the Council Amending Directive (EU) 2018/2001 on the Promotion of the Use of Energy from Renewable Sources, Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency, COM/2022/222 Final of 18.5.2022.” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A222%3AFIN.

———. 2023. “European Green Deal: EU Agrees Stronger Legislation to Accelerate the Rollout of Renewable Energy.” March 30, 2023. https://ec.europa.eu/commission/presscorner/detail/en/IP_23_2061.

EC Directorate-General for Energy. 2023. “Member States Agree New Ambition for Expanding Offshore Renewable Energy.” New Announcement. 2023. https://energy.ec.europa.eu/news/member-states-agree-new-ambition-expanding-offshore-renewable-energy-2023-01-19_en.

EC Directorate-General for Energy, Jurga Tallat-Kelpšaitė, Robert Brückmann, Jörn Banasiak, Boris Valach, Vlad Surdea-Hernea, John Szabó, et al. 2023. *Technical Support for RES Policy Development and Implementation - Simplification of Permission and Administrative Procedures for RES Installations (RES Simplify): Final Report*. Luxembourg: Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/949ddae8-0674-11ee-b12e-01aa75ed71a1/language-en/format-PDF/source-search.

EIA. 2022. "Europe Relies Primarily on Imports to Meet Its Natural Gas Needs." 2022. https://www.eia.gov/todayinenergy/detail.php?id=51258.

Ember. 2023. "Ready, Set, Go: Europe's Race for Wind and Solar." 2023. https://ember-climate.org/insights/research/europes-race-for-wind-and-solar/.

EU. 2015. *EU Climate Policy Explained*. Edited by Jos Delbeke and Peter Vis. Routledge.

European Central Bank. 2022. "A New Age of Energy Inflation: Climateflation, Fossilflation and Greenflation." 2022. https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220317_2~dbb3582f0a.en.html.

European Parliament. 2023. "Draft Agenda 11-14 September 2023." July 18, 2023. https://www.europarl.europa.eu/doceo/document/OJ-9-2023-09-11_EN.pdf.

Fouquet, Roger, and Peter J.G. Pearson. 2012. "Past and Prospective Energy Transitions: Insights from History." *Energy Policy* 50, no. January (January): 1–7. https://doi.org/10.1016/j.enpol.2012.08.014.

Freeman, Christopher, and Francisco Louçã. 2001. *As Time Goes by. From the Industrial Revolution to the Information Revolution.* Oxford: Oxford University Press.

Grubler, Arnulf, and Charlie Wilson. 2013. *Energy Technology Innovation: Learning from Historical Successes and Failures*. Cambridge Core. Cambridge: Cambridge University Press. https://doi.org/10.1017/cbo9781139150880.

Grubler, Arnulf, Charlie Wilson, and Gregory Nemet. 2016. "Apples, Oranges, and Consistent Comparisons of the Temporal Dynamics of Energy Transitions." *Energy Research & Social Science* 22, no. January (January): 18–25. https://doi.org/10.1016/j.erss.2016.08.015.

Hake, Jürgen-Friedrich, Wolfgang Fischer, Sandra Venghaus, and Christoph Weckenbrock. 2015. "The German Energiewende – History and Status Quo." *Energy* 92: 532–46. https://doi.org/10.1016/j.energy.2015.04.027.

Hall, Peter A. 1993. "Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in Britain." *Comparative Politics* 25, no. 3: 275. https://doi.org/10.2307/422246.

Hanna, Ryan, Ahmed Abdulla, Yangyang Xu, and David G. Victor. 2021. "Emergency Deployment of Direct Air Capture as a Response to the Climate Crisis." *Nature Communications* 12, no. 1: 368. https://doi.org/10.1038/s41467-020-20437-0.

Heinrich, Andreas, and Kacper Szulecki. 2017. "Energy Security in Europe, Divergent Perceptions and Policy Challenges," 33–59. https://doi.org/10.1007/978-3-319-64964-1_2.

Helm, Dieter. 2002. "Energy Policy: Security of Supply, Sustainability and Competition." *Energy Policy* 30, no. 3 (February): 173–84. https://doi.org/10.1016/s0301-4215(01)00141-0.

Hughes, Thomas P. 1986. "The Seamless Web: Technology, Science, Etcetera, Etcetera." *Social Studies of Science* 16, no. 2: 281–92. https://doi.org/10.1177/0306312786016002004.

IEA. 2021. "Net Zero by 2050 - A Roadmap for the Global Energy Sector." https://iea.blob.core.windows.net/assets/beceb956-0dcf-4d73-89fe-1310e3046d68/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.

———. 2022a. "A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas." 2022. https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas.

———. 2022b. "Renewables 2022." Paris. https://www.iea.org/reports/renewables-2022.

Ikenberry, G John. 1986. "The Irony of State Strength: Comparative Responses to the Oil Shocks in the 1970s." *International Organization* 40, no. 1 (January): 105 137. https://doi.org/10.1017/s0020818300004495.

Inchauste, Gabriela, and David G Victor. 2017. *The Political Economy of Energy Subsidy Reform*. World Bank. https://doi.org/10.1596/978-1-4648-1007-7.

IPCC. 2022a. "Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (Eds.)]." https://doi.org/10.1017/9781009157926.

———. 2022b. "Summary for Policymakers." In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, et al. Cambridge, UK and New York, NY USA: Cambridge University Press.

IRENA. 2022. "Renewable Power Generation Costs in 2021." 2022. https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.

Jacobsson, Staffan, and Volkmar Lauber. 2006. "The Politics and Policy of Energy System Transformation—Explaining the German Diffusion of Renewable Energy Technology." *Energy Policy* 34, no. 3 (January): 256--276. https://doi.org/10.1016/j.enpol.2004.08.029.

Jakhmola, Avi, Jessica Jewell, Vadim Vinichenko, and Aleh Cherp. 2023. "Projecting Feasible Medium-Term Growth of Wind and Solar Power Using National Trajectories and Hindcasting." https://doi.org/10.2139/ssrn.4501704.

Jewell, Jessica, and Elina Brutschin. 2019. "The Politics of Energy Security." In *The Oxford Handbook of Energy Politics*, edited by Kathleen Hancock and Juliann Allison, 247–74. https://doi.org/10.1093/oxfordhb/9780190861360.013.10.

Jewell, Jessica, and Aleh Cherp. 2023. "The Feasibility of Climate Action: Bridging the inside and the Outside View through Feasibility Spaces." *WIREs Climate Change*. https://doi.org/10.1002/wcc.838.

Jewell, Jessica, Vadim Vinichenko, David McCollum, Nico Bauer, Keywan Riahi, Tino Aboumahboub, Oliver Fricko, et al. 2016. "Comparison and Interactions between the Long-Term Pursuit of Energy Independence and Climate Policies." *Nature Energy* 1, no. 6 (January): 1–9. https://doi.org/10.1038/nenergy.2016.73.

Jewell, Jessica, Vadim Vinichenko, Lola Nacke, and Aleh Cherp. 2019. "Prospects for Powering Past Coal." *Nature Climate Change* 9, no. 8 (January): 592–97. https://doi.org/10.1038/s41558-019-0509-6.

Kern, Florian, C Kuzemko, and C Mitchell. 2014. "Measuring and Explaining Policy Paradigm Change:: The Case of UK Energy Policy." *Policy & Politics* 42, no. 4. https://doi.org/10.1332/030557312x655765.

Kern, Florian, and Karoline S. Rogge. 2016. "The Pace of Governed Energy Transitions: Agency, International Dynamics and the Global Paris Agreement Accelerating Decarbonisation Processes?" *Energy Research & Social Science* 22: 13–17. https://doi.org/10.1016/j.erss.2016.08.016.

Kester, Johannes, and Benjamin K. Sovacool. 2017. "Torn between War and Peace: Critiquing the Use of War to Mobilize Peaceful Climate Action." *Energy Policy* 104: 50–55. https://doi.org/10.1016/j.enpol.2017.01.026.

Kingdon, John W. 2014. *Agendas, Alternatives and Public Policies*. Second. Pearson Education Limited.

Knill, Christoph, and Jale Tosun. 2012. *Public Policy: A New Introduction*. New York: Palgrave Macmillan.

Kontogianni, A., Ch. Tourkolias, M. Skourtos, and D. Damigos. 2014. "Planning Globally, Protesting Locally: Patterns in Community Perceptions towards the Installation of Wind Farms." *Renewable Energy* 66: 170–77. https://doi.org/10.1016/j.renene.2013.11.074.

Kurrer, Christian, and Nicoleta Lipcaneanu. 2023. "Environment Policy: General Principles and Basic Framework. Fact Sheets on the European Union. European Parliament." 2023. https://www.europarl.europa.eu/factsheets/en/sheet/71/environment-policy-general-principles-and-basic-framework#:~:text=EU%20environment%20policy%20dates%20back,called%20for%20an%20action%20programme.

Kuzemko, Caroline. 2013. "Ideas, Power and Change: Explaining EU–Russia Energy Relations." *Journal of European Public Policy* 21, no. 1 (June): 58 75. https://doi.org/10.1080/13501763.2013.835062.

Lægreid, Ole Martin, Aleh Cherp, and Jessica Jewell. 2023. "Coal Phase-out Pledges Follow Peak Coal: Evidence from 60 Years of Growth and Decline in Coal Power Capacity Worldwide." *Oxford Open Energy* 2. https://doi.org/10.1093/ooenergy/oiad009.

Leipprand, Anna, Christian Flachsland, and Michael Pahle. 2020. "Starting Low, Reaching High? Sequencing in EU Climate and Energy Policies." *Environmental Innovation and Societal Transitions* 37: 140–55. https://doi.org/10.1016/j.eist.2020.08.006.

Markard, Jochen. 2018. "The next Phase of the Energy Transition and Its Implications for Research and Policy." *Nature Energy* 3, no. 8 (January): 628–33. https://doi.org/10.1038/s41560-018-0171-7.

McKinsey. 2023. "Land: A Crucial Resource for Europe's Energy Transition." 2023. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/land-a-crucial-resource-for-the-energy-transition.

Meckling, Jonas, Nina Kelsey, Eric Biber, and John Zysman. 2015. "Winning Coalitions for Climate Policy." *Science* 349, no. 6253: 1170–71. https://doi.org/10.1126/science.aab1336.

Meckling, Jonas, Thomas Sterner, and Gernot Wagner. 2017. "Policy Sequencing toward Decarbonization." *Nature Energy* 2, no. 12: 918–22. https://doi.org/10.1038/s41560-017-0025-8.

Mercom India. 2023. "India Missed 2022 Renewables Target as Rooftop Solar and Wind Fell Short." 2023. https://www.mercomindia.com/india-missed-2022-renewables-target.

NewClimate Institute. 2023. "Climate Policy Database." 2023. https://climatepolicydatabase.org/policies.

Odenweller, Adrian, Falko Ueckerdt, Gregory F. Nemet, Miha Jensterle, and Gunnar Luderer. 2022. "Probabilistic Feasibility Space of Scaling up Green Hydrogen Supply." *Nature Energy*, 1–12. https://doi.org/10.1038/s41560-022-01097-4.

Pahle, Michael, Dallas Burtraw, Christian Flachsland, Nina Kelsey, Eric Biber, Jonas Meckling, Ottmar Edenhofer, and John Zysman. 2018. "Sequencing to Ratchet up Climate Policy Stringency." *Nature Climate Change* 8, no. 10 (January): 861–67. https://doi.org/10.1038/s41558-018-0287-6.

Pavlenko, Anastasia. 2022. "Energy Transitions in the European Union in Times of Crisis. Master of Science Thesis, Central European University, Vienna, Austria."

Pierson, Paul. 2000. "Increasing Returns, Path Dependence, and the Study of Politics." *The American Political Science Review* 94, no. 2: 251–67. https://doi.org/10.2307/2586011.

Pirani, Simon, Jonathan Stern, and Katja Yafimava. 2009. "The Russo-Ukrainian Gas Dispute of January 2009: A Comprehensive Assessment." https://www.oxfordenergy.org/publications/the-russo-ukrainian-gas-dispute-of-january-2009-a-comprehensive-assessment/.

"Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 Establishing the Framework for Achieving Climate Neutrality and Amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')." 2021. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119.

Reiner, David M. 2016. "Learning through a Portfolio of Carbon Capture and Storage Demonstration Projects." *Nature Energy* 1, no. 1: 15011. https://doi.org/10.1038/nenergy.2015.11.

Reuters. 2009. "TIMELINE: Gas Crises between Russia and Ukraine." 2009. https://www.reuters.com/article/us-russia-ukraine-gas-timeline-sb-idUSTRE50A1A720090111.

Rogelj, Joeri, Oliver Geden, Annette Cowie, and Andy Reisinger. 2021. "Net-Zero Emissions Targets Are Vague: Three Ways to Fix." *Nature* 591, no. 7850: 365–68. https://doi.org/10.1038/d41586-021-00662-3.

Sabatier, Paul A., and Christopher M. Weible. 2007. "Theories of the Policy Process," 189–220. https://doi.org/10.4324/9780367274689-7.

Schumacher, K., F. Krones, R. McKenna, and F. Schultmann. 2019. "Public Acceptance of Renewable Energies and Energy Autonomy: A Comparative Study in the French, German and Swiss Upper Rhine Region." *Energy Policy* 126: 315–32. https://doi.org/10.1016/j.enpol.2018.11.032.

Smil, Vaclav. 2010. *Energy Transitions : History, Requirements, Prospects*. Santa Barbara: Praeger.

SolarPower Europe. 2023. "It's Not Curtailment. It's Waste. A Joint Letter to the European Commission and the Respective Governments of the 19 European Solar and Renewables Associations.," August 1, 2023. https://www.solarpowereurope.org/advocacy/policy-letters/it-s-not-curtailment-it-s-waste.

Sovacool, Benjamin K. 2016. "How Long Will It Take? Conceptualizing the Temporal Dynamics of Energy Transitions." *Energy Research and Social Science* 13, no. January (January): 202–15. https://doi.org/10.1016/j.erss.2015.12.020.

Sovacool, Benjamin K., and Frank W. Geels. 2016. "Further Reflections on the Temporality of Energy Transitions: A Response to Critics." *Energy Research and Social Science* 22, no. January (January): 232–37. https://doi.org/10.1016/j.erss.2016.08.013.

Stern, Jonathan. 2006. "The Russian-Ukrainian Gas Crisis of January 2006." https://www.oxfordenergy.org/publications/the-russian-ukrainian-gas-crisis-of-january-2006/.

Stokes, Leah C. 2016. "Electoral Backlash against Climate Policy: A Natural Experiment on Retrospective Voting and Local Resistance to Public Policy." *American Journal of Political Science* 60, no. 4: 958–74. https://doi.org/10.1111/ajps.12220.

Suzuki, Masahiro, Jessica Jewell, and Aleh Cherp. 2023. "Are Energy Transitions under Climate Policies Different? Comparing Electricity Transitions in the G7 and the EU in 1960-2022 with Climate Target Requirements." *In Review in Energy Research and Social Science*.

SVT. 2022. "Kommuner Stoppar 78 Procent Av Alla Vindkraftverk (Municipalities Stop 78% of All Wind Power Plants)." SVT Nyheter. 2022. https://www.svt.se/nyheter/inrikes/kommuner-stoppar-78-procent-av-alla-vindkraftverk.

Szulecki, Kacper. 2020. "Securitization and State Encroachment on the Energy Sector: Politics of Exception in Poland's Energy Governance." *Energy Policy* 136: 111066. https://doi.org/10.1016/j.enpol.2019.111066.

The Council of the European Communities. 1986. "Council Resolution of 16 September 1986 Concerning New Community Energy Policy Objectives for 1995 and Convergence of the Policies of the Member States (86/C 241/01)." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31986Y0925%2801%29.

The Council of the European Union. 2009. "The Presidency Conclusions (11 and 12 December 2008). 17271/1/08 REV 1." https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/104692.pdf.

UN. 1992. "The United Nations Framework Convention on Climate Change." 1992. https://unfccc.int/resource/docs/convkp/conveng.pdf.

UNFCCC. 1997. "Kyoto Protocol to the United Nations Framework Convention on Climate Change. Final Draft by the Chairman of the Committee of the Whole." 2303 U.N.T.S. 162. https://unfccc.int/documents/4220.

———. 2015. "The Paris Agreement." 2015. https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf.

Vinichenko, Vadim. 2018. "Mechanisms of Energy Transitions: National Cases and the Worldwide Uptake of Wind and Solar Power. Doctoral Dissertation. Central European University, Budapest, Hungary."

Vinichenko, Vadim, Aleh Cherp, and Jessica Jewell. 2021. "Historical Precedents and Feasibility of Rapid Coal and Gas Decline Required for the 1.5°C Target." *One Earth* 4, no. 10: 1477–90. https://doi.org/10.1016/j.oneear.2021.09.012.

Vinichenko, Vadim, Jessica Jewell, Johan Jacobsson, and Aleh Cherp. 2023. "Historical Diffusion of Nuclear, Wind and Solar Power in Different National Contexts: Implications for Climate Mitigation Pathways." *Environmental Research Letters* Accepted.

Vinichenko, Vadim, Marta Vetier, Jessica Jewell, Lola Nacke, and Aleh Cherp. 2023. "Phasing out Coal for 2 °C Target Requires Worldwide Replication of Most Ambitious National Plans despite Security and Fairness Concerns." *Environmental Research Letters* 18, no. 1: 014031. https://doi.org/10.1088/1748-9326/acadf6.

Wang, Nan, Keigo Akimoto, and Gregory F. Nemet. 2021. "What Went Wrong? Learning from Three Decades of Carbon Capture, Utilization and Sequestration (CCUS) Pilot and Demonstration Projects." *Energy Policy* 158: 112546. https://doi.org/10.1016/j.enpol.2021.112546.

Widmaier, Wesley W., Mark Blyth, and Leonard Seabrooke. 2007. "Exogenous Shocks or Endogenous Constructions? The Meanings of Wars and Crises." *International Studies Quarterly* 51, no. 4: 747–59. https://doi.org/10.1111/j.1468-2478.2007.00474.x.