The effects of renewable energy generation on electricity prices

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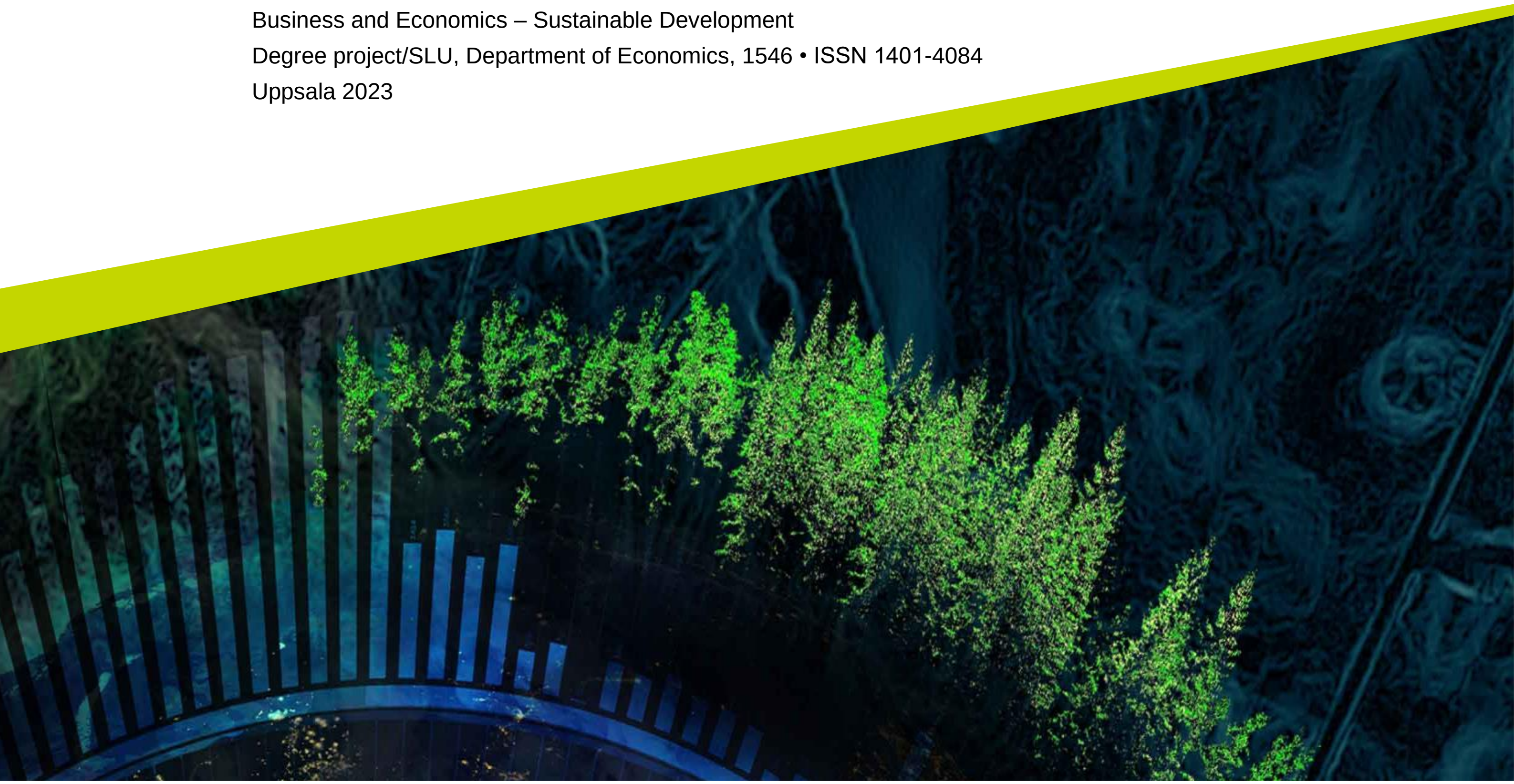

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Abstract

This thesis investigates the effect of different electricity generation sources on the price of electricity in Denmark, Finland, Norway, and Sweden. This is done by using panel data regressions with annual data for the period between 2004 and 2021. The results indicate that variations in the share of electricity generation from wind power is the only electricity generations source that is statistically significant at the 5 per cent significance level. An increase in the share of wind power is related to a decrease in the price. Electricity generated from solar power is statistically significant only at the 10 per cent significance level and is related to an increase in the electricity price. Electricity generated from hydropower and combustible fuels do not have a significant relationship with electricity price. In addition, increasing the price of oil also showed to associate with an increase of the electricity price. Nonetheless, it is crucial to interpret the results with caution due to the data used being annual, which may lead to the loss of nuances when using mean values.

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1. Introduction

The prices of electricity in Europe have rapidly increased over the last couple of years (Holmberg & Tagerås 2022). There have also been changes in the electricity market on a larger time scale with the conversion from fossil fuel to renewable energy sources (Hu et al. 2021). Different countries have different shares of electricity sources depending on their own unique conditions, and this is one of the reasons prices of electricity vary between different countries.

The aim of this thesis is to examine the effect of various electricity generation sources on the price of electricity, focusing on potential differences between renewable and non-renewable sources. The study is limited to the electricity markets in Denmark, Finland, Norway, and Sweden, covering the period between 2004 and 2021. These countries are selected since there have been other studies made to other markets, such as Germany (Graf et al. 2014), Italy (Cataldi et al. 2015), Greece (Giannini et al. 2019), and Turkey (Berk & Torun 2019), countries that receive a lot more sunshine hours than the countries in this thesis which are located in northern Europe. The selected countries are close to each other geographically, but their electricity generation mix is quite different from each other. In 2021, Norway almost exclusively generated electricity from renewable energy sources (92 per cent from hydropower and 7 per cent from wind power), whereas about one third of Sweden and Finland electricity generation originated from nuclear power, and Denmark generated about half of its electricity from wind power. Appendix 1 presents the distribution of the electricity generation sources for each country in 2021.

None of the selected countries generates a significant portion of their electricity from combustible fuels. Among the selected countries, Finland and Sweden are the most similar. However, Sweden's share of hydropower is nearly double that of Finland. There are differences between the distributions within the renewable electricity sources between the countries. Finland, Norway, and Sweden primarily rely on electricity from hydropower for their renewable electricity generation, while Denmark predominantly uses wind power. A shared characteristic among all four countries is that solar power contributes only a minor share to their overall electricity generation. Furthermore, all countries generated only a small part of electricity from combustible fuels in the later years of the selected time period.

Previous research has primarily focused on examining the effects of wind power and solar power on electricity prices. This thesis aims to contribute to the existing literature by investigating the effects of hydropower in addition to wind power and solar power. In addition, this thesis explores how renewable electricity mix affects electricity prices in countries with limited solar power potential. Understanding the relationship between renewable generation and electricity prices helps stabilising electricity prices in the future.

The results indicated that increasing the share of electricity generation from wind power was associated with a decrease in the electricity price. Increasing the share of electricity generated from solar power was statistically significant only at the 10 per cent significance level, and was associated with an increase of the electricity price. Electricity generated from hydropower and combustible fuels did not significantly relate to the price of electricity. In addition, an increase in the import price of oil also showed to have a significant relationship with the price of electricity, with an increase in oil price being associated with an increase in the price of electricity. As the data used in this study was annual the results should be interpreted with caution due to the potential loss of nuances when using mean values.

The remainder of this thesis is organised as follows. Chapter 2 contains a literature review. Chapter 3 describes the method and the data. Chapter 4 shows the results from the regression. Chapter 5 offers a discussion of the results. Finally, chapter 6 contains the conclusions from this study.

2. Literature review

The electricity market differs from other markets since there needs to be a balance between supply and demand in real time. This is because electricity cannot be stored (at least not in any relevant capacity), and an imbalance would lead to a power outage. Electricity in Sweden, Norway, Finland, and Denmark are traded on three different markets; the day-ahead market, the intraday market, and the balancing market (Guillen et al. 2020). Nord Pool is by far the largest market, and the vast majority of electricity is traded in the day ahead market, about 70 per cent of the market share in 2013 (Guillen et al. 2020; Swedish Competition Authority 2013). In the day-ahead market electricity is traded by the hour in the day before delivery, this market is also referred to as the spot market. After the day-ahead market closes, hourly prices are published for the following day and the intraday market opens. In the intraday market electricity can be traded until one hour before consumption. This market is used to balance out the market if there is a reason to believe that the prognosis from the day before has changed. For example, if the weather forecast predicted a lot of wind, indicating there would be a lot of wind power produced, and that forecast proved to be faulty then there will not be as much electricity produced and this will then be compensated for in the intraday market. When the intraday market closes there is still a possibility to trade in real time in the balancing market. As the name suggests, this market is used to make sure there is always a balance between production and consumption to avoid a power outage. For each market, the adjustments to achieve balance between production and consumption gets finer and finer.

Most of the existing literature on how renewable energy sources affect the electricity price discuss the merit order effect (Berk & Torun 2019; Brancucci Martinez-Anido et al. 2016; Cataldi et al. 2015; Giannini et al. 2019). The merit order effect occurs when electricity is generated from a source with zero or negligible variable costs, which lowers the starting bid on the day ahead market and consequently affects prices (Berk & Torun 2019). This effect is not exclusive to electricity from renewable energy, but also applies to for example nuclear power (Brancucci Martinez-Anido et al. 2016). Brancucci Martinez-Anido et al. (2016) also pointed out that the effect from hydro and nuclear power is more stable than the effects from solar and wind power. This would indicate that more electricity from solar and wind power leads to a higher volatility than if more electricity originates from hydro or nuclear power.

Giannini et al. (2019) studied the merit order effect on the Greek market and found that solar power had a significant decreasing effect on electricity prices. This drove out the most expensive plants, plants with high marginal costs (mainly fossil fuel dependent sources). Berk & Torun (2019) came to the same conclusion when they studied the Turkish market and found that wind power significantly decreased the price of electricity.

Cataldi et al. (2015) studied the merit order effect on the Italian market and found evidence of decreasing the electricity price when both wind and solar generated electricity increased. They also stated that solar power reduces the price of electricity during the time that the sun is shining. However, the need for lowering prices is the highest during evening and night-time when the possibility for solar power is low (Auer et el. 2013).

Brancucci Martinez-Anido et al. (2016) studied the impact of wind power on electricity prices in Germany, and they concluded that over-forecasting wind power in the weather forecast will increase the price of electricity, since the electricity generated from wind power will be less than predicted. The opposite is also true if wind power is under-forecasted: electricity prices will decrease when there is more electricity being produced than predicted. Similarly, Hu et al. (2021) found evidence suggesting that errors in wind power forecasting had a negative effect on intraday market prices in central and southern Sweden, but not in the northern parts of Sweden where there is less wind power.

Bundgaard and Ragnarsson (2022) who study the international market's effects on Swedish electricity prices conclude that exporting electricity will increase the price while importing will decrease the price. This is because a country will import electricity when the price abroad is lower than the domestic price, and export when it is higher than the domestic electricity price. Accordingly, since Sweden and Norway have been net exporting countries for most of the years between 2004 and 2021 (Eurostat 2023a: 2023b), this should have increased the price on electricity in both countries. In Finland and Denmark, which have been net importing countries, the price should have decreased. The report by Bundgaard and Ragnarsson (2022) also analysed how isolating the Swedish electricity market from the rest of the world would affect Sweden and concluded that the overall effect on society would be negative. This is mainly because even though being a net exporting country, Sweden cannot produce all the electricity it needs at all times. If no export or import is allowed, there will not be enough electricity at times, and when the production is higher than the consumption it will not be possible to sell the excess, meaning a loss of revenue. On the same topic, Morawetz & Schöniger (2022) show how the share of transmission capacities that allow a country to balance the infeed from intermittent renewable electricity, such as wind or solar power, through import and export affects the variance more than the infeed itself, meaning that a country who is more connected with other markets decreases the effects on the variance. They conclude that there is a significant effect on price variance from wind power in Sweden and Denmark, but that there is no significant effect from solar power in the same countries. They also point out that hydropower differs from solar and wind power since it can be more regulated since water can be stored, and used when needed while solar and wind power only can be used when the weather allows for it.

In a report from Energiforsk (2022) it was ascertained that the sudden price increase in both CO2-allowances and natural gas during 2021 strongly affected marginal costs in thermal power which in turn increased the electricity price in southern Sweden substantially. Because of the integration between the markets within Nord Pool, higher prices in markets who are more dependent on fossil fuels also increased the price in Sweden.

Guillen et al. (2020) studied market integration and how shocks affect connected markets making up Nord Pool. They found that Sweden, Norway, and Denmark, most of the time, affect the volatility of the price in the other countries in the market more than the rest of the market affects the volatility in these three countries. They also found evidence that the price volatility in net importing countries, such as Finland and Denmark, are affected more by price increases than when the price decreases.

3. Methodology and data

3.1 Data

All the variables used contained annual data from 2004 until 2021. The reason for this time period was that this was the longest time period that data were available for all variables. The data was yearly since the shares of the different electricity generation sources could only be found as yearly data. This was a flaw with the data since yearly means loses some of the nuances, and data for shorter time periods would have been preferred. However, such data were not available for all variables at the time this thesis was conducted.

The dependent variable in the regressions is Price and the data for this variable was collected from Nord Pool (2023). Prices are means for yearly trading prices in the day-ahead market without any added fees or tax and was measured in thousand EURO/GWh. It was recalculated from EURO/MWh to better match the rest of the data and avoid numerical issues when interpreting the results. For Sweden (since 2011), Norway, and Denmark, who are divided into multiple pricing zones, the mean for the pricing zones in each country were used as the mean for the whole country.

Hydro is the share of electricity produced from hydropower as a share of total amount of electricity produced, Wind is the share of electricity produced from wind power as a share of total amount of electricity produced, Solar is the share of electricity produced from solar power as a share of total amount of electricity produced and Combust is the share of electricity produced from combustible fuels as a share of total amount of electricity produced. All these variables were measured in per cent. The data for each source as well as the total gross amount of electricity produced in each country were collected in GWh from Eurostat (2023c: 2023d). From these values, the share for each country for each year were calculated and used for the analysis by dividing the produced amount of electricity for the respective share with the total amount of electricity generated and taking those times one hundred. There was other electricity generation sources not included in this thesis since there was no data available for all four countries.

GWh refer to total gross electricity consumption as a share of total amount of electricity produced and was measured in per cent. The data was collected from

Eurostat (2023e) and was then divided by the total amount of electricity produced (Eurostat 2023d) and taken times one hundred to obtain the share. This variable was used since the price of electricity is affected by the demand at any given time.

Oilprice refer to the world crude oil importing prices and was measured in EURO/barrel. The data for this variable was collected from OECD (2023) in dollars/barrel and then recalculated into EURO/barrel using the exchange rate from OFX (2023). This variable was chosen since it is known to have an effect on the price of electricity (Energiforsk 2022).

Import and Export measures the amount of electricity that was imported and exported respectively for each year as per cent of the total amount of electricity produced. The data for the amount of electricity imported and exported was collected from Eurostat (2023a: 2023b) and then divided with the total amount of electricity produced (Eurostat 2023d) and times one hundred to obtain the shares. These variables were used since they have been proven to have a direct effect on the price of electricity by for example Bundgaard and Ragnarsson (2022).

Table 1 Variable descriptions and their expected signs in the regression.

Variable	Description	Expected sign
$Price_{x,t}$	Average price of electricity (thousand EUR/GWh) in country x at year t.	Dependent variable
$Hydro_{x,t}$	Share of electricity produced from hydropower (in per cent) for country x at year t.	-
$Wind_{x,t}$	Share of electricity produced from wind power (in per cent) for country x at year t.	-
$Solar_{x,t}$	Share of electricity produced from solar power (in per cent) for country x at year t.	-
$Combust_{x,t}$	Share of electricity produced from combustible fuels, mainly fossil fuel (oil, gas, and coal), (in per cent) for country x at year t.	+
$GWh_{x,t}$	Consumed amount of electricity as a share of total production of electricity (in per cent) for country x at year t.	+
$Oilprice_{x,t}$	Oil import prices (in EURO/barrel) for country x at year t.	+
$Import_{x,t}$	Imported electricity as a share of total production of electricity (in per cent) for country x at year t.	-
$Export_{x,t}$	Exported electricity as a share of total production of electricity (in per cent) for country x at year t.	+

Descriptive statistics in Table 2 show the number of observations, mean, standard deviation, minimum value, and maximum value for each variable. The table shows that the dataset is balanced, meaning there are no missing values, since all variables contains 72 observations.

Table 2 Summary statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
price (1000 €/GWh)	72	38.63412	12.7789	9.258333	88.025
hydro (%)	72	39.74411	36.24192	.0374178	98.97652
solar (%)	72	.4059765	.9563818	0	4.109249
wind (%)	72	11.30566	15.26837	.140206	56.84294
combust (%)	72	2.941736	5.704881	.0059369	23.05808
consumption (%)	72	104.1058	14.13549	84.41335	131.0238
oilprice (€/barrel)	72	56.36386	15.66818	29.04747	87.41678
import (%)	72	20.34852	16.28674	2.403426	64.72273
export (%)	72	16.20412	11.05919	1.326498	46.14697

3.2 Model

To find out how the energy sources affect electricity prices, panel data regression models were estimated using STATA. The primary choice for this thesis was to also do individual regressions for each country to be able to compare them. However, due to the number of observations for each country only being 18 this was not possible since the result would not have been reliable when the number of observations is less than 20. Therefore, only regressions for the whole region were considered. To obtain a better relationship between the dependent variable and the independent variables, the dependent variable Price was log-transformed before doing the regressions.

Equation 1 shows the regression equation. Each variable is explained in Table 1, β_0 represents the intercept and ε_t is the error term.

The regression model with log-transformed price is given as:

$$LogPrice_{x,t} = \beta_0 + \beta_1 Hydro_{x,t} + \beta_2 Wind_{x,t} + \beta_3 Solar_{x,t} + \beta_4 Combust_{x,t} + \beta_5 GWh_{x,t} + \beta_6 Oilprice_{x,t} + \beta_7 Import_{x,t} + \beta_8 Export_{x,t} + \beta_9 year_t + \beta_{10} country_x + \varepsilon_{x,t} \quad (1)$$

3.3 Method

To check for outliers in the data set, scatterplots were used. As no outliers was detected, all the observations were retained for the analysis. Subsequently, a correlation matrix was created to check for any perfect multicollinearity among the variables.

Two regressions were performed and then compared to determine the best fit for the data. The first regression used panel data regression with fixed effects, and the second regression was panel data regression with random effects. A Hausman test was conducted to determine which model best fitted the data between the model with fixed effects and random effects. The mean root standard errors (MRSE), Rho and the adjusted R-square values were also noted. After each regression, a visual test was performed by plotting the residuals over time to detect heteroscedasticity.

4. Results

This section presents the results of the regression analysis. The regression helps to understand the relationship between the variables and the price of electricity.

The Hausman test was conducted to compare the fixed effects and random effects regressions, testing whether the differences in coefficients between the models was systematic. The null hypothesis states that the differences were not systematic, while the alternative hypothesis suggests that they were systematic. The p-value from the Hausman test was 0.7498, indicating that the null hypothesis could not be rejected. As a result, the model with random effects was selected for this analysis, as shown in Table 3. The results from the regressions with both fixed effects and random effects are provided in Appendix 3.

Table 3 Panel data regression with random effects.

Variables	Estimates (standard errors in parentheses)
hydro	-0.00143
	(0.00246)
solar	0.198*
	(0.102)
wind	-0.0243**
	(0.0119)
combust	-0.0116
	(0.00974)
GWh	0.277
	(0.223)
oilprice	0.00966***
	(0.00228)
import	-0.271
	(0.224)
export	0.285
	(0.226)
Constant	-24.56
	(22.39)
Observations	72

R-squared	0.2942
Adj. R-square	0.1891
Rho	0
RMSE	0.2975
Number of countries	4
***** p<0.01, ** p<0.05, * p<0.1**	

The plots created to detect heteroscedasticity did not show any cone or fan shaped pattern in the residuals, indicating that there was no heteroscedasticity present. While there is no perfect multicollinearity shown in the correlation matrix, there were some correlations between wind power and solar power, as well as between wind power and export that could be important to consider in interpreting the results.. The correlation matrix is available in Appendix 2.

Wind power was the only statistically significant electricity generation sources in the regression on the 5 per cent significance level. An increase in the share of wind power was related to a decrease in electricity price. The share of solar power was significant only at the 10 per cent significance level, and an increase in the share was associated with an increase of the price of electricity. The other shares, hydropower, combustible fuels, the shares of consumed amount of electricity (GWh), import and export were not significant in this regression.

The import price of oil (oilprice) was also highly significant at the 1 per cent significance level. Increasing the import price of oil was associated with an increase in electricity price.

The R-square of the regression was 0.2942 and the adjusted R-square, accounting for the number of variables, was 0.1891. This means that the model explains 18.91per cent of the variation of the price of electricity. Rho for the regression was 0, and the root mean square error of the regression was 0.2975, which should be considered low given that the log-transformed price ranged from 2.2255 to 4.4777 with an average of 3.6004 and standard deviation of 2.2255.

5. Discussion

When interpreting the results, it is important to keep in mind that the data used was annual and may not capture the changes that occur throughout the year. With that in mind, the following chapter will provide a discussion of the results presented in the preceding chapter.

The share of hydropower was not significantly associated with changes in the price of electricity, which is surprising considering that hydropower is one of the main sources of electricity in this study. In 2021, approximately 54% of the electricity generated in Denmark, Finland, Norway, and Sweden combined originated from hydropower. The lack of significance in the variable could be influenced by the data being yearly, but it could also be due to the fact that the variable is relatively constant with not much variation over time. If there is no variation in the variable, there are no changes for the regression to capture. The limited variation in the share of hydropower is likely due to the possibility to plan for hydropower further in advance than solar power and wind power.

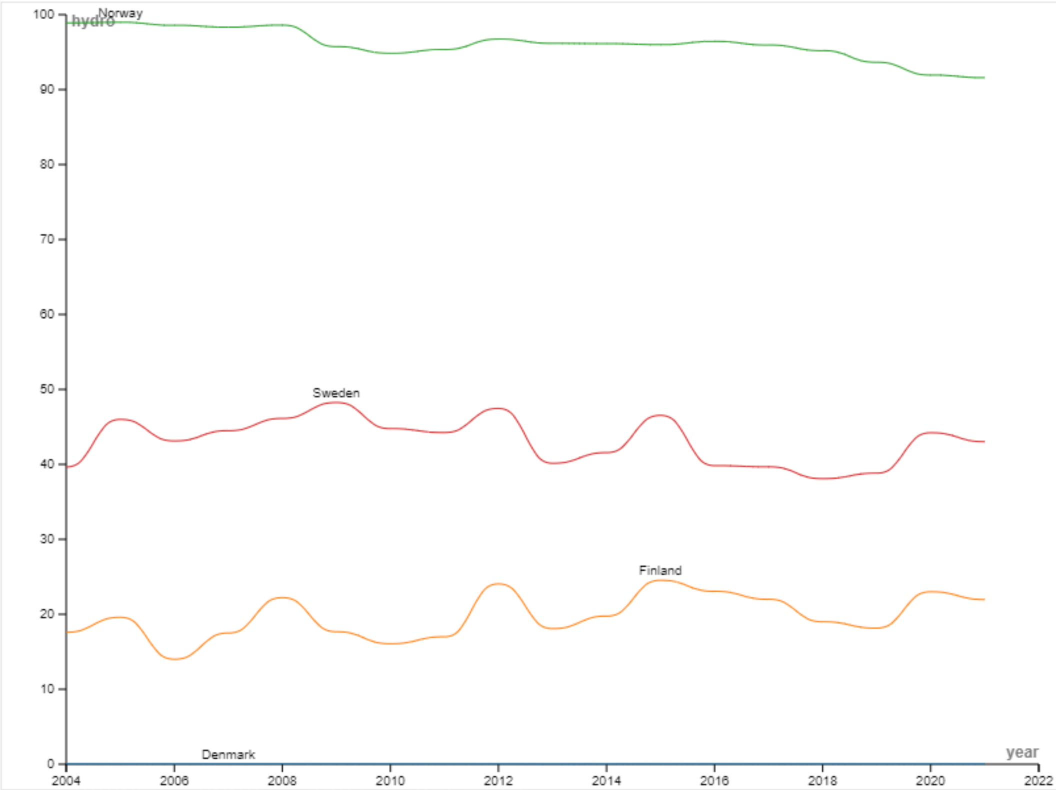

Figure 1 Electricity generation from hydropower over time in per cent.

The share of electricity generated from solar power was statistically significant only at the 10 per cent significance level and was positively associated with an increase in the electricity price, which was not the expected result. This could be attributed to the fact that electricity is typically generated from solar power during daytime in the summer semester when electricity is relatively cheaper. Allocating a portion of the electricity generated from solar power would result in a decrease of electricity generated from other sources. Solar power has increased rapidly in Denmark; however, the share was only about 4 per cent in 2021. In Finland, Norway, and Sweden, the shares of electricity generated from solar power were less than 1 per cent in each country.

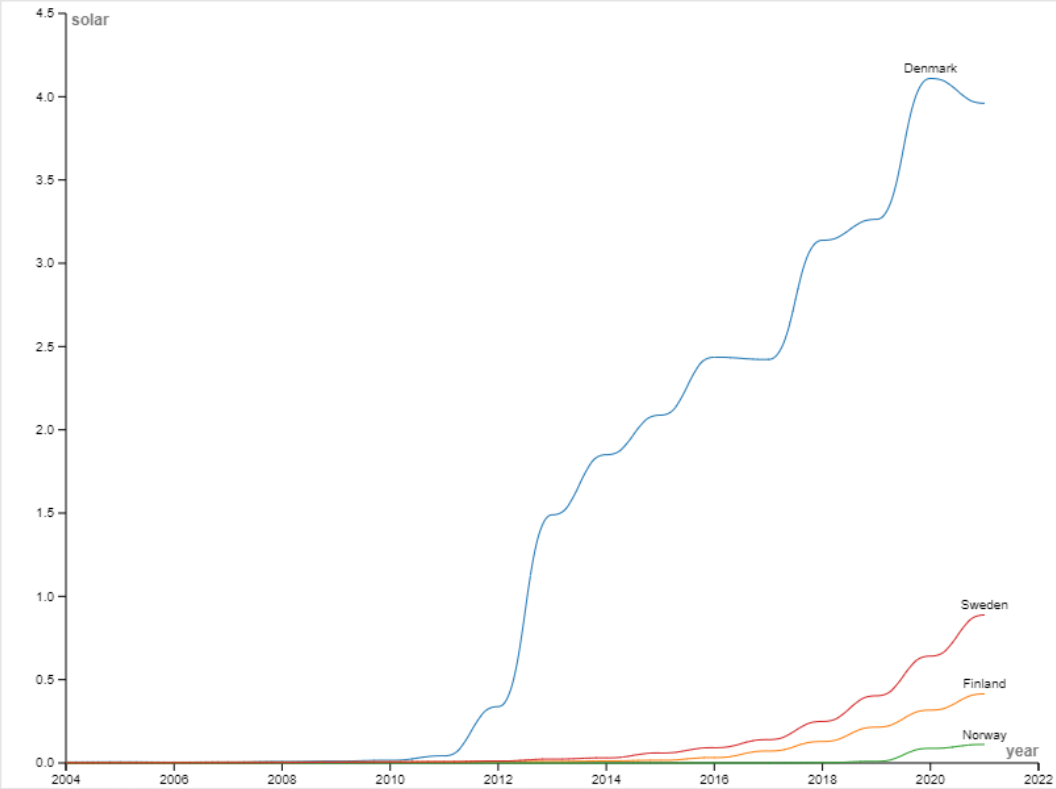

Figure 2 Electricity generation from solar power over time in per cent.

The share of wind power was statistically significant at the 5 per cent significance level. Increasing wind power was associated with a decrease in the price of electricity, which was the expected result. Wind power is the primary source of electricity generation in Denmark, and the share has rapidly increased in all four countries. The significance of the share of wind power in the regression is likely due to its uncontrollable and unpredictable nature, particularly in long-term planning. These findings are consistent with previous studies by Giannini et al. (2019), Cataldi et al. (2015), and Hu et al. (2021), who also reported that wind power reduced prices in the Greek, Italian, and Swedish market, respectively. Wind power has low marginal costs which is probably the reason for the price lowering effect.

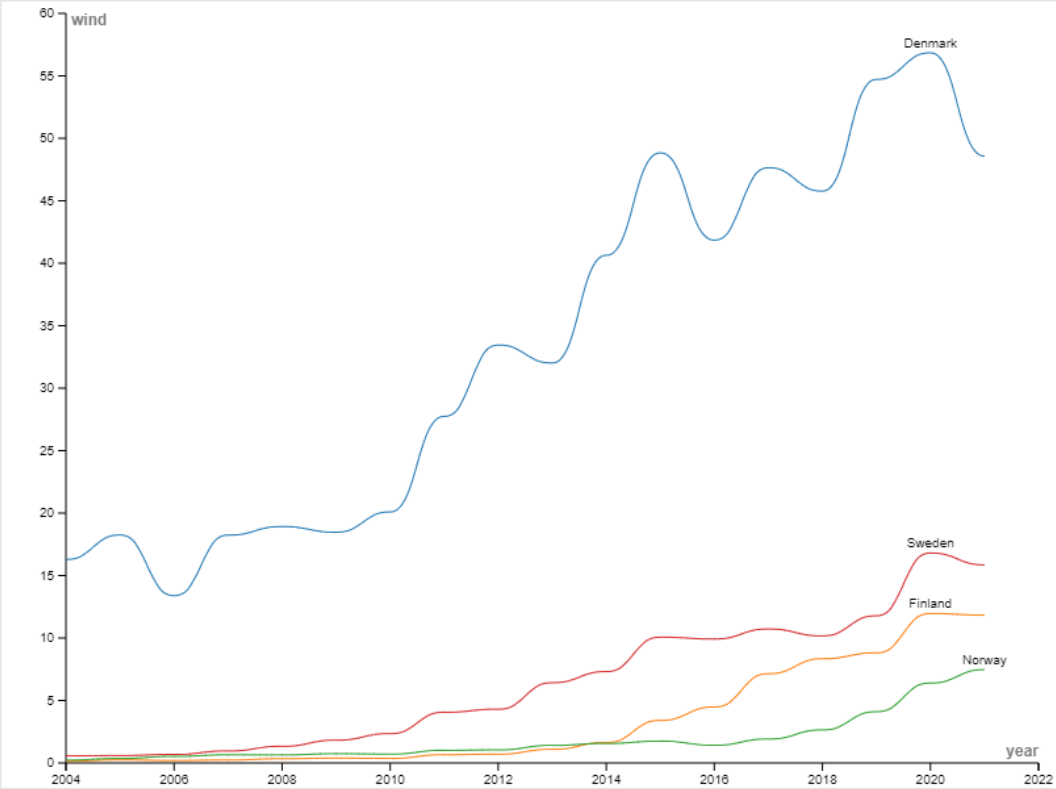

Figure 3 Electricity generation from wind power over time in per cent.

It is surprising that the share of electricity generated from combustible fuels did not show a significant relationship with the price of electricity. There have been substantial changes in the share of combustible fuels in Finland, however the other three countries, Denmark, Norway, and Sweden have maintained a relatively stable level of electricity generated from combustible fuels over time. Given that Finland is the second smallest market and Sweden and Norway are roughly twice the size of Finland, it is possible that the changes in the variable originating from Finland are too small to show a significant relationship with the price of electricity.

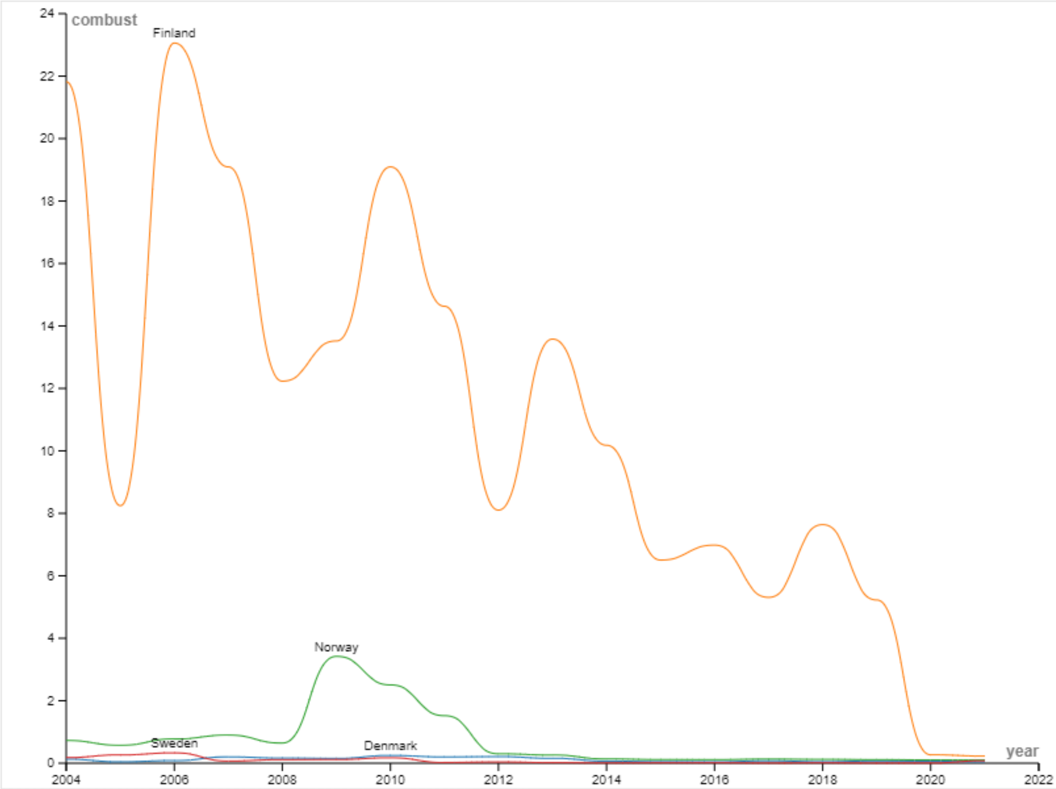

Figure 4 Electricity generation from combustible fuels over time in per cent.

The consumption as a share of production (GWh) was not statistically significant in the regression. The price is set where the demand curve and the supply curve meet. However, the lack of effect of demand on price could be due to demand being highly inelastic. It suggests that consumers tend to consume a similar amount of electricity regardless of the price. This can be easily visualised as even when price increases, people still require a certain baseline of electricity for essential activities like heating their homes and cooking food.

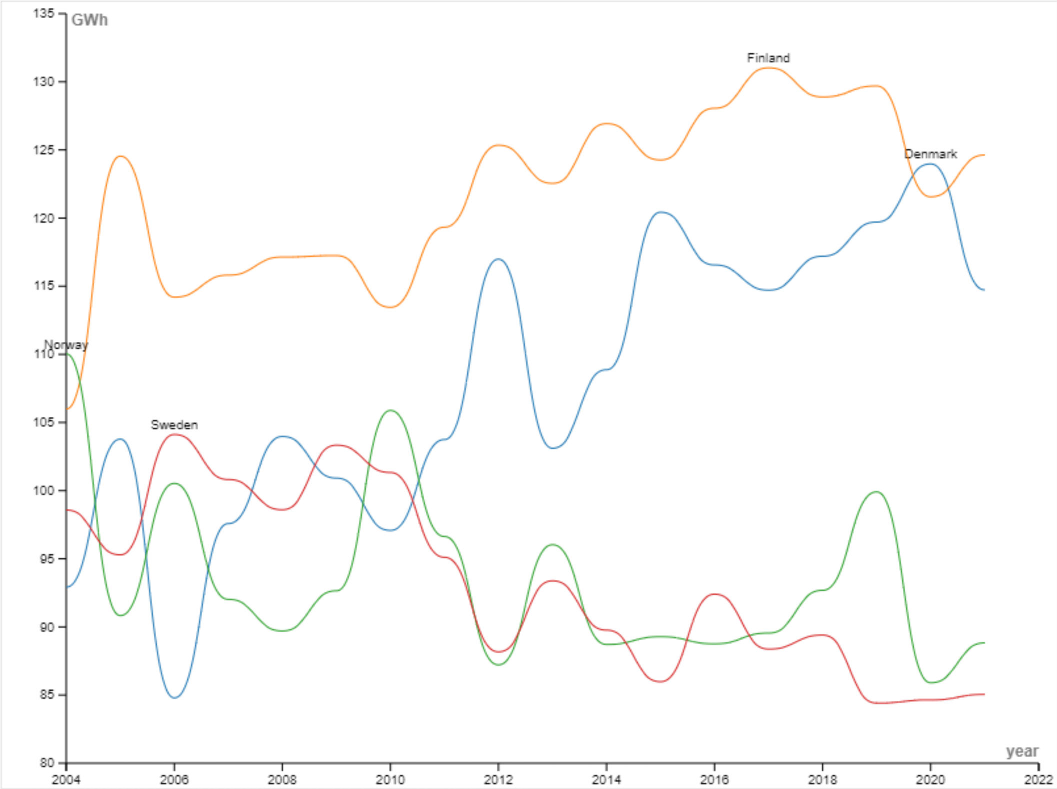

Figure 5 Consumption as share of production over time.

The price of oil is statistically significant at the 1 per cent significance level, indicating that an increase in the oil price is positively associated with an increase of the price of electricity. This result aligns with expectations since oil is utilised for some production of electricity, particularly in the case of combustible fuels. Although none of the countries in question generate a significant amount of electricity originating from oil, other countries in the Nord Pool market, such as the United Kingdom, Germany, and the Baltics do (Energiforsk 2022). Since the markets are connected with each other, these effects spill over to their neighbouring countries. Norway is the only country with transmission networks to the United Kingdom, and Sweden and Denmark have direct connections to Germany, and Finland is connected to the Baltics through Estonia. The United Kingdom, Germany and Estonia all generate electricity originating from oil (Svenska Kraftnät 2020: Eurostat 2023c)

Figure 6 Transmission grid for electricity 2020. Source: Svenska Kraftnät 2020.

Import and export as shares of production are not statistically significant in the regression. Both import and export exhibit limited variation, except for import in Denmark. The higher fluctuations in Denmark can be attributed to their larger production of electricity from wind power compared to the other countries. Wind power is not possible to regulate or plan in any great extent which makes Denmark more vulnerable than the other countries since they need to meet their demand without being able to meaningfully scale their own production, making Denmark more dependent on import and export.

It is important to note that Norway is the only country with the majority of its electricity generation accounted for in this thesis. The shares of hydropower, wind power, solar power, and combustible fuels collectively account for approximately 100 per cent throughout the whole time period. While for Sweden, the electricity generation accounted for is about 50 per cent, for Finland it is between 30 and 40 per cent, and for Denmark it starts at only 20 per cent and reaches about 60 per cent in the latter years of the time period.

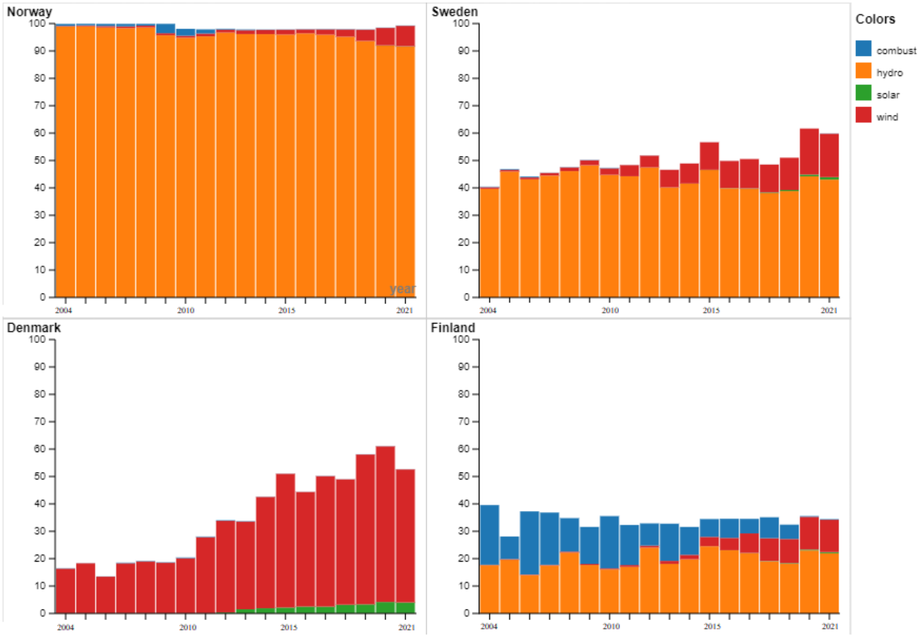

Figure 7 Distribution of shares for the respective countries between 2004 and 2021.

It should also be pointed out that there may be additional variables influencing the price of electricity that were not included in this regression analysis. The relatively low adjusted R-square value indicates that there are other variables that are affecting the price. For example, by including electricity generation from nuclear power would increase the share of electricity generation accounted for in Sweden and Finland to about 90 per cent in Sweden and 60-70 per cent in Finland. These unaccounted variables, including nuclear power, are considered omitted variables, and their exclusion from the analysis may result in biased estimates.

Rho being 0 in the output of the regression is also worth noticing, since this indicates that none of the variation in the electricity price can be explained by differences between the countries. Therefore, the variables affecting the price of electricity is independent of the geographic area researched in this thesis.

It is also important to consider the possibility of endogeneity, which implies a correlation between the independent variables and the error term, and bidirectional causality, for example between variables such as electricity consumption and electricity prices. Both endogeneity and bidirectional causality have the potential to introduce bias into the estimates. Additionally, the presence of measurement errors during data preparation or when transferring results from STATA to this thesis should be acknowledged. Such measurement errors can introduce bias into the estimates as well.

The previously mentioned high correlation between solar power and wind power, as well as between export and wind power is also of concern. Wind is created from changes in temperature, and solar power can be produced when the sun shines, but much less is produced when the sun does not shine. This makes both variables dependent on weather. A control variable for weather, particularly temperature, was originally considered for this thesis. However, due to the data being yearly there was no sufficient variation in the data for this variable. Despite the correlations being higher than desired, there is no evidence of perfect multicollinearity. As a result, it was determined to retain all the variables in the analysis.

Another limitation of this thesis is that the variable representing the solar share does not differentiate between photovoltaic solar power and solar thermal energy. While photovoltaic solar power utilises light to generate energy, solar thermal energy uses the heat from the sun instead. Similarly, the share of wind power does not distinguish between offshore wind power and onshore wind power. Combining both types of solar power and both kinds of wind power into one variable each may have resulted in loss of information.

There could also be a problem in using shares as measure. When the production from one source increases, it affects not only the share of that source but also the shares of all other sources simultaneously. However, using shares instead of the absolute amount of electricity takes into consideration the different sizes of the countries and promotes comparability. It would have been possible to use the amount produced from each source instead of shares. To regulate for the difference in sizes, the amount of electricity could be divided by the size of the population in each country to get consumption per capita, which would even out the data as well.

To gain a better understanding of how different energy generation sources affect the electricity price, future studies could consider using more granular data such as quarterly, monthly, or daily data, if accessible. Additionally, conducting separate analyses for each country would be valuable when more observations are available and the data span over a longer time period for each country, allowing for meaningful comparisons between them. If possible, expanding the data set to include additional sources would be beneficial, ideally accounting for all electricity generation in each country.

6. Conclusion

The study uses panel data between 2004 and 2021 for Denmark, Finland, Norway, and Sweden, to examine the relationship between the shares of different electricity generation sources and electricity prices. The result indicate a significant relationship between the share of electricity generated from wind power and the price of electricity at the 5 per cent significance level, where an increase of the share of wind power was associated with a decrease of the price of electricity. The share of solar power was significant only at the 10 per cent significance level, and an increase in the share indicates an increase of the price of electricity. However, the analysis did not find a significant association between the share of electricity generated from hydropower and combustible fuels, and the price of electricity. Nonetheless, it is important to note that the data was collected on a yearly basis, potentially resulting in some information loss. If the data had been more granular, the results might have been different.

Unfortunately, the statistically significant shares of electricity generation sources in this study were all renewable, while the share of electricity generated from combustible fuels, the only non-renewable source, was not statistically significant. Consequently, this prevented a comparison between the effects of renewable and non-renewable energy generation sources as initially intended. Nonetheless, the lack of significance in the shares of hydropower and combustible fuels provides valuable insight into their relationship with electricity prices, suggesting that their effects are not statistically significant on yearly basis. It is important to note that this thesis does not disprove the findings of the previously mentioned studies, which utilised data on shorter time intervals.

Of course, the price is not the only factor to consider when determining the optimal energy mix for electricity generation. Other aspects such as the level of emissions generated during production and the overall environmental impact, are equally important. The shares of electricity generated from renewable energy sources have shown a consistent upward trend in recent years, yielding positive environmental outcomes in terms of improved air quality, reduced emissions, and contributing to the mitigation of global warming. However, in the pursuit of both lower prices and a healthier environment, it is crucial to recognize that our society is reliant on uninterrupted access to electricity, and it is essential to meet the ever-growing demand. For this reason, electricity production must be reliable and consistent, as well as environmentally friendly, and from the consumer's perspective, the price should be low as well. To secure all these goals, a well-balanced electricity generation mix is probably the best idea.

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Appendix 1

Table 4 Distribution of electricity sources 2021. Source: Eurostat.

Country	Hydropower	Wind power	Solar power	Nuclear power	Combustible fuels
Sweden	43 %	16 %	1 %	31 %	<1 %
Finland	22 %	12 %	<1 %	32 %	<1 %
Norway	92 %	7 %	<1 %	0 %	<1 %
Denmark	<1 %	49 %	4 %	0 %	<1 %

Appendix 2

Correlation matrix, values above 0.8 and below -0.8 is not considered a problem.

Table 5 Correlation matrix.

	price	hydro	solar	wind	combust	GWh	oilprice	import	export
price	1.00								
hydro	-0.16	1.00							
solar	0.11	-0.41	1.00						
wind	0.05	-0.58	0.89	1.00					
combust	0.07	-0.24	-0.21	-0.33	1.00				
GWh	-0.10	0.75	-0.52	-0.72	-0.10	1.00			
oilprice	0.39	-0.01	-0.05	0.01	-0.02	-0.02	1.00		
import	0.16	-0.76	0.73	0.80	0.05	-0.86	0.01	1.00	
export	0.03	-0.44	0.68	0.87	-0.52	-0.60	0.04	0.54	1.00

Appendix 3

Table 6 Regression models.

VARIABLES	Panel regression with fixed effects	Panel regression with random effects
hydro	-0.0247	-0.00143
	(0.0178)	(0.00246)
solar	0.296**	0.198*
	(0.118)	(0.102)
wind	-0.0316**	-0.0243**
	(0.0122)	(0.0119)
combust	-0.0182	-0.0116
	(0.0143)	(0.00974)
GWh	0.326	0.277
	(0.221)	(0.223)
oilprice	0.00977***	0.00966***
	(0.00225)	(0.00228)
import	-0.322	-0.271
	(0.223)	(0.224)
export	0.318	0.285
	(0.224)	(0.226)
Constant	-28.25	-24.56
	(22.19)	(22.39)
Observations	72	72
R-squared	0.343	0.2942
Adj. R-square	0.2268	0.1891
RMSE	0.2927	0.2975
Rho	0.9249	0
Number of geo	4	4

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