From ambitions to reality: The renewable electrification of the EU in a changing energy landscape.

An analysis of wind and solar power growth rates and the feasibility of reaching national and EU level targets

Bachelor's thesis within Global Systems Engineering

EDVIN DANNÄS
ELINOR FUNK
DANIEL LARSSON
EMMA ROOS
JOHAN SÖDERBERGH
LISA VIND

DEPARTMENT OF SPACE, EARTH AND ENVIRONMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

Supervisor: Vadim Vinichenko, Department of Space, Earth and Environment
Supervisor: Avi Jakhmola, Department of Space, Earth and Environment
Examiner: Jessica Jewell, Department of Space, Earth and Environment

Bachelor's thesis 2023
SEEX16-23-09
Department of Space, Earth and Environment
Chalmers University of Technology
SE - 412 96 Gothenburg, Sweden

Cover photo: Wind turbines and solar panels visualization, constructed by image generative tool DALL:E.

Typeset in LaTeX
Gothenburg, Sweden 2023-05-10.

Abstract

In 2022 the EU introduced the strategic renewable energy plan for 2030, REPowerEU, with the purpose of reducing dependency of Russian fossil fuels, following the European energy crisis caused by the war in Ukraine. In 2019 all EU Member States established and submitted National energy and climate plans (NECPs) to the European Commission, and since the introduction of the REPowerEU plan some countries have suggested updated targets, which are interesting to study for potential changes in ambitions.

Here we analyze growth rates implied in targets for installed capacity of wind and solar power for 2030. By fitting growth models to historical capacity data for EU countries, maximum historical growth rates are extracted which are then used for assessing feasibility of national targets. Further, national targets are compared to contributions allocated by electricity system size from REPowerEU capacity targets. Finally, the REPowerEU targets are compared to aggregated national targets, for both wind and solar power.

We find that 2019 targets imply growth rates that are generally in line with historical maximum growth rates. However, the updated targets following the REPowerEU plan are in most cases significantly higher and require historically unprecedented growth rates. And comparing recent updated targets, following the introduction of the REPowerEU plan with 2019 NECPs, there is a significant increase in ambitions. We also find that there is a large span in planned contributions with some countries, like Denmark and Germany, having high ambitions for both wind and solar power but the majority of EU countries having planned contributions significantly below their allocated contributions by electricity system size. The combined planned national expansions of solar and wind capacity do not amount to the levels stated in REPowerEU, therefore in order to fulfill this plan, there is a need for increased ambitions in national targets for renewable electricity.

Keywords: solar PV, wind power, growth, renewables, electricity, national energy targets, NECP, REPowerEU

Acknowledgements

We would like to extend our sincere appreciation and gratitude to Vadim Vinichenko and Avi Jakhmola. With great commitment to their roles as supervisors, always with passionate engagement to our work on this thesis and constructive feedback on the progress, they made this bachelor thesis an inspiring and rewarding experience for the whole group.

Table of Contents

1 Introduction

According to IPCC (2021-2023) global warming is the heating of Earths atmosphere, ocean and land since the pre-industrial period (between 1850 and 1900) as a consequence of human influence. Energy production and usage is the main cause of GHG emissions in the world (Ritchie & Roser, 2020). The European Commission (n.d.-c) states that energy usage is the cause of 75% of all greenhouse gas emissions within the European Union (EU). Therefore, transforming the energy system is central in reaching climate targets and preventing further global warming. In order to mitigate global warming the EU has set forth a climate and energy framework which includes reducing greenhouse gas emissions, achieving a higher share of renewable energy, and improving energy efficiency (European Commission, n.d.-a). According to the European Environment Agency (2022) the electricity sector within the EU will have a critical role and contribute greatly in meeting the climate targets for 2030.

In June 2022 a new energy and climate plan *REPowerEU* was suggested, as a consequence of Russia's invasion of the Ukraine (European Commission, 2022d). The Russo-Ukrainian war has caused political tension between EU countries and Russia, which has disrupted the European energy market as it is dependent on Russian fossil fuels (IEA, n.d.). This has created further incentive for EU Member States to transform their energy systems (Proedrou, 2023). It is of interest to study if this is reflected in EU Member States national targets. Furthermore, to consider whether or not historical growth and national targets are in line with the REPowerEU plan.

1.1 Background

This section provides a description over the history of energy and climate targets in the EU. There is an emphasis on how the targets are governed using National Energy and Climate Plans (NECP) and the new REPowerEU plan. This is followed by a description of how models of technological adoption can be used to evaluate target feasibility.

1.1.1 A brief history of energy targets in the EU

The renewable electricity targets of wind and solar power that will be given attention to in this report are based on EU's current energy policies, which have been developed since the early 1990s (Skjærseth, 2021). There was no vision of a common energy policy before that, despite its importance of various interest groups (Maris & Flouros, 2021). When EU started to develop energy and climate targets they were handled separately from related areas and Member States had varied interests, which created problems in the policy making (Skjærseth, 2021). Over the years, the policy has developed into a more comprehensive energy and climate policy, and the level of ambition in terms of goal setting has also gradually developed. In 2007, EU set targets for 2020 to reduce GHG emissions by 20% (compared to 1990 levels), increase the share of renewable energy within the EU to 20% of total energy and improve energy efficiency by 20% (Skjærseth, 2021).

During the United Nations (UN) climate conference in Paris 2015, the EU contributed with an updated goal of 40 % reductions in GHG emissions by 2030 compared to 1990 (Skjærseth, 2021). The EU's 2030 targets build on the previous targets for 2020 (Oberthür, 2019). All three targets of 20% for 2020 were achieved (European Environment Agency, 2021), including the target of 20% renewable energy share in gross final energy consumption (IRENA, 2022a). IRENA (2022a) states that a contributing factor to this could be the decreased energy consumption during the COVID-19 pandemic. Regardless, the new goal for 2030 was adopted by all the 28 EU Member States at the time. The UN-led Paris Agreement prompt all countries to procedurally submit and maintain their respectively undertaken climate actions starting from 2020 in the form of Nationally Determined Contributions (NDCs) (Skjærseth, 2021). Updated NDCs shall be delivered by countries every five years to ensure and reinforce their efforts.

This five-year cycle is aligned with the five-year cycle for the submission of the EU countries National Energy and Climate Plan (NECP) (Oberthür, 2019). In the NECPs, EU Member States have to describe their contribution to EU's targets for global emission reduction. The NECPs cover the period 2021-2030 and concerns energy efficiency, renewable energy and greenhouse gas emissions as well as interconnections and research and innovation (European Commission, 2019b). A draft NECP was first submitted by each Member State in 2018. According to European Union (2018) each country should take several factors into account when setting their targets in the NECP, such as economic and geographical conditions, level of electricity interconnection between Member States and earlier targets and efforts. The draft was then reviewed by the European Commission and given recommendations based on EU's nationally determined contributions (European Commission, 2019b). The final NECP was to be submitted by 31 December 2019. Member States of EU are required to submit an updated plan by 30 June 2023 (European Commission, 2019a).

In 2019, the EU also presented a plan to raise the climate ambitions. The plan is called the European Green Deal (EGD) and strives to reach net zero GHG emissions by 2050 (European Commission, n.d.-b). A part of the EGD is *Fit for 55*, which is a proposal suggesting that climate and energy policies should fit the target of 55% reduction of GHG emissions by 2030. A schematic view of these event is presented in figure 1.

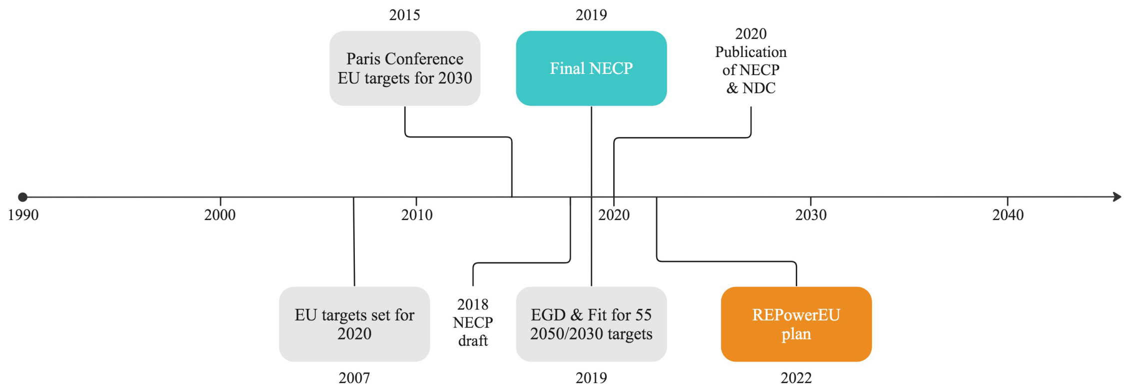


Figure 1: A schematic view of the selected events described in the section 1.1.1, A brief history of energy targets in the EU. Final NECP and REPowerEU are highlighted in blue and orange respectively, as they play a particularly important role in this report.

1.1.2 Updated energy plan: REPowerEU

Since the publication of the 2019 NECPs, the EU has suggested updated targets with the REPowerEU climate and energy plan (European Commission, 2022c). The plan covers energy savings, production of clean energy and diversification of energy supplies and aims to end the dependence on Russian fossil fuels before 2030. According to the European Union a large increase in renewable energy sources is needed within the EU for the new climate plan to be feasible. Furthermore, the European Commission states that they want to increase the ambitions for renewables by raising the share of renewable energy from 40% to 45% in the

EUs overall energy mix by 2030 (European Commission, n.d.-c). This concerns the electricity, transport and heating and cooling sectors. The European Commission estimates that in order to reach the share of 45% stated in European Commission (2022d) renewables should account for 69% of electricity production, as communicated in the complementing working document (European Commission, 2022b). The installed capacity of wind and solar needed to achieve this share is estimated to be a total of 592 GW solar photovoltaics (solar PV) and 510 GW wind power. Figure 2 shows the installed capacity of wind and solar power within the EU since the 2000s. Furthermore, it illustrates the linear growth needed to meet the estimated requirements in capacity of wind and solar power.

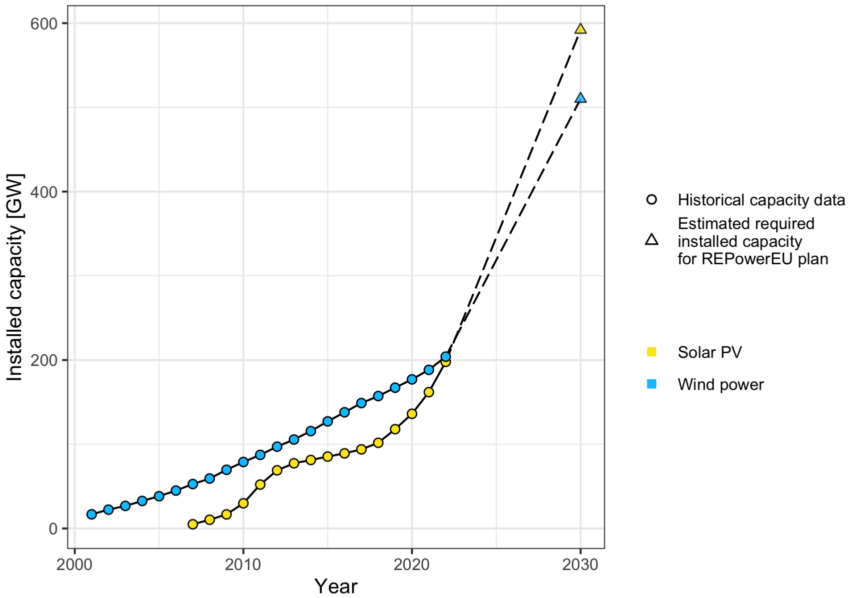


Figure 2: The historical development of solar PV and wind power (both onshore and offshore) in the EU is illustrated together with the linear growth required to meet estimated required installed capacity of the energy sources. Historical data is illustrated with a circle and the triangles mark the estimated required installed capacities to reach the 2030 REPowerEU plan, which is 510 GW for wind power and 592 GW for solar PV (European Commission, 2022b).

For the European Union to be able to reach the set climate targets, it faces an energy transition (European Commission, 2021) and the REPowerEU plan will require large, rapid deployment of renewable technologies (European Commission, 2022a). Among renewable energy sources, wind and solar power respectively are the number one and third largest generators in the EU (Eurostat, 2023). The importance of these two energy sources is stressed by the European Commission (European Commission, 2022a, 2022d), and as can be seen in figure 2, a massive increase in deployment of solar PV and wind power is required to meet the European Commission's estimates for the REPowerEU plan.

1.1.3 Measuring energy transition and target feasibility

Technological adoption in social systems has been found to follow the pattern of an "S-curve" (Rogers, 2003; Grübler, 1996). First there is a phase of slow growth, then the growth accelerates and finally it stagnates. The S-curve model has been applied to evaluate the development of wind and solar power in countries (see Gosens, Hedenus, and Sandén (2017); Bento and Fontes (2015)) and in Europe (see Madsen and Hansen (2019); Dalla Valle and Furlan (2011)). Cherp, Vinichenko, Tosun, Gordon, and Jewell (2021) has created a visualization tool [1] which fits "S-curve" models to generation data of wind and solar power for 67 countries. They used S-curve

[1]For reference link to POLET visualization tool: http://applets.polet.network/shiny/fitted_curves/

models to derive the maximum historical growth rate of wind and solar power to assess feasibility of IPCC's (The Intergovernmental Panel on Climate Change) climate mitigation scenarios based on historical precedence. This method can be used to give an indication of whether or not it is possible to reach climate targets or if historically unprecedented growth is required. While it is true that the future will inevitably differ from the past, historical data can still serve as a benchmark for assessing target feasibility (Jewell & Cherp, 2023).

1.2 Aim

The aim of this study is to assess whether the growth of wind and solar power in the EU countries required to reach the 2030 REPowerEU targets is in line with historical precedents and the current national targets. In order to achieve this, the following research questions will be answered:

1. What are the historical growth rates of wind and solar power in the EU Member States?
2. How does this growth compare to the growth rates required to reach the national targets set for 2030?
3. Have the Member States updated their national targets following the introduction of the REPowerEU proposal, and how do these updates compare to the national targets as of 2019?
4. Are national targets consistent with REPowerEU targets?

Additionally, this project aims to contribute to enhanced public understanding of renewable energy growth by updating the *Web application by the POLET research group.* (n.d.).

1.3 Scope

The scope of the project is categorized into two parts: technological and geographical scope. Concerning the technological scope, this thesis is restricted to solar and wind power. Potential alternative energy sources include geothermal energy, biomethane and fossil-free hydrogen which are all low-carbon sources and mentioned in the REPowerEU plan (European Commission, 2022d). For wind power, a distinction is made between onshore and offshore technology. Both of these are included, however, filtering criteria was applied to historical data for the task of combining or keeping the two types separated. Details of the criteria are presented in section 3, Method. Solar power includes two technologies, solar PV and thermal solar power. In this thesis only Solar PV is included in the analysis, and the terms solar PV and solar power are used interchangeably.

Geographically, this study focuses on EU Member States. Therefore, when studying historical and target data, EU Member States are used as target cases, whereas non-EU countries are used as reference cases. Using data for non-EU countries together with corresponding data for EU Member States gives more data upon which conclusions might be drawn. The reference case data will be part of the growth rate analysis and of the POLET visualization tool updates. In the analysis of growth rates, some countries may be non-representative due to small total electricity supply (TES) or too small share of a certain energy technology. Such data is excluded according to filtering criteria specified in section 2.3, Data analysis.

2 Prior research

The previous research connected to the study can be divided into five key parts starting with the potential of wind and solar power in terms of technological and geographical conditions. This is followed by an explanation of factors affecting deployment of renewables. Thereafter, potential effects of crisis on renewables and feasibility of reaching REPowerEU targets will be addressed. Finally, there will also be a part about previous research on growth models.

2.1 Potential of wind and solar power

Wind and solar power has a critical role in mitigation of climate change (IRENA, 2022b; Creutzig et al., 2017; Barthelmie & Pryor, 2021). The advantages that supports this are the relatively short time frame from initiation to completion of wind and solar power projects, and that they are two of the cheapest available sources (IRENA, 2022b). Solar energy alone is said to have the technical potential of at least 1500 EJ per year, which would markedly exceed the projected global energy demand in 2050 of 1000 EJ ($\approx$ 28000 TWh) per year (Creutzig et al., 2017). In this sense, technical potential is defined as "the achievable energy generation of a particular technology given system performance, topographic limitations, and environmental and land-use constraints". Nonetheless, there are studies claiming that the potential of solar and wind power is dependent on their site of installation in the world (see Prvlie, Patriche, and Bandoc (2019); Lu, McElroy, and Kiviluoma (2009)). These different conditions are not only depending on geographical differences as wind abundance and solar irradiation, but on spatial policies as well (Sahoo, Zuidema, van Stralen, Sijm, & Faaij, 2022). A study by Perpiña Castillo, Batista e Silva, and Lavalle (2016) investigated the suitability for solar power in the EU. One of the main findings from this article was that the potential for solar PV, based on a group of biophysical and socio-economic factors, is highest around the Mediterranean Sea and the lowest in Northern Europe. Regarding the geographical potential for wind energy in Europe, stronger winds are observed near the Atlantic Ocean and other coastal areas (Enevoldsen et al., 2019).

2.2 Factors affecting deployment of renewable energy

Scholars have examined factors effecting increase in capacity of renewables (see Aguirre and Ibikunle (2014); Kilinc-Ata (2016); Dong (2012); Bird et al. (2005)). Commonly used explanatory variables are GDP, total electricity net consumption, gas and coal prices, energy security and climate policies. Bird et al. (2005) reviewed wind power development in the United States, using climate policies as a variable. They state that climate policies have an impact on wind power growth but it is not the only affecting parameter. Kilinc-Ata (2016) studied the impact of renewable energy policies on renewable capacity growth in the EU and the US, with a focus on policy instruments. A result from this study was that energy policies stimulate growth in renewables, however the extent of influence varies depending on the type of policy instrument.

2.3 Effects of disruption on energy targets

Previous literature suggests that there are uncertainties in how climate action and the deployment of renewable energy is affected by crisis. Skjærseth (2021) state that events which disrupt stability can provide an opportunity for ambitious climate policies. However, they also find that disruption can lead to less ambitious ones.

One of the main reasons for the REPowerEU plan is concerns regarding energy security (European Commission, 2022c) and literature provides different views on how energy security affects commitment to renewable energy. Aguirre and Ibikunle (2014) found that energy policies tend to be more lenient when there is risk of not meeting energy demand. Additionally, Dong (2012) found that there is a positive correlation between net oil imports and the deployment of wind power. Kilinc-Ata (2016) on the other hand found that energy security, measured by imports and exports, was not pertinent for growth of renewable energy. This means that there is an uncertainty in this correlation.

Some scholars have also studied the implications of the Russo-Ukrainian war on the decarbonization of the energy sector. Proedrou (2023) conducted a case study on how the decarbonization of the EU has been affected by Russia's invasion of the Ukraine. They find that the geopolitical situation between the EU and Russia has accelerated and facilitated EU's renewable energy transition. Furthermore, the limited supply of gas in the EU has resulted in higher demand of clean energy, which creates a necessary incentive for the energy transition. Similarly, Trunina, Pryakhina, and Yakymets (2022) state that interests related to long term energy independence could lead to investments in renewable energy as a consequence of the war. However, in the short term, energy security will be the EU's main priority, even at the cost of returning to fossil fuels (see Borowski (2022)).

At the time of writing the REPowerEU plan is still only a suggestion, there are different interests among the EU Member States. According to Maris and Flouros (2021) and Skjærseth (2021) this results in a difference in ambition for developing renewable energy and meeting the energy targets. Skjærseth (2021) also state that because of their coal dependency, many Central and East European countries have historically opposed more ambitious energy and climate policies.

2.4 Feasibility of reaching REPowerEU targets

The International energy agency (IEA) researches the feasibility of reaching the REPowerEU targets in 2030 (IEA, 2022). The study includes the sectors electricity, heating and transport, differing from this report which solely focuses solely on wind and solar power. As a result from their research, it was stated that the increase of capacity in renewable electricity in EU is insufficient to reach REPowerEU's 2030 renewable electricity goals.

2.5 Adoption and growth in wind and solar deployment

As stated in the background, S-curved models have been used in literature to evaluate the development of wind and solar power (Madsen & Hansen, 2019; Gosens et al., 2017; Dalla Valle & Furlan, 2011; Bento & Fontes, 2015). Gosens et al. (2017) examine market adoption and growth of solar and wind power in various countries using S-curves, concluding that countries which have implemented the technologies later reach higher growth rates than early adopters. Explanatory variables used in the analysis are the gained knowledge from early adopters and additionally they conclude that GDP has a strong connection to growth. Grubler, Wilson, and Nemet (2016) also state that later adopting markets are associated with faster transition speeds, however, they achieve lower market penetration. Furthermore, they state that adoption time also depends on other factors and generally increase with complexity. On the contrary, Cherp et al. (2021) conclude that later introduction to wind and solar power does not lead to faster growth. However, they consider European Union as an early adopting market.

3 Method/Implementation

The key part of the method is measuring the speed of technology deployment using growth models and assessing feasibility of future targets by analysing historical data. The corresponding tasks are implemented in three parts: data collection, data analysis and web application update. These parts were carried out simultaneously.

3.1 Data collection

The main focus of the data collection part of this study was to find data of 2030 targets for wind and solar PV for the EU27 countries. The EU27 countries with corresponding country codes are found in Table1.

Code	Country	Code	Country
AT	Austria	IE	Ireland
BE	Belgium	IT	Italy
BG	Bulgaria	LT	Lithuania
CY	Cyprus	LU	Luxembourg
CZ	Czech Republic	LV	Latvia
DE	Germany	MT	Malta
DK	Denmark	NL	Netherlands
EE	Estonia	PL	Poland
ES	Spain	PT	Portugal
FI	Finland	RO	Romania
FR	France	SE	Sweden
GR	Greece	SI	Slovenia
HR	Croatia	SK	Slovakia
HU	Hungary		

Table 1: The EU27 countries with corresponding country code, in alphabetical order. Source: European Union (European Union, n.d.).

The national targets include electricity targets for solar PV and wind from the 2019 NECPs, as well as the updated electricity targets from 2022. These updated targets were collected only if they were reported after the introduction of the REPowerEU plan. Both electricity generation targets and electricity capacity targets were intended to be found. All targets collected are for 2030, except for France's which are for 2028. In countries where offshore wind in 2030 targets accounts for a significant amount, a distinction was made between offshore and onshore wind. This amount was considered to be 20% of the total wind generation. However, if the total generation for offshore was less than 20%, the targets for offshore and onshore were merged into the category onshore. The national targets could be already approved targets, policy proposals, political statements or laws. When a target was expressed as a range of values, the average value of the upper and lower bound was noted. Values for the projected TES of 2030 for each country was sought as well.

Occasionally only the electricity demand for a country was found, instead of the electricity supply. In those cases, the two were assumed to be equivalent. To enhance clarity of the different classes of data collected, they are visualized in Figure 3. After finishing the data collection, each data point was reviewed by other members in the group.

In addition, historical data on the capacity of solar PV and wind for the EU27 countries was collected from IRENA (IRENA, 2023a, 2023b) and IEA (IEA, 2023). For most countries, the

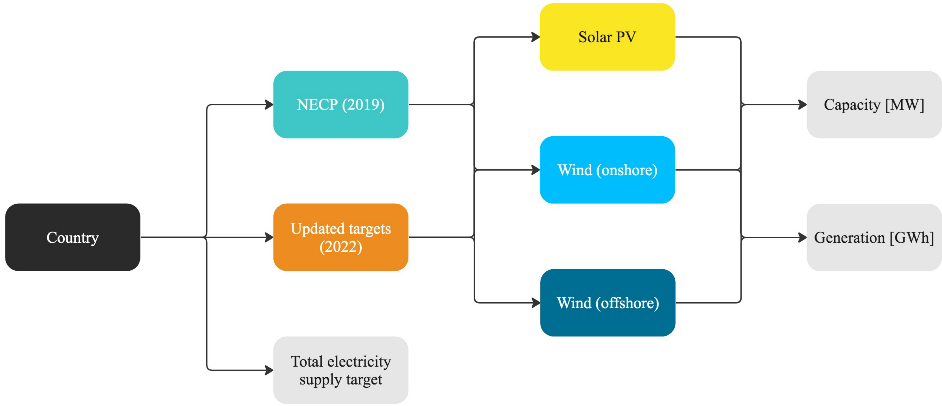


Figure 3: The figure visualizes the different classes of data sought in this project, where "Country" represents each of the EU27 countries. All the targets collected are for 2030, except the targets for France that are for 2028.

years of the data ranged from 1990s or early 2000s up to 2021.

In absence of either the capacity or generation target, a conversion was utilized to obtain one value from the other. To perform this conversion, a load factor (LF) was applied, calculated by the following formula:

$$LF = \frac{(ge \times 1000)}{(ac \times 24 \times 365)} \tag{1}$$

where ge is the generation of electricity [GWh] for a year and ac is the average of the capacities [MW] reported at the end of two consecutive years (e.g. for 2021 capacity an average of capacities reported in the end of 2020 and 2021 were used). For conversion the average load factor for the five most recent years with existing data was used. The values for ge and ac were collected from historical data series.

The most used sources for the collection of data were NECPs, IRENA and IEA. Additionally, some values were retrieved from governmental websites or documents, newspapers providing insights on renewable energy. In the cases of data being extracted from newspapers and other websites, the source was examined to assess its credibility. Occasionally values for the categories in Figure 3 could not be found in written format and had to be extracted from a plot. In these cases, the tool WebPlotDigitizer (Rohatgi & Ankit, 2022) was used. All sources utilized for the data collection together with their corresponding values can be accessed in Appendix A, Table8.

3.2 Data analysis

When analysing historical growth, data on installed capacity was used instead of yearly generated electricity. There are two reasons for this choice. Firstly, installed capacity is a more consistent measure of growth, since it is independent of fluctuations in load that is caused by external factors. Secondly, the targets in REPowerEU are expressed in installed capacity, making this a convenient choice.

Logistic and Gompertz growth models were fitted to historical capacity data using the LevenbergMarquardt algorithm, according to the method outlined by Cherp et al. (2021). The two models are defined by the following equations:

$$\text{Logistic (Log): } f(t) = \frac{L}{1 + e^{-k(t-t_0)}} \tag{2}$$

$$\text{Gompertz (Gmp): } f(t) = Le^{-e^{-k(t-t_0)}} \tag{3}$$

where L is the upper asymptote that the curve is approaching as t increases, k is the growth constant deciding the steepness of the curve and t_0 is the time at the inflection point, at which maximum growth rate is attained. f gives a quantitative measure of the diffusion of the technology that is being studied for a given time t. Both growth models are "S"-shaped curves, or sigmoid functions, characterised by an initially small growth rate which increases to its maximum value in the inflection point, to then decrease when the curve is approaching its asymptote in L. The property that distinguishes the two models is the location of the inflection point. The logistic function is symmetric around its inflection point, while the Gompertz model at this point is offset to 37% of the roof, L, allowing a prolonged growth after the inflection point. Our choice of using these models is in accordance with the article by Cherp et al. (2021).

Before fitting the models to the historical data it was filtered. The filtering criteria used are in accordance with Cherp et al. (2021) and specified as; an electricity supply over 30 TWh/year, where solar PV, onshore wind power or offshore wind power respectively has exceeded 0.1% of the total energy supply for at least six consecutive years and 1.0% for at least two. Henceforth, these criteria will be referred to as initial filtering.

Three characteristics of deployment were extracted from the fitted models: maximum growth rate (G), growth duration and level of maturity. G is obtained by differentiating equations (2) and (3) and setting $t = t_0$, which gives $Lk/4$ for the logistic model, and Lk/e for the Gompertz model. For further characteristics of G, see Cherp et al. (2021). Maturity refers to the ratio of the current value to the upper asymptote of the fitted curve, while growth duration (dT) refers to the timespan from 10% to 90% maturity. The data was then filtered according to the following criteria:

- If (maturity (Log) < 0.5) or (maturity (Gmp) < 0.16) $\Rightarrow$ accelerating growth, G is not reported. The historical growth rate of these countries is excluded from further analysis, except for tables 4 and 5, where the average growth rate of the three latest years is reported instead of G.

- If (maturity (Gmp) ≥ 0.16) and ($0.5 \leq$ maturity (Log) < 0.9) $\Rightarrow$ stable growth, G is reported.

- If (maturity (Log) ≥ 0.9) $\Rightarrow$ stagnating growth, G is reported.

- If dT < 2 years for solar or dT < 4 years for wind, the curve is classified as *Short dT* regardless of maturity parameters, and G is not reported. This since a very short growth period can not be assumed to be representative of long term growth.

Due to the G-values extracted from the two models being very consistent (Figure 4), these were averaged before further analysis.

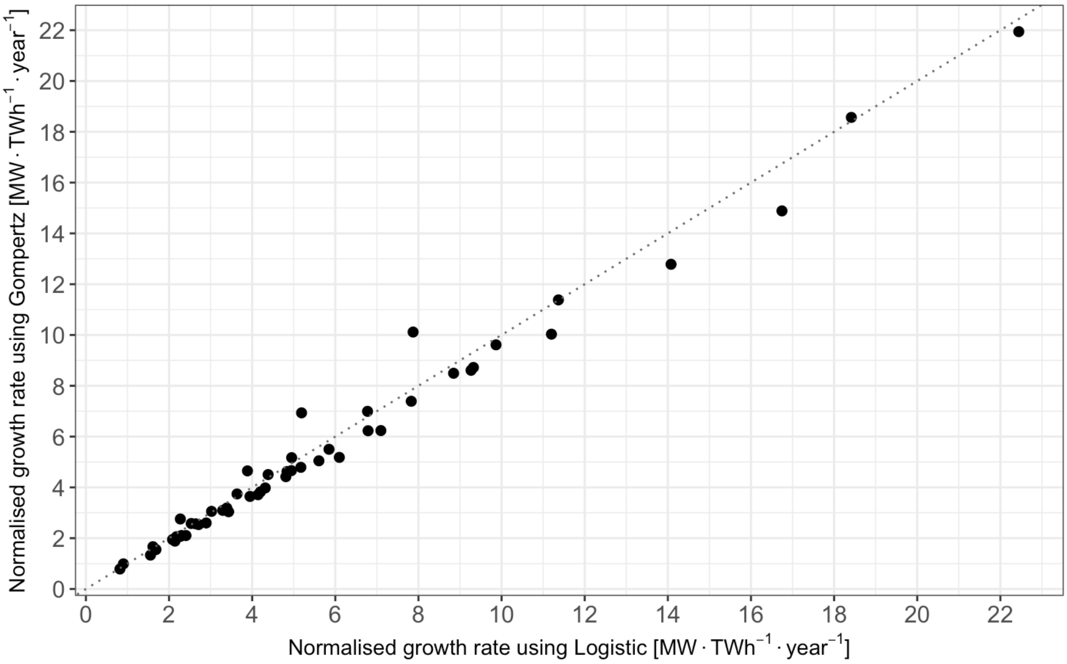


Figure 4: Normalized maximum growth rates of EU and non-EU countries using the Logistic and Gompertz growth models. The figure shows a high level of agreement between the two.

For comparability between countries, maximum growth rates were normalized by total electricity supply (at the inflection point), giving a maximum *relative* growth rate, *G.norm.*[2] Hereon, ”normalized growth rates” will refer only to normalized *maximum* historical growth rates if not specifically stated otherwise.

Historical maximum growth rates were then compared to implied growth rates to reach targets. The implied growth rates were calculated assuming linear growth from the installed capacity at the time at which a goal was set, and was used as an indicator of ambitions. So,

$$\text{implied growth rate} = \frac{(\text{capacity target}) - (\text{previously installed capacity})}{\Delta t} \tag{4}$$

where previously installed capacity is the installed capacity in the year that a target was set, and Δt is the time between the year a target was set and the year that a target refers to.

For the relative ambitions the implied growth rates were normalized by the total electricity supply at the time a target was set. The result of this is similar to when using an average of electricity supply at the time a goal was set and the estimated supply for 2030, as shown in Figure 20, Appendix A. This justifies the choice of using historical data on electricity supply for normalization and enables the inclusion of countries without existing estimations on future supply in the analysis. And the occurrence of small yearly changes in total electricity supply is not relevant here since the only purpose of the normalization is to relate the growth rates to

[2]More precisely this is the normalized maximum growth rate, which not necessarily is the same as maximum relative growth rate because of changes in electricity supply. However, the total consumption in Europe has been fairly stable during the last decades, only exhibiting an approximate 30% increase since year 1990, making this inaccuracy less significant (Enerdata, 2022).

the order of magnitude of a country's power system, to investigate any possible correlation, not the specific value.

For example, in the case of solar PV in Germany the 2030 target from the 2019 NECP is 97 924 MW (Table8 in Appendix A), and the installed solar PV capacity in 2019 was 48 912 MW. Assuming linear growth this implies required installments of an additional 4456 MW per year to reach the target. By dividing this value with the total electricity supply in 2019 (568.3 TWh), the normalized implied growth rate from the 2019 NECP target is calculated to be 7.84 MW/(TWh · year).

Historical growth rates and implied growth rates in energy targets were used for the following comparative analysis. 2019 NECPs were compared to recent target updates in order to identify changes in ambitions following the REPowerEU initiative. The targets were also analyzed with respect to factors such as total electricity supply and current installed capacity, in order to investigate possible correlations. Total electricity supply is used as a proxy for electricity system size and hereon, if not stated otherwise, system size refers to total electricity supply. National targets (both NECP and updates) were compared to historical data. Maximum historical growth rates were used as a feasibility measure, i.e. as an indicator of the shift in deployment speed needed to reach the set targets.

A main part of this analysis is to look at national contributions to EU-level targets, and possible patterns in contributions for the different electricity sources. National ambitions were compared to an ideal contribution calculated from the estimated installed capacity for wind and solar PV needed to reach REPowerEU target on renewable energy. These ideal contributions were allocated for every country based on electricity system size according to the following formula:

$$\text{Allocated contribution (country X)} = \text{EU target} \cdot \left[\frac{TES_X}{\sum\limits_{EU countries} TES_i} \right] \tag{5}$$

where total electricity supply is averaged for the last five years with available data, to adjust for random fluctuations. The EU targets allocated here are the projected installed capacities needed to reach the targets set by REPowerEU, 592 MW for solar PV and 510 MW for wind power (European Commission, 2022b). This is an allocation of total installed capacities and not the difference from current installed capacities. The unit of the allocated contribution is the same as the EU target, here MW. The choice of using total electricity supply as basis for allocation of contributions is further discussed in section 5.2.4.

For comparability between countries a contribution ratio was calculated as following:

$$\text{Contribution ratio} = \frac{\text{Planned contribution}}{\text{Allocated contribution}} \cdot 100 \quad [\%] \tag{6}$$

If a country has a contribution ratio of 100% for a specific technology it means that the ambitions are in line with what they could be expected to do, as per the chosen allocation formula. For example, the average total electricity supply for the last five years in Germany is 573.7 TWh, and the aggregated average supply for all EU countries is 2877.5 TWh, giving Germany a 20% share of the total electricity supply in the EU. The estimated required solar PV capacity to reach the REPowerEU target is 592 MW (IEA, 2022). 20% of this is 118 MW, which then is the allocated contribution for Germany. The planned contribution of Germany for solar PV as per the 2022 updated target is 215 MW (Table8 in Appendix A), giving the country a contribution ratio of 182%.

Finally, the combined planned contributions from Member States were compared to the REPowerEU target in order to evaluate if the national targets were enough, or otherwise what additional capacity would be needed in order to reach this target. For countries where recent updated targets could not be found the 2019 NECPs were used.

All data processing and analysis was made using *R* programming software, including packages *minpack.lm* for curve fitting, *ggpmisc* for statistical analysis and *Tidyverse* for data wrangling and creating descriptive plots of data. Linear regressions were made using function *stat_fit_glance* with method *lm*.

3.3 POLET application

The POLET application (see Figure 5) was updated with the most recent available data for generation, which is data from 2021 for most countries. To improve the visualisation tool, data over wind power was split into onshore and offshore wind in the application if the initial filtering criteria for offshore wind was met. Furthermore, a new feature and new data over installed capacity was added to the visualisation tool. This was done so that it is possible to select between capacity and generation data. Previously the application only had generation data. The functionality of the app was also improved. The web application was managed using the *Shiny R* package. Figure 5 shows an image of the POLET web application (*Web application by the POLET research group.*, n.d.) and for more information see (Cherp et al., 2021).

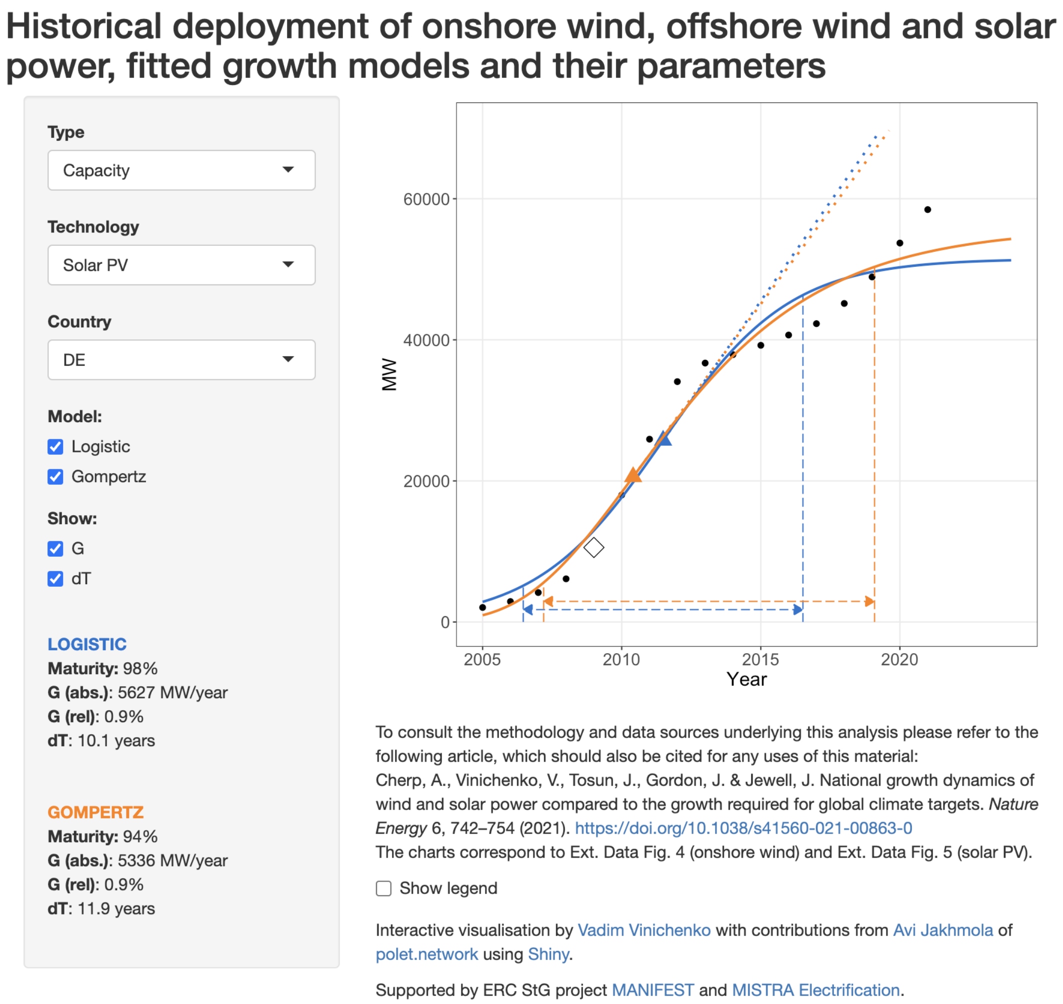


Figure 5: Image of the POLET web application (*Web application by the POLET research group.*, n.d.). For more information on the application see (Cherp et al., 2021)

4 Results and analysis

The results is presented in four parts: historical growth rates, national targets, national contributions to EU targets and finally the aggregated target analysis.

4.1 Historical growth rates

Table 2 and 3 shows the EU27 countries which passed the initial filtering criteria for solar PV and wind. The tables include historical growth rates and results from the dT and maturity filtering.

For solar PV, only five EU Member States qualified for historical growth analysis: Germany, France, Greece, Hungary, and Italy. Their historical growths can be seen in Table2. France is the only country of these five with stable growth, whereas the remaining have stagnating growth. Among the Member States that did not qualify for historical growth analysis, six countries have accelerating growth and three countries have stagnating growth, but none passed the filtering criteria for dT. The rest of the EU27 countries (13 countries) did not pass the initial filtering criteria.

Solar PV					
Code	**Country**	**Historical growth [MW/year]**	**Maturity**	**dT filter**	**Passed all filtering**
AT	Austria	-	Accelerating	N/A	No
BE	Belgium	-	Accelerating	N/A	No
BG	Bulgaria	-	Stagnating	Short dT	No
CZ	Czech Republic	-	Stagnating	Short dT	No
DE	Germany	5481.28	Stagnating	Passed	Yes
DK	Denmark	-	Accelerating	N/A	No
ES	Spain	-	Accelerating	N/A	No
FR	France	1265.77	Stable	Passed	Yes
GR	Greece	988.14	Stagnating	Passed	Yes
HU	Hungary	626.57	Stagnating	Passed	Yes
IT	Italy	7649.11	Stagnating	Passed	Yes
NL	Netherlands	-	Accelerating	N/A	No
PT	Portugal	-	Accelerating	N/A	No
RO	Romania	-	Stagnating	Short dT	No

Table 2: Historical growth and filtering results for the E27 countries which passed the initial filtering criteria for solar PV. In the column "Maturity", maturity of the growth is classified. In the column "dT filter" "Passed" indicates that the dT filtering criteria was met and "Short dT" means it was not met. Not applicable (N/A) displays that there is no dT, since the growth is accelerating. "Passed all filtering" indicates whether or not country passed both the Maturity and dT filter.

Regarding onshore wind, Table3 shows the 17 Member States that met the initial filtering criteria. Out of these, 14 passed all filtering criteria and qualified for historical growth analysis, whereas Greece, Hungary and Romania did not due to accelerating growth or short dT. For offshore wind, Germany and Denmark passed all the filtering criteria, while Belgium and Netherlands still have accelerating growth. The rest of the EU27 countries did not pass the initial filtering criteria.

Wind									
Code	**Country**	**Historical growth [MW/year]** (onshore)	**Maturity** (onshore)	**dT filter** (onshore)	**Passed all filtering**	**Historical growth [MW/year]** (offshore)	**Maturity** (offshore)	**dT filter** (offshore)	**Passed all filtering**
AT	Austria	232.86	Stable	Passed	Yes	-	-	-	No
BE	Belgium	194.57	Stable	Passed	Yes	-	Accelerating	N/A	No
BG	Bulgaria	188.51	Stagnating	Passed	Yes	-	-	-	No
DE	Germany	2854.71	Stable	Passed	Yes	1547.94	Stagnating	Passed	Yes
DK	Denmark	176.94	Stagnating	Passed	Yes	135.62	Stable	Passed	Yes
ES	Spain	2208.67	Stagnating	Passed	Yes	-	-	-	No
FI	Finland	363.57	Stable	Passed	Yes	-	-	-	No
FR	France	1358.94	Stable	Passed	Yes	-	-	-	No
GR	Greece	-	Accelerating	N/A	No	-	-	-	No
HU	Hungary	-	Stagnating	Short dT	No	-	-	-	No
IE	Ireland	331.85	Stable	Passed	Yes	-	-	-	No
IT	Italy	955.81	Stagnating	Passed	Yes	-	-	-	No
NL	Netherlands	305.09	Stable	Passed	Yes	-	Accelerating	N/A	No
PL	Poland	792.40	Stagnating	Passed	Yes	-	-	-	No
PT	Portugal	619.46	Stagnating	Passed	Yes	-	-	-	No
RO	Romania	-	Stagnating	Short dT	No	-	-	-	No
SE	Sweden	1269.50	Stable	Passed	Yes	-	-	-	No

Table 3: Historical growth and filtering results for the E27 countries which passed the initial filtering criteria for wind. In the column "Maturity", maturity of the growth is classified. In the column "dT filter" "Passed" indicates that the dT filtering criteria was met and "Short dT" means it was not met. Not applicable (N/A) displays that there is no dT, since the growth is accelerating. "Passed all filtering" indicates whether or not country passed both the Maturity and dT filter.

As seen in Figure 6 there is a clear correlation ($P \ll 0.05$) between maximum historical growth rate and total electricity supply for onshore wind and solar PV. For offshore wind there is too few data points for establishing a meaningful relationship.

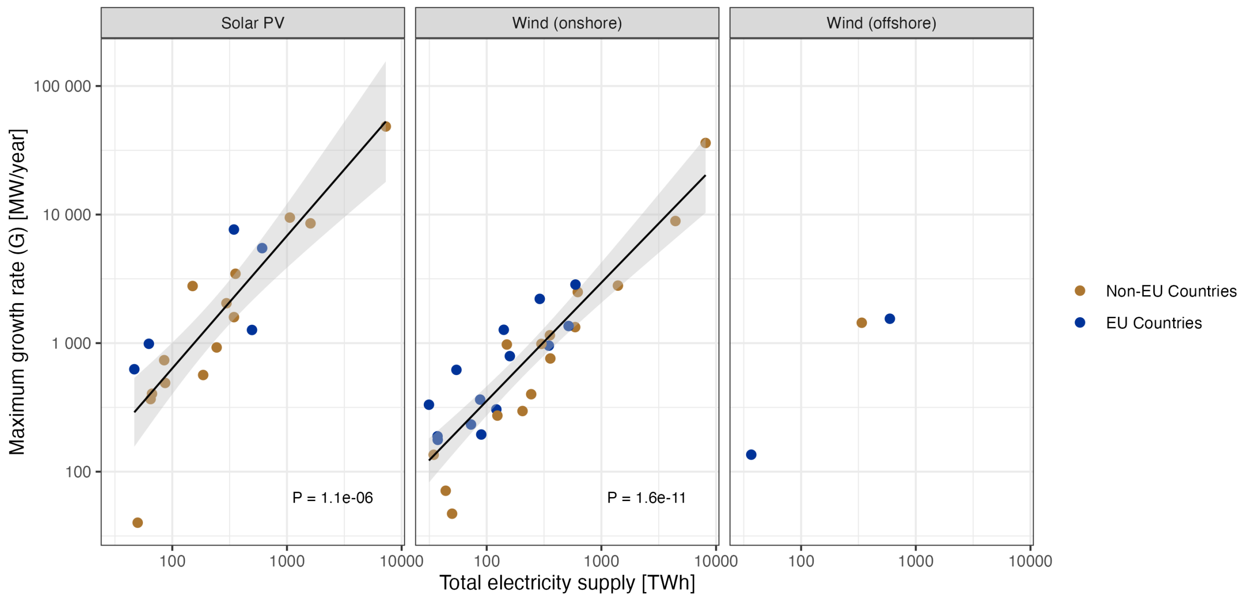


Figure 6: Maximum growth rate (G) of installed capacity and total electricity supply (TES) of EU and non-EU countries for all sources (solar PV, offshore and onshore wind). Note the logarithmic scale on both x-axis and y-axis. In the plots for solar pv and onshore wind are linear regressions accompanied by 95% confidence intervals. For offshore wind there is too few data for any meaningful statistical analysis.

Figure 7 illustrates the maximum growth rates in Figure 6 normalized by system size (total electricity supply). The figure shows that the normalized growth rates for solar PV has a high dispersion, which can be observed by looking at the values for Italy (IT) and France (FR).

Both countries have similar sized electricity systems, but Italy has an almost five times higher noramlized growth rate of solar PV compared to France.

Regarding onshore wind, there is less of a dispersion of the data points with some exceptions. For example, the noramlized growth rate in Ireland (IE) is more than two times larger than Bulgaria's (BG), and that of Portugal (PT) is almost five times larger than the noramlized growth rate in Austria (AT). The figure also seems to illustrate a negative relationship between maximum possible normalized growth rates and electricity system size. For offshore wind, there is not enough data points to perform an analysis on the historical growth.

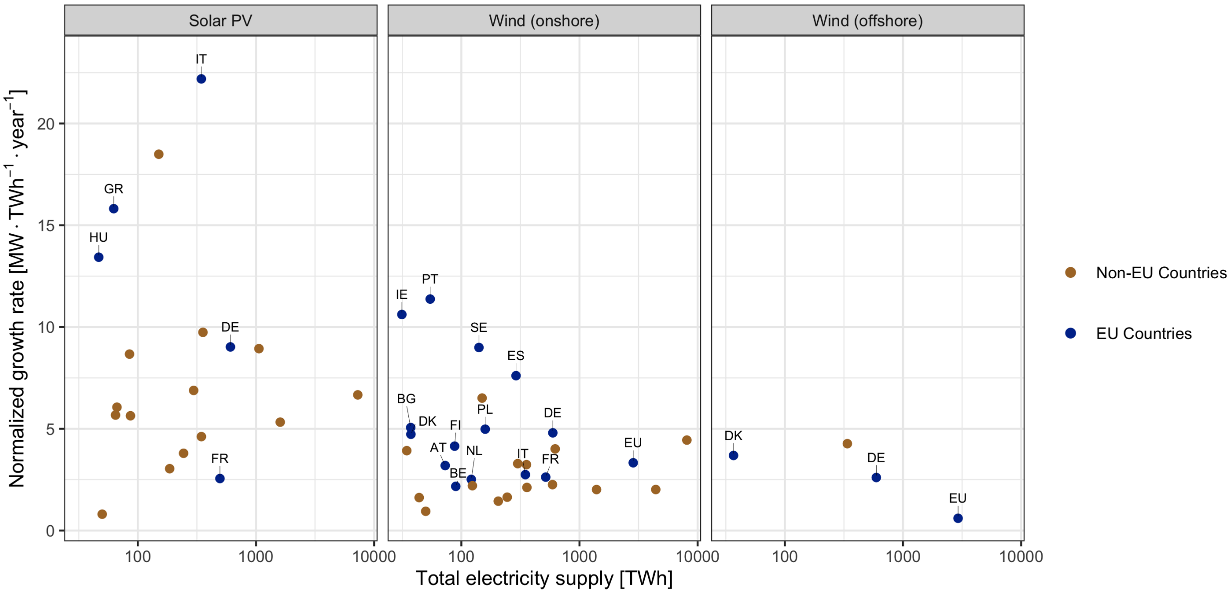


Figure 7: Maximum historical growth rates in capacity from figure 6, normalized by electricity system size for solar PV, onshore and offshore wind electricity.

4.2 National targets

4.2.1 National targets compared to historical growth rates

Figure 8 compares the normalized historical growth rates illustrated in Figure 7 to the growth rates required to reach the national targets. According to the figure, solar PV targets from 2019 NECPs are in line with the historical growth rates. This is also true for onshore wind. However, for the updated targets there is a shift to higher growth rates with some data points significantly above the historical benchmark.

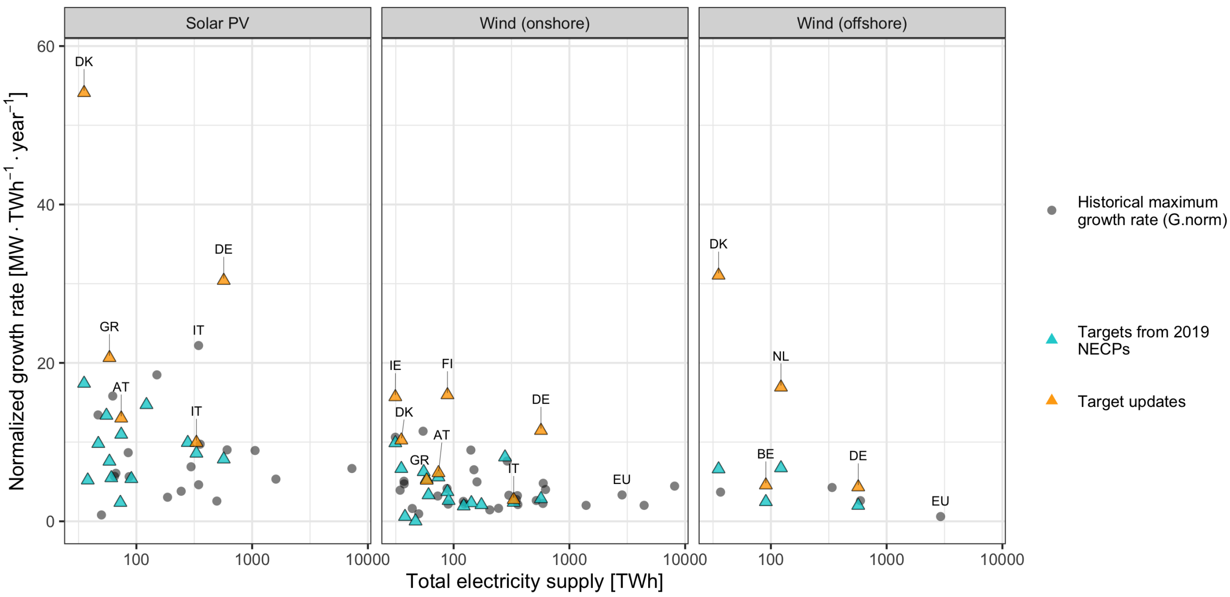


Figure 8: Normalized implied growth rate from 2019 and updated targets of EU countries for solar PV, onshore and offshore wind electricity are shown together with maximum historical growth rates in capacity, normalized by electricity system size for solar PV, onshore and offshore wind electricity.

The tables 4 and 5 contains the data used in figures 7 and 8, excluding the historical data for non-EU countries. In addition, the average historical growth rates of the last three years were used for the countries that did not pass the filtering criteria and is presented with the grey cells (except for countries with stagnating growth, such as solar PV in Bulgaria).

Table 4 displays the solar PV growth rates required to reach each EU Member State's targets for 2030, as well as their historical growth rates. The results under "Share growth rate" show that eleven EU countries have implied growth rates required to reach their targets that are lower than maximum historical growth rates. However, there are no target updates available for these countries (marked with *), except for Italy. For eleven countries, the opposite is true and the growth rates needed to reach their targets are historically unprecedented. These include Denmark and Germany, amongst others. The target updates highlighted with orange are updates stated to be direct consequences of REPowerEU.

		Solar PV growth rate [MW/(TWh · year)]			Share growth rate
Code	**Country**	**Historical**	**2019 target**	**Target update**	**Target / Historical**
AT	Austria	5.53	9.86	14.48	2.62
BE	Belgium	9.47	5.36	-	0.57*
BG	Bulgaria	-	5.19	-	-
CY	Cyprus	12.87	11.55	-	0.9*
CZ	Czech Republic	-	2.36	-	-
DE	Germany	9.02	7.84	30.39	3.37
DK	Denmark	4.77	17.40	54.10	11.34
EE	Estonia	12.81	2.74	-	0.21*
ES	Spain	10.9	9.93	-	0.91*
FI	Finland	0.99	0.95	1.06	1.07
FR	France	2.56	-	-	-
GR	Greece	15.82	7.76	20.64	1.30
HR	Croatia	0.76	3.31	4.11	5.41
HU	Hungary	13.43	9.8	-	0.73*
IE	Ireland	1.05	1.08	26.31	25.06
IT	Italy	22.19	8.57	9.94	0.45
LT	Lituania	6.2	4.78	-	0.77*
LU	Luxembourg	3.69	12.84	-	3.48*
LV	Latvia	0.31	-	-	-
MT	Malta	8.34	3.74	-	0.45*
NL	Netherlands	26.39	14.71	-	0.56*
PL	Poland	10.58	2.96	-	0.28*
PT	Portugal	7.02	13.36	-	1.9*
RO	Romania	-	5.48	-	-
SE	Sweden	2.68	1.56	-	0.58*
SI	Slovenia	2.61	8.01	-	3.07*
SK	Slovakia	0.7	1.85	-	2.64*
EU	European Union	9.21	-	17.03	1.85

Table 4: Historical growth rates of solar PV compared to growth rates required to reach 2030 targets for EU Member States. For countries that did not pass the filtering criteria and have accelerating growth the three year average was calculated. In the table these entries are marked with gray. If the "Share growth rate" is higher than 1, the target set for 2030 requires a growth rate that is historically unprecedented and is marked with red. For the values less than 1, the opposite is true and the values are marked with green. The * implies that the 2019 target growth rate was used when calculating the share, since there was no updated targets available. The target updates marked with yellow are updates stated to be direct consequences of REPowerEU.

Concerning onshore wind, Table 5 shows that there are nine countries with maximum historical growth rates that are higher than their implied target growth rates. Three of these countries have updated targets: Greece, Croatia and Italy. The table also displays that 13 Member States have implied target growth rates that are historically unprecedented. For offshore wind, only Belgium out of the four countries have a higher historical growth rate than implied growth rate required to reach its target. Once again, the target updates highlighted with orange are updates stated to be direct consequences of REPowerEU.

		Wind electricity growth rate [MW/(TWh year)]						Share growth rate	
Code	Country	Historical (onshore | offshore)		2019 Target (onshore | offshore)		Target update (onshore | offshore)		Target / Historical (onshore | offshore)	
AT	Austria	3.00	-	5.58	-	6.11	-	2.04	-
BE	Belgium	2.17	5.27	2.61	2.46	-	4.57	1.20	0.87
BG	Bulgaria	5.06	-	0.59	-	-	-	0.12*	-
CY	Cyprus	0.00	-	0.72	-	-	-	-	-
CZ	Czech Republic	0.11	-	0.79	-	-	-	7.17*	-
DE	Germany	4.80	2.06	2.83	1.99	11.45	4.32	2.39	2.1
DK	Denmark	4.73	3.69	6.64	6.59	10.24	31.05	2.16	8.41
EE	Estonia	0.23	-	8.22	-	-	-	35.76*	-
ES	Spain	7.61	-	8.1	-	-	-	1.06*	-
FI	Finland	4.15	-	3.72	-	15.95	-	3.84	-
FR	France	2.62	-	-	-	-	-	-	-
GR	Greece	9.26	-	5.30	-	5.16	-	0.56	-
HR	Croatia	7.50	-	3.47	-	6.23	-	0.83	-
HU	Hungary	-	-	0.01	-	-	-	-	-
IE	Ireland	10.52	-	9.89	-	15.70	-	1.49	-
IT	Italy	2.75	-	2.37	-	2.72	-	0.99	-
LT	Lituania	3.48	-	5.74	-	-	-	1.65*	-
LU	Luxembourg	1.61	-	0.98	-	-	-	0.61*	-
LV	Latvia	0.09	-	13.26	-	-	-	147.33*	-
MT	Malta	0.00	-	-	-	-	-	-	-
NL	Netherlands	2.51	4.11	1.91	6.73	-	16.92	0.76*	4.12
PL	Poland	4.98	-	2.07	-	-	-	0.42*	-
PT	Portugal	11.37	-	6.24	-	-	-	0.55*	-
RO	Romania	-	-	3.32	-	-	-	-	-
SE	Sweden	8.99	-	2.32	-	-	-	0.26*	-
SI	Slovenia	-	-	0.86	-	-	-	-	-
SK	Slovakia	0	-	1.51	-	-	-	-	-
EU	European Union	3.33	0.61	-	-	13.95		-	

Table 5: Historical growth rates of wind capacity compared to growth rates required to reach 2030 targets for EU countries. For countries that did not pass the filtering criteria and have accelerating growth the three year average was calculated. In the table these entries are marked with gray. If the "Share growth rate" is higher than 1, the target set for 2030 requires a growth rate that is historically unprecedented and is marked with red. For the values less than 1, the opposite is true and the values are marked with green. The * implies that the 2019 target growth rate was used when calculating the share, since there was no updated targets available. The target updates marked with yellow are updates stated to be direct consequences of REPowerEU.

Both Table4 and 5 illustrates that more than half of the EU27 countries with data require growth rates higher than their maximum historical growth rates in order to reach their targets. The tables also highlights that there are missing data, mainly for target updates.

4.2.2 National targets 2019 compared to recent updates

Figure 9 shows the normalized growth rates required to meet NECP targets from 2019 and target updates. The figure includes targets of all EU27 countries, and demonstrates similar dispersion as in Figure 7. The target updates generally show an increase in ambition on the national level.

Some countries have target updates which require considerably larger growth rates than their

2019 NECPs. These include: Denmark (DK), Ireland (IE), Germany (DE) and Greece (GR) for solar PV; Finland and Germany for onshore wind; Denmark, the Netherlands (NL) and Ireland for offshore wind.

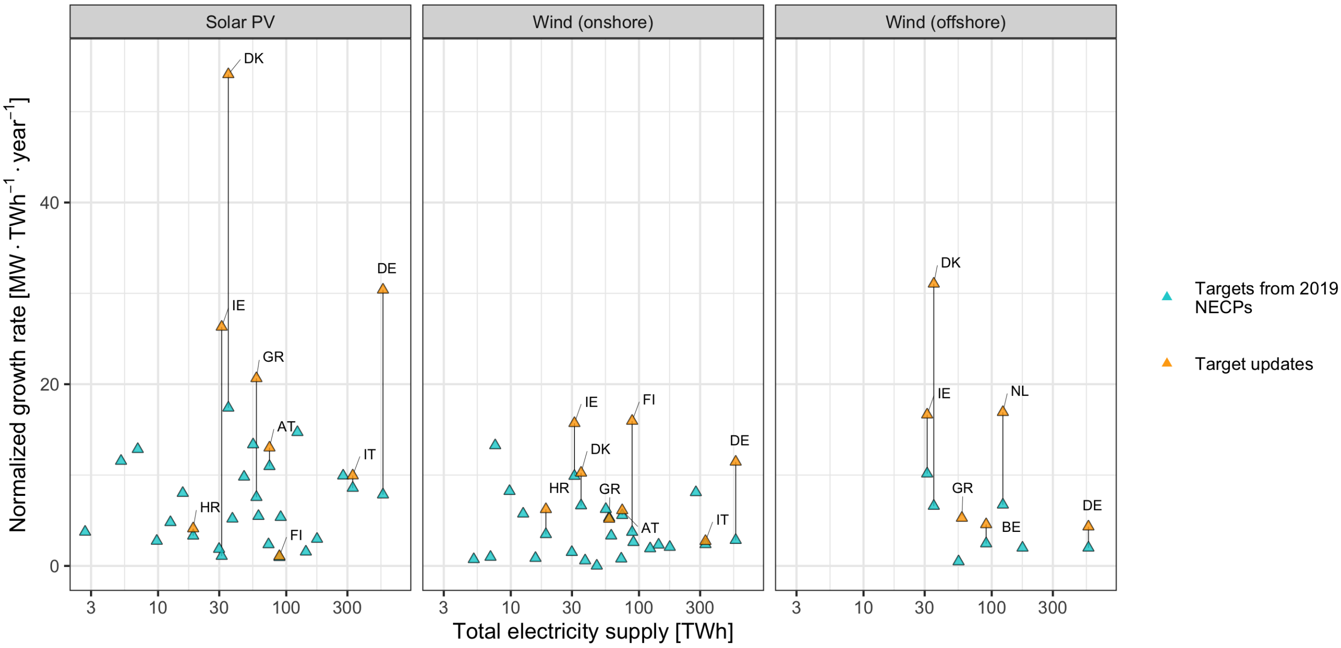


Figure 9: Normalized implied growth rate from 2019 and updated targets of EU countries for solar PV, onshore and offshore wind electricity.

4.2.3 Technological preferences

Figure 10 shows the required normalized growth rates of wind power and solar PV to reach the 2019 and updated targets. The figure illustrates that most EU Member States have higher solar PV targets compared to wind power, implying a faster growth of solar PV in EU.

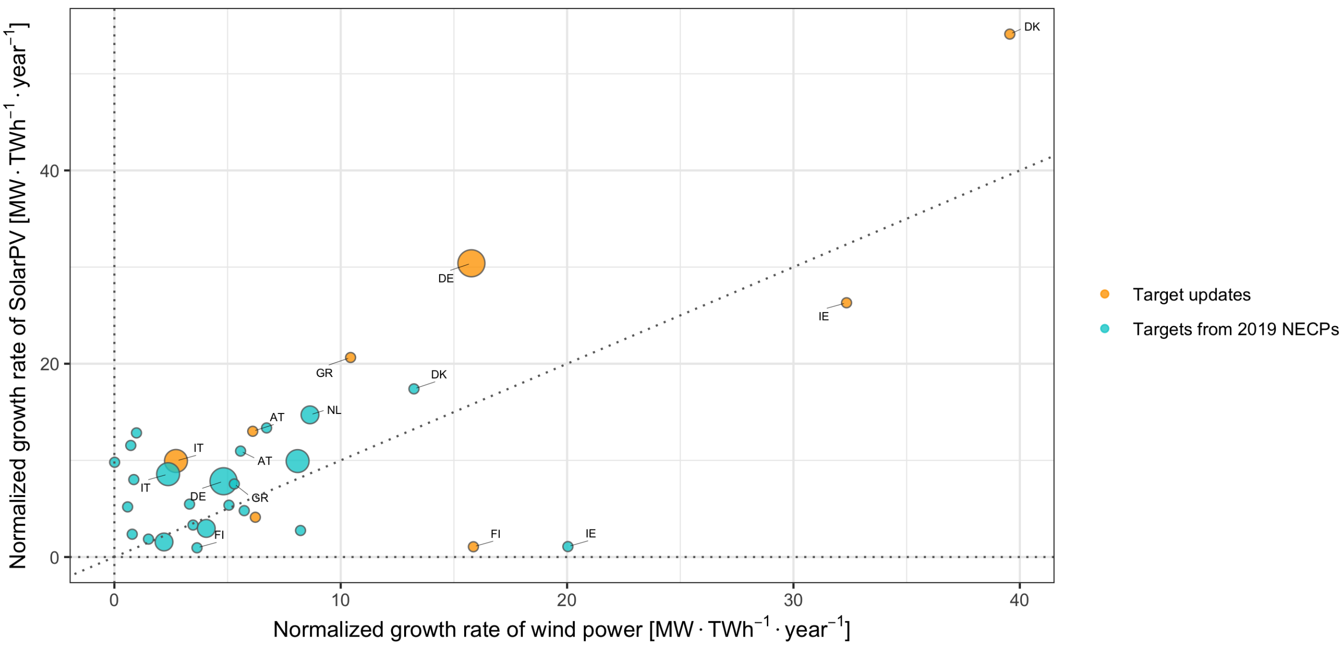


Figure 10: Normalized growth rates required to reach the 2019 NECP targets (blue dots) and the target updates (orange dots) for wind electricity on the x-axis, and solar PV on the y-axis. The dotted line shows where there is equal amount of solar PV and wind growth. The size of the dots represents the size of the country's electricity system.

4.3 Contributions of EU Member States to the REPowerEU targets

4.3.1 Solar PV contribution analysis

There are currently only five countries that have set targets that are in line with their allocated share of the REPowerEU target on installed solar PV capacity, which can be observed in Figure 11. These countries are Germany (DE), Netherlands (NL), Greece (GR), Denmark (DK) and Ireland (IE). Note the logarithmic scales skewing the visual impression; for example, both Denmark and Germany have planned contributions significantly above their allocated contribution, indicating strong ambitions. There seems to be no indication that countries with larger allocated contributions are not able to fulfill this commitment, based on the ambition of national targets, e.g. while Germany has the largest allocated contribution of all EU countries, their national ambitions still greatly exceeds these levels.

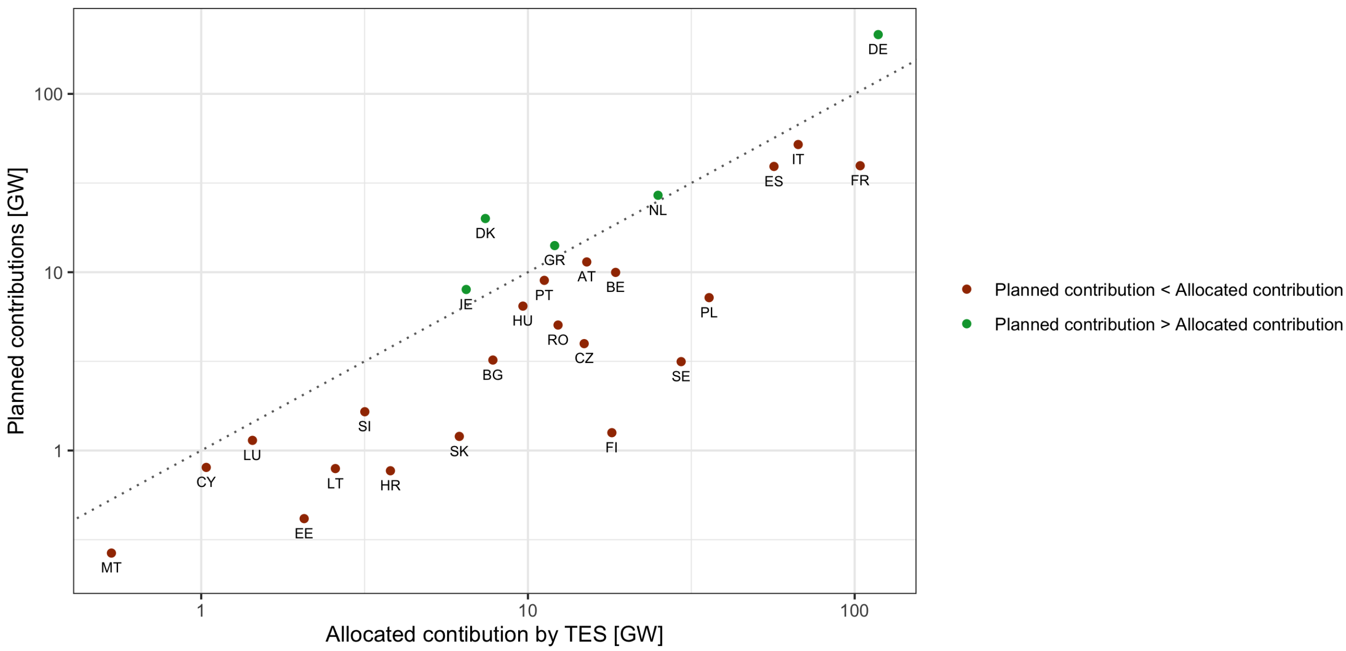


Figure 11: Planned contributions and allocated contributions of installed solar PV capacity for all EU countries. The dotted line shows the relation 1:1, with countries above this line colored green, and those below colored red. Note that logarithmic scales have been used.

Figure 12 displays the contribution ratios of installed solar PV capacity for all EU countries, with 100% representing that planned contributions are equal to allocated contributions. The figure shows a wide range in contribution from Finland (FI) at 7% to Denmark (DK) at 270%. All values are found in Appendix, Table7.

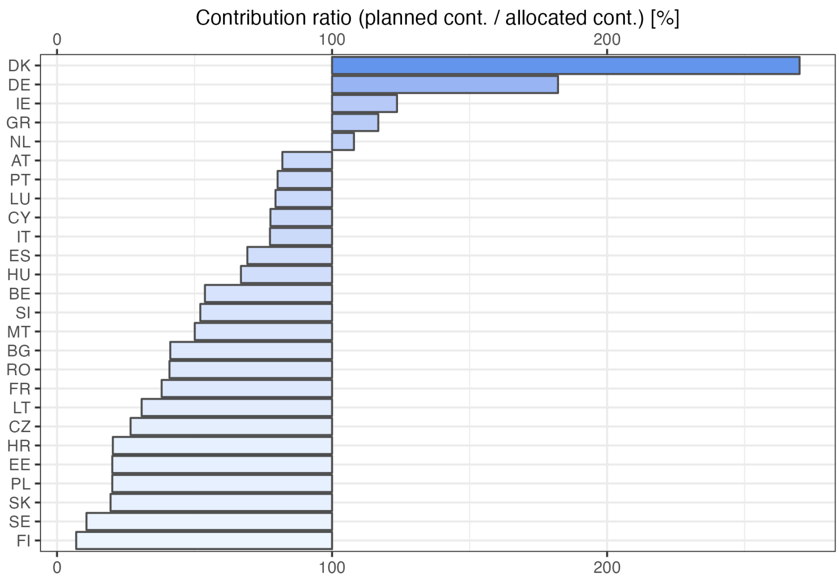


Figure 12: Contribution ratio of installed solar PV capacity for all EU countries. A contribution ratio of 100% means that planned contributions are equal to allocated contributions.

Figure 13 shows EU countries colored by solar PV contribution ratio, with darker colors representing a larger ratio. A pattern of decreasing contributions for higher latitudes can be observed, which align with decreased solar irradiance (see Sweden and Finland). Exceptions from this are Denmark and Germany with remarkably high contribution ratios, indicating strong ambitions.

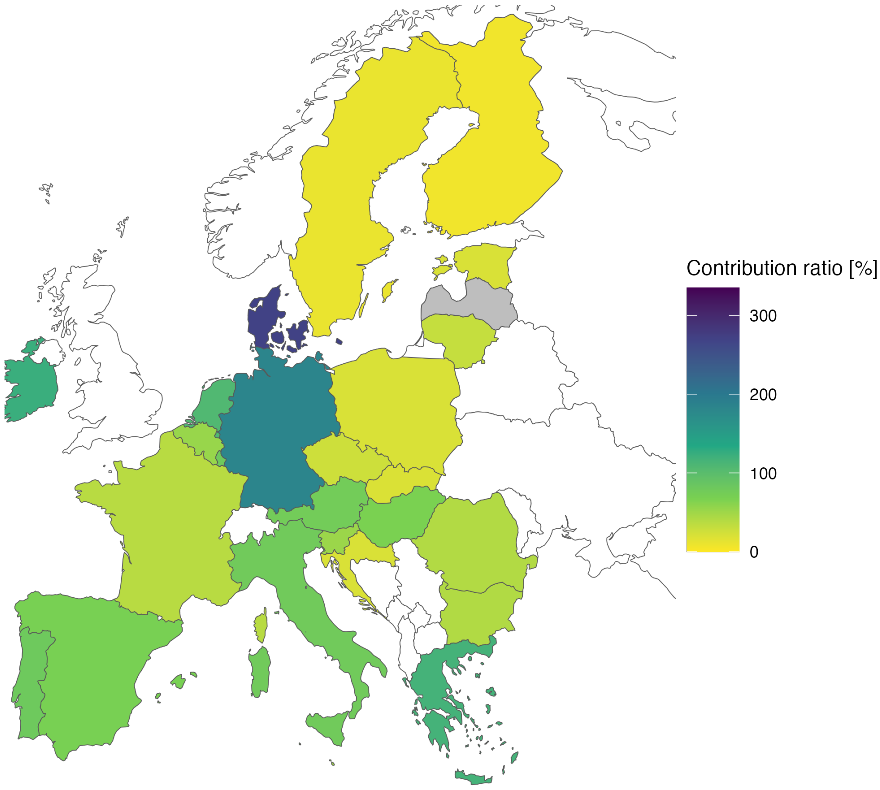


Figure 13: Contribution ratio of installed solar PV capacity for all EU countries. There is no data available for Latvia. Countries that are not colored are not members of the EU.

4.3.2 Wind power contribution analysis

For installed wind capacity, there are currently only six countries that have set targets that are in line with their allocated share of the REPowerEU target, which can be observed in Figure 14. These countries are Germany (DE), Spain (ES), Netherlands (NL), Finland (FI), Denmark (DK) and Ireland (IE). As for Figure 11, note the logarithmic scale skewing the visual impression; Denmark and Ireland have planned contributions significantly above their allocated contribution, indicating strong ambitions. Again, there seems to be no indication that countries with larger allocated contributions are not able to fulfill this commitment, based on the ambition levels in national targets.

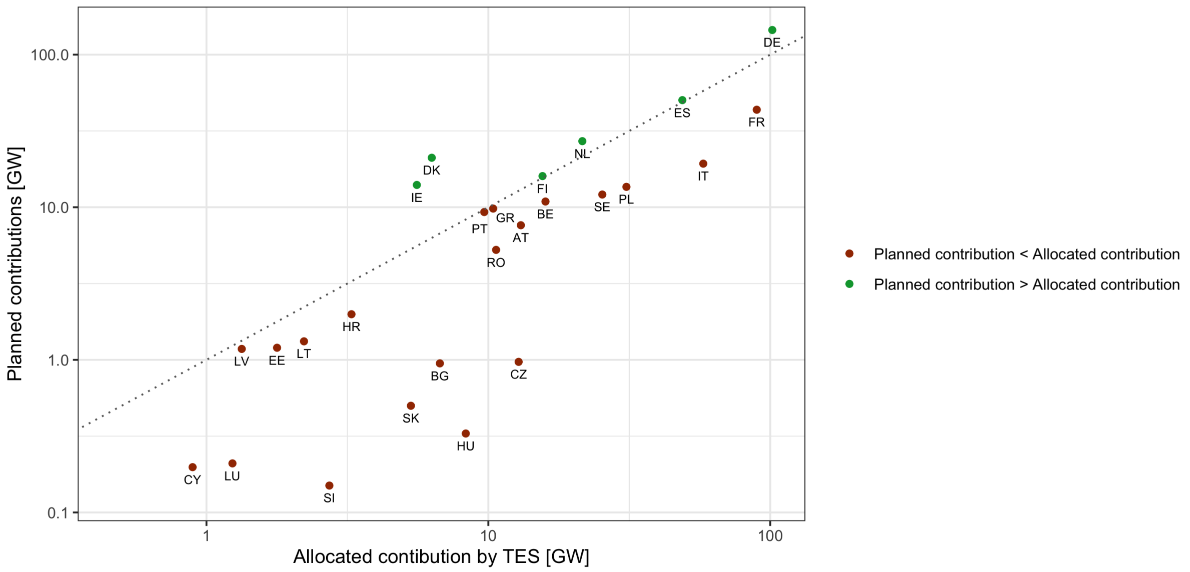


Figure 14: Planned contributions and allocated contributions of installed wind capacity (on- and offshore) for all EU countries. The dotted line shows the relation 1:1, with countries above this line colored green, and those below colored red. Note the logarithmic scales.

Figure 15 displays the contribution ratio of installed wind capacity for all EU countries, showing the wide range in contribution with Hungary (HU) at 4% and Denmark (DK) at 335%. All values are found in Appendix, Table7.

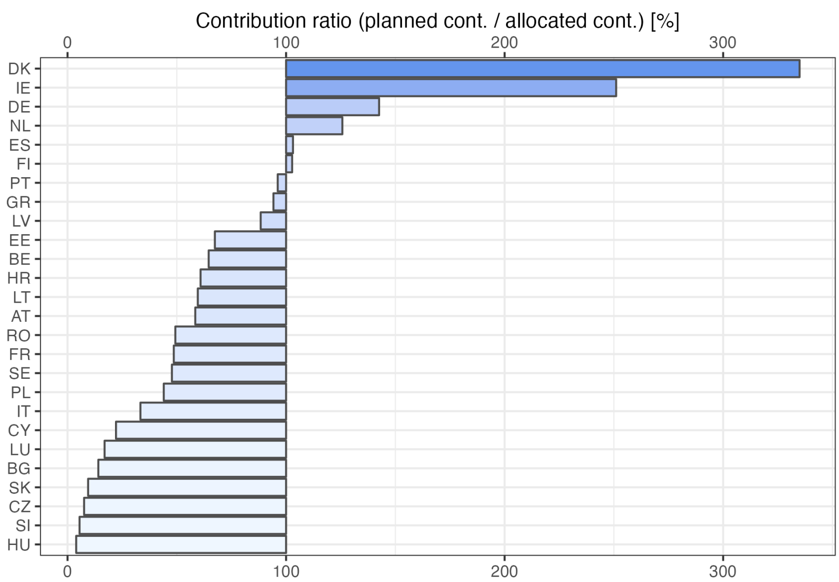


Figure 15: Contribution ratio of installed wind capacity for all EU countries. A contribution ratio of 100% means that planned contributions are equal to allocated contributions.

Figure 16 shows EU countries colored by wind power contribution ratio, with darker colors representing a larger ratio. A pattern of lower contributions for non-coastal countries can be observed, which align with poorer wind conditions. See Denmark and Ireland as examples of countries with good conditions and also very high planned contributions, and oppositely Czech Republic, Slovakia, Hungary and Slovenia as examples of countries with a low contribution ratio.

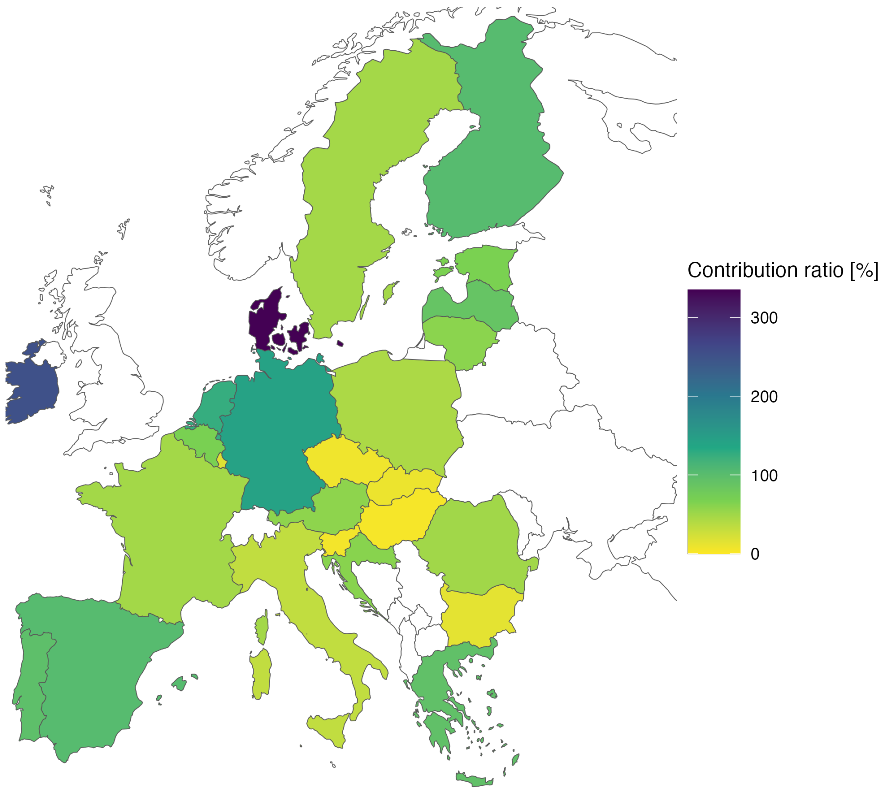


Figure 16: Contribution ratio for all EU countries. There is no data available for Malta. Countries that are not colored are not members of the EU.

4.4 Aggregated target analysis on EU level

Figures 17 and 18 displays the 2030 targets on installed solar PV and wind capacity of EU Member States, the current installed capacity as well as the accumulated capacities, for all countries. The green lines shows the estimated installed capacity required to reach the REPowerEU target, which is 592 GW for solar and 510 GW for wind (both on- and offshore) (European Commission, 2022b).

Figure 17 shows that Germany (DE) has a solar PV capacity target that is higher than the total current installed capacity for all other EU countries combined. Similarly, Figure 18 displays that Germany's target for wind is almost as large as the EU's current installed capacity of wind power.

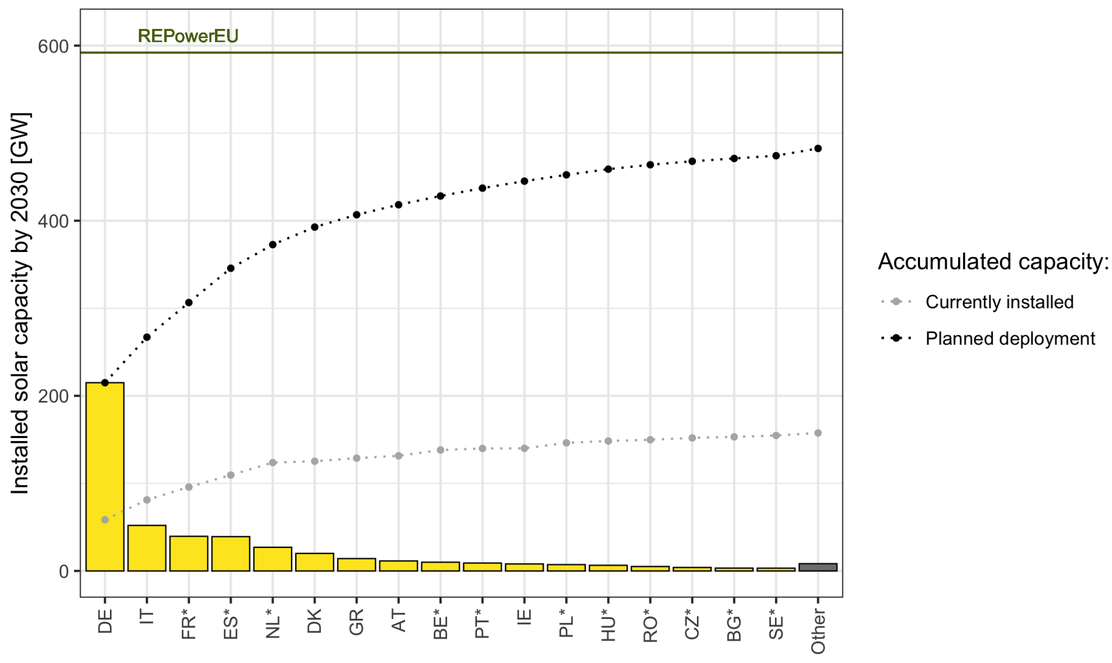


Figure 17: The planned contributions on installed solar capacity for 2030 for EU countries. The green line represents the projected solar PV capacity needed in the EU to reach the REPowerEU target for 2030, 592 GW (IEA, 2022). The dotted black line is the accumulated installed capacity, beginning from the left with the largest absolute contributor, and at the rightmost showing the total combined contributions from the Member States. The total contributions amounts to 483.6 GW. The corresponding grey line displays the accumulated installed capacity at the end of 2020 and 2021. The ”other” category includes the 12 countries with the least planned contributions of solar PV. * implies that the target from 2019 was used since there was no updated target available.

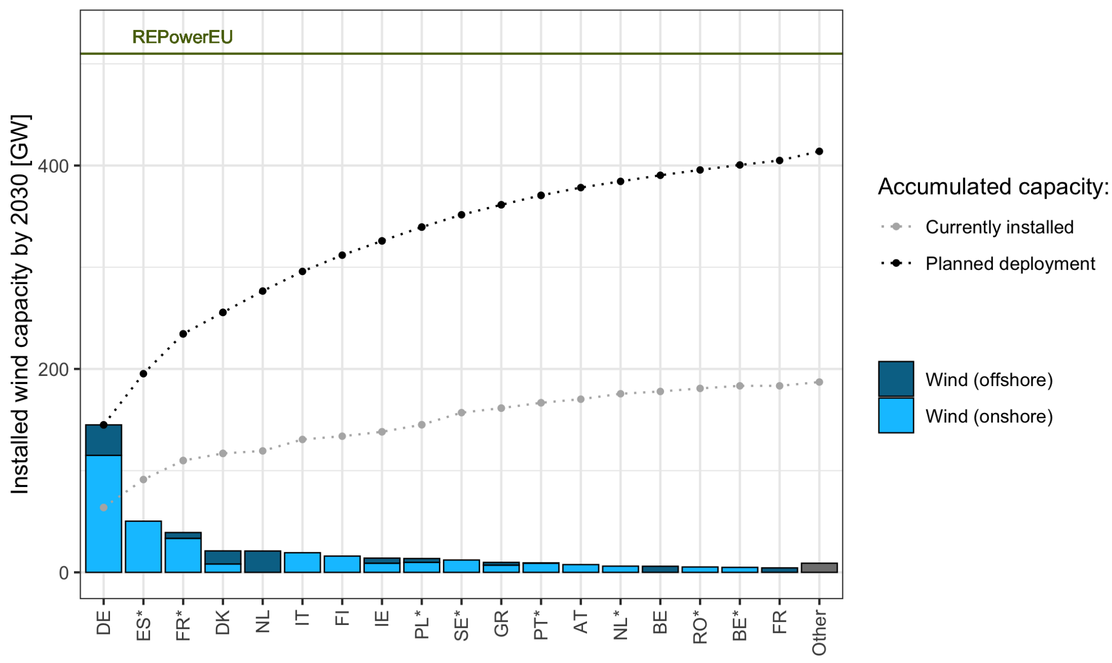


Figure 18: The installed wind capacity for 2030 of EU countries, divided into off- and onshore wind for countries with a significant amount (over 20%) of expected offshore wind in 2030. The green line represents the projected wind capacity needed in EU to reach the REPowerEU target for 2030, 510 GW (European Commission, 2022b). The dotted black line is the accumulated installed capacity, beginning from the left with the largest absolute contributor, and at the rightmost showing the total combined contributions from the Member States. The total contributions amounts to 413.4 GW. The ”other” category includes the 12 countries with the least planned contributions of wind. * implies that the target from 2019 was used since there was no updated target available.

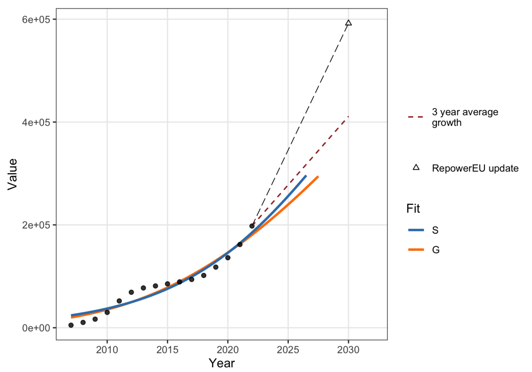
Both figures show that national targets, despite implying a significant increase in installed capacity, are not sufficient to meet the 2030 REPowerEU capacity targets. Comparing the REPowerEU targets (green line) with the planned total capacities of 2030 from national targets (black dotted lines), the amount of extra solar PV and wind capacity needed to reach the targets can be calculated.

$$\text{Solar PV [GW]: } 592 - 483.6 = 108.4 \tag{7}$$

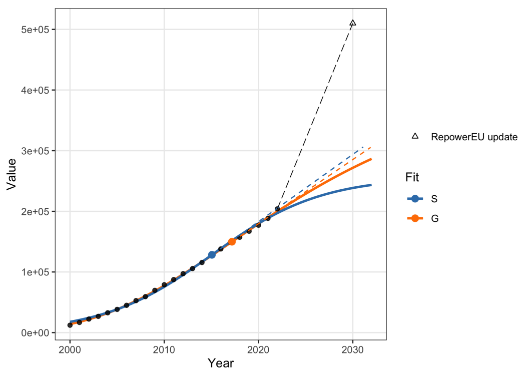
$$\text{Wind [GW]: } 510 - 413.4 = 96.6 \tag{8}$$

The result of this is that there is a need to increase the overall national targets by 108.4 GW of solar PV capacity, and 96.6 GW of wind capacity by 2030 to reach the REPowerEU targets. This translates to a required capacity increase in targets by 22.4% for solar PV and 23.2% for wind.

Figures 19a and 19b investigates the feasibility of reaching the REPowerEU targets in terms of capacity. They visualize the trajectories of solar and wind electricity of EU as a whole, as well as the required capacities of wind and solar PV in 2030 to reach the REPowerEU targets. According to Figure 19a, the installed capacity of solar PV is accelerating, but the rate is not yet enough to reach the targets (compare REPowerEU target to extended three year average growth rate). Figure 19b instead shows a stable growth of wind, with the two dotted lines representing the maximum growth rates extended from the inflection point. This illustrates that the growth rate required to reach the REPowerEU target is historically unprecedented.



(a) Total installed capacity of solar PV in EU. Gompertz and Logistic models are fitted to historical data. The dashed red line shows the average growth rate for the last three years extended from the last data point. The dashed black lines displays the implied growth rates required to reach the REPowerEU targets.



(b) Total installed capacity of wind (onshore and offshore) in EU. Gompertz and Logistic models are fitted to historical data. The blue and orange dashed lines shows the maximum growth rate of wind in EU extended from the inflection point. The dashed black lines displays the implied growth rates required to reach the REPowerEU targets.

Figure 19: Solar PV and wind electricity trajectories in EU.

5 Discussion and conclusion

This section provides a discussion of the results including main findings, limitations of the study as well as recommendations on further research. Lastly, a conclusion will be presented.

5.1 Main findings

5.1.1 A radical shift in deployment of wind and solar power in EU Member States

The historical data indicates unstable properties of solar PV growth in EU countries. 13 countries do not pass the initial filtering criteria, and of the 14 that pass these criteria on total supply, six countries exhibit accelerating growth and three countries have short dT. There are only five countries passing all filtering criteria (see Table 2). For all of EU, Solar PV has an accelerating growth (see Figure 19a). This agrees with that solar power is one of the fastest growing renewable energy sources in the EU (see Eurostat (2023)). Due to the instability of historical data it is difficult to determine future growth with confidence.

The historical data also shows that few countries have achieved stable growth of offshore wind. However, the majority of the countries have achieved stable growth of onshore wind (see Table 5). Several of the countries with stagnating growth in both wind and solar PV (see Table 2 and 3) have increased their electricity targets, implying re-initiated acceleration of deployment. An example of this is offshore wind in Germany, which according to the model has reached stagnating growth. Despite this, the updated targets include an increase in offshore wind capacity by around 10 000 MW by 2030 compared to the 2019 target (Appendix, Table 8). Due to the radical shift in ambitions the maturity of deployment is not a representative measure of future growth.

5.1.2 A need for historically unprecedented growth rates

More than half of the EU Member States that pass the dT filtering criteria will require historically unprecedented growth rates in order to reach their targets set for 2030, according to tables 4 and 5. More specifically, this is true for 11 out of 22 countries for solar PV and 11 out of 20 countries for wind. Among the remaining countries, some have not yet updated their targets. The countries with targets that are feasible with respect to historical growth rates are Italy for solar PV, and Italy, Belgium and Croatia for onshore wind. However, none of these countries have targets that amount to their the allocated contribution (see figures 12 and 15). Germany is an example of a country with updated targets that imply historically unprecedented growth rates, and it can be seen in figures 12 and 15 that the country have a planned contribution that is significantly above their allocated contribution. However, this does not have to be a sign of in-feasibility, but could also be an indication of a shift in ambitions.

5.1.3 Increased ambitions following the introduction of the REPowerEU plan

When comparing the 2019 NECP targets with the updated targets (Figure 9), there is a general increase in target ambitions on national level. For solar PV, Denmark, Ireland, Germany and Greece are countries requiring considerably lager growth rates to achieve their updated targets compared to their NECPs. This is also true for the onshore wind targets of Finland and Germany, and the offshore wind targets of Denmark, Netherlands and Ireland.

Certain updates from 2022 are presented as a direct effect of the REPowerEU directives, but not all (see tables 4 and 5). On the other hand, 16 out of 27 countries have not yet updated their targets (see A, Table 8). The REPowerEU plan aims to increase energy independence (European Commission, 2022d) and as mentioned previously energy insecurity can affect commitment in renewables both positively and negatively (see Dong (2012); Aguirre and Ibikunle (2014)). It has also been said that the Russian invasion, and the energy insecurity that followed, has made fossil fuel prices increase (see Trunina et al. (2022)). This could support the assumption that energy target raises are consequences of the war, which would align with prior research saying that the Russian invasion increased incentive for the energy transition (see Proedrou (2023)).

5.1.4 Higher national ambitions are needed to reach REPowerEU targets

According to figures 17 and 18, the national laws, targets and projections set by the individual Member States of EU are not enough to reach the REPowerEU targets set for 2030. In order to achieve the targets, there is a need to increase the solar PV and wind capacity targets by 22.4% and 23.2% respectively. This is in line with what IEA concluded: that the increase of capacity in the EU is insufficient to reach REPowerEU's 2030 renewable electricity objectives (IEA, 2022). Furthermore, there are uncertainties in the targets used in the analysis as several of the targets are non-binding projections and estimations. This might reinforce the risk of EU countries not meeting their targets as they are not legally obliged to do so.

It can be seen in Figure 11 and Figure 14 that five countries for solar PV and six countries for wind fulfill their allocated contribution ratio. As mentioned earlier, not all countries have yet updated their climate targets following the REPowerEU, since the deadline for updates is in June 2023 (European Commission, 2019a). A possible limitation with this result is that some countries may not have a large focus on solar PV and wind. Northern European countries, for example, have disadvantages in developing solar power (Perpiña Castillo et al., 2016). Figure 13 illustrates this pattern, with Finland and Sweden having low solar PV contributions while the contribution rates are generally higher for countries in the south. Concerning wind, countries closer to the Atlantic Ocean have better conditions for wind electricity (Enevoldsen et al., 2019). This can be observed in Figure 16 to some degree, as Ireland, Denmark, the Netherlands, Spain and Portugal have higher contribution rates than certain countries further to the east. Another observation from the figure is that countries with little to no coastal areas have low contributions to the REPowerEU wind targets. In addition, there are other factors affecting the contribution ratio of renewable energy sources, such as competing interests (Maris & Flouros, 2021; Skjærseth, 2021).

5.2 Limitations

As of March 2023, eight countries had updated their solar PV targets, eight had updated their onshore targets and four their offshore targets. The remaining countries lack updates. The shortage of updates could result in that the combined national capacity targets for 2030 in figures 17 and 18 are lower than in reality. This could imply that the REPowerEU targets are more reachable than what can be interpreted from the results of the data.

For the tables 4 and 5, the average growth rates of the last three years was used for those countries that did not pass the filtering criteria. This could possibly result in historical growth rates that are not accurate representations of these countries.

Moreover, this study has largely overlooked explanatory analyses, which may have revealed other factors that could influence the results. For example, the reliance EU countries have on Russian gas and fossil fuels in general. This could mean that countries independent of Russian gas might have raised their targets regardless of the war in Ukraine.

There are also other factors not included in this study which could affect growth of renewable energy. Climate policies often stimulate growth in renewables (Kilinc-Ata, 2016) and other factors like GDP, fossil fuel prices and market complexity not mentioned in this analysis also affect growth (see Aguirre and Ibikunle (2014); Kilinc-Ata (2016); Dong (2012); Bird et al. (2005); Grubler et al. (2016)). This further implies that there is an uncertainty in the analysis and the feasibility of targets being met.

As stated in section 5.1.1, some countries that have reached a stagnating phase of growth (see Table 5) have raised their targets in a manner that implies further accelerating growth. This suggests that the mathematical models used to describe growth might not cover all possible affecting factors. For example, in this study, the possibility of radical technological development of solar PV and wind is excluded. This is a limitation that might lead to patterns in deployment unpredictable by this study.

In this analysis an allocation of contributions was made based on total electricity supply, which infer that larger countries (countries with a larger electricity system) should take a bigger responsibility. However, this does not take into account the potential for the different electricity sources in a specific country. A low relative contribution level in this thesis is not necessarily an indicator of low ambitions, but could also mean that a country has low potential for an energy source or that there is an alternative renewable energy source that is dominant.

5.3 Recommendations for further research

For further research within this area, one recommendation is to add the targets from the updated NECPs which is due 30 June 2023. This will likely provide a more updated view of the EU countries' current ambitions and also to what extent EU is on track to reach its REPowerEU targets for 2030.

It could also be worthwhile to further look into the specific plans for fulfilling the national targets, which were excluded in this report. When a country presents a climate target that would need an historically unprecedented growth to be reached, there might be specific plans for how this could be achieved that can be evaluated. Perhaps there is currently a major financial investment in specific solar PV and wind projects, that will result in this growth. Possible technical improvements and financial investments are interesting to investigate in further research. Certain energy sources, as geothermal energy and fossil free hydrogen, were also excluded from this analysis, but it could be beneficial to include these when analysing the feasibility of reaching the REPowerEU targets.

The formula used for deciding the countries' contributions to the REPowerEU target is a rough formula for allocation. For further studies this formula could be refined to include other factors, such as potential for the technology or GDP. This might result in a more justified picture of the allocated contributions. One could also look at allocation made by EU, which is stated in their responses to submitted NECPs.

5.4 Conclusions

This study aimed to analyse whether the growth of wind and solar PV in the EU countries required to reach the 2030 REPowerEU targets are in line with historical precedents and the current national targets. As a result, it was found that the data implies that there is a need for historically unprecedented growth in many countries to meet national targets for 2030. Consequently, it may be challenging for most EU Member States to achieve their 2030 targets relying solely on historical evidence. In addition, it was discovered that the updates of the energy targets have in general increased. Several countries mention REPowerEU in their target updates, meaning that it is reasonable to assume that the war has created incentive for raising target ambitions.

Another main finding of this study is that the national targets are not consistent with REPowerEU targets since the sum of their targets falls short in comparison to the total REPowerEU plan. In order to reach the REPowerEU plan, an additional 108.4 GW of solar PV capacity is needed, meaning an increase in targets by 22.4%. For wind capacity, an additional 96.6 GW is required for the targets to be coherent, which corresponds to an increase of 23.2%. An allocated contribution ratio for achieving the estimations in the REPowerEU plan was calculated. A mere five out of the 27 EU Member States was found to meet their contribution ratio. It is important to note that 16 out of the 27 EU Member States have not yet updated their energy targets following the introduction of the REPowerEU plan.

When interpreting this result it is important to bear in mind that not all countries have favorable conditions for solar PV and wind. In addition, there are plenty of factors affecting growth in renewables, and not all of these are included in this analysis. More factors could have been considered when evaluating the feasibility of reaching the energy targets for 2030.

Additionally, this work has made a contribution by presenting a table with all updated solar PV and wind targets available as of March 2023 (Table8 in Appendix A) and an updated version of the web application by the POLET research group (*Web application by the POLET research group.*, n.d.).

6 Societal and ethical aspects

Climate change, fossil fuels and renewable energy sources are politically charged topics, especially concerning the vast economic size of the fossil fuel industry. This study involves these complex subjects, making the ethical and societal issues important to keep in mind.

The study is an evaluation of whether it is feasible for European countries to achieve EU-level targets or not. This final evaluation can affect policymakers in the countries in question. The result of the study could indicate that a country is well on its way to achieve the targets, or it could indicate that the country is far off and the policymakers needs to reconsider. Either way the result provides knowledge that the society can utilize and adapt to, which is a positive outcome. In addition, that the progress of the development in European countries is examined by independent actors is crucial and engenders positive values.

Regarding the method of the project, it is limited to treating existing data. Since it does not involve research on people or other subjects which could lead to new discoveries, but instead will aim to provide insights from data, we believe that the method needs no further ethical analysis. However, naturally the sources used in the study was carefully chosen and evaluated.

References

Aguirre, M., & Ibikunle, G. (2014). *Determinants of renewable energy growth: A global sample analysis* (Vol. 69). https://doi.org/10.1016/j.enpol.2014.02.036

Barthelmie, R. J., & Pryor, S. C. (2021). Climate change mitigation potential of wind energy. *Climate*, *9*(9). https://doi.org/10.3390/cli9090136

Bento, N., & Fontes, M. (2015). *Spatial diffusion and the formation of a technological innovation system in the receiving country: The case of wind energy in portugal* (Vol. 15). https://doi.org/10.1016/j.eist.2014.10.003

Bird, L., Bolinger, M., Gagliano, T., Wiser, R., Brown, M., & Parsons, B. (2005). Policies and market factors driving wind power development in the united states. *Energy Policy*, *33*(11), 1397-1407. https://doi.org/10.1016/j.enpol.2003.12.018

Borowski, P. F. (2022). Mitigating climate change and the development of green energy versus a return to fossil fuels due to the energy crisis in 2022. *Energies*, *15*(24), 9289. 10.3390/en15249289

Cherp, A., Vinichenko, V., Tosun, J., Gordon, J., & Jewell, J. (2021). National growth dynamics of wind and solar power compared to the growth required for global climate targets. *Nature Energy*, *6*, 742754. https://doi.org/10.1038/s41560-021-00863-0

Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy*, *2*(9). https://doi.org/10.1038/nenergy.2017.140

Dalla Valle, A., & Furlan, C. (2011). *Forecasting accuracy of wind power technology diffusion models across countries* (Vol. 27) (No. 2). https://doi.org/10.1016/j.ijforecast.2010.05.018

Dong, C. (2012). *Feed-in tariff vs. renewable portfolio standard: An empirical test of their relative effectiveness in promoting wind capacity development* (Vol. 42). https://doi.org/10.1016/j.enpol.2011.12.014

Enerdata. (2022). *World Energy Climate Statistics Yearbook 2022, Electricity domestic consumption.* Retrieved 2023-04-25, from https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html

Enevoldsen, P., Permien, F.-H., Bakhtaoui, I., von Krauland, A.-K., Jacobson, M. Z., Xydis, G., ... Oxley, G. (2019). How much wind power potential does europe have? examining european wind power potential with an enhanced socio-technical atlas. *Energy Policy*, *132*, 1092-1100. https://doi.org/10.1016/j.enpol.2019.06.064

European Commission. (n.d.-a). *2030 climate energy framework.* https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-energy-framework_en. (Accessed: 2023-04-29)

European Commission. (n.d.-b). *A european green deal, striving to be the first climate-neutral continent.* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. (Accessed: 2023-05-06)

European Commission. (n.d.-c). *Renewable energy targets.* https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en. (Accessed: 2023-05-10)

European Commission. (2019a). *National energy and climate plans.* https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en. (Accessed: 2023-04-10)

European Commission. (2019b). *National energy and climate plans (necps).* https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en. (Accessed: 2023-02-02)

European Commission. (2021). *'fit for 55': delivering the eu's 2030 climate target on the* *way to climate neutrality.* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550&from=EN. (Accessed: 2023-01-27)

European Commission. (2022a). *Eu solar energy strategy.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A221%3AFIN&qid=1653034500503. (Accessed: 2023-04-28)

European Commission. (2022b). *Implementing the repower eu action plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2022%3A230%3AFIN. (Accessed: 2023-04-13)

European Commission. (2022c). *Repowereu: affordable, secure and sustainable energy for europe.* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en. (Accessed: 2023-01-27)

European Commission. (2022d). *Repowereu plan.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483. (Accessed: 2023-04-13)

European Environment Agency. (2021). *Trends and projections in europe 2021.* https://-doi.org/10.2800/80374

European Environment Agency. (2022). *Greenhouse gas emission intensity of electricity generation in europe.* https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1. (Accessed: 2023-05-06)

European Union. (n.d.). *Eu country profiles.* https://european-union.europa.eu/principles-countries-history/country-profiles_en. (Accessed: 2023-04-28)

European Union. (2018). *Regulation (eu) 2018/1999 of the european parliament and of the council.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0001.01.ENG. (Accessed: 2023-05-02)

Eurostat. (2023). *Renewable energy statistics.* https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Wind_and_water_provide_most_renewable_electricity.3B_solar_is_the_fastest-growing_energy_source. (Accessed: 2023-04-12)

Gosens, J., Hedenus, F., & Sandén, B. A. (2017). *Faster market growth of wind and pv in late adopters due to global experience build-up* (Vol. 131). https://doi.org/10.1016/j.energy.2017.05.046

Grubler, A., Wilson, C., & Nemet, G. (2016). Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions. *Energy Research amp; Social Science*, *22*, 1825. 10.1016/j.erss.2016.08.015

Grübler, A. (1996). Time for a change: On the patterns of diffusion of innovation. *Daedalus*, *125*(3), 19–42. Retrieved 2023-05-06, from http://www.jstor.org/stable/20027369

IEA. (n.d.). *Russia's War on Ukraine.* Retrieved 2023-05-04, from https://www.iea.org/topics/russias-war-on-ukraine

IEA. (2022). *Is the european union on track to meet its repowereu goals?* https://www.iea.org/reports/is-the-european-union-on-track-to-meet-its-repowereu-goals. (Accessed: 2023-04-10)

IEA. (2022). *Renewables 2022.* Retrieved from https://www.iea.org/reports/renewables-2022

IEA. (2023). *World energy balances.* (Data retrieved 2023-01-26 from IEA World Energy Statistics and Balances (database), https://doi.org/10.1787/data-00512-en)

IPCC. (2021-2023). *Sixth Assessment Report.* Retrieved 2023-02-07, from https://www.ipcc.ch/assessment-report/ar6/

IRENA. (2022a). *Renewable energy targets in 2022 - a guide to design.*

IRENA. (2022b). *Renewable power generation costs in 2021.*

IRENA. (2023a). *Electricity generation (GWh) by Country/area, Technology, Grid connec-*

tion and Year. (Data retrieved 2023-01-26 from IRENASTAT (database), https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__PowerCapacityandGeneration/ELECGEN_2023_cycle1.px/)

IRENA. (2023b). *Installed electricity capacity (MW) by Country/area, Technology, Grid connection and Year.* (Data retrieved 2023-01-26 from IRENASTAT (database), https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__PowerCapacityandGeneration/ELECCAP_2023_cycle1.px/)

Jewell, J., & Cherp, A. (2023). The feasibility of climate action: Bridging the inside and the outside view through feasibility spaces. *WIREs Climate Change*. 10.1002/wcc.838

Kilinc-Ata, N. (2016). The evaluation of renewable energy policies across eu countries and us states: An econometric approach. *Energy for Sustainable Development*, *31*, 83-90. https://doi.org/10.1016/j.esd.2015.12.006

Lu, X., McElroy, M. B., & Kiviluoma, J. (2009). Global potential for wind-generated electricity. *Proceedings of the National Academy of Sciences*, *106*(27), 10933-10938. https://doi.org/10.1073/pnas.0904101106

Madsen, D. N., & Hansen, J. P. (2019). *Outlook of solar energy in europe based on economic growth characteristics* (Vol. 114). https://doi.org/10.1016/j.rser.2019.109306

Maris, G., & Flouros, F. (2021). The green deal, national energy and climate plans in europe: Member states compliance and strategies. *Administrative Sciences*, *11*, 3-5. https://doi.org/10.3390/admsci11030075

Oberthür, S. (2019). Hard or soft governance? the eus climate and energy policy framework for 2030. *Politics and Governance*, *7*, 18-20. https://doi.org/10.17645/pag.v7i1.1796

Perpiña Castillo, C., Batista e Silva, F., & Lavalle, C. (2016). An assessment of the regional potential for solar power generation in eu-28. *Energy Policy*, *88*, 86-99. https://doi.org/10.1016/j.enpol.2015.10.004

Proedrou, F. (2023). Eu decarbonization under geopolitical pressure: Changing paradigms and implications for energy and climate policy. *Sustainability*, *15*(6), 5083. 10.3390/su15065083

Prvlie, R., Patriche, C., & Bandoc, G. (2019). Spatial assessment of solar energy potential at global scale. a geographical approach. *Journal of Cleaner Production*, *209*, 692-721. https://doi.org/10.1016/j.jclepro.2018.10.239

Ritchie, H., & Roser, M. (2020). *Emissions by sector.* Retrieved 2023-04-29, from https://ourworldindata.org/emissions-by-sector

Rogers, E. M. (2003). *Diffusion of innovation* (5th ed.). The Free Press.

Rohatgi, & Ankit. (2022). *Webplotdigitizer: Version 4.6.* Retrieved from https://automeris.io/WebPlotDigitizer

Sahoo, S., Zuidema, C., van Stralen, J. N., Sijm, J., & Faaij, A. (2022). Detailed spatial analysis of renewables potential and heat: A study of groningen province in the northern netherlands. *Applied Energy*, *318*, 119149. https://doi.org/10.1016/j.apenergy.2022.119149

Skjærseth, J. (2021). Towards a european green deal: The evolution of eu climate and energy policy mixes. *Int Environ Agreements*, *21*, 2541. https://doi.org/10.1007/s10784-021-09529-4

Trunina, I., Pryakhina, K., & Yakymets, S. (2022). *Research on the development of renewable energy sources in the world due to the war in ukraine.* IEEE. 10.1109/MEES58014.2022.10005696.

Web application by the POLET research group. (n.d.). Retrieved 2023-02-08, from http://applets.polet.network/shiny/fitted_curves/

A Appendix

Code	Country	Historical growth [MW/year] (onshore | offshore)		Maturity (onshore | offshore)		dT filter (onshore | offshore)		Historical growth [MW/year] (Solar PV)	Maturity (Solar PV)	dT filter (Solar PV)
AT	Austria	232.86	-	Stable	-	Passed	-	-	Accelerating	N/A
BE	Belgium	194.57	-	Stable	Accelerating	Passed	N/A	-	Accelerating	N/A
BG	Bulgaria	188.51	-	Stagnating	-	Passed	-	-	Stagnating	Short dT
CY	Cyprus	-	-	-	-	-	-	-	-	-
CZ	Czech Republic	-	-	-	-	-	-	-	Stagnating	Short dT
DE	Germany	2854.71	1547.94	Stable	Stagnating	Passed	Passed	5481.28	Stagnating	Passed
DK	Denmark	176.94	135.62	Stagnating	Stable	Passed	Passed	-	Accelerating	N/A
EE	Estonia	-	-	-	-	-	-	-	-	-
ES	Spain	2208.67	-	Stagnating	-	Passed	-	-	Accelerating	N/A
FI	Finland	363.57	-	Stable	-	Passed	-	-	-	-
FR	France	1358.94	-	Stable	-	Passed	-	1265.77	Stable	Passed
GR	Greece	-	-	Accelerating	-	N/A	-	988.14	Stagnating	Passed
HR	Croatia	-	-	-	-	-	-	-	-	-
HU	Hungary	-	-	Stagnating	-	Short dT	-	626.57	Stagnating	Passed
IE	Ireland	331.85	-	Stable	-	Passed	-	-	-	-
IT	Italy	955.81	-	Stagnating	-	Passed	-	7649.11	Stagnating	Passed
LT	Lituania	-	-	-	-	-	-	-	-	-
LU	Luxembourg	-	-	-	-	-	-	-	-	-
LV	Latvia	-	-	-	-	-	-	-	-	-
MT	Malta	-	-	-	-	-	-	-	-	-
NL	Netherlands	305.09	-	Stable	Accelerating	Passed	N/A	-	Accelerating	N/A
PL	Poland	792.40	-	Stagnating	-	Passed	-	-	-	-
PT	Portugal	619.46	-	Stagnating	-	Passed	-	-	Accelerating	N/A
RO	Romania	-	-	Stagnating	-	Short dT	-	-	Stagnating	Short dT
SE	Sweden	1269.50	-	Stable	-	Passed	-	-	-	-
SI	Slovenia	-	-	-	-	-	-	-	-	-
SK	Slovakia	-	-	-	-	-	-	-	-	-

Table 6: The EU27 normalized maximum growth rate of onshore, offshore wind and Solar PV capacity, together with the results from the dT and maturity filtering.

			Solar PV			Wind		
Code	**Country**	**TES average (5 year)**	**Allocated contribution [GW]**	**Planned contribution [GW]**	**Ratio solar**	**Allocated contribution [GW]**	**Planned contribution [GW]**	**Ratio**
AT	Austria	73,57	15,14	12,4	0,82	13,04	7,62	0,58
BE	Belgium	89,96	18,55	9,98	0,54	15,95	10,30	0,65
BG	Bulgaria	37,96	7,81	3,22	0,41	6,73	0,95	0,14
CY	Cyprus	5,04	1,04	0,80	0,78	0,89	0,20	0,22
CZ	Czech Republic	72,24	14,86	3,98	0,27	12,81	0,97	0,08
DE	Germany	573,71	118,03	215	1,82	101,71	145	1,43
DK	Denmark	35,53	7,41	20	2,70	6,30	21,10	3,35
EE	Estonia	10,04	2,07	0,42	0,20	1,78	1,20	0,67
ES	Spain	275,22	56,62	39,18	0,69	48,79	50,33	1,03
FI	Finland	87,80	18,06	1,26	0,07	15,57	16,00	1,03
FR	France	505,32	103,96	39,55	0,38	89,58	43,55	0,49
GR	Greece	58,67	12,07	14,10	1,17	10,40	9,80	0,94
HR	Croatia	18,44	3,79	0,77	0,20	3,27	1,99	0,61
HU	Hungary	46,91	9,65	6,45	0,67	8,32	0,33	0,04
IE	Ireland	31,46	6,47	8	1,24	5,58	14	2,51
IT	Italy	326,43	67,16	52	0,77	57,87	19,30	0,33
LT	Lituania	12,51	2,57	0,79	0,31	2,22	1,32	0,60
LU	Luxembourg	6,98	1,44	1,14	0,79	1,24	0,21	0,17
LV	Latvia	7,53	1,55	-	-	1,33	1,18	0,88
MT	Malta	2,58	0,53	0,27	0,50	0,46	-	-
NL	Netherlands	121,56	25,01	27	1,08	21,55	27,10	1,26
PL	Poland	174,24	35,85	7,20	0,20	30,89	13,60	0,44
PT	Portugal	54,55	11,22	9	0,80	9,67	9,30	0,96
RO	Romania	60,09	12,36	5,05	0,41	10,65	5,26	0,49
SE	Sweden	143,08	29,44	3,15	0,11	25,37	12,11	0,48
SI	Slovenia	15,40	3,17	1,65	0,52	2,73	0,15	0,05
SK	Slovakia	29,97	6,17	1,20	0,19	5,31	0,50	0,09

Table 7: Results from calculation of allocated contribution for all EU27 countries for both solar PV and wind power. ”Planned contribution” is the countries’ planned total installed capacity 2030 in the respective energy sources. If the ratio is less than 1 a county contributes less than the allocated contribution.

				Capacity [MW]						Generation [GWh]							
Code	Country	Fuel	Year	NECP 2019 target		2019 classification	Target update		Classification	NECP 2019 target		Target update		Total generation 2030 [GWh]		Total electricity supply target 2030 [GWh]	
AT	Austria	SolarPV	2030	10620.76	*	Projection	11415.80	*	Law (EAG)	11666.67	1	12540	2			84000	3
		Wind.On	2030	7760.46	*	Projection	7622.32	*	Law (EAG)	16666.67	4	16370	5				
BE	Belgium	SolarPV	2030	9975.76	*	Projection				9730.82	6			159765.89	7	166249.12	**
		Wind.Off	2030	4000	8	Target	6000	9	Target								
		Wind.On	2030	4900	10	Projection											
BG	Bulgaria	SolarPV	2030	3216	11	Projection								30600	12	26622.08	**
		Wind.On	2030	948	13	Projection											
CY	Cyprus	SolarPV	2030	804	14	Projection										6200	15
		Wind.On	2030	198	16	Projection											
CZ	Czech Republic	SolarPV	2030	3975	17	Projection								84567.19	18	72334.19	**
		Wind.On	2030	970	19	Projection											
DE	Germany	SolarPV	2030	97924	20	Target	215000	21	Target					608809	22	575059.09	**
		Wind.Off	2030	19996	23	Target	30000	24	Target								
		Wind.On	2030	70899	25	Target	115000	26	Target								
DK	Denmark	SolarPV	2030	7842	27	Projection	20000	28	Unclear							46350	29
		Wind.On	2030	6983.37	*	Projection	8200	30	Unclear	22864.58	31						
		Wind.Off	2030	4262.09	*	Projection	12900	32	Unclear	15549.31	33						
EE	Estonia	SolarPV	2030	415	34	Target										17294.48	35
		Wind.On	2030	1200	36	Target											
ES	Spain	SolarPV	2030	39181	37	Target										306190	38
		Wind.On	2030	50333	39	Target											
FI	Finland	SolarPV	2030	1150.68	***	Projection	1258.80	***	Projection	1077	40	1178.2	41			101196	42
		Wind.On	2030	5834.58	*	Projection	15997.94	*	Projection	17188	43	47128.1	44				
FR	France	SolarPV	2028	39550	45	Target								627000	46	570547.69	**
		Wind.Off	2028	5700	47	Target											
		Wind.Off	2030				4400	48	Target								
		Wind.On	2028	33450	49	Target											
GR	Greece	SolarPV	2030	7700	50	Projection	14100	51	Unclear							61797	52
		Wind.On	2030	7000	53	Projection	7100	54	Unclear								
		Wind.Off	2030				2700	55	Unclear								
HR	Croatia	SolarPV	2030	768	56	Projection	770	57	Projection					17819	58	25876.75	**
		Wind.On	2030	1364	59	Projection	1990	60	Projection								
HU	Hungary	SolarPV	2030	6454	61											-	
		Wind.On	2030	329	62												
IE	Ireland	SolarPV	2030	431	63	Projection	8000	64	Target							46499.50	65
		Wind.Off	2030	3525	66	Projection	5000	67	Target								
		Wind.On	2030	7512	68	Projection	9000	69	Target								
IT	Italy	SolarPV	2030	52000	70	Target	52000	71	Target					337184	72	385481.28	**
		Wind.On	2030	19300	73	Target	19300	74	Target								
LT	Lithuania	SolarPV	2030	792	75	Projection								7147.80	76	25680.72	**
		Wind.On	2030	1322	77	Projection											
LU	Luxembourg	SolarPV	2030	1139.99	****	Target				1112	78			1931	79	12582.78	**
		Wind.On	2030	209.59	****	Target				674	80						
LV	Latvia	SolarPV	2030													8326.68	81
		Wind.On	2030	1179	82	Projection											
MT	Malta	SolarPV	2030	266	83	Projection								6326	84	10275.09	**
		Wind.On	2030														
NL	Netherlands	SolarPV	2030	27000	85	Projection								120000	86	122094.23	**
		Wind.Off	2030	10000	87	Target	21000	88	Target								
		Wind.On	2030	6100	89	Projection											
PL	Poland	SolarPV	2030	7200	90	Projection								201200	91	209307.98	**
		Wind.Off	2030	3800	92	Projection											
		Wind.On	2030	9800	93	Projection											
PT	Portugal	SolarPV	2030	9000	94	Projection								72937	95	74377.15	**
		Wind.On	2030	9300	96	Projection											
RO	Romania	SolarPV	2030	5054	97	Projection								77985	98	76635.20	**
		Wind.On	2030	5255	99	Projection											
SE	Sweden	SolarPV	2030	3151.06	***	Projection				2949.3	100			148571.4	101	128347.94	**
		Wind.On	2030	12113.4	*	Projection				35023	102						
SI	Slovenia	SolarPV	2030	1650	103	Projection								17724	104	19087.15	**
		Wind.On	2030	150	105	Projection											
SK	Slovakia	SolarPV	2030	1200	106	Projection								35355.31	107	37804.59	**
		Wind.On	2030	500	108	Projection											

Table 8: All data values for targets from 2019 and target updates found during the collection of data. * Converted from generation. ** Converted from total generation. *** Converted from generation using DK solarPV loadfactor. **** Converted from generation using BE solarPV loadfactor. ***** Converted from generation using BE onshore wind loadfactor. For references see below.

References for data in Table8 is as follows:

1, 3, 4: Federal Ministry Republic of Austria Sustainability and Tourism, National energy and climate plans (NECPs) (2019). Retrieved March 1, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps

2, 5: Schöniger, F., Resch, G. (2022, May). Modelling activities related to the Austrian 100% RES electricity target for 2030. Lecture, Wien. Retrieved March 1, 2023, from https://www.energy-community.org/dam/jcr:6cf14630-a4c4-4e93-a215-a71ec3835937/20210518_NECP_Reg_Exchange_Modelling_XV_Presentation_AT_100%25_RES_TUW.pdf.

6-8, 10: National Energy and Climate Plan, NECP 2021-2030, Section B - Analytical Basis Current data and projections (2019). Retrieved March 1 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps

9: North Sea Energy Cooperation (2022). Joint Statement on the North Seas Energy Cooperation. Retrieved March 3 2023, from https://energy.ec.europa.eu/topics/infrastructure/high-level-groups/north-seas-energy-cooperation_en

11-13: Ministry of the Environment and Water, INTEGRATED ENERGY AND CLIMATE PLAN OF THE REPUBLIC OF BULGARIA (2019). Retrieved March 23, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps

14-16: Cyprus Integrated national energy and climate plan for the period 2021-2030 (2020). Retrieved 20 mars 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps

17-19: National Energy and Climate Plan of the Czech Republic (2019). Retrieved March 3 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps

20, 22, 23, 25: Integrated National Energy and Climate Plan (2019). Retrieved February 28, 2023, from https://commission.europa.eu/energy

-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
21, 24, 26: Appunn, K. Wettengel, J. (2022). Germanys 2022 renewables and efficiency reforms. Clean Energy Wire . Retrieved 2023-05-06, from https://www.cleanenergywire.org/factsheets/germanys-2022-renewables-and-energy-reforms
27, 29, 31, 33: Danish Ministry of Climate Energy and Utilities, Denmarks Integrated National Energy and Climate Plan under the REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Governance of the Energy Union and Climate Action (2019). Retrieved February 27 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
28, 30: Klimaaftale om grøn strøm og varme 2022 (2022). Retrieved February 28, 2023, from https://www.regeringen.dk/media/11470/klimaaftale-om-groen-stroem-og-varme.pdf
32: Ritzau (2022). Denmark set to multiply green energy capacity by 2030, Energy Watch. Retrieved February 27 2023, from https://energywatch.com/EnergyNews/Policy___Trading/article14189516.ece
34-36: Estonias 2030 National Energy Estonias 2030 National Energy and Climate Plan (NECP 2030) (final version) (2019). Retrieved March 27 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
37-39: INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN 2021-2030 (2019). Retrieved March 1, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
40, 42, 43: Ministry of Economic Affairs and Employment of Finland. (2019). Finlands Integrated Energy and Climate Plan. Retrieved March 8 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
41, 44: Rystad Energy (2022). Finland, Denmark and Sweden leading on the green revolution. Retrieved May 6 2023, from https://www.rystadenergy.com/news/finland-denmark-and-sweden-leading-on-the-green-revolution
45-47, 49: INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN for FRANCE (2020). Retrieved March 28, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
48: North Sea Energy Cooperation (2022). Joint Statement on the North Seas Energy Cooperation. Retrieved March 3 2023, from https://energy.ec.europa.eu/topics/infrastructure/high-level-groups/north-seas-energy-cooperation_en
50, 52, 53: HELLENIC REPUBLIC Ministry of the Environment and Energy. (2019). National Energy and Climate Plan. Retrieved March 8 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
51, 54, 55: Taiyangnews (2023). As Greece Revises National Energy Climate Plan, Solar Is Seen As Largest Power Source In Long Run. Retrieved March 8 2023, from https://taiyangnews.info/markets/greece-targets-34-5-gw-total-pv-capacity-by-2050/
56, 58, 59: MINISTRY OF ENVIRONMENT AND ENERGY (2019). Integrated National Energy and Climate Plan for the Republic of Croatia. Retrieved March 21 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
57, 60: Abi Larkin (2002). GlobalData: Croatia to achieve its renewable targets, but will have vulnerable supply security. Energy Global. Retrieved March 21 2023, from https://www.energyglobal.com/special-reports/25112022/globaldata-croatia-to-achieve-its-renewable-targets-but-will-have-vulnerable-supply-security/
61, 62: Ministry of Innovation and Technology. National Energy and Climate Plan. Retrieved March 22 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
63, 65, 66, 68: Department of Communications, Climate Action Environment, National Energy Climate Plan 2021-2030 (2019). Retrieved March 2, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
64, 67: Department of the Environment, Climate and Communications (2022). Climate Action Plan 2023. Retrieved March 2 2023, from https://www.gov.ie/en/publication/7bd8c-climate-action-plan-2023/
69: North Sea Energy Cooperation (2022). Joint Statement on the North Seas Energy Cooperation. Retrieved March 3 2023, from https://energy.ec.europa.eu/topics/infrastructure/high-level-groups/north-seas-energy-cooperation_en
70, 73: Ministry of Economic Development, Ministry of the Environment and Protection of Natural Resources and the Sea and Ministry of Infrastructure and Transport (2019) INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN. Retrieved March 20 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
72: Tsvetomira, T. (2019, January 14). Italy plans 50 GW PV, 18.4 GW Wind to meet 2030 target. Renewablesnow.com. https://renewablesnow.com/news/italy-plans-50-gw-pv-184-gw-windto-meet-2030-target-639356/
71, 74: LA GIUNTA REGIONALE (2022). APPROVAZIONE RAPPORTO PRELIMINARE AMBIENTALE E SCHEMA DI PIANO ENERGETICO AMBIENTALE AI FINI DELLA PROCEDURA DI VALUTAZIONE AMBIENTALE STRATEGICA
75-77: NATIONAL ENERGY AND CLIMATE ACTION PLAN OF THE REPUBLIC OF LITHUANIA FOR 2021-2030 (2019). Retrieved March 8 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
78-80: "Ministère de lEnvironnement, du Climat et du Développement durable (2018). LUXEMBOURGS INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN FOR 2021-2030. Retrieved March 8 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps"
81, 82: LATVIAS NATIONAL ENERGY AND CLIMATE PLAN 20212030 (2019). Retrieved March 20 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
83, 84: Maltas 2030 National Energy and Climate Plan December 2019 (2019). Retrieved March 20 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
85-87, 89: Ministry of Economic Affairs and Climate Policy (2019). Integrated National Energy and Climate Plan 2021-2030. Retrieved March 1 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
88: Netherlands Enterprise Agency, Plans 2030-2050 (2023). Retrieved March 1, 2023, from https://english.rvo.nl/information/offshore-windenergy/offshore-windenergy-plans-2030-2050
90-93: MINISTRY OF NATIONAL ASSETS, EXECUTIVE SUMMARY OF POLANDS NATIONAL ENERGY AND CLIMATE PLAN FOR THE YEARS 2021-2030 (NECP PL) (2019). Retrieved March 23, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
94-96: PORTUGAL NATIONAL ENERGY AND CLIMATE PLAN 2021-2030 (NECP 2030) (2019). Retrieved March 7 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
97-99: The 2021-2030 Integrated National Energy and Climate Plan (2020). Retrieved March 28, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
100-102: The Ministry of Infrastructure, Swedens Integrated National Energy and Climate Plan (2020). Retrieved March 28, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
103-105: INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN OF THE REPUBLIC OF SLOVENIA (2020). Retrieved March 23, 2023, from https://commission.europa.eu/energy-climate-change-environment/implementation-EUcountries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps
106-108: SLOVAK MINISTRY OF ECONOMY, Integrated National Energy and Climate Plan for 2021 to 2030 (2019). Retrieved March 28, 2023, from https://energy.ec.europa.eu/system/files/2020-03/sk_final_necp_main_en_0.pdf

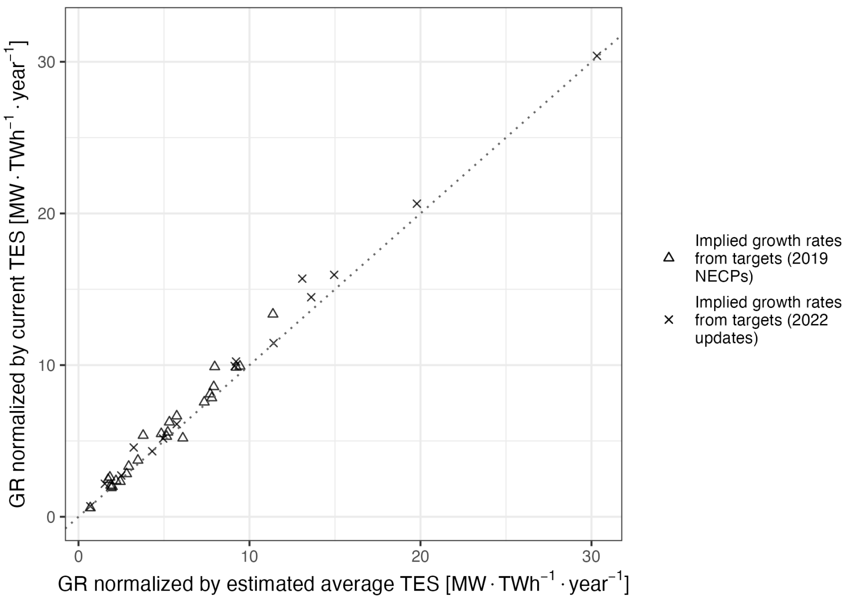


Figure 20: The figure shows implied growth rates in targets normalized by TES at the setting of the goal (y-axis) and normalized by average of TES at the setting of the goal and estimated TES for 2030 (x-axis). The dotted line shows the relation 1:1, and the two methods can be observed to be very consistent. The countries included are those that pass filtering for historical data.