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Are renewable sources displacing fossil fuels in electricity generation?

A panel data investigation on global data

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Abstract:

As the consequences of climate change is increasing the need of replacing fossil fuels with renewable energy globally is becoming more urgent. A central question that has been questioned in the literature is that if the world is on track on a transition away from fossil fuels or if we are only adding renewable energy to the energy mix in a world that continues to grow and consume more energy. Because of the above mentioned, this thesis aims to investigate if the increased generation of electricity from renewable sources are displacing the generation of electricity from fossil fuels. This is tested using a time and country fixed effects model including 176 countries with yearly observations from 2000 to 2020. The result from the regression showed that one additional kWh electricity generated from renewable sources has not statistically managed to displace one kWh of electricity generated from fossil fuels, net of controls. Previous studies using a similar methodology but on older time frames has shown result were almost no displacement has occurred when renewable sources have been added. The result from this thesis should not be interpreted as that the transition is not going to happen since it might be that the global initiatives taken around the globe to make the transition happen is not get visible in the numbers used in thesis, but the result does on the other hand indicate that several economic, political, and social factors has made the transition to renewables difficult, and that we should not assume that renewable energy will replace fossil fuels for electricity generation without policy measures that supports the transition.

Keywords: Climate change, Energy transitions, Green Growth, Displacement Paradox, Jevons Paradox, Panel Data

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1. Introduction

The increasing consequences of climate change have urged the need of replacing fossil fuels with renewable energy (IPCC, 2023). A central question that needs to be considered is if the world is on track of a transition away from fossil fuels or if we are only adding renewable energy to the energy mix in a world that continues to grow and consume more energy (Ritchie et al., 2022). The purpose of this thesis is to examine if the world is transitioning away from fossil fuels to renewable sources for electricity generation, or if we are only adding renewable energy sources on top our use of fossil fuels for electricity generation. This is important from an economic and environmental point of view since it highlights the important question if it is reasonable to expect that expanding the use of renewable sources for electricity generation will displace the use of fossil fuels and lower the global emissions. If not, the expansion of renewable sources only expands the total electricity supply, and the result of that could be sustained or increased emissions of greenhouse gases.

Research made on the topic have found that electricity generation from renewable sources has not been able to displace electricity generation from fossil fuels. Research by York (2012) investigated this globally, and the results showed that almost no displacement had occurred during the time frame of 1960 to 2009. On the same topic Greiner et al. (2022) investigated the displacement of fossil fuels in electricity generation from renewable sources on the time frame of 1960 to 2015, the result was a very modest displacement.

This thesis is investigating a narrower and more recent time frame of 2000 to 2020 where several steps has been taken globally to make the transition to renewables from fossil fuels more likely to happen. One of the big steps taken is that the world community has via the United Nations climate change conferences of the Parties (COP) meetings developed goals and pledges since 1992 to assess progress in dealing with climate change and develop binding obligations for countries to reduce their greenhouse gas emissions. At the same time the cost of renewable energy sources like solar and wind have decline substantially during the last decades, and because of this, renewable sources for electricity generation has been deployed in an increasing rate (Ritchie et al., 2022).

Even though the above-mentioned factors would indicate that the transition is on the way, the world has continued to grow and its need for electricity and energy has grown (Ritchie

et al., 2022). And as the world is relying on advanced technologies and energy efficiency to curve the emissions (Sandberg et al., 2019), theories like the Jevons Paradox argues that more efficient production could lead to more overall consumption and by that making the need for resources to increase instead of decline which would make the transition harder (Polemi et al., 2008).

Based on the above the research question for this thesis is:
Is the increased generation of electricity from renewable sources displacing the generation of electricity from fossil fuels? More specifically, the hypothesis that the increase of renewable sources for generating electricity per capita is displacing the use of fossil fuels for electricity generation is tested.

To answer the research question if renewable sources are displacing fossil fuels for electricity generation a fixed effects unbalanced panel data model has been applied. In the model, the dependent variable, per capita electricity generation from fossil fuels measured in kilowatt hours, has been regressed against the main independent variable, per capita electricity generation from renewable sources measured in kilowatt hours, together with several control variables controlling for structural factors. Fixed effects for both country and time have been used to control for omitted variables that vary across countries but not over time and omitted variables that vary across time but not across countries. The model used is a displacement model developed by York (2012) that has been used on earlier work on the topic. The regression has been run on 176 countries covering the period 2000 to 2020. The data for the model is gathered from Our World in data (Ritchie & Roser, 2018; Ritchie et al., 2022) and The World bank (The World Bank, 2022a, 2022b, 2022c).

As a delimitation, this paper will examine if the increase of renewable sources for electricity generation displaces fossil fuels used for electricity generation and not on the displacement of fossil fuels used for all energy consumption, which aside from electricity also includes heating and transport (Ritchie et al., 2022).

Global electricity is generated from fossil fuels, renewables and nuclear. As another delimitation this thesis will focus on fossil fuels and renewables since this thesis is investigating global data, and there are only 32 countries in the world that have nuclear power for electricity generation (Ritchie et al., 2022).

The different parts after this introduction are organized as follows: In section 2 a literature review will be presented on previous work covering energy transitions and empirical studies on the topic. Next, section 3 will present the theories that forms the theoretical framework for this study. In section 4 the data and methodology will be presented. After that, in section 5, the results will be presented and discussed followed up by conclusions in section 6 with comments for further research on the topic.

2. Literature review

In this section, we establish why the transition needs to happen, how transitions have developed in the past, and how different impacts are influencing the current development to a future where renewable energy is the main source of energy. This is done by connecting information from large associations to the literature written on the topic.

To understand why an energy transition needs to happen with a displacement of fossil fuels we turn to the latest Intergovernmental Panel on Climate Change (IPCC) sixth assessment report that was published in 2023. The IPCC (2023) states that human activities via greenhouse gas emissions have unequivocally been the reason for global warming. The average surface temperature has been 1.1 degrees Celsius higher in 2011-2020 than what it was 1850-1900. During the period 2011-2020 the emissions from greenhouse gases have continued to increase where the emissions arise from land use and land-use change, lifestyles and patterns of production and consumption (IPCC, 2023).

To be able to mitigate further greenhouse gas emissions, disruptive changes in existing economic structures must happen (IPCC, 2023). To speed up the climate actions and to milden the consequences, several financial, fiscal, institutional, and regulatory reforms must be implemented and transitions in all sectors and systems are necessary to achieve sustained emissions reductions (IPCC, 2023).

2.1 Historical energy transitions

York & Bell (2019) has looked at the major energy transitions in the past and it has shown that no established energy source has declined when a new energy source has been introduced. This is shown in all the major energy shifts (biofuels to coal, coal to oil, and oil to natural gas). The trend from the earlier energy transitions is that all energy sources has grown even if the new energy source took a large share of the total energy consumption. The earlier transitions of new energy sources have not shown a decline in the leading energy source, but on the other hand this has not been the goal of countries or industries in the past. The goal has been to find new ways to provide more energy (York & Bell, 2019).

Fouquet (2016) argues that the price of energy services has played a crucial role in earlier transitions, were new sources often had a higher initial cost but over time when the technology got improved the price of the source declined, which made it competitive against the leading source of energy at that time. For a larger energy transition to occur, the price of the new source had to fell substantially (Fouquet, 2016). Looking at the current energy transition from fossil fuels to renewable sources for electricity generation the price of onshore wind has declined 70 % and solar photovoltaic has declined 89 % between 2009 and 2019 surpassing the price of electricity generated by all fossil fuel sources during this period (Ritchie et al., 2022).

The speed of transitions in the past has been strongly impacted by how the leading industry reacts to the new competitors (Fouquet, 2016). The dominant position from large energy firms has put pressure on governments to try to stop the new competitor. As an example, evidence that Fouquet (2016) presents indicates that a large expenditure on lobbying by energy intensive companies has slow and halt US climate policy during the last centuries. The size of these companies in the global economy makes it possible for them to delay the transition to renewable and low carbon sources through their financial and political power (Fouquet, 2016).

Observations from earlier energy transitions has shown that when a new energy source has taken a larger share of the energy market the increase in energy consumption has been major (Fouquet, 2016). Transitions from biomass to coal and from coal to oil led to large increases of energy consumption. If the history repeats itself, it could have major implications for the transition to renewables where a large increase of demand for electricity may lead to larger emissions if it continues to be generated from fossil fuels (Fouquet, 2016).

2.2 The transition to renewable energy

The data shows that the development and deployment of renewable sources is clearly underway where the share of renewable sources for electricity generation have increased from 19.07 % in 2000 to 28.46 % in 2020 (Ritchie et al., 2022). Although it is not clear that the increase in electricity generated from renewable sources is displacing the use of fossil fuels for electricity generation. Coal is the main resource for generating electricity in world, and its share has declined from 38.2 % in 2000 to 35.39 % in 2020, the other two fossil fuels used for electricity generation are gas and oil; gas has increased its share from 18.5 % to 23.42 % and

oil have decreased from 7.84 percent to 2.7 percent. During the same period the electricity generation have increased globally from 15000 TWh to 26750 TWh (Ritchie et al. 2022).

The implementation and development of renewable energy sources is an outcome of scientific/technological research and policy initiatives (Bhattarai et al., 2022). This has shown to be true where economies with great resources have been better at implementing clean energy policies than poorer countries which has resulted in better and faster development of renewable energy sources. Bhattarai et al. (2022) argues that the development of renewable energy is in general strongly linked with global policy.

An important arena for global climate policy is the returning meetings of the international treaty, named the United Nations Framework Convention on Climate Change (COP). It was in 1992 created as a framework for combating climate change by limiting the increase in global temperature and coping with impacts that were, already then, unavoidable. A big strengthen of the efforts to respond to climate change were implemented in 1997 via the Kyoto protocol legally bound developed countries to emission reduction targets, (UNFCCC, 2023).

In 2015 the twenty-first COP meeting was held in Paris and is one of the most important meetings to date because the Paris Agreement charted a new course in the efforts globally to reduce climate change. The aim of the agreement is to keep the global temperature well below two degrees above the pre-industrial levels. To reach the goals, the meeting announced large financial flows will ensure enhanced capacity for countries to reach their own set out goals for emission reduction and to support the most vulnerable countries to reach their national goals. Another central part of The Paris Agreement is to support and enhance transparency of actions taken in different countries (UNFCCC, 2023).

Even though the global policy is important for the global transition Bhattarai et al. (2022) argues that governments are primarily responsible for the transition to renewable energy. By setting achievable targets, developing necessary infrastructure, capacity building, institutional reforms creating good environments for research and development the transition can be achieved (Bhattarai et al., 2022). Jacobsen & Fisher (2021) points out that carbon pricing should also be part of countries climate policies.

Carbon pricing policy is a mean of control that comes from the idea that the pollutant pays for its pollution, and a carbon price that is well designed is an indispensable part of reducing emissions in an efficient way. When the pollutant must pay it activates incentives in the economy where companies and citizens must take emissions into account when making decisions about energy use, production and technology investments, and consumption habits (Jacobsen & Fisher, 2021). Another important impact of climate policy is that carbon pricing has shown to be a good tool for innovation (Jacobsen & Fisher, 2021).

As of 2020, 58 different carbon pricing instruments where in operation globally covering 15.1 % of global emissions which is higher compared to year 2000, were 7 instruments covering less than 1 % of global emissions. Some countries, such as Sweden, Switzerland, Finland, and Norway to name a few, have managed to implement carbon pricing instruments at a price level where it can make a great difference on emissions (The World Bank, 2021). Although, in 2020 most carbon prices globally lie far below the USD 40-80/tCO_2 needed to reach the 2-degree Celsius goal of the Paris Agreement, only 3,76% of global emissions are covered by a carbon price above or at that price (The World Bank, 2021). This is partly due to that many developing countries is lagging in implementing such policies. Also, both developed and developing countries have policies that foster the use of fossil fuels that is supported by geo-politics, current market conditions, social poverty, and lack of capital investment (Bhattarai et al., 2022).

Another factor is the large capital cost of renewable energy sources makes a transition harder for countries that is heavily relying on coal and have a weak economy. Best (2017) found that countries with more financial capital are more likely to transition from fossil fuels to more renewable sources than lower income countries. In 2017, the capital cost of electricity generation from a coal plant were almost one-sixth of a solar when compared equally installed capacity which makes the deployment of coal more sufficient for low-income countries (Best, 2017). A future with renewable energy demands a transition away from fossil fuels, that creates friction with the current energy regime such as the OPEC countries who was invested large in the fossil fuel market, and they will not discard their investment which will have big negative impacts on their societies. (Bhattarai et al., 2022).

There are also several other factors that could influence the development of renewable sources. One important factor that Bhattarai et al. (2022) argues for is the factor of power

stability when incorporating new renewable electricity sources into a present grid is large due to generation capacity of each of the renewable sources are smaller than fossil fuel-based systems. Chen et al. (2019) points out that the high volatility in electricity generation of many renewable sources makes the development challenging as it can cause negative impacts on power stability.

Environmental problems have occurred due to the scaling up of renewable energy sources, which has caused drastic alterations to land use and landscape. Deploying solar can have serious implications on other land use like agriculture or forest and there has been raised concerns of nature conversation and aquatic biodiversity being impacted by hydropower plants and dams (Bhattarai et al., 2022).

Another factor is the one of social acceptance that has influenced the deployment of renewable energy around the world. The transition to renewable energy is costly and price increases for end-users is often not welcomed by the community, which can cause the efforts for a increased transition to be compromised (Bhattarai et al., 2022).

2.3 Empirical literature

This section will present previous research that has investigated similar topics to the one in this thesis. The contribution of this thesis to the knowledge in this field will also be discussed in this section.

The displacement of electricity generated from fossil fuels by non-fossil sources has been studied by York (2012) who analyzed annual data for 132 countries over the period of 1960 to 2009 using a panel data approach. He analyzed if the generation of electricity from non-fossil fuels displaced the generation of electricity from fossil fuels measured in per capita kilowatt hours. The result showed that the displacement effect from the renewable sources were -0,089 kwh, meaning that one additional kilowatt hour generated by a non-fossil fuel source displaced only -0,089 kwh generated by fossil fuels.

McGee (2014) investigated on a similar topic if organic farming reduces greenhouse gas emissions from agricultural production in USA. The panel data analysis on 49 states covering the timeframe of 2000 to 2008 found that the increase of certified organic farming did

not lead to decreased emissions, instead it found that when certified organic farming is increasing, both the total amount of greenhouse gas emitted from agricultural production and the intensity of emissions per acre of agricultural land.

Greiner et al. (2018) investigated whether natural gas displaced the use of coal for electricity generation, and in that way reduced emissions. Natural gas produces lower carbon emissions than coal per unit of electricity and is suggested to help mitigate the climate change. To address this question they examined the connection between the growth in emissions from natural gas to the changes in emissions from coal. In their panel data model covering the years 1960 to 2013 for 176 countries, they found that the CO_2 emissions from natural gas did not displace CO_2 emissions from coal.

In another research by Greiner et al. (2022) they analyzed how non-hydro renewable energy sources displaced the use of fossil fuels for electricity generation using panel data for 109 nations from 1960-2015. Their findings from their panel data regression model where that a small displacement of fossil fuels had occurred, meaning in their model that one unit of increase in per capita kwh from renewable sources displaced only 0.193 per capita kwh fossil fuels. In the same study they used a narrower timeframe of 1997-2015, since from 1997 a significant change in in the percentage of electricity generated from non-hydro renewable sources were observed within their sample. The result showed that no displacement of fossil fuels had occurred (Greiner et al., 2022).

2.4 Summary and research gap

In summary, all empirical research presented has found that the introduction of renewable or less harmful energy sources has not been able to displace fossil fuels or emissions. One indicator to these research results is the time frame that goes back a long time were the presence of means of control for carbon emission reduction has been scarce or the price of renewable energy sources for electricity generation such as wind and solar has not been as cheap as electricity generated from fossil fuels.

This research will fill a gap in the research by investigating a more recent period where the price of renewables has declined significantly and means of control such as carbon pricing has been implemented to stimulate the transition to renewables. This research is important since

it gives an updated indication on if the world is on its way to displace fossil fuels with renewables.

3. Theoretical framework

This section will first introduce green growth followed by a presentation of theories connected to two different environmental paradoxes observed in the past that has explained why new technologies could theoretically have difficulties displacing already established sources, or why efficiency measures could have counterproductive outcomes. The first one is the Displacement paradox followed by the Jevons Paradox.

The world is facing environmental degradation and climate change due to unrestrained economic growth and the dominant and widely accepted solution to this is green growth (Sandberg et al., 2019). Green growth proposes a decoupling of growth in the economy from the use of natural resources. To achieve this decoupling, the green growth relies on the development of advanced technologies which will improve the resource efficiency of production, that allows production and consumption to grow while the use of natural resources, and by that the environmental impact, to decline. Green growth assumes that growth in consumption per capita and growth in population can continue to higher levels, since higher efficiency in production will keep the use of resources from growing (Sandberg et al., 2019).

3.1 Displacement paradox

The displacement paradox or paperless office paradox is a phenomenon that has been noted in many fields and industry research (Greiner et al., 2018). A body of earlier research have found that the effectiveness of new technologies or resources, such as renewable energy, displace already established technologies which the green growth is relying on, have not occurred as expected or at it was meant to do. Evidence come from industries such as automobiles, communication, agriculture, and renewable energy (Greiner et al., 2018). These unexpected outcomes have varied, but the research has found that the cause of why the displacement did not occur can in many instances be attributed to that newly introduced technologies and resources is being utilized to increase production and consumption (Greiner et al., 2018).

The theoretical explanation of the displacement paradox focuses on how firms in capitalist economies has the power to drive growth and increase profits. York (2018) discusses how market forces driven by growth have been dominating in most countries and economies around the world, where industries and firms primary focus is to make profits. For this reason, new technologies are deployed to increase profits, and not to conserve resources. To further accumulate wealth, the producers work to create markets and increase the consumption of their products in those markets so they can further their accumulation of wealth (York, 2018).

According to Greiner et al. (2018) we cannot therefore assume that a new resource or technology will simply replace an established one because firms seek to produce more products and increase consumption frequency. This dynamic has shown to prevent less environmentally harmful resources and technologies from replacing more harmful ones, particularly in the case of "green" technologies (Greiner et al., 2018).

3.2 Jevons Paradox

In addition to the theory of the displacement paradox, The Jevons Paradox presents reasons why efficiency measures suggested in green growth might lead to higher resource use and energy demand, not less. The Jevons Paradox was first introduced 1865 by the British economist William Stanley Jevons. What he observed was that the efficiency improvements in the use of coal in Scotland between 1830 and 1863 increased the demand for coal ten-fold, not decrease as one would expect (Sorrel, 2009).

When energy efficiency is increased and that lowers the consumption of inputs, the price of production decreases. When the price of production decreases, demand and in turn consumption increases, and the result is the Jevons Paradox. As a resource becomes more affordable and efficient to use, current resources will be used more, or new technology will be made available that has more features and options (Polemi et al., 2008).

Jevons defined an effect called the rebound effect. According to Sorrel (2009) the rebound effect is larger term for a variety of mechanisms that limits the potential savings in energy efficiency. This rebound effect can have both direct and indirect effects on both the production and the consumption side where the efficiency gain which lowers the price lets the demand rise and by that also the energy demand. An economy-wide rebound effect is the sum

of all direct and indirect effects. A rebound of more than 100 percent is called a backfire where the expected energy savings lead to an overall increase in energy consumption (Sorrel, 2009).

From the idea of Jevons Paradox, energy efficiency as means of reducing carbon emissions could be counterproductive and it would have profound implications for sustainability (Sorrel, 2009). Polemi et al. (2008) states that the paradox is a real threat to the world security and to the environment and that it shows that more efficient technology is not the cure-all to the environmental problems of global warming.

3.3 Summary of theories

Based on the theories from these paradoxes, implementations of new technologies such as renewable energy, or efficiency measures, as the green growth is assuming will handle the issues of global warming and environmental degradation, can have many unintended consequences. Such consequences could be that new sources of energy being used in addition instead of replacing the current source, or that energy efficiency cause a higher demand for energy or at least aren't as effective in reducing the need for energy. This is driven by market mechanisms where companies trying to expand their markets and by that increase the overall energy demand like in the Displacement Paradox. Or that energy efficiency measures explained through the Jevons Paradox, can increase the demand for energy when production of goods becomes cheaper which in turn increases the demand for those goods, which leads to increased production and a higher energy demand. Sandberg et al. (2019) also states that there is no evidence that the green growth has managed to decouple economic growth from the use of natural resources during the last two decades in developed countries.

From these theories it could be questioned if the implementation of renewable energy for electricity generation could be able to displace fossil fuels for electricity generation in an ever-growing world. To test this, statistical analyses is performed on global data to see if a displacement has occurred.

4. Empirical analysis

This section will present the empirical analysis by first covering the data with the descriptive statistics, this is followed by a method part explaining the econometric model used.

4.1 Data and Descriptive statistics

The data for this paper are collected from Our World in Data (Ritchie & Roser, 2018; Ritchie et al., 2022) which is a trusted source in research and media and The World Bank (The World Bank, 2022a, 2022b, 2022c) which is a global organisation handling global development data. The analysis builds upon global panel data during the period of 2000 to 2020. Panel data consists of both cross-sectional and time series data and as this thesis wants to investigate the displacement of fossil fuels globally, over time, a panel data approach was selected for the investigation.

Following is an explanation of the variables used in this thesis. The dependent variable is Per Capita electricity generation from fossil fuels measured in kilowatt hours (fossil), fossil fuels include coal, gas, and oil sources used for electricity generation (Ritchie et al., 2022). The independent variable of main interest is Per capita electricity generation from renewables measured in kilowatt hours (renew). Electricity generation from renewable sources include generation from hydropower, solar, wind, geothermal, biomass and tidal sources (Ritchie et al., 2022).

Additional variables are included in the regression to control for structural factors that has been used in earlier research using a similar methodology (York, 2012; Greiner et al., 2018; Greiner et al., 2022). The following control variables are included in the model: the percentage of GDP derived from manufacture activities, such activities have shown be very energy and electricity intensive; the percentage of population living in urban areas (urban), since countries that is more urbanized have shown to use more electricity than less urbanized countries; the percentage of population that is working age (popu), between 15-64, since they engages more in production and consumption activities than other age groups in the society; and finally gross domestic product per capita measured in constant 2015 US dollar (gdp), which is included to control for the effects of economic activity (Greiner et al., 2018).

Table 1 presents the descriptive statistics for the variables used in this paper. The table presents number of observations, mean, standard deviation, minimum and maximum values for the different variables. This unbalanced panel data set contains yearly observations from 2000 to 2020 for 176 countries. The period was chosen due to data availability and that a more recent period was of interest compared to earlier research on the topic. A few countries were eliminated due to lack of data in the dependent or main independent variable.

Table 1. Descriptive statistics of the variables.

Variables	Obs.	Mean	Std. Dev.	Min	Max
Per Capita electricity generation from Fossil fuels measured in kilowatt hours (fossil)	3696	2516.25	3225.26	0	21034.74
Per Capita electricity generation from Renewables measured in kilowatt hours (renew)	3696	1226.36	4334.34	0	56755.71
Percentage manufacture of GDP (manu)	3430	12.47	6.97	0.23	49.88
Percentage of population living in urban (urban)	3696	60.65	23.13	8.25	100
GDP per capita measured in 2015 constant USD (gdp)	3622	14613.86	19853.67	255.10	128757.9
Percentage of population between 15-64 (popu)	3675	63.42	6.65	47.74	86.08

From the descriptive statistics in Table 1 we can note that for both the dependent variable and the independent variable has a minimum value of zero. This means that in a single year a country did not generate any electricity from the sources included in the different variables. For renewables this is quite common in year 2000 with 38 different countries that did not produce any electricity from renewable sources, in 2020 there were only 12 countries. For fossil fuel generation there where 3 countries who did not generate any electricity from fossil fuels during the period in the dataset, those are Albania, Iceland, and Bhutan.

The mean value for both the dependent and main independent value are on the lower spectrum compared to the maximum value. This indicates that most countries have a generation

of electricity around the mean with a few countries being more electricity intensive per capita. The country with the most electricity per capita generated by fossil fuels are Bahrain and for renewable sources are Iceland.

4.2 Methodology and Econometric model

The model to be estimated is a panel data model that is developed by York (2012), the model has been used earlier to investigate displacement of different energy sources. The main independent variable, that is in this thesis, per capita electricity generation from renewables measured in kilowatt hours coefficient has a straightforward interpretation; if the estimated coefficient shows a statistically significant result of -1, it indicates that for each unit of electricity from renewable sources that is generated, one less unit of electricity from fossil fuel sources is generated, net of controls. If the estimated coefficient shows a statistically significant result between 0 and -1 it indicates a partial displacement of fossil fuels and a value of 0 or higher indicates that increasing the electricity generation from renewable sources have no effect on the displacement of electricity generation from fossil fuels (York, 2012).

Therefore the hypothesis for the model can be stated as:

H_0: The increase of renewable sources for generating electricity per capita is displacing the use of fossil fuels for electricity generation.
H_1: The increase of renewable sources for generating electricity per capita is not displacing the use of fossil fuels for electricity generation.

With the variables of interest and the displacement model defined the panel data model that we want to estimate has the following form:

$$fossil_{it} = \alpha_i + \beta_1 renew_{it} + \beta_2 manu_{it} + \beta_3 urban_{it} + \beta_4 gdp_{it} + \beta_5 popu_{it} + \varepsilon_{it} \quad (1)$$
$$; i = 1, \dots, 176 \; t = 1, \dots, 21$$

In the above equation (1), the subscript i stands for country and t stands for year. Panel data contains observations of cross-sectional data over time, this makes a panel data model rich with information, and by that can improve the efficiency of econometric estimates over cross-sectional data or timeseries data because it usually contains more degrees of freedom and more sample variability (Hsiao, 2007). Because both the information on the intertemporal dynamics

and the individuality of the entities is contained within a panel data model it allows one to control for omitted variables. The two most common models used to estimate a panel data model are the fixed effects model and the random effects model (Hsiao, 2007). These two models are to be estimated, and as a robustness check on the fixed effects model a panel data first difference model will also be estimated. Following are explanations of the models used.

A fixed effect model is used when you want to control for omitted variables that vary across entities but do not change over time (Stock & Watson, 2020). A fixed effect model is often referred as the within estimator as fixed effects focuses on within entity variation and ignores between variation. These fixed effects from the individual entities are assumed to be correlated with the independent variables A entity fixed effects model often looks like this in its basic form:

$$Y_{it} = \alpha_i + X'_{it}\beta + \varepsilon_{it} \quad (2)$$

In the above equation (2), α_i denotes the unobserved variables in each entity, which in our case stands for country (Stock & Watson, 2020). Variables that could vary across countries but not over time based on the literature review could be financial capital in the short term, environmental possibilities to build the renewable energy and the current energy regime that do not want a transition to happen.

The same way an entity fixed effects control for variables that vary across entities but do not change over time, a time fixed effect model can control for variables that vary across time but not across entities. A time effect model looks like this in its basic form:

$$Y_{it} = \lambda_t + X'_{it}\beta + \varepsilon_{it} \quad (3)$$

In equation (3), λ_t denotes the unobserved variables that vary across time but are the same for each country (Stock & Watson, 2020). Such variables based on the literature review could be the price of renewable energy sources, influences from global climate policy. Because there probably are omitted variables that vary both across entities and time, a model using both time and country fixed effects could be appropriate. Because of this, a time and country fixed effects model will be estimated.

The other model that is often used with panel data is the random effects model, which is often called the between estimator. The model assumes that the variation across individual units is uncorrelated with the independent variables, it assumes that it is random. A random effect model looks like equation (4) in its basic form where the intercept term β_0 forms part of the error term (Hsiao, 2007).

$$Y_{it} = \beta_0 + X'_{it}\beta + \alpha_i + \varepsilon_{it} \quad (4)$$

A Hausman test is usually used to determine which of the fixed or random effects models that fits the data better (Hausman, 1978). A statistical test is used to detect endogenous regressors in a regression model. If there are endogenous regressors in the model the OLS estimator will fail due to the assumption that there is no correlation between an independent variable and the error term. The null hypothesis in the Hausman test is that the random effects is the appropriate model while the alternative model implies that the fixed effects model is the best suited model. To determine the appropriate model, a chi-square statistic is used. The interpretation of the test is if the P-value implied by the chi-square statistic is small (less than 0.05) we should reject the null hypothesis and use the fixed effects model (Hausman, 1978).

As a robustness check for the fixed effects model a first difference panel data model is estimated. Like the fixed effect model, first difference also attempts to solve for the omitted variables that varies across entities but not over time. A first difference model can be more efficient than a fixed effects model if the error term is a random walk which could lead to spurious results (Stock & Watson, 2020). The model in its basic form looks like this:

$$\Delta Y_{it} = \Delta X'_{it}\beta + \Delta\varepsilon_{it} \quad (5)$$

The different panel data models were estimated using the statistical program Stata (Stata Corporation, 2013). Clustered standard errors were used on all models to control for heteroskedasticity and autocorrelation. The clustering of each entity in a panel data model allows the regression errors to have correlation within each cluster but is assumed to not be correlated across clusters. There can be a large difference between clustered standard errors

and heteroskedasticity-robust standard errors due to the heteroskedasticity-robust standard errors do not allow for autocorrelation in the error term (Stock & Watson, 2020).

5. Results and Discussion

In this section the estimated results are presented from the time and country fixed effect, first difference and random effects models, this is followed by a discussion on the results. All results are rounded to 3 decimals.

Table 2. Results of the models estimated

Variables	Time and country fixed effects	First difference model	Random effects
Per Capita electricity generation from Renewables (kWh)	-0.043 [-0.115, 0.028] (0.036)	-0.075*** [-0.127, -0.023] (0.026)	-0.057 [-0.141, 0.026] (0.0428)
Percentage manufacture of BNP	-5.711 [-26.954, 15.517] (10.757)	4.994 [-3.551, 13.539] (4.358)	-0.446 [-22.264, 21.371] (11.131)
Percentage of population living in urban	22.268* [-3.518, 48.055] (13.062)	25.461* [-0.26, 51.18] (13.062)	8.555 [-12.635, 29.746] (10.811)
GDP per capita (constant 2015)	0.017 [-0.014, 0.050] (0.016)	0.054*** [0.034, 0.075] (0.010)	0.015 [-0.013, 0.044] (0.014)
Percentage of population between 15-64	75.758** [23.452, 128.063] (26.496)	40.586** [4.730, 76.441] (18.287)	72.073*** [25.805, 118.341] (23.600)
constant	-3759.569 [-7077.639, -441.499] (1680.801)	-10.685 [-25.700, 4.328] (7.657)	-2709.026 [-5258.550, -159.501] (1300.801)
R-squared: Overall Whitin Between	 0.1814 0.0807 0.1787	 0.0347	 0.1817 0.0628 0.1790

*95 % confidence interval are reported in brackets and clustered robust standard errors in parentheses. *** depicts significance at 1%, ** significance at 5% and * significant at 10 %.*

To determine whether the fixed or random effects model were best suited for our data the Hausman test was run. The result from the test (see Appendix) showed a highly significant test statistic which lets us reject the null hypothesis of the test, which means that the fixed effects model is best suited.

In table 2 the results of the time and country fixed effect and the first difference models show similar results in the coefficient of the main independent variable. The time and fixed model have a result of -0.043 and the first difference model has a coefficient of -0.075. This tells us that the time and country fixed effects model is robust compared to a differenced model and does not show any spurious result that can come from a model that is not stationary in its time series data.

Following is an interpretation of the different control variables. The first control variable, percentage manufacture of BNP has a coefficient of -5.71 in the time and country fixed effects model, the coefficient for the first difference has a coefficient of 4.99, and the coefficient for the random effects model has a coefficients of -0.05 which are not a statistically significant result from zero, meaning that one percentage more of BNP that is drawn from manufacture had not statistically effect on the use of fossil fuels for electricity generation.

The second control variable, percentage of population living in urban did not either show a statistically significant result from zero in any of the models with a coefficient of 22.26 for the time and fixed effect model, 25.46 for the first difference model and 8.55 for the random effects model.

The third control variable, GDP per capita (constant 2015 US dollar) are in the three models very close to zero showing no statistically significant effect in the time and country fixed effects model with a coefficient of 0.01 or in the random effects model with a coefficient of 0.01, in the first difference model, it showed a very modest statistically significant coefficient of 0.05.

The last control variable and the structural factor with a larger negative impact on the displacement during our period of interest is the percentage of population between 15-64 with a statistically significant result at for all models with a coefficient of 75.75 for the time and country fixed effects, a coefficient of 40.58 for the first difference model, and a coefficient of

72.07 for the random effects model meaning that with more people in working age has a positive impact on the use of fossil fuels for electricity generation. Below will the main findings from the time and country fixed effect model be discussed.

The overall R^2 of the time and country fixed effects model showed an explanatory level of 18.14 %. This explanatory level is similar to earlier research by Greiner et al. (2022) who, with a similar methodology had an overall R^2 of 16 %. The time and country fixed effects model explains 8.07 % of the within variation and 17.87 % of the between variation.

The model has examined how much one additional kWh electricity generated from renewables has managed to displace one kWh of electricity generated from fossil fuels. The result points at an almost nonexistent displacement for our period of interest of 2000-2020. From the results of the time and country fixed effect model we can see that a one unit increase in per capita kWh electricity generated from renewables reduces the per capita kWh electricity generated by fossil fuels by 0.043 (since the coefficient is -0.043) with a 95% confidence interval for displacement of -0.115 to 0.028 kWh. The coefficient for renewable electricity coefficient is significantly different from -1 which indicates that a displacement of fossil fuels used for generating electricity has not occurred during the years between 2000-2020 and it's not statistically significant different from 0 which indicates that a statistically significant partial displacement has not occurred.

The result shows a similar result as the research by York (2012) whose result with a similar methodology showed a very modest displacement of -0.089. Greiner et al. (2022) who also investigated the displacement of fossil fuels in electricity generation had a coefficient of -0.193 using a similar methodology.

From the viewpoint of the Displacement paradox it may not be so strange that the previous research on the topic and this thesis shows similar results. The paradox has shown that the search for growth and accumulation of assets in the capitalist economic paradigm of today could make it hard for added sources of energy to the system to displace a current energy source. Also from the perspective of green growth that is heavily relying on energy efficiency to decouple the growth from environmental degradation the Jevons Paradox shows that the efficiency measures might not have the big, intended effect that the green growth is relying on.

On the other hand has a large share of the world community agreed on limiting the global warming and countries have implemented different means of control such as carbon pricing, and the price of renewable electricity sources such as solar and wind has sharply decreased during the period this research is investigating. But the result of almost no displacement indicates that the forces such as power stability, environmental issues, current energy regime resistance, and social acceptance discussed in the literature review is hindering the transition to occur, and that the prices globally for emitting carbon dioxide has most likely been too low to make a sustainable impact. From this, it is perhaps not very surprising that the regression result indicates that electricity generated by renewable sources has not been able to displace electricity generated by fossil fuels.

Finally, it is important to note that the result might be biased due to the sample distribution which could potentially skew the result towards a displacement closer to zero. This is due to the large numbers of smaller countries in the sample with small changes in their per capita electricity generation from both renewables and fossil fuels.

It is also important to mention a possible measurement bias in the results due to the possibility that all sources of fossil fuels are not included in the sample. For example, diesel used for generation of electricity is not clearly stated as included in oil sources in the dataset used in this thesis. How biased depends on the size of the fossil fuels not included relative to the total volume of fossil fuels used for electricity generation. On the other hand, in other trusted sources like The World Bank, that also measures electricity generation from fossil fuels, oil sources refer to most crude oil and petroleum products, which includes diesel and many other oil products (The World Bank, 2023). From this, it is likely that most sources of fossil fuels used for electricity generation are included in the sample.

6. Conclusions

This thesis had the aim to investigate if the increased electricity generation from renewable sources had displaced the generation of electricity from fossil fuels. To answer the research question, a panel data model was built based on 176 countries over the period of 21 years ranging from 2000 to 2020. The result indicated that displacement of fossil fuels used for electricity generation has not occurred. Specifically, the result from the time and country fixed effects model showed that a 1 kWh per capita increase in electricity generated from renewable energy did not show a statistically significant result of any displacement of kWh per capita generated electricity from fossil fuels.

The earlier empirical studies mentioned in this thesis show that there has only been a very modest displacement of fossil fuels or other environmentally harmful sources occurring earlier when new technologies have been introduced. The reason why the result from this thesis could have shown a different result is because of global policy initiatives for the environment that has been taken and that the price of electricity generation from renewable sources have sharply decreased during the last decades.

The result from this thesis should not be interpreted as the transition to renewables is not going to happen. It might be the case that this thesis is as well as the earlier research on the topic is looking at a period where the result of initiatives taken around the globe to address the global warming has not yet been visible in the numbers. But the result does give an indication of that we should not assume that renewable energy will replace fossil fuels for electricity generation in a growing world without policy measures that assists the transition.

This thesis has touched upon many factors, such as economic, political, and social factors, that has and are influencing the transition to a renewable future. Further research on the topic could be to investigate what policy measures that so far has had the largest impact for the transition and find the key factors that the world community must work on to make sure that the transition away from fossil fuels will happen.

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Appendix

Hausman test

	Coefficients (b) fe	(B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
renew	-.0433957	-.0574329	.0140372	.0019628
manu	-5.718635	-.4466999	-5.271935	1.08065
urban	22.26847	8.555425	13.71304	3.199425
popu	75.75802	72.07372	3.684296	2.664293
gdp	.0178857	.0153534	.0025322	.0024234

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 56.39
Prob>chi2 = 0.0000