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What is the relationship between renewable energy and sustainable development?

Henry Nwagbara

Abstract

Climate change is one of the major environmental problems which we face as a society today. There are natural causes for fluctuations of climate change, but humans have accelerated this more recently. As economic growth continues, it because increasingly important to mitigate the effects of climate change. Demand for goods and services rises in lockstep with population growth. While this is may be met, it has its consequences on the environment in the form of pollution, such as carbon dioxide (CO2) emissions. As a result, we must find a way to achieve sustainable development. In this regard, renewable energy (RE) resources appear to be the most efficient and effective solutions. This is the reason why there is a connection between RE and sustainability. RE sources are occupying a greater share the energy mix each year, showing that the transitional to a more sustainable future is imminent. This research uses econometric analysis to find the effects of RE, population and gross domestic product (GDP) on sustainable development within Europe. Results suggest that the effect of RE is not only negative, but the size of the effect is much greater in comparison to the other explanatory variables. It is believed that the conclusions and recommendations for this research will be useful to policymakers.

1 Introduction

The purpose of the present study is to explore the effect of RE on sustainable development. Technology's convertible currency is energy. The entire fabric of society as we know it would crumble if we didn't have energy. The need for more and more energy is increased as populations grow faster than the average of 2%. Enhanced lifestyles and rising energy demand go hand in hand. Environmental difficulties such as air pollution, acid precipitation, ozone depletion, forest destruction, and radioactive material emissions are all linked to energy supply and use issues – although the focus of this research will be on global warming. If mankind wants to attain a bright energy future with minimal environmental repercussions, these concerns must be addressed concurrently. There is enough of evidence to show that if humans continue to degrade the environment, the future will suffer.

The United Nations (UN) has stressed the steps countries should take by 2030 for sustainable development by defining 17 Sustainable Development Goals (SDGs). Everyone should have access to inexpensive, reliable, contemporary, and sustainable energy, according to the seventh goal. Solving today's environmental concerns necessitates long-term prospective measures for long-term sustainable growth. RE resources appear to be one of the most efficient and effective alternatives in this regard, explaining why there is a strong link between RE and long-term development. As countries boost their usage of RE, the likelihood of meeting the UN's 2030 targets rises as well. As a result, this research demonstrates the significance of industrialised countries' use of RE in terms of long-term development.

A major challenge is to expand the amount of RE in the supply system. RE is considered an important resource in many countries around the world, on a global scale less than 15% of primary energy supply is from RE. Sources such as wind and solar, only constitute a very small share of the total supply. However, the potential is substantial. And in some regions and countries, the share of RE has grown substantially during the last couple of decades.

This research It will be divided into several sections. First, an introduction of both sustainable development and RE will be presented, followed by a review of the literature on various aspects of climate change – trends, causes, and mitigation. Econometric analysis and hypothesis testing will be used to investigate the impact of RE, as well as other explanatory variables, on sustainable development. After then, the results will be given together with an in-depth analysis. The research's limitations will also be discussed. Our conclusions will be drawn after that, along with a policy evaluation for policymakers.

2 Literature review

2.1 Climate change

Past and present fluctuations in climate

On a global scale, climate change is a major problem that we face. It is defined by Nasa (2021) as long-term changes in temperature and weather patterns. Over the last decade, global warming because of increased greenhouse gas (GHG) emissions has become a serious scientific and political issue. The greenhouse effect occurs when infrared light is trapped by

GHGs and particles in a planetary atmosphere, and the atmospheric CO2 levels have grown by around 25% since 1850 because of fossil fuel consumption (Mitchell, 1989). The Earth's surface would be 33 degrees Celsius colder without CO2, making it critical to track emissions and take measures to reduce them.

Jones et al (1986) observed that worldwide average temperatures increased between 1861 and 1984, with the difference increasing annually from around -0.4 degrees Celsius to 0.2 degrees Celsius. This data also illustrates that the northern hemisphere's sea temperature varies more than the southern hemispheres. However, some critique is that the time series' credibility is questioned because the spatial coverage is less than 75%. Prior to 1900, just about a third of the world was covered. Nonetheless, the trend of rising temperatures continues.

Similar findings were discovered by Rohde et al (2013), who used data from the year 1753. They compiled a collection of 14.4 million mean monthly temperature records from 44,455 sites by combining monthly and daily thermometer readings from 14 separate databases. The data is given as a comparison between 1950 and 1980. There were considerable changes in average temperature change between 1753 and the early 1900s, ranging from -1.2 degrees Celsius to -0.2 degrees Celsius, but the overall trend suggests that temperature is rising with time. However, because of the same issue of minimal Earth coverage, the results in the earlier time were more ambiguous.

More recent research demonstrates that global average tropospheric temperatures have been rising since the 1900s, with the most recent portion of the record (at the time of the study) showing a strong rise since the mid-1970s (Graham,1995). Between 1970 and 1991, worldwide average land surface air temperatures fluctuated, though in a smaller range than previous data discovered in the literature - the largest temperature change was 0.6 degrees Celsius. Returning to Rohde et al's findings, the latter half of the data demonstrate that temperature change fluctuated less in the 1900s but rose at a far higher rate in all hemispheres than in the 19th century. By the year 2000, the temperature had risen by 1 degree Celsius.

Reasons for previous climate change?

Natural causes can be used to explain previous climatic changes. Earth has seen a natural cycle of cold glacial and warm interglacial eras during the last million years or more, which is mostly driven by gradual changes in the earth's orbit but accelerated by greenhouse gases (Gov.uk, 2021). These are known as Milankovitch Cycles, which cause changes in the amount of solar energy received by the Earth, as well as its latitudinal and seasonal distribution (Berger, 1978). Another natural reason is periodic volcanic eruptions, which also emit CO2 (Robock, 2000) - climatic change is caused by geographical and seasonal variations in received radiation (Bennet, 1990).

Modern climate change, on the other hand, is dominated by human forces. According to time series data from Karl et al (2003), global temperature has risen dramatically since the base year of 1958. By 2000, global temperatures have grown by up to 0.6 degrees Celsius annually. They also discovered that CO2 levels have risen by 31% since pre-industrial times, from 280 parts per million by volume (ppmv) to over 370 ppmv today, owing to increased combustion of fossil fuels such as coal, oil, and gas, which releases more CO2 into the atmosphere and causes more warming. Andrew (2008) describes this modern climate change as the greatest example of market failure ever witnessed, as the negative externality effects of pollution have grown.

CO2 emissions are produced in practically all industrial processes, such as material extraction from the earth's crust, production transportation, and so on (Huisingh et al, 2015). Temperature has been increasing at an exponential rate, as shown in the studies presented, and this can be explained by the recent increase in industrial practise. As total CO2 emissions rise, necessary reforms in industrial processes are falling behind (Stal, 2015). Increased urbanisation, aerosol usage, and deforestation all have an influence (Han et al, 2014). Increased economic growth has resulted in these factors. This is accompanied by increased demand for goods and services, resulting in more industrial operations that hurt the environment. Data from the Bank of England (2020) shows that from 1270 and 2015, GDP per capita increased at an exponential rate, however it only began to rise substantially in the mid-1970s. According to the Environmental Kuznets Curve (EKC), as GDP per capita rises, so does environmental deterioration (Dinda, 2004) – although it will eventually reach a ‘turning point’ where it will lessen. The IPAT identity is another tool that aids in the assessment of environmental effect (York et al, 2003): where environmental impact (I) = Population + affluence (A) + technology (T). CO_2 emissions have increased in the past as PAT has increased.

Why is it important to manage climate change?

Increased demand for cooling energy will accompany warming. According to research, the demand for cooling energy increases by 5 to 20% for every 1.8°F increase in temperature, while the demand for heating energy decreases by 3 to 15% for every 1.8°F increase in temperature (Scott and Huang, 2007), resulting in significant increases in electricity use and higher peak demand in most regions. It will very certainly have an impact on some RE sources, such as hydropower generation. It also poses specific health risks to humans. Heatwaves and strong storms have direct health consequences, as can air pollution and many climate-sensitive viral diseases. Between 1999 and 2003, more than 3,400 deaths in the United States were reported because of severe heat (Lead, 2008). As the temperature rises, this figure will worsen, resulting in a further loss of human capital. The Paris Agreement recognises that climate change is a global emergency. It was signed in 2015, and it establishes long-term goals to significantly reduce global GHG emissions to keep global warming below 2 degrees Celsius, review countries' commitments every five years, and provide financing to developing countries to mitigate climate change, strengthen resilience, and improve their ability to adapt to its effects. The agreement now has 192 signatories (UN, 2016).

2.2 Sustainable development

The UN has used the term ‘sustainable development’ often, defining it as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (Imperatives, 1987). Others, however, argue there is more to it; Hopwood et al. (2005) describe it as an attempt to connect growing concerns about a variety of environmental challenges with socio-economic concerns in broad terms. These two sorts of issues have been added to O'Riordan's (1989) sustainable development mapping. By putting them on an axis, it becomes clear that diverse perspectives on the sustainable development debate have a beneficial relationship between socioeconomic well-being and environmental concerns. Sustainable development is critical because it allows us to maintain economic progress while limiting environmental damage. The 'economic problem' confronts all societies: how to make the greatest use of limited resources while meeting unlimited demands and wants (Possumah and Ismail, 2016). In this context, fossil fuels are finite resources, but as living standards rise, so does energy consumption, necessitating a diversification of energy production methods to achieve long-term sustainability – here is where RE sources are important (*more on this in **2.3***).

In 1950, world population was estimated at around 2.6 billion people. It reached 5 billion people in 1987, 6 billion in 1999 and by 2020 it was 7.7 billion (UN, 2021a). With constant population growth comes an increasing demand for goods and services provided by natural resources - Namahoro (2021) found that population and economic growth positively affect CO2 emissions in the long-term at the regional level. In 2015 the UN set up the SDGs, a collection of 17 interlinked goals. Number 7 has the most relevance to this research – ensure access to affordable, reliable, sustainable, and modern energy for all (UN, 2021b). Dincer (2000) found that the wealthy industrialized economies which contain 25% of the world's population consume 75% of the world's energy supply. However, over the years there has been good progress in this; global access to electricity increased from 83% in 2010 to 90% in 2019 (UN, 2021b). During this period, most of the increases occurred in populous low/middle income countries such as Brazil, India, China, Indonesia, and Pakistan reflecting greater equality between the developed/developing world. Furthermore, the share of RE in total fine energy consumption increased gradually from 16.4 percent in 2010 to 17.1 percent in 2018, which is only a small increase – nevertheless progress towards sustainable development has been made in this area.

CO2 is a widely used indicator of sustainable development, but what can we do achieve this? The UK has employed tradeable pollution permits, in which businesses are given permission to produce a particular amount of pollution because of their operations, which they are free to buy and sell amongst themselves (Mr Banks, 2021). Since its inception in 2005, the EU Emissions Trading System (ETS) has played a critical role in decreasing GHG emissions in a cost-effective manner. Between 2005 and 2019, ETS-covered installations lowered emissions by around 35% (Europa, 2021). However, due to good incentive to connect self-interest with societal interest, the carbon tax is the most effective economic tool for accomplishing the goals of the Paris Agreement on climate change mitigation. With a carbon price of $139/tCO2, Sweden now has the highest carbon price in the world. Since the establishment of the Swedish carbon tax in 1991, the Swedish economy has grown by 60%, while CO2 emissions have reduced by 25%. (Our World in Data, 2018). There is also command and control regulation, which limits the behaviour of individuals and businesses. The Environmental Protection

Agency established the Energy Star programme in 1992 as a worldwide benchmark for energy efficient products. Other government requirements demand products to utilise 20-30% less energy (Energy star, 2022).

Since developed economies in general have greater levels of economic growth relative to developing economies, it may be more beneficial to look at them as it is more important for them to consider ways to develop sustainably. Developed economies as such must start making progress towards the sustainable development goals first, as well as the targets set by the UN since they have the means to do so. In the European Union (EU), RE sources are currently employed unevenly and insufficiently. RE sources provide only about 7.8%–8% of the EU's overall gross inland energy consumption, even though many of them are abundantly available and have significant real economic potential. The EU's energy import dependency is already at 53.1 percent (Menegaki, 2011). This is particularly true for oil and gas, which will increasingly originate from sources farther away from the EU, thus posing geopolitical dangers. Economic growth achieved from RE sources is decoupled from depletion of resources and global warming.

2.3 Renewable energy

To reduce CO2 emissions and local air pollution, the world must quickly transition to low-carbon energy sources. This might be accomplished through RE sources; they have the potential to be a long-term replacement for fossil fuels (Nationalgeographic.org, 2012). The production of clean energy is increasing. Hydroelectric power has long been the most common kind of RE around the world, but other sources such as wind and solar are rapidly gaining popularity. RE produced 941 TWh of energy in 1965, but by 2020, they produced 7444 TWh (Ritchie and Roser, 2020). The Paris Agreement, signed in 2015, has undoubtedly aided the expansion of RE. Furthermore, its percentage of RE in worldwide power generation has increased by 20% to 29%, up from 27% in 2019, indicating that it is steadily growing. Given the finite nature of fossil fuels, an increase in RE generation will facilitate the transition to a more sustainable future.

Hydropower

Hydropower is a vital energy source that uses water travelling from higher elevations to lower elevations to drive turbines and generate electricity. Dam projects with reservoirs, run-of-river, and in-stream projects all fall under the category of hydropower projects, and they differ in size. The primary energy is provided by gravity and the height the water falls on to the turbine. The potential energy of the stored water is the mass of the water, the gravity factor and the head defined as the difference between the dam level and the tail water level. Hydropower discharges practically no particulate pollution, can upgrade quickly, and it can store energy for many hours (Owusu and Asumadu-Sarkodie, 2016).

Solar power

Solar energy is the energy source for RE systems that directly draw on the Sun's energy. Solar energy is used in some RE technologies, such as wind and ocean thermal, after it has been absorbed and changed to other forms on the earth. Solar energy technology uses solar irradiance to generate electricity through photovoltaic (PV) and concentrating solar power, to provide thermal energy, to meet immediate lighting demands, and, theoretically, to produce fuels for transportation and other uses (Edenhofer et al, 2011).

Wind energy

Wind's growth as a significant source of global energy has propelled it to the forefront of renewable energy sources. Wind can be found all throughout the world, with some areas having very high energy density. (Manwell et al, 2010). Wind energy uses the kinetic energy of moving air to generate electricity. The primary application of the importance to climate change mitigation is the generation of power from huge turbines on land or at sea (in sea or fresh water). Onshore wind energy solutions are currently being developed and deployed on a significant scale). Wind turbines are machines that transform wind energy into electricity.

Energy Security / energy mix

Energy security is described as "the consistent availability of energy in a variety of forms, in sufficient amounts, and at reasonable prices" (Miller, 2010). Given the interdependence of economic growth and energy consumption, access to a reliable energy supply is a political priority as well as a technical and financial challenge for both developed and developing countries, because prolonged disruptions would cause serious economic and basic functionality problems in most societies (Baghat, 2006). In comparison to fossil fuels, RE sources are more equitably dispersed over the world and are less traded on the market. RE reduces energy imports, contributes to portfolio diversity, lessens an economy's exposure to price volatility, and represents chances to improve global energy security. It can also help to improve the reliability of energy services, particularly in locations where grid connection is often limited. Security can be improved by having a wide portfolio of energy sources, as well as effective management and system design (Edenhofer et al., 2011).

As of 2019, the cleanest countries in the world were Iceland and Norway, which produced 77% and 66% of their energy from renewable sources respectively. Brazil and Sweden also produced a significant amount too (45% and 42%). The United Kingdom produced only 14% (Ritchie and Roser, 2020). As previously discussed, the burning of fossil fuels accounts for around three quarters of global greenhouse emissions which has various impacts on the planet. These emissions increase each year, meaning that the world must shift away from fossil fuels and towards an energy mix dominated by low-carbon sources of energy such as renewables.

As for the future of RE, we can expect that it they will occupy a greater proportion within the energy mix. The EU has set a target to reduce GHG emissions by 80-90% in 2050 in comparison to 1990 (Olabi, 2016) – for this to happen, there must be a growing trend towards clean energy as such. RE may offer the best prospects for their long-term replacement for fossil fuels. However, they differ in many important ways from fossil fuels, particularly in that they are energy flows rather than stocks. The most important RE sources, are also intermittent, necessitating major energy storage as these sources increase their share of total energy supply (Moriarty and Honnery, 2016). Maintaining ecosystem services further limits the potential for RE. The natural world provides many ecosystem services, such as provision of food, water, and climate regulation. However, land intensive RE systems – particularly hydroelectricity inevitably reduces such service provision, which is adverse for sustainability. For example, in 2006 the Yangtze River Dolphin became extinct due to the building of the Three Gorges Dam in China causing a loss in habitat for the species (Visual stories, 2022).

2.4 Renewable energy and sustainable development

Although there was different regression analysis in the literature there was none which focused on directly RE and its' impact on sustainable development. Other variables used in there were gross domestic product (GDP), population growth and corruption (Asumadu-Sarkodie and Owusu, 2017; Zhang et al, 2016). However, focusing on just RE and sustainable development, the common theme in the literature is that they are intimately related – RE negatively affects CO2 emissions (Namahoro, 2021), and that it is important for governments and societies to utilise sustainable energy resources in terms of renewables (Dincer, 2000; Kaygusuz and Kaygusuz, 2002; Güney, 2019). This research will further test if this is true, and to what extent. A benefit of carrying out this research is that it will make use of more recent data than what has been used in the current literature – meaning that we can see what the effect of RE has been within the last few years, as the importance for diversifying energy sources grows.

Connolly et al's (2016) study presents the scenario for a 100% RE system in Europe by the year 2050. According to the findings, the total yearly cost of the EU energy system will be around 3% higher than the fossil fuel alternative in 2050, and 12% higher to achieve a 100% RE system. Rather than the availability of cost-effective alternatives, progress toward a 100% RE system will most likely be defined by political will and society's ability to deploy appropriate technologies.

3 Methodology

Econometrics is the most suitable method to use in this context, as it quantitatively applies statistical and mathematical models using data to the analysis of economic phenomena (Kennedy, 2008). It shows the relationship between dependent and independent variables, from which the historical data can then be used to forecast future trends. A grand literature review will only allow use of previous models, from which to judge a conclusion. It focuses on qualitative data, whereas the two indicators that will be used are quantitative. Surveys also focus on qualitative data, which is relies on normative statements from individuals. It is best to use real-world data which will enable testing of the two variables that will be used.

For this research, a panel set of countries will be used. It refers to the pooling of observations on a cross-section of households, countries, firms, etc. over several time periods (Lancaster, 1990). There are several benefits to using it. Firstly, it controls for individual heterogeneity. Time series and cross section studies not controlling this heterogeneity run the risk of obtaining biased results (Moulton, 1986). Panel data also give more informative data, more variability, less collinearity amongst the variables, more degrees of freedom and more efficiency. Panel data also provides more useful information, more variety, less inter-variable collinearity, more degrees of freedom, and greater efficiency. Multicollinearity is a problem in time-series research. Panel data also has the advantage of being able to uncover and measure impacts that are difficult to notice in pure time-series data (Baltagi and Baltagi, 2008). There will be more result to make a judgement from, rather than using one country which may have more emphasis on clean energy. Countries with similar development status will be used. It would be less useful comparing developed countries with developing countries, as developed countries in general will have a greater share of RE consumption. Therefore, this research will test the following hypothesis:

Ho: RE consumption has a positive effect on sustainable development within a European context.

H1: RE consumption has a negative effect on sustainable development within a European context

For RE, the variable that will be used is energy consumption by renewables (% of final energy consumption) energy production by TWh will not be appropriate because the size and population differences between the countries means that there will be differences in energy consumption regardless. RE consumption might have increased, but it may not have relative to consumption from fossil fuels. Another option which was considered, but not used, was investment into RE sources. Prior research shows several ways of measuring sustainable development. Mitchell (1996) used different indicators. Firstly, percentage of GNP spent on environmental defence – the benefit is that it shows the proportional spending of an economy towards environmental defence. However, it doesn’t account for importing of resources and labour. Another one is quality of life index – it is a key element of sustainability which identifies basic, physical, and cultural needs, but focuses too much on human needs. Expenditure on research & development is also a good option as it focuses on the innovation of new process, however more recently, Zhang et al (2016) used CO2 emissions - the main greenhouse gas in causing climate change. It is better because carbon is in many natural stores, influenced by human activities and high CO2 levels can have health impacts. Therefore, CO2 emissions will be used as a variable in this research. Population and GDP will also be used in this research as previous literature has used it in their models. GDP will be used over GDP per capita here, to separate the variable with population.

From the EU countries, ten were selected to be part of the research – between the years 1990-2018. These are all OECD countries, as they are the ones which have data from one of our sources, *OECD.Stat*: Austria, Czech Republic, Greece, Denmark, Ireland, Italy, Lithuania, Luxembourg, Slovenia, Spain. The goal of the OECD is to promote the economic welfare of its members. The members and partners represent 80% of world trade – these countries have similar goals, so they will be good for comparison. Other than Italy and Spain, the rest of the countries have a similar amount of GDP as of 2020. Of the latter, Slovenia's was the lowest in 2020 ($53.6 billion) whereas Austria's was the highest ($433.3 billion). Italian and Spanish GDP was $1.9 and $1.3 trillion respectively. The selected countries have a good spread across Europe – north, south, east, west, and central, which paints a good picture of the entire continent.

By doing a panel data regression, we will have additional information and variability, which will minimise estimation biases that would arise from aggregating groups into one statistic. Our model will be as follows:

$$LogCO2 = c + \beta_1 LogGDP + \beta_2 LogPopulation + \beta_3 Renewable\_energy$$

Table 1: Variables for the model

Variable	**Description**	**Source**
Log(CO2_emissions)	*Logarithmic transformation of tonnes of carbon dioxide emissions, thousands*	*Stats.oecd.org*
Log(GDP)	*Logarithmic transformation of gross domestic product*	*Stats.oecd.org*
Log(Population)	*Logarithmic transformation of population*	*Stats.oecd.org*
Renewable_energy	*RE consumption (% of total final energy consumption)*	*ec.europa.eu/eurostat*

Table 1 above shows the variables which will be used in this research, with their description and relevant sources.

4 Empirical results and Data analysis

Figure 1: Regression 1 – Ordinary Least Squares

Dependent Variable: LOG(CO2_EMISSIONS)
Method: Panel Least Squares
Date: 03/09/22 Time: 11:50
Sample: 1990 2018
Periods included: 29
Cross-sections included: 10
Total panel (unbalanced) observations: 285

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.433213	0.185765	-7.715197	0.0000
LOG(GDP)	0.196498	0.018141	10.83188	0.0000
LOG(POPULATION)	0.668702	0.020490	32.63632	0.0000
RENEWABLE_ENERGY	-3.174676	0.186176	-17.05203	0.0000

R-squared	0.956965	Mean dependent var	10.99984
Adjusted R-squared	0.956506	S.D. dependent var	1.200863
S.E. of regression	0.250443	Akaike info criterion	0.082768
Sum squared resid	17.62485	Schwarz criterion	0.134031
Log likelihood	-7.794457	Hannan-Quinn criter.	0.103318
F-statistic	2082.865	Durbin-Watson stat	0.029392
Prob(F-statistic)	0.000000		

Figure 1 above shows the ordinary least squares regression (OLS) which was run with EViews. In this model, the independent variables are all statistically significant. Both GDP and population have a positive effect on CO2 emissions, whereas the variable we are interested in (RE) has a negative effect on it. More specifically, if RE consumption share were to increase by 1%, CO2 emissions will decrease by approximately 3.17%. If GDP were to increase by 1%, CO2 emissions would increase by 0.2%. Finally, if population had a 1% increase, CO2 emissions will increase by 0.69%. Of all the variables in the model, share of RE consumption has the greatest effect on CO2 emissions. However, the problem with this OLS model is that it neglects the panel structure of the data – the individual heterogeneity of the model. It assumes all the cross sections in the model possess the same characteristics when they have unique attributes.

Figure 2: Regression 2 – Fixed effect model

Dependent Variable: LOG(CO2_EMISSIONS)
Method: Panel Least Squares
Date: 03/09/22 Time: 11:53
Sample: 1990 2018
Periods included: 29
Cross-sections included: 10
Total panel (unbalanced) observations: 285

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.43194	1.227592	10.12710	0.0000
LOG(GDP)	0.261067	0.020748	12.58290	0.0000
LOG(POPULATION)	-0.263676	0.085819	-3.072468	0.0023
RENEWABLE_ENERGY	-3.018217	0.140893	-21.42199	0.0000

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.996046	Mean dependent var	10.99984
Adjusted R-squared	0.995871	S.D. dependent var	1.200863
S.E. of regression	0.077162	Akaike info criterion	-2.241279
Sum squared resid	1.619480	Schwarz criterion	-2.074674
Log likelihood	332.3822	Hannan-Quinn criter.	-2.174491
F-statistic	5709.482	Durbin-Watson stat	0.304620
Prob(F-statistic)	0.000000		

In the second regression shown in *figure 2*, we move to the fixed effect model to adjust for this. Although each independent variable is still statistically significant, in the fixed model population now has a negative effect on CO2 emissions – but still less impactful than that of RE. It suggests that if it were to increase by 1%, CO2 emissions would fall by 0.26%. This result was unexpected, as the literature suggests that population has a positive effect on CO2 emissions. The previously mentioned IPAT identity all suggests that population is a positively related with environmental impact. Possible reasons for this might be the selection of countries used, or error in the dataset. This time, for a proportional increase in GDP, tonnes of CO2 emissions will increase by 0.26%. If RE consumption were to increase by 1%, CO2 emissions will decrease by approximately 3.02%. It has given a similar coefficient estimate for our variable of interest in both the OLS and fixed effect model. However, in this model, the unique attributes of each cross-section are only accounted for in the intercept of the model.

Figure 3: Regression 3 – Random effect model

Dependent Variable: LOG(CO2_EMISSIONS)
Method: Panel EGLS (Cross-section random effects)
Date: 03/09/22 Time: 11:54
Sample: 1990 2018
Periods included: 29
Cross-sections included: 10
Total panel (unbalanced) observations: 285
Swamy and Arora estimator of component variances

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.837550	0.838630	5.768395	0.0000
LOG(GDP)	0.212302	0.019651	10.80385	0.0000
LOG(POPULATION)	0.255042	0.059549	4.282914	0.0000
RENEWABLE_ENERGY	-2.958044	0.139330	-21.23051	0.0000

Effects Specification

	S.D.	Rho
Cross-section random	0.298400	0.9373
Idiosyncratic random	0.077162	0.0627

Weighted Statistics

R-squared	0.616215	Mean dependent var	0.531398
Adjusted R-squared	0.612117	S.D. dependent var	0.136474
S.E. of regression	0.086045	Sum squared resid	2.080441
F-statistic	150.3934	Durbin-Watson stat	0.240965
Prob(F-statistic)	0.000000		

Unweighted Statistics

R-squared	0.756104	Mean dependent var	10.99984
Sum squared resid	99.88740	Durbin-Watson stat	0.005019

Figure 3 shows the third regression which was run using the random effects model, which accounts for individual heterogeneity of each of the cross sections and intercepts. Population has a positive effect on CO2 emissions again; as does GDP, which is the same as with the OLS model. For a 1% increase in these, the effect on CO2 emissions would be 0.26% and 0.21% respectively. RE still negatively effects CO2 emissions but slightly less than as shown on the fixed effect model. If RE consumption was increased by 1%, CO2 emissions will decrease by approximately 2.96%.

To find which is better to use out of the fixed or random effect model to discuss results, a Hausman Test was run (Mutl and Pfaffermayr, 2011), where:

Ho: Random effect model is more efficient

H1: Fixed effect model is more efficient

Figure 4: Hausman Test

Correlated Random Effects - Hausman Test
Equation: Untitled
Test cross-section random effects

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	71.055496	3	0.0000

Cross-section random effects test comparisons:

Variable	Fixed	Random	Var(Diff.)	Prob.
LOG(GDP)	0.261067	0.212302	0.000044	0.0000
LOG(POPULATION)	-0.263676	0.255042	0.003819	0.0000
RENEWABLE_ENERGY	-3.018217	-2.958044	0.000438	0.0040

Cross-section random effects test equation:
Dependent Variable: LOG(CO2_EMISSIONS)
Method: Panel Least Squares
Date: 03/09/22 Time: 11:54
Sample: 1990 2018
Periods included: 29
Cross-sections included: 10
Total panel (unbalanced) observations: 285

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.43194	1.227592	10.12710	0.0000
LOG(GDP)	0.261067	0.020748	12.58290	0.0000
LOG(POPULATION)	-0.263676	0.085819	-3.072468	0.0023
RENEWABLE_ENERGY	-3.018217	0.140893	-21.42199	0.0000

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.996046	Mean dependent var	10.99984
Adjusted R-squared	0.995871	S.D. dependent var	1.200863
S.E. of regression	0.077162	Akaike info criterion	-2.241279
Sum squared resid	1.619480	Schwarz criterion	-2.074674
Log likelihood	332.3822	Hannan-Quinn criter.	-2.174491
F-statistic	5709.482	Durbin-Watson stat	0.304620
Prob(F-statistic)	0.000000		

Figure 4 shows the results of the Hausman test. Since the P-value for the test value is below 0.05, we can reject the null hypothesis, meaning that the fixed effect model is more efficient for our dataset. Both the adjusted R^2 and R^2 for the fixed effect model is 99.7%, meaning that this model has very strong explanatory power of the independent variables CO2 emissions. Approximately this percentage of the observed variation can be explained by them model's inputs.

With use of a panel dataset of ten EU countries, we can see how our independent variables effect sustainable development. According to our final model – the fixed effect, population is the only variable which disproved the theory that the literature said. Of course, the IPAT identity suggests that population positively impacts environmental impact, whereas our regression gave a negative sign, which might be due to problems with research design or data collection. For instance, between 1990-1994 there was missing GDP data for which may have affected the population coefficient – the missing data was not available on *OECD.stat*. From 1995 onwards, Lithuania had a falling population which may have led to a distortion of measurement error (Baltagi and Baltagi, 2008). Combined effects of major political, economic, and social transitions have led to large scale emigration in Lithuania (Ubarevičienė and Van Ham, 2017) - however this lies outside the scope of our research.

On the other hand, the model shows that GDP growth positive effects CO2 emissions, which is as expected. It is the only positive variable in our model. The EKC can explain this (although it uses GDP per capita). A possible reason why the two variables are positively related is that the panel countries may not have yet reached a 'turning point'. Theory and previous literature tell us that GDP rises in lockstep with the rise in production, consequently meaning an increase in the usage of fossil fuels and an increase in CO2 emissions (Mitić et al, 2017).
Finally, share of RE consumption confirms what the literature shows – that the two variables are negatively related. Effectively, an increase in the proportion of RE within the energy mix should decrease CO2 emissions as they are infinite resources. From the dataset, every country had a trend of an increasing share, which is good as it shows understanding of the importance of the transition towards clean energy. The important thing to note here is the effect of RE relative to the other variables. Since a negative relationship is what is desired, it would be much more useful to increase our consumption from RE sources such as sun, wind, and hydro, as difference between this and the other variables is over 2%.

As a result, we can reject our null hypothesis. So, we do not reject the alternate hypothesis and conclude that RE consumption has a negative effect on sustainable development within a European context.

5 Policy recommendations

There are several policy implications which could be used to increase the share of RE consumption. Firstly, to promote improved economic efficiency, subsidies can be utilised to counteract market failures and externalities such as CO2 emissions. The Chinese government, for example, has adopted a range of subsidy strategies to accelerate the growth of RE sources. (Shen and Lou, 2015). However, it has led to problems such as overcapacity, lack of funds, excessively fierce competition etc. There is also an opportunity cost as money spent on subsidy may be better used elsewhere, which will suit the economic situation.

Another policy which could be used is provision of education. The market failure of climate change caused by the negative externality of CO2 emissions may be partially due to asymmetric information. Education is one of the most effective solutions to the problems faced by society. RE education's broad goals are to provide practical knowledge and understanding of facts, concepts, principles, and technology for harnessing RE sources (Kandpal and Broman, 2014). Governments may want to consider adding more RE content as part of school syllabus, and universities may want to provide may want to provide more programmes around it. Ultimately, the role of a RE education program should increase the consumption from RE sources.

If it is feasible given a countries climate, policymakers may want to directly provide large scale RE projects, which will undoubtably cause RE consumption to increase a lot, depending on the amount of investment. Núñez de Balboa is the largest solar photovoltaic plant in Europe. It has a capacity of 500 megawatts and is expected to provide electricity to more than 250,000 people. This plant also has the added benefit of being able to remove roughly 215,000 tons of hazardous CO2 emissions each year (Solarfeeds, 2021). An external benefit of these projects is that they created jobs, however the initial investment of course, is very expensive.

Fostering support for RE at a local level might be a better alternative. This is because it would be much cheaper than provision on a regional/national scale, and it might act as an incentive for other local communities around the area to follow. There are different ways which it can build public support for renewables, such as promoting local community and individual ownership of renewables. Also, by ensuring RE ownership, and ensuring that renewable support systems, particularly for low-income households, remain cheap. For example, include extensive local community ownership of onshore wind turbines in Denmark and Germany (International Energy Agency, 2018).

There are also policies which can be used which are focused on CO2 emissions – some of which were previously mentioned in the literature review. Firstly, the carbon tax can be increased in countries where it is already in use or implemented if it is not already. As stated in the literature, it is the most effective tool in mitigating climate change. Since it increases the price of carbon, it acts as a disincentive to consuming carbon, which would cause economic agents look for alternatives such as renewables. However, literature suggests that carbon taxes tend to be regressive in developed economies developed economies (Callan et al, 2009), so this has relevance with our panel dataset. The carbon tax will pose a bigger burden on low-income earners than high-income earners, which will reproduce income inequality. However, in developing economies it has been concluded that such taxes are either neutral or progressive. So, if need be, it would be safer to use carbon tax in these economies.

Command and control regulation are mandated environmental policy that regulation influences behaviour by law, incentives, threats, and agreements. Discharge standards, licenses, quotas, and restricted usage are common tools (Tang et al, 2020). As a result, they reduce CO2 emissions through industrial processes, and may provide an incentive to incorporate more sustainable measures to their business. But because a complicated set of rules has been constructed, a major concern here would be the cost of enforcement.

An alternative for policymakers would be to subsidise the production of electric vehicles, as they are zero emissions. Overall, they will reduce the amount of CO2 emissions – petrol and diesel vehicles emit huge amounts of CO2 every day. Nearly a third of the EU's total CO2 emissions are attributed to transportation, with road transportation accounting for 72% (Europarl, 2019). The automotive company Tesla is accelerating the world's transition to sustainable energy with electric cars. Ever since, electric car production has become more popular amongst other automotive companies.

6 Limitations and future research

There are a few limitations on this our model which would have made for better research. *1) The model is simple:* It assumes that there are only three explanatory variables for CO2 emissions, which is very unrealistic. Had It included more, we might see that some of our coefficients may be over/understated. *2) Study only uses European countries:* It only paints what it is happening in a European context. It will show differentiating results by continent where the explanatory variables will be different. For example, Asian countries are known to have faster population growth, so the sign for this variable may be positive when using a dataset for those countries as opposed to in our fixed effect model. *3) Lack of data:* As previously mentioned, there is some missing data for Lithuania which may have altered our regression results. It would be advised for future researchers that these changes are made to see better results and conclusions.

7 Conclusions

The main finding of this research is that renewable energy and sustainable development are related negatively – the effect of renewable energy is much greater in size relative to the other independent variables used in this. All the results were statistically significant, as well as the R^2 and adjusted R^2 being greater than 0.9, suggesting that the relationship between variables is caused by more than chance, and the explanatory power of each is high. However, population disproved what the literature said in our fixed effect model – which is more efficient according to the Hausman Test. It suggested a negative relationship with carbon dioxide emissions, but as mentioned this may have been due to error and distortion of measurement within the panel dataset. There are various policies which can be used to increase renewable energy consumption, as well as limit the emissions of carbon dioxide. They each have drawbacks; however, it would be recommended to policymakers to test these out as it is essential that we achieve sustainable development to mitigate the effects of climate change in the future. Future research my want to consider the limitations of this one. By including more independent variables, using a different set of countries, and ensuring a complete dataset, better results may be obtained. Although share of renewable energy consumption has been increasing over the years, a question to ask is will renewables be able to fully replace fossil fuels? This would be ideal, however given that each renewable energy source is reliant on flows within climatic conditions in relevant countries. Therefor it may not be feasible, but it is something that time will be able to tell. It would be important to consider this whilst trying to achieve energy security, as we will need constant and reliable energy sources in the future, especially as economic growth occurs. Nonetheless, a fall in carbon dioxide emissions must be accompanied with other greenhouse gases, as they also have their own negative impacts on the environment. This will help achieve sustainable development in a broader sense than just carbon dioxide emissions. Ultimately, this will mitigate the effect of climate change in the future.

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9 Appendix

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Not all dissertations and research projects will involve research activities that give rise to ethics concerns. This form, *NBS/Ethics02*, is the appropriate form to complete if your research activity ***does not involve*** the collection of unpublished 'primary' data, as described below, ***nor does it involve*** the use of unpublished data held by public or private bodies *for any purpose other than that intended when collected*. Please complete this form, ask your supervisor or Module Leader to counter-sign it and submit it in accordance with the requirements of your module.

During the course of your research, you may decide to undertake research involving any of the research activities set out below. If you wish to do so, please consult with your Module Leader or supervisor and complete either form *NBS/Ethics03* or *NBS/Ethics04*, as appropriate.

By completing and signing this form, you are declaring that you will not:

- Collect, store and analyse data from, or that relate to, living human beings – unless the data are already in the public domain in some published form and have been obtained from said public domain (subject also to any terms & conditions associated with data-use).

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Name of student(s) **Henry Nwagbara**
Student registration number(s) **N0848091**

Programme of Study **Economics/Economics with Business/Economics with International Finance and Banking/Business Management and Economics**

Module name and code **BUSI32629 Research Project**

Working title of research project **What is the relationship between renewable energy and sustainable development?**

Declaration
I hereby agree that this project will be conducted in strict accordance with this protocol.
Signed (student/s) Nwagbara Date 3/9/12

I confirm that the student has stated clearly in their research proposal that this project will not involve any primary data collection, nor give rise to issues under either the Data Protection Act, 2018, or the General Data Protection Regulation.

Signed (Module Leader) Date December 2021