Examining the dependency of feed-in tariff effectiveness on wind capacity concentration

An exploratory journey

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Abstract

Feed-in tariffs are a support instrument used to promote investment in wind energy. This paper examines how feed-in tariff levels stimulate wind growth, and if the effectiveness of a feed in tariff depends on domestic wind power concentration. The study contains an exploratory analysis of eight countries in the European Union where fitted line plots are used to visualize and interpret the relationship between feed-in tariff levels and wind growth. The same variables form a basis for the computation of a country-based feed-in tariff effect factor. The effect factor relies on simplified assumptions that limit the study's findings to a suggestive level. There was a positive correlation between the effect factor and wind concentration, indicating that feed-in tariff effectiveness had a positive relationship to wind concentration. Furthermore, the results indicate a positive but heterogeneous wind growth relationship to changes in feed-in tariff levels across different countries. The characteristics of the growth reaction are suggested to be influenced by the long-term consistency of feed-in tariff support.

Keywords: Wind energy, Energy policy, Feed-in tariffs, European Union

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Abbreviations

EC	European Commission
EU	European Union
FiT	Feed-in Tariff
IEA	International Energy Agency
RE	Renewable Energy
SLU	Swedish University of Agricultural Sciences

1. Introduction

Renewable energy sources have during the last few decades received increasing attention as they play an important role in combating climate change, dependence of imported energy and increasing prices of fossil energy sources. Many countries have set goals to shift towards renewable energy production. Dependency on import of fossil fuels has since the outbreak of the war in Ukraine become a more pressing matter of national security. Additionally, regulatory support of renewable energies (RE) increases the cost competitiveness of new energies (Schmalensee 2011). In order to meet the goals set by the Paris Climate agreement in 2015, many governments have set goals to decarbonize their respective energy sectors by growing the share of renewable energy sources. The European Union (EU) has actively pursued the promotion and support of RE. As of today, the EU pursues an emissions reduction of at least 55% by 2030 from 1990 levels (regulation 401/2009/EC).

Among renewable energy sources, wind energy has emerged as a highly cost competitive and commercialized renewable energy source in recent years. Wind energy is a fast growing energy source and is expected by the International Energy Agency (IEA) to be the largest electrical energy source in Europe by 2027 (IEA, 2022). Wind energy produces no polluting emissions and has been in use for centuries in Europe and more recently in the United States and other nations.

To incentivize the growth of wind power, governments have implemented market-based support policies. Feed-in tariffs (FiTs) have since the 1990s become a prominent and cost-effective policy instrument with widespread usage in promotion of renewable power, including wind. In 2021, 92 countries worldwide used feed-in policies to promote renewable energy (REN21, 2022). Though specifics of the tariffs differ between implementations, the central features of a FiT is a long-term contract guaranteeing a set price to producers of renewable electricity and priority access to the electricity grid. An FiT thus makes investment in renewable energy more attractive by reducing purchase security risk as well as price fluctuation risk.

The aim of this report is to better understand how FiT policies stimulate wind growth by analyzing the relationship between FiT levels and wind capacity growth per capita, as well as to investigate the dependency of wind support policy effectiveness on relative wind concentration. The study provides exploratory analysis on the relation between FiT levels and wind capacity growth in eight countries in the EU with a variety of policy contexts. Based on suggestions from existing literature on the subject, we hypothesize that FiT effectiveness has a negative correlation to relative wind capacity, implying that countries with high wind capacities per capita would experience a relatively lesser growth effect from FiTs.

1.1 Theoretical background

1.1.1 Discrepancies of FiTs

Despite the common objectives and basic structure, wind FiTs exhibit substantial variations between countries. These differences arise from factors such as national policy goals, available resources and energy infrastructure. As such, the specific design of FiTs, including the tariff levels, contract duration, and adjustment mechanisms, can be tailored to the unique circumstances and policy objectives of each country.

The goal of FiTs is to incentivize investment in renewable energy by making its production safer and more financially stable, thereby also the deployment of renewable energy capacity. Jenner et al. (2013) paints factors by which FiTs vary. Firstly, a FiT can be structured as either a fixed-price tariff, independent of electricity price variation, or a premium tariff, adding a set increase to the given current electricity price to producers. In the EU, Denmark is the notable exception, employing premium tariffs as opposed to the more conventional fixed-price policy. Secondly, FiTs vary by cost allocation. The difference between the tariff and the market price can be paid either among electricity consumers, or by the state. Limitations on the costs associated with a FiT may also vary. Furthermore, contract durations and degression rates of the tariffs differ between implementations. A digression rate determines the gradual decline of the tariff amount over time. FiTs often include degression rates as the tariffs are typically designed to provide support and stability during the earlier stages of an RE project.

1.1.2 Literature background on FiTs

In "A review on global wind energy policy", Saidur et al. (2010) note that wind energy policy could help increase power generation as well as stimulate the energy industry. Increased use of wind energy can in addition to reduction of greenhouse gas emissions also enhance national security and protect consumers from price spikes following supply shocks of fossil energy input factors. The article concludes that FiTs, along with Renewable Portfolio Standards, incentives, pricing laws and quota systems, are the most useful energy policies in practice today in terms of stimulating wind power development. The researchers note, however, that the optimal model for a tariff is dependent on the context and goals of different countries.

Nordensvärd and Urban (2015) describe FiTs in a less optimistic light. The article analyzes the partially hampering effects of Germany's extensive use of FiTs using extensive qualitative interviews with key actors in energy firms. The researchers find that the long-term profitability increase that FiTs provide for renewable energy producers can establish a socio-technical paradigm that is "locked in". Lock-in is defined as a form of inertia, or a plateau, where cultural and/or economic benefits for producers act as a barrier for development of potentially superior alternatives. This concept can be applied to both technological and policy landscapes. The nature of FiTs being paid per unit of energy produced creates a direct incentive to scale up the capacity in the current technological and policy landscape, while important supporting areas, such as the do grid system, do not receive the same financial stimulus lag behind the increased wind capacity, creating an underfunded bottleneck for wind power development. The article concludes that FiTs for wind rather favor specific wind innovation than fueling an energy transition towards wind.

Blazquez et al. (2018) analyze and propose the existence of a paradox created by the promotion of renewables on the electricity market. The liberalization of the electricity market has led to marginal costs of power production to largely determine electricity prices. The very low marginal costs of many renewable energy sources, including wind, would cause a decrease in electricity price as renewable market shares increase. This would infer that, as renewable energy share increases, it would become less profitable. Following the same logic, the rentability of renewable energy sources is dependent on fossil sources with higher marginal costs, driving electricity prices up for all producers. Policies that successfully increase the share of renewable power could therefore be decreasing in effectiveness as the share of renewable power increases. A simple analysis of the market side perspective is performed, where renewable penetration in the electricity market is linked to a decrease in electricity prices in three European countries. FiTs are discussed as a potential way of managing the impact of the paradox, but a guaranteed price that is above the production costs of renewable energy sources requires increased public spending on the policy as renewable power share expands. The study forms a basis for the research hypothesis that wind FiTs become less effective in promoting wind capacity growth, as profitability decreases with a larger share of renewables used.

An example of a previous study evaluating FiT effectiveness is Dijkgraaf et al. (2018). The study employs an empirical panel data test of the effectiveness of FiTs in stimulating growth in photovoltaic capacity per capita. FiT data from 30 OECD member states are gathered and tested in three econometric models. It makes use of extensive policy data from each country (tariff level, duration and cap). Importantly, control vectors for non-FiT policy variables are included, as well as a measure for the consistency of a FiT, measured by the standard deviation of the tariff amounts. The study finds that FiTs have a positive effect on a country’s yearly added photovoltaic capacity per capita, while also highlighting the importance of the consistency of a FiT. It is stated that the effect of a FiT policy can be seven times larger if its features are well designed. While the paper analyzes solar energy and not wind energy, the method used still provides important insight into important features affecting the effectiveness of FiTs that are applicable to our analysis.

1.1.3 Other wind promoting policy instruments

Many of the countries observed in the study make prevalent use of tendering procedures for distribution of benefits to wind producers. A tendering scheme entails the public authority auctioning of financial support contracts for selected RE projects instead of the contracts being set through direct agreements between the authority and the RE producer. While a tendering scheme can serve as means of distributing FiT contracts, they can also be used to distribute other kinds of contracts, such as specific remunerations or quota-based incentives.

Other examples of policies for wind promotion are tax incentives or exemptions, investment grants and financing incentives. While these policies usually do not make out the main part of a RE support scheme, they are often used in combination with other instruments (Gonzales et al, 2016).

2. Methods

2.1 Study design

This paper raises the question of the possibility of the heterogeneity of FiT effectiveness for wind power being dependent on the concentration of wind power in a country. This study used wind FiT data from eight different European countries to explore the differences in FiT effect on population weighted wind capacity growth in the countries observed. This was an exploratory study, comparing the implementation effects of FiTs in eight European countries. The aim was to provide insight into potential stages in the development of a country's wind sector where FiTs would be more suitable to use.

The study's main outcome variables on which the analysis was built were mean levels of FiT and wind capacity growth per capita based on existing literature by Dijkgraaf et al (2018). The measure of FiT effectiveness was based on the two outcome variables.

2.2 Statistical analysis

In order to visualize the statistical relationships between FiT levels and wind capacity growth for all observed countries, data on FiT levels and wind capacities were fitted to each other in plots using Stata 16/IC (v 16, StataCorp LLC, College Station, TX, USA). Excel was used to correlate a measured variable of FiT effect to wind capacity concentrations, based on wind capacity and FiT data. The correlations and graphs constituted the results of this study and were interpreted on a country-by-country basis, as well as on an integrated basis, including all countries.

2.3 Data

Yearly data for mean FiT levels in USD/MWh for wind between 2000-2019 across eight EU countries were gathered from OECD statistics database, amounting to a total of 160 observations. Wind capacity data were obtained from

Our World in Data. Population indicators such as GDP per capita and population were sourced from the World Bank.

To produce the exploratory graphs, time series line plots were used to visualize the relationship between wind capacity per capita and FiT levels. The graphs were then analyzed and put into the policy context of each country to explain the phenomena seen in the graphs.

The measure of effectiveness for a FiT was determined to be the cumulative amount of wind capacity growth per capita divided by the maximum level of FiT support during the observed period. The FiT effect factor was designed to take into account the nature of a FiT distribution.The maximum level of FiTs over the measured period of 20 years was used to account for the long-term design of FiT contracts. When FiTs levels are suddenly removed, producers still receive benefits according to long-term contracts and thus high payments are made even when FiTs are lowered. Conversely, the growth effects of a FiT contract are distributed over longer times. Therefore, the cumulative wind capacity growth per capita numbers were used instead of yearly observations.

A crude FiT effect factor was calculated as follows:

$$FITEFF_i = \frac{fitmax_i}{auc\_wcgpc\_tot_i}$$

$FITEFF_i$ represents the FiT effect factor for country i. $fitmax_i$ represents the highest FiT value observed in country *i* in the measured time period of 2000-2019, and $auc\_wcgpc\_tot_i$ represents the area under the curve of the wind capacity growth per capita in country *i* during the same time period. The estimation of the effect variable makes key assumptions that affect the accuracy of the results. The first assumption made is that there are no interfering mechanisms in the relationship between FiT levels and wind capacity growth per capita. It is presumed that FiT levels are the only cause of wind capacity growth. The second assumption made is that differences in FiT designs across countries are negligible when measuring the effect factor.

3. Results

3.1 Wind concentrations

Figure 1 shows the wind concentration development for all eight countries over the period 2000-2019. Denmark (maroon) continually has the highest wind concentration. A remarkable period of growth can be seen in Finland (yellow) and Sweden (dark blue) in the latter half of the observed period.

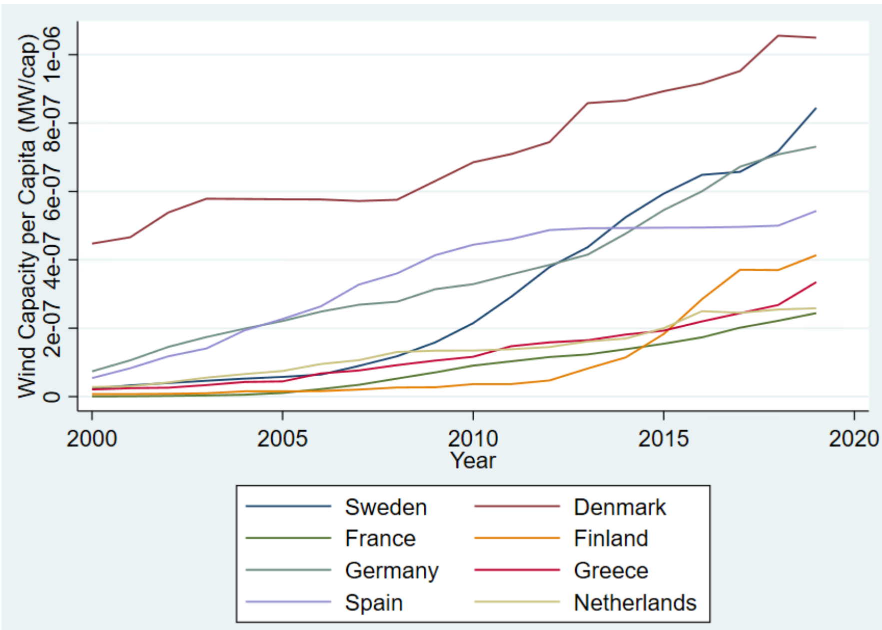

Figure 1. Wind concentration development by country.

The y-axis displays wind capacity per capita and the x-axis displays the time period (2000-2019). Different color lines represent eight countries observed in the study.

3.2 Denmark

The Danish results as shown in Figure 2 show high wind capacity growth in periods of FiT support. The Danish FiT levels are comparatively low, despite the large growth reactions.

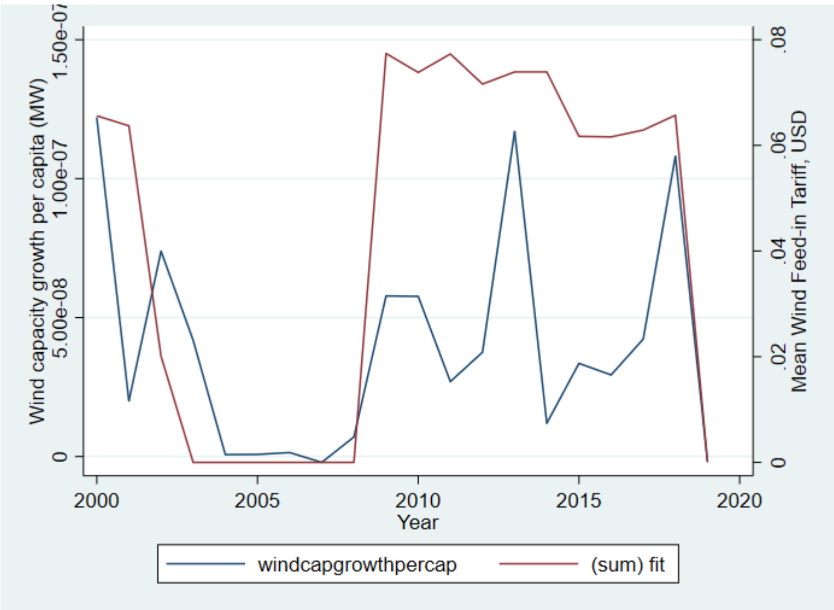

Figure 2. Danish FiT and wind capacity growth relationship.
On the y-axis we see wind capacity growth per capita for Denmark (blue) fitted to the mean levels in USD/MWh of Danish wind FiTs (red) and on the x-axis the time period 2000-2019.

3.3 Finland

Figure 3 displays nominal wind growth in Finland until several years after a sudden increase in FiT levels. The growth effect reached its peak in 2016, five years after the peak values of Finnish FiT support in the time period.

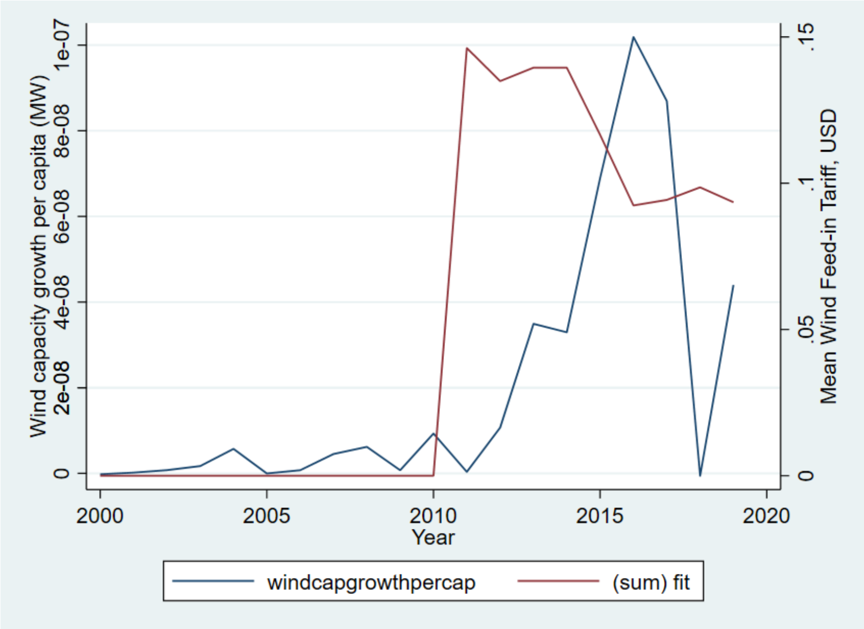

Figure 3. Finnish FiT and wind capacity growth relationship.

On the y-axis we see wind capacity growth per capita for Finland (blue) fitted to the mean levels in USD/MWh of Finnish wind FiTs (red) and on the x-axis the time period 2000-2019.

3.4 France

Figure 4 shows continuous high French FiT levels until 2015. Wind capacity development experiences a drop preceding the end of FiT support, but recovers in subsequent years. Overall, growth levels are low as compared to the other countries observed.

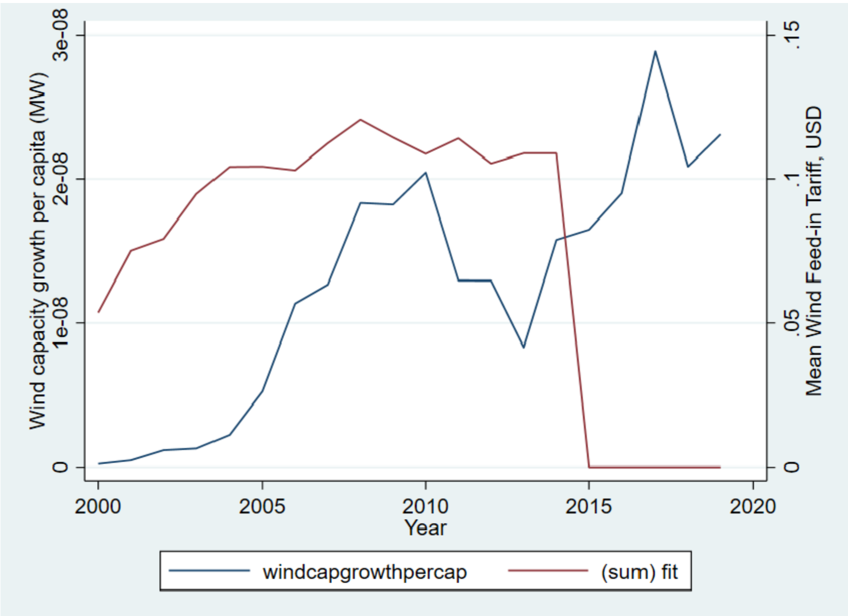

Figure 4. French FiT and wind capacity growth relationship.

On the y-axis we see wind capacity growth per capita for France (blue) fitted to the levels in USD/MWh of mean wind FiTs for France (red) and on the x-axis the time period 2000-2019.

3.5 Germany

Figure 5 shows that Germany makes continuous use of FiT support. Wind support is also relatively stable at medium to high levels throughout the time period.

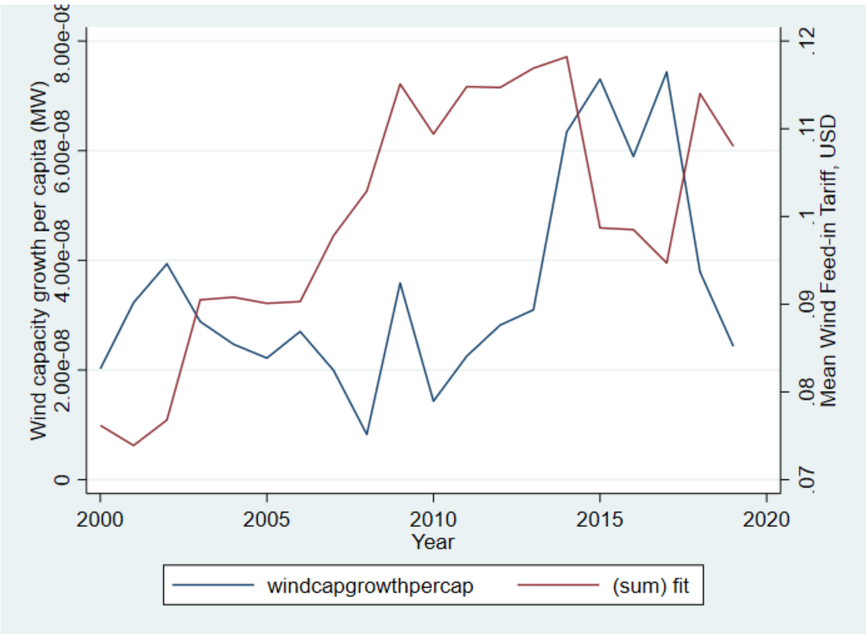

Figure 5. German FiT and wind capacity growth relationship.

On the y-axis we see wind capacity growth per capita for Germany (blue) fitted to the levels in USD/MWh of mean wind FiTs for Germany (red) and on the x-axis the time period 2000-2019.

3.6 Greece

Greece has high FiT levels during 2006-2016, as shown in Figure 6. In 2017, there is an abrupt drop in FiT levels. Wind capacity growth levels are continually low until 2019 where we see a spike increase.

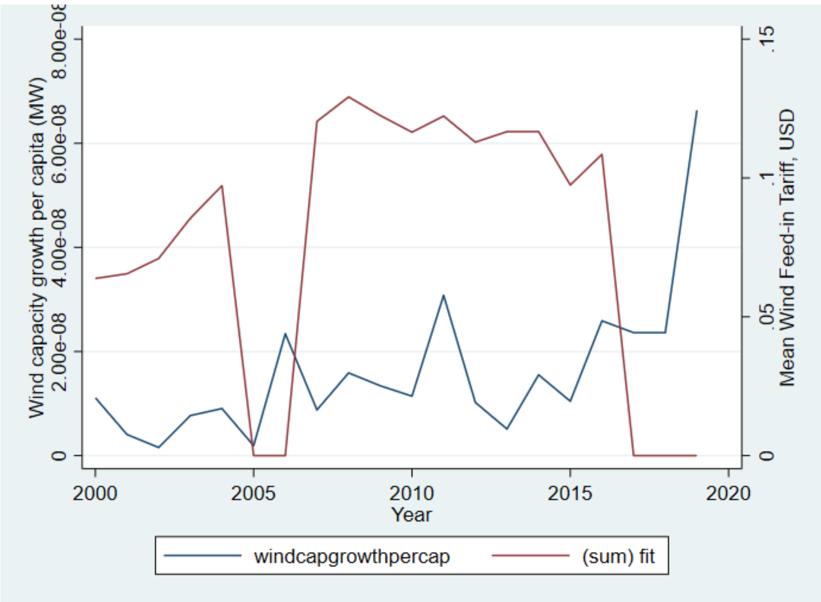

Figure 6. Greek FiT and wind capacity growth relationship.

On the y-axis we see wind capacity growth per capita for Greece (blue) fitted to the levels in USD/MWh of mean wind FiTs for Greece (red) and on the x-axis the time period 2000-2019.

3.7 The Netherlands

Figure 7 shows a growing Dutch FiT commitment after 2003. However, wind capacity growth numbers are sporadic and generally low, possibly indicating ineffective implementation of the support instrument.

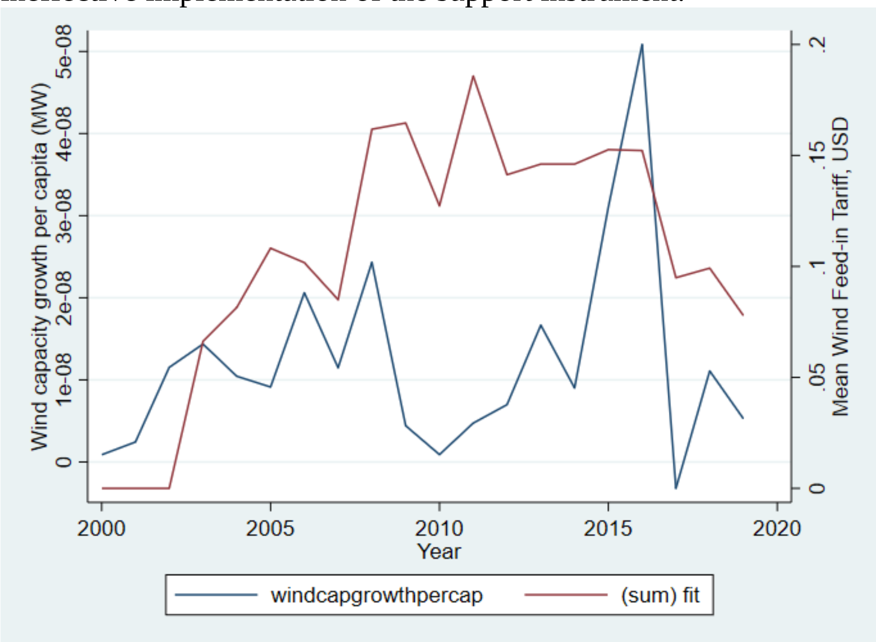

Figure 7. Dutch FiT and wind capacity growth relationship.

On the y-axis we see wind capacity growth per capita for the Netherlands (blue) fitted to the mean levels in USD/MWh of Dutch wind FiTs (red) and on the x-axis the time period 2000-2019.

3.8 Spain

Figure 8 shows Spanish FiT levels closely following the shape of FiT levels during the support years of 2000-2013. Growth levels are moderate compared to other countries in the sample.

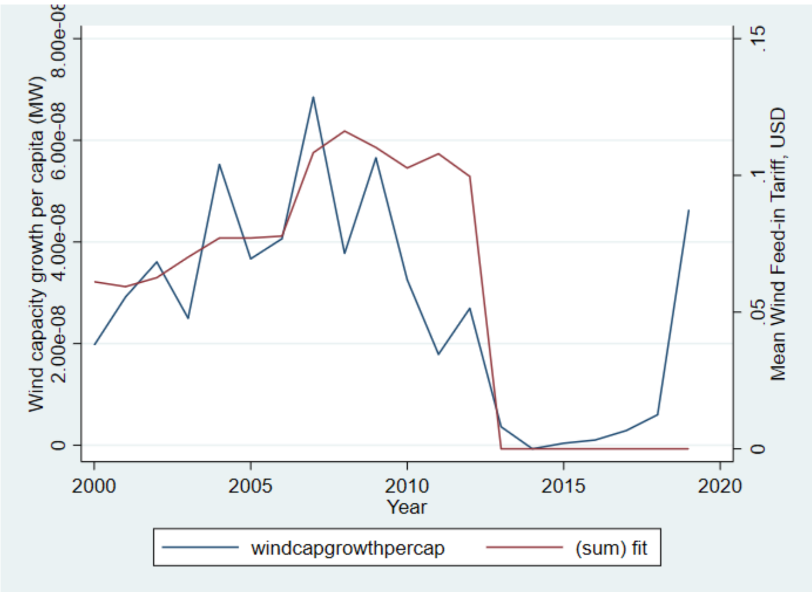

Figure 8. Spanish FiT and wind capacity growth relationship.
On the y-axis we see wind capacity growth per capita for Spain (blue) fitted to the mean levels in USD/MWh of Spanish wind FiTs (red) and on the x-axis the time period 2000-2019.

3.9 Sweden

Figure 9 shows FiT support ending from initially low levels in 2003. However, wind capacity growth reaches high levels. The Swedish example shows significant wind growth that is clearly not caused by FiT support.

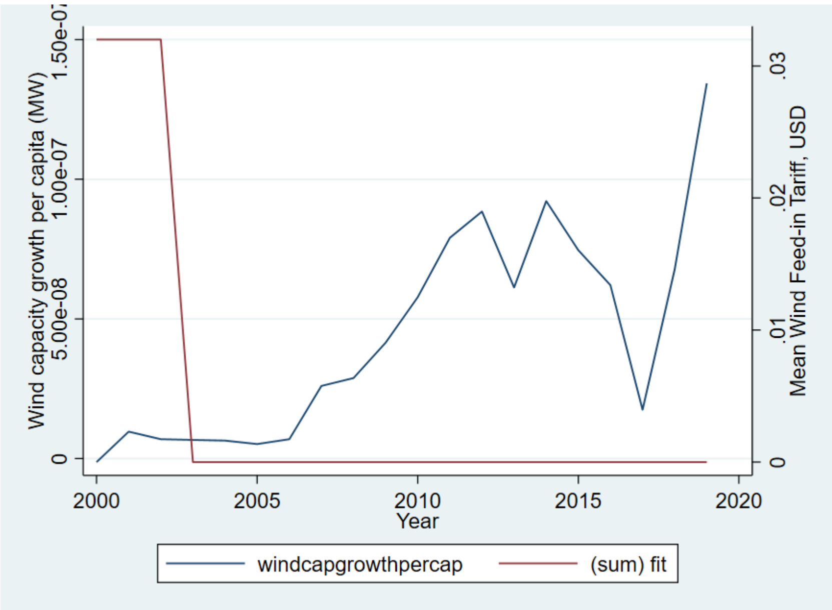

Figure 9. Swedish FiT and wind capacity growth relationship.
On the y-axis we see wind capacity growth per capita for Sweden(blue) fitted to the mean levels in USD/MWh of Swedish wind FiTs (red) and on the x-axis the time period 2000-2019.

3.10 Effect factors and correlations

FiT effect factor calculated for each country is displayed in Table 1. The corresponding components of the FiT effect factor are listed. The Netherlands has the lowest FiT effect factor, while Sweden has the highest value. Additionally, the average wind capacity concentration can be seen in Table 1. Notably, Denmark has the highest average wind concentration. The correlations (including and excluding Sweden) are based on the FiT effect factor and the average wind concentration for each country.

Table 1. Correlations of FiT effect factor to wind capacity concentration.

	*auc_wcgpc_tot *e-7*	*fit_max*	*Growth per fit_max*	*avgwindcappercap *e-7*	*growth per fit per avgwindcappercap*	
Country	Integrated wind growth per capita	Max FiT level	FiT effect factor	Avg. wind capacity concentration	FiT Effect / Wind Density ratio	Correlations
Denmark	7,26	0,0774	93,79844961	7,14	13,13703776	*FiT effect to wind capacity concentration*
Finland	3,88	0,1462	26,53898769	1,05	25,27522637	**0,369656636**
France	2,38	0,1206	19,73466003	0,887	22,24877118	*Sweden excluded*
Germany	6,64	0,1182	56,17597293	3,63	15,47547464	**0,9763836249**
Greece	2,81	0,1292	21,74922601	1,28	16,99158282	
Netherlands	2,4	0,1858	12,91711518	1,36	9,497878807	
Spain	5,09	0,1162	43,80378657	3,54	12,37395101	
Sweden	8,05	0,032	251,5625	3	83,85416667	

4. Exploratory analysis

4.1 European Union context

All tested countries share the goals set by the European Green Deal, and are regulated by the EU’s Energy and Environmental State aid guidelines. In September of 2001, the EU gave indicative renewable targets of 12 % for the EU as a whole to promote renewable energy sources so that global climate targets are reached. Our results, as shown in figure 1, show a significant increase in wind concentration for all countries tested, indicating shared progress towards renewable targets. The renewables targets have been revised and increased several times and made legally binding in 2018 (directive 2018/2001/EC). Provisional agreements have also been reached in 2023 to increase the renewable percentage to 42,5%. The study, however, is limited to observations from 2000 to 2019 and thus more recent developments are not investigated. European regulations and guidelines for the design of RE promotion policies are included. Several observed countries shift their policies to include contract distribution through tendering schemes as endorsed by the EU regulation (directive 2018/2001/EC).

4.2 Denmark

As is evidenced in Figure 1, the Danish wind concentration is the highest of all sampled countries. The difference is especially large in the beginning of the measured period. This is due to Danish government support for wind energy development having been continuous and multi-faceted since the 1980s. Several extensive wind support policies have been in place over the observed time period including a premium FiT scheme as well as a tendering system being in place since 2009. The majority of Denmark's wind capacity growth has taken place in the 1990s (IRENA-GWEC, 2013).

The graphical results as seen in Figure 2 show a relatively close synchronization of support periods in 2000-2001 as well as 2009-2018, showing high levels of capacity growth in support periods and lower growth in years with no support. The FiT effect factor calculated in Table 1 is the second highest in the sample, indicating that Denmark has used relatively low FiT amounts whilst achieving high levels of wind growth during support periods. The Danish case exemplifies a high wind concentration environment where FiT support stimulates high levels of growth.

4.3 Finland

Finland has had no RE support policy until 2011 (Figure 3), when a rigorous premium FiT scheme was put into force. Subsequent wind capacity growth has been fast, though a lagged reaction of wind capacity growth to FiT policy implementation can be seen in Figure 3. The FiT scheme was altered to distribute remuneration through a tendering process in 2018. In Figure 3, a sudden dip in wind capacity growth can be seen in the same year of the policy alteration, possibly indicating investor uncertainty in a changing policy landscape. However, the significant growth in wind concentration during the 2010s (Figure 1) reflects effective implementation of the wind support policy in an environment with low initial wind concentration. While the Finnish FiT effect factor, as seen in Table 1, is moderate, it must be considered that number is held back by the low growth years before the implementation of FiT support.

4.4 France

Out of the countries tested, France has the lowest average wind capacity per capita, at around 0,89 Watt per capita, as indicated by Figure 1. French FiTs, named “First Purchase Obligation Agreements” with a standard contract length of 15 years, were removed in 2016 (active since 2000) in favor of a so-called additional remuneration system, providing premium contracts distributed through a tendering scheme (Tazi et al, 2020). However, due to the long-term contracts provided to producers, many were still receiving benefits from FiTs after they ended. FiTs were set higher than typical electricity market prices. The drop in FiT support in 2015, as seen in figure 4, is due to the shift in policy to the additional remuneration scheme. Though the latter policy is very similar in nature to a premium FiT, the subsidy payments are defined differently by the OECD database and are therefore not registered. French wind capacity growth largely remains at similar levels after the policy shift in 2015, though a dip can be observed before the shift in 2013, perhaps pointing to investor uncertainty as news of policy shifts are noted.

4.5 Germany

Germany, along with Denmark, has historically been the most prolific and consistent user of FiT policies of the countries observed. Out of the countries in the sample, Germany is the only country to use FiTs as its main wind support policy over the entire study period. This can be seen in our results, where Germany is the only country that has continuous positive FiT levels. Beyond their consistent use, Germany has provided wind energy producers with long contracts spanning 20 years. This implies that producers can benefit from high FiT levels even after the decline in value of new contracts, creating an attractive environment for investors. Wind capacity shows medium to high levels of growth throughout the time period in figure 5, matching the image of a secure environment for wind investment. Though FiT support is continuous, the design of the policy has shifted. In 2017, the German Renewable Energy Sources Act (EEG) was modified to transition to an auction system, distributing FiT contracts through a tendering scheme. Although the changing nature of the policy has to be taken into account when examining specific policies, the FiT effect remains largely unchanged for wind producers and thus should not affect the strength of FiT effectiveness tests and subsequent correlations made. Overall, the German example shows strong growth in an environment of high wind concentration with consistent FiT support.

4.6 Greece

Greek wind concentration, as seen in Figure 1, is continually in the lower half of the country sample. The results show high FiT levels in the period of 2006-2016 (Figure 6). In the corresponding time period, Greece made use of onshore and offshore wind FiTs at a fixed price level with a contract length of 10 years. Although wind capacity growth levels are increased as compared to pre-2006 levels, the growth levels remain low compared to other countries in the sample.

Furthermore, the results show a sudden drop in FiT levels from 2017. This is due to Greece transitioning from a FiT support scheme to a feed-in premium based on a tendering system in January 2017 (RES LEGAL Europe, 2019). The new support system is not measured as FiT in the OECD database, meaning that licenses for a fixed quota of renewable energy production are auctioned to producers. The subsequent increase in wind capacity growth in 2019 is thus not mainly attributable to FiT levels.

The combination of a sustained period of high FiT levels in an environment of low wind concentration corresponding to comparatively low levels of wind growth is a clear indicator speaking against the research hypothesis.

4.7 Netherlands

While the Dutch share of RE sources has doubled between 2008 and 2019 (IEA 2020), the Netherlands still have a relatively low wind concentration among the countries tested, having the second lowest wind capacity per capita in 2019. A premium FiT scheme named the SDE+ has been the main policy instrument of wind promotion since 2003, along with other renewable and low-carbon sources (RES LEGAL Europe, 2019). The introduction of the SDE+ is seen in Figure 7 as FiT levels increase from zero to around 0,07 USD/MWh with further subsequent increases. The subsidy program has been well funded and has provided high FiT levels to wind projects with long contract lengths of 15 years over the majority of the measured time period. However, wind capacity growth has been inconsistent and less responsive to FiT support than other countries in the sample. The Dutch results paint the image of a low wind concentration environment where high levels of FiT subsidies fail to stimulate high wind growth. The Dutch FiT effect factor as shown in correspondingly is the lowest out of all eight countries.

4.8 Spain

The Spanish government has consistently used FiTs as a major policy instrument for promotion of all RE sources since 1994 (Ringel, 2006). Spain has had a strong development in the wind power sector, placing in the top half of the countries tested in wind capacity per capita, being the only southern European country to do so (Figure 1). In 2013, feed-in support for wind was cut, as seen by the sudden drop in FiT levels in Figure 8. The FiT support system was replaced by a specific remuneration scheme in 2014 (RES LEGAL Europe, 2019). However, due to a slump in renewable investments caused in part by a lack of financial means for RE support and tariff deficits from support years retroactively being charged to self-consumption RE producers, RE investments were hampered until the removal of the charges to producers in 2018 (IEA, 2021). The low wind capacity growth between 2013-2018 in Figure 8 clearly shows the effect of the lack of wind investments. The Spanish case shows an environment with high wind concentration where wind growth reactivity to FiT support instruments is high, though growth levels are moderate.

4.9 Sweden

The case of Swedish wind FiT support and its relation to wind capacity growth is dubious, caused by the very low FiT levels and their early cutoff in 2003 (Figure 9), when a quota-based RE certificate system was introduced (Nilsson et al, 2004). The certificate system is still active and has been the main RE support policy since 2003, including for wind, having developed the second highest wind concentration per capita behind Denmark in 2019 (Figure 1). Though wind capacity growth has been remarkable, it cannot be attributed to FiT support. The Swedish case clearly decouples any strict causal relationship between FiT levels and wind capacity growth, showing that growth is not dependent on FiT levels. Sweden has been removed from the second correlation test due to FiTs being abandoned early in the study period.

4.10 Integrated analysis

It can be interpreted from the graphical results that changes in FiT levels generally can be tied to a positive reaction in wind capacity growth. The positive relationship is in line with previous research on FiT effectiveness (Dijkman et al 2018, Jenner et al 2013). However, the size and nature of a growth reaction to FiT changes are observed to be highly heterogeneous between countries. While the FiT to wind capacity growth relationship for each country has unique and differing characteristics there are certain recurring themes that can be observed from the graphical results. Firstly, in countries with long and consistent FiT support, such as Denmark, Spain and Germany, wind capacity growth developments are notably synchronized to FiT levels. Countries with less consistent FiT support, such as Greece and the Netherlands, show less reactivity in wind capacity growth to changes in FiT levels. This implies that wind sectors in countries where support has been consistent more quickly can adapt to changes in policy. The quick reactivity of a mature wind market stands in contrast to the example of Finland, where the sudden introduction of an extensive wind support policy has a delayed reaction in terms of wind capacity growth by several years.

A second recurring theme in several countries in the sample is a wind capacity growth dip ahead of a change in wind policy. Notable examples include France experiencing a decline in wind capacity growth ahead of the policy change in 2015, as well as a similar dip in Spain in 2011-2012, preceding the change to a specific remuneration scheme in 2014. The pattern of dips in wind capacity growth may be due to investor caution in uncertainty over the future of policy. Investor caution is suggested by Dijkgraaf (2018) to be a potential cause for lapses in wind investments, and the results of this study support this implication.

When correlating the FiT effect factor to average wind capacity concentration in the study period, a positive coefficient is reached (Table 1). The exclusion of Sweden due to other policy instruments causing most Swedish wind capacity growth further reinforces the positive correlation. When looking at the integrated wind growth per capita, the three countries with the highest accumulated growth are also the countries with the highest wind concentrations during the entire study period, when excluding Sweden (Figure 1).

5. Discussion and conclusion

The numerical results show a positive correlation between FiT effectiveness and wind concentration, thus going against the research hypothesis. There are however several factors to consider before accepting the results. Firstly, the FiT effect factor on which the correlation is based relies on the assumption that there are no interfering mechanisms in the connection between FiT levels and wind capacity growth. This can be seen in multiple cases to be a problematic assumption, as there are many other active wind policy instruments in the countries tested, most clearly exemplified by the case of Sweden, where the high levels of wind growth occur during a period when a non-FiT support system for wind is active. Although the assumptions made for the study's design diminish the reliability, they provide a basis from which the exploratory analysis can be more easily understood and compared between different countries. To overcome the limitations set by the study, government spending data on wind energy could serve as a proxy for the total efforts of public authorities to promote wind energy. Spending data on specific policies would also shed more light on the effect of wind promoting policies from a cost effectiveness perspective.

A second consideration to be made is that the FiT effect factor incorporates the total area under the curve of wind capacity growth. Thereby, the measure includes a multitude of periods where wind capacity growth is observably unrelated to FiT levels after shifting policies away from FiTs, as exemplified by Sweden after 2003. While the exclusion of Sweden partly mitigates this issue, the problem remains prevalent in several countries, such as France after 2015 and Spain after 2013. The results of the correlation tests, which are based on the FiT effect factor, are therefore to be taken with caution.

GDP per capita is a factor accounted for by previous studies examining FiT effectiveness (Dijkgraaf et al 2018, Jenner et al 2013). Indeed, the three highest values in the FiT effect factor variable used in this study are also among the highest in average GDP per capita over the study period. It makes obvious sense that wind capacity can be more easily expanded by a richer country, and any interpretation of the analysis should take this into account. There are however notable exceptions to the pattern of GDP per capita dependent wind growth. The Netherlands have the single lowest FiT effectiveness level of all countries tested, despite being the country with the highest average GDP per capita in the tested sample over the study period.

The use of a sample exclusively consisting of countries within the European Union is done to provide a similar policy landscape, where the centralized climate goals and regulatory guidelines for RE policy provide cross-country policy contexts where direct comparison is more feasible. While the study's focus on EU countries maximizes the commonalities in policy landscapes between the countries tested, the implications of a definitive answer to the research question would have implications for policymakers worldwide. A further study with a more rigorous numerical analysis could be done to further explore the research topic.

While the simplified assumptions on which the correlation results rely limit the study from definitively concluding the research hypothesis stating FiT effectiveness in being negatively dependent on wind concentration, the findings contradict implications from existing literature. The study finds no support for suggestions by Nordensvärd & Urban (2015) and Blazquez et al. (2018) that increased renewable percentages and prolonged wind policies could lead to complications in stimulating wind growth with FiTs.

5.1 Conclusion

The interpretations of the graphical results indicate a positive relationship between wind capacity growth per capita and FiT levels that is highly heterogeneous across different countries. Furthermore, the study suggests that the consistency of wind support could affect the characteristics of the growth response to a FiT policy, as countries with highly consistent support show a tendency towards faster growth reactions following changes in FiT levels.

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