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THE NEXUS BETWEEN RENEWABLE ENERGY CONSUMPTION AND ECONOMIC GROWTH

Evidence from the Nordic countries

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ABSTRACT

Jonne Koistinen: The Nexus between Renewable Energy Consumption and Economic Growth – Evidence from the Nordic Countries
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One of the most pressing issues of our time is climate change, with its negative consequences increasingly present in media coverage and everyday life. As a result, economies are looking for ways to mitigate and adapt to these shifts in climate patterns and rising global temperatures while maintaining sustainable economic growth. As a part of these efforts, renewable energy has gained significant attention. However, despite its widely acknowledged environmental benefits, its economic implications remain less clear.

For these reasons, this thesis seeks to examine the relationship between renewable energy consumption and economic growth, focusing on the Nordic countries between 2000 and 2019. The main method of analysis is a fixed effects panel regression, supported by relevant theoretical and empirical literature to provide a solid framework. Additionally, the Nordic countries form an interesting subject of study as they are among the global leaders in renewable energy adoption. Moreover, to the best of the author's knowledge, no prior research has focused specifically on this region, making this thesis a valuable contribution to existing literature.

The theoretical and empirical literature point to a complex and context-dependent relationship between economic growth and renewable energy consumption, further highlighting the importance of this study. The empirical results of this thesis indicate a positive relationship between the two variables in the Nordic countries. Specifically, a one percent increase in renewable energy consumption is associated with a 0.1 to a 0.4 percent increase in gross domestic product, depending on the model specification.

These findings suggest that increasing renewable energy consumption does not hinder economic growth. This implies that policymakers can promote renewable energy to achieve sustainable development goals without the worry of adverse effects on economic growth. However, as renewable energy technologies continue to evolve, ongoing research is necessary to stay up to date. Additionally, sector-specific or regional studies could help better tailor energy policy to economic needs. Overall, this thesis contributes to the growing body of research supporting the compatibility of environmental sustainability and economic development in advanced economies.

Keywords: renewable energy, economic growth, sustainable development, panel data analysis, fixed effects regression, sustainability, energy economics

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Contents

1. Introduction

1.1. Motivation

Climate change and its negative consequences are among the most pressing issues of the modern world. With concerns over food security, economic stability and extreme weather conditions, these negative consequences are increasingly prominent in media coverage and everyday life. As a result, sustainable development is playing a growing role in national and international economic policy.

Human activity, especially among energy consumption, is one of the main factors contributing to climate change. According to the International Energy Agency (IEA) the production and consumption of energy is responsible for 75% of greenhouse gas emissions[1] (IEA, n.d.). Therefore, many countries are looking to increase their renewable energy consumption, recognising it as one of the key factors in slowing down climate change. For example, the European Union has set a goal for renewable energy to account for at least 42.5% of total energy consumption by the year 2030 (European Commission, n.d.). Similarly, Finland has set a goal of reducing its emissions by 60% compared to 1990 levels by the same year, with renewable energy forming one possible pathway to achieve this target (Ministry of the Environment, n.d.).

However, while the environmental benefits of renewable energy are widely acknowledged, its economic implications, especially in terms of growth are less clear. This raises the question: how does this transition toward renewable energy affect economic performance? Therefore, this thesis seeks to examine the relationship between renewable energy consumption and economic growth. More specifically, the thesis studies the relationship in the Nordic countries, from 2000 to 2019.

The Nordic countries, Finland, Sweden, Norway, Denmark and Iceland provide a unique case for study, as they are a group of countries with similar economic structures and more interestingly, are

[1] Greenhouse gases are gases in the atmosphere that trap heat, e.g. carbon dioxide, CO_2

clear forerunners in renewable energy adoption. For example, in 2019 the Nordic average of renewables in total energy consumption was 55.4%[2] while the average in the European Union was only 19.4% (World Bank, n.d.). This high level of adoption allows for an examination of whether the effects of renewable energy consumption differ in contexts where the energy transition is already well advanced. Additionally, to the best of the author's knowledge, this is the first empirical study to focus specifically on the Nordic region, in this context, thus offering new insights into the renewable energy — economic growth nexus.

1.2. Background

The United Nations defines renewable energy as: *"energy derived from natural sources that are replenished at a higher rate than they are consumed."* The main forms of renewable energy include solar power, wind power, hydropower, geothermal energy and bioenergy. Solar, wind and hydropower are relatively self-explanatory, as they harness energy from the sun, wind and moving water, respectively. Geothermal energy relies on the Earth's internal heat that is naturally available and can be used for heating or to generate electricity. Bioenergy, meanwhile, is produced using organic materials, such as wood, charcoal, manure and agricultural crops. These materials are called biomass, and are generally used in rural areas for cooking, lighting and heating. Compared to fossil fuels such as coal and oil, generating energy from renewable sources results in significantly lower greenhouse gas emissions, making them a key component in mitigating climate change (United Nations, n.d.).

However, as the transition to renewable energy does not happen in a vacuum, policymakers must weigh environmental goals against economic considerations. Therefore, it is important to understand how renewable energy consumption interacts with economic performance. Here, the concept of economic growth plays an important role. Economic growth is defined as the increase in the real value of goods and services produced. It is usually measured by the annual percentage change in real Gross Domestic Product (GDP), and it is closely linked with improvements in living

[2] Author's own calculation based on data from the World Bank WDI-database.

standards, including better healthcare, education and infrastructure. For these reasons it is also a key focus in political discourse and economic research.

As modern economies rely heavily on the global energy system, the relationship between energy consumption and economic growth has received considerable attention in academic literature. This vast body of research has led to the development of four main hypotheses to describe the relationship:

1. Growth hypothesis: Energy consumption plays a central role in the economic growth process, either directly or as a supplement to labour and capital. According to this hypothesis increasing energy consumption leads to economic growth.

2. Conservation hypothesis: Energy consumption is a result of economic growth. In other words, energy consumption increases when the economy grows. Under this hypothesis reducing energy consumption does not significantly hinder growth.

3. Feedback hypothesis: Energy consumption and economic growth are interconnected. Growth drives energy use, which in turn supports further growth.

4. Neutrality hypothesis: Energy consumption has minimal or no role in the economic growth process.

(Apergis & Payne, 2012, p.734.) Empirical research on the topic has not yet produced a universal consensus on the most accurate hypothesis. Instead, support for each hypothesis tends to vary across countries and methodologies used. These hypotheses and empirical findings will be discussed in more detail in upcoming sections.

1.3. Research Method and Structure

This thesis aims to uncover information about the relationship between renewable energy consumption and economic growth. The main method of analysis is a statistical panel regression, applied to a dataset covering the Nordic countries from 2000 to 2019. A panel regression suits this research particularly well as it captures both cross-country and time-series variation, while also controlling for unobserved heterogeneity across countries.

The focus on the Nordic countries, Finland, Sweden, Norway, Denmark and Iceland, is motivated by their comparable economic structures and global leadership in renewable energy adoption. Their high renewable energy shares make them a particularly interesting subject of study and enable the opportunity to examine how renewable energy consumption influences economic outcomes in economies that are already well advanced in the energy transition. Furthermore, limited prior research on the area presents an opportunity to contribute new empirical insights.

The time period of 2000-2019 provides a sufficiently long dataset to capture relevant trends and developments. Moreover, the period is cut off at 2019 to ensure that economic disruptions caused by the Covid-19 pandemic do not affect the analysis. Additionally, data from 2020 onwards is less complete and potentially biased due to the exceptional circumstances of the global crisis.

The remainder of the thesis is structured as follows: Section 2 presents the theoretical background and aims to provide a comprehensive framework using an array of relevant theoretical research. Section 3 reviews previous empirical studies related to renewable energy consumption and economic growth. Section 4 outlines the development and trends of energy consumption and economic growth in the Nordic region. Section 5 provides the empirical methodology and results. Finally, section 6 concludes the thesis, summarizes findings and discusses limitations and avenues for future research.

2. Theoretical framework

2.1. Mainstream growth theory and energy inclusion

One of the most well-known growth models is Solow's (1956) growth model. It models economic growth as a function of technological development, labour and capital. However, it does not explicitly include energy. One could argue that the model takes energy into account through the technological development or capital parameters. Additionally, the Solow model has been criticized as per capita growth is only due to technological development, which is an exogenous parameter, and the model is not able to explain why some economies grow and others do not or why economies grow at different paces (Romer, 2012, p. 27-30).

In response to the limitations on technological development, endogenous growth models (see e.g. Lucas 1988; Romer 1990), were developed to explain technological progress as an outcome of economic activity. For example, technological development is due to human capital accumulation (Lucas, 1988), or research and development (Romer, 1990). Schumpeterian growth models (see e.g. Aghion & Howitt, 1992) further extend this and highlight the role of innovation, competition and creative destruction. However, all these "mainstream" models ignore the role of energy and natural resources in the economic growth process.

On the other hand, concerns over resource depletion highlighted the need to add natural resources and energy to growth models (see e.g. Solow, 1974; Stiglitz, 1974a; Dasgupta & Heal, 1974). In these models capital accumulation is needed to compensate for resource depletion. Additionally, when there is more than one input, in this case capital and natural resources, there are many possible paths for economic growth, depending on technological conditions and institutional arrangements. Technological conditions include factors such as the mix of renewable and non-renewable sources and the initial endowment of capital and resources, whereas the institutional arrangements can include factors such as market structure and the system of property rights, that is private versus common property. (Stern, 2011, p.29.) For example, Stiglitz (1974a) studies an economy with limited natural resources. He argues that even though there are limited natural resources, which are necessary for production, the economy does not have to eventually stagnate and decline as technical change and capital accumulation can offset the adverse effects, as long as the share of capital is more than that of natural resources (Stiglitz, 1974a, p.131). However, the same model, if put under competition, can produce a result, where resources are exhausted and consumption and welfare fall to zero (Stiglitz, 1974b, p.144-145). This highlights the various paths that economic growth can take depending on the model assumptions. Additionally, some models, such as Tahvonen (1996), model energy more explicitly and even add renewable sources. However, although these models provide some insights into the economic growth process with natural resources and energy, they are more focused on optimal resource allocation instead of economic growth. Thus, making them less relevant for the scope of this study.

Although the models discussed so far are not able to show the nexus between renewable energy and economic growth, they are still important to note and briefly discuss as they form the basis for newer models that are able to convey the role of renewable energy in the economic growth process. It is also good to note that the literature on these topics is vast, and the research presented here only scratches the surface of it. In the next sub-sections I will present growth models that incorporate renewable and non-renewable energy into the economic growth process. I will then use the ideas and predictions presented in these models to discuss the four key hypotheses on the role of energy in economic growth.

2.2. A simple growth model with renewable energy

Arbex and Perobelli (2010) propose a growth model that incorporates renewable and non-renewable energy inputs. They use Solow's (1956) model as a starting point and develop it, using ideas from resource extraction models such as that of Dasgupta and Heal (1974). The model described below is from Arbex and Perobelli (2010). It is good to note that the paper integrates an input-output model with the basic macroeconomic model to investigate the impact of economic growth on sectoral energy use. However, I have not included the input-output model here as it is not as relevant for the scope of this thesis.

The model starts with the assumptions of perfect mobility of goods and services and all markets are perfectly competitive. The economic agents are households, firms, government and the rest of the world and time runs in a discrete sequence. In the original paper the economy has m sectors that produce m different goods and services. However, as the sectoral approach does not change the outcomes of the growth model, I will present the model as one sector. In the economy all production is done by one representative profit-maximizing firm, whose production function is the following:

$$Y_{it} = A_t K_t^{\alpha} L_t^{\beta} Z_t^{\kappa} E_t^{\varepsilon}, \tag{1}$$

where Y_t is output, K_t capital, L_t labour, Z_t renewable resources used as energy input, E_t non-renewable resources used as energy input, $\alpha, \beta, \kappa, \varepsilon > 0$ and $\alpha + \beta + \kappa + \varepsilon = 1$. Additionally, the function displays constant returns to scale, meaning that if all inputs are increased by the same proportion, output increases by the same proportion as well. Technological development, A_t, is Hicks-neutral as it can be shown in $A_t F(K_t L_t Z_t E_t)$ and it changes over time at a constant rate, $A_{t+1} = (1 + g_A)A_t$. Capital is accumulated assuming a given rate of depreciation δ, shown as,

$$K_{t+1} = S_t + (1 - \delta)K_t \tag{2}$$

and the representative firm is assumed to save an exogenous fraction, s, of total income in each period,

$$S_t = sY_t, \tag{3}$$

where $0 < s < 1$.

In the model non-renewable and renewable resources are used as sources of energy in the production of goods and services. As in the resource depletion models, non-renewable sources, such as coal, oil and gas, are depleted as they are used. N_t is the remaining stock of a non-renewable source at the beginning of period t and the model assumes that in each period a fraction, $s^E \in (0,1)$, of the remaining stock is used in production, meaning $E_t = s^E N_t$, where $s^E > 0$. The depletion of the exhaustible natural resource from one period to the next is given by,

$$N_{t+1} = N_t - E_t$$

$$N_{t+1} = N_t - s_t^E N_t. \quad (4)$$

On the other hand, renewable resources accumulate from period to the next, which can be described as,

$$R_{t+1} = z_t R_t - s^Z R_t, \quad (5)$$

where R_t is the stock of renewable resources in period t and $z_t > 1$, which shows how much of the stock is renewed each period. As with the non-renewable resources a fraction, $s^Z \in (0,1)$, of the renewable resource is used, that is, $Z_t = s_t^Z R_t$.

The total amount of labour inputs used is described by

$$L_{t+1} = \left(1 + g_{L_t}\right) L_t, \quad (6)$$

where g_{L_t} is the exogenous growth rate of the labour force. Additionally, the goods market equilibrium in a small open economy is

$$Y_t = C_t + I_t + G_t + X_t - M_t, \quad (7)$$

where personal consumption is C_t, investments is I_t, government spending is G_t and net exports are $NE_t = X_t - M_t$. These seven equations form a basis for interpreting the growth model with renewable and non-renewable resources and perfect mobility of commodities. In the special case of $\kappa = 0\ and\ \varepsilon = 0$ the model comes down to a basic Solow model, where resources and energy are of no importance. (Arbex & Perobelli, 2010, p.45.)

To further inspect the model dynamics some additional algebra is needed. By inserting $E_t = s^E N_t$ and $Z_t = s^Z R_t$ into equation (1) we get

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} (s^Z R_t)^{\kappa} (s^E N_t)^{\varepsilon}. \quad (8)$$

Then dividing both sides by L_t gives,

$$y_t = A_t \left(\frac{K_t}{L_t}\right)^{\alpha} \left(\frac{s^Z R_t}{L_t}\right)^{\kappa} \left(\frac{s^E N_t}{L_t}\right)^{\varepsilon}$$

$$y_t = A_t (s^Z)^{\kappa} (s^E)^{\varepsilon} k_t^{\alpha} R_t^{\kappa} N_t^{\varepsilon} L_t^{-\kappa-\varepsilon}, \tag{9}$$

where $y_t = Y_t/L_t$ and $k_t = K_t/L_t$. By taking logs and time differences, we get equation,

$$g_{y_t} = a g_{k_t} + g_A + \kappa g_{R_t} + \varepsilon g_{N_t} - (\kappa + \varepsilon) g_{L_t}, \tag{10}$$

where $g_{bt} = lnb_t - lnb_{t-1}$ for $b = y, k, A, R, N \text{ } and \text{ } L$. Here the growth rate of the stocks of the renewable $\left(g_{r_t}\right)$ and non-renewable $\left(g_{N_t}\right)$ resources are approximately $(z_t - s^Z) \text{ } and - s^E$. Therefore, making the output per worker

$$g_{y_t} = a g_{k_t} + g_A + \kappa (z_t - s^Z) + \varepsilon s^E - (\kappa + \varepsilon) g_{L_t}. \tag{11}$$

Finally, the capital-output ratio (k_t/y_t) converges toward a steady state level, meaning that the output and capital per worker growth rates have to converge towards the same rates. Furthermore, there cannot be a steady state because of the presence of technological change, instead there is a balanced growth path where capital, output, and consumption grow at a common constant rate. The constant common rate is approximately given by,

$$g_{y_t} \approx \frac{1}{\beta+\kappa+\varepsilon} g_{A_t} + \frac{\kappa}{\beta+\kappa+\varepsilon} (z_t - s^Z) - \frac{\varepsilon}{\beta+\kappa+\varepsilon} s^E - \frac{\kappa+\varepsilon}{\beta+\kappa+\varepsilon} g_{L_t}, \tag{12}$$

which can be derived by setting $g_{y_t} = g_{k_t}$ in equation (11) and solving.

Using equation (12), we can inspect different aspects of the dynamics of the output growth rate g_{y_t}. First, technological progress g_{A_t} has a stronger effect on economic growth when natural resources are absent compared to when they are present. So, if the economy relies highly on natural resources, that is κ and ε have high values, it experiences lower returns on technological development. Second, population growth implies a drag on economic growth. Increasing labour and capital presses on the limited supply of non-renewable resources, which can imply slower growth through diminishing returns. Next, another drag on growth arises, as the stock of non-renewable resources decreases through time. This causes diminishing returns to capital and labour.

Here the larger the extraction of non-renewable sources s^E is, the faster they will be depleted causing the negative influence from diminishing returns to other factors grow faster. However, using renewable resources in production can offset the drag, as the regenerating stock of renewable resources has a positive effect on other factors and contributes to economic growth. By differentiating equation 12 with respect to renewable on non-renewable energy income shares, we get

$$\frac{\delta g_{y_t}}{\delta \kappa} = \left(z_t - s^Z - g_{L_t}\right)/(1-a)$$

and

$$\frac{\delta g_{y_t}}{\delta \varepsilon} = -\left(s^E + g_{L_t}\right)/(1-a).$$

Here we can see that a higher share of non-renewable energy has a negative effect on growth, which is in line with the drag caused by the use of non-renewable resources. However, the relationship between the share of renewable resources and growth cannot be determined as it depends on the combination of the regeneration rate and population growth. (Arbex & Perobelli, 2010, p.46.)

Finally, in the very long run the economy will converge from a stage where both resources are used to one where all energy is from renewable sources as the exhaustible resources are depleted. Now the equilibrium depletion rate, s^E, and the non-renewable income share, ε are zero. To ensure that renewable resource availability keeps up with its usage in production and the economy maintains a constant growth path, the rate of regeneration, z_t needs to be equal to $1 + s^Z$. Thus, the growth rate is given by

$$g\tilde{}_{y_t} \approx \frac{1}{\beta+\kappa} g_{A_t} + \frac{\kappa}{\beta+\kappa}\left(1 - g_{L_t}\right). \qquad (13)$$

Assuming the labour and renewable shares stay the same, i.e. the exhaustion of non-renewable resources is reflected in a higher capital share, the growth rate $g\tilde{}_{y_{it}}$ is higher than $g_{y_{it}}$ given in equation (12), meaning that the economy grows faster when only renewable resources are available. (Arbex & Perobelli, 2010, p.47.)

Overall, the model seems to predict that renewable energy consumption should have a positive impact on economic growth. Additionally, it shows that transitioning from non-renewable energy sources toward renewable energy sources should have a positive effect on the economy. However, this is a simple model, and it does not take into account various factors, such as investments needed to convert natural resources into energy or possible differences in energy efficiency from renewable and non-renewable sources. Also, the model's treatment of renewable energy as a stock-based resource, limits its ability to represent all forms of renewable energy. While the stock-based approach is valid for certain renewables, such as biomass or biofuels, where the resource is physically consumed and must regenerate before it can be used again, it is less appropriate for flow-based renewables such as solar and wind power. These resources are not depleted through use, instead their availability depends on natural conditions, such as sunlight or wind, rather than resource regeneration.

Despite these limitations, it is still a useful model to demonstrate some of the foundations also used in more complex frameworks. Next, I will present some more complex models that take more factors into account, when modelling how renewable and non-renewable energy affect economic growth.

2.3. Endogenic renewable energy growth models

Barretto (2018) presents a theoretical framework where energy is incorporated into an endogenous Lucas (1988) type growth model. The model explicitly shows the interaction and substitution between fossil fuels and renewable energy in a growing economy that is energy dependent. In the model non-renewable energy, i.e. fossil fuels, have a fixed initial stock and can be extracted from the ground at an endogenously determined extraction rate. Alternatively, energy can be produced from renewable sources at some capital cost. The economy can operate with either form of energy or with both simultaneously, however the energy forms are imperfect substitutes and at the start of the model energy produced from non-renewable sources is more effective. However, the model assumes that the quality of energy from renewable sources is subject to improvement, whereas the productivity of fossil fuels is fixed, thus making the gap between the two energies reduce over time. (Barretto, 2018, p.196 & 198.)

The model starts off with a fixed amount of fossil fuel that is more plentiful and productive than renewable energy. As fossil fuels are relatively abundant the model predicts rising per capita commodity consumption. However, as the stock of fossil fuels reduces, their price starts to slowly rise, increasing the incentive for renewable energy. As renewable energy improves and becomes more abundant, it eventually surpasses fossil fuel's capacity, resulting in fossil fuel prices to spike and plummet. The expanding ability to produce renewable energy eventually replaces fossil fuel altogether. However, if the productivity of renewable energy is not up to the standard of fossil fuel the economy will experience a decrease in consumption until its productivity is able to catch up to that of fossil fuel. (Barretto, 2018, p.198.)

Overall, the model predicts a gradual substitution from non-renewable to renewable energy, which begins slow and picks up momentum. However, the economy may experience a decrease in consumption during the transition if renewable energy is not productive enough. The study finds that the larger the initial productivity difference between the two energy sources the greater the downturn and cost to society will be. On the other hand, as long as society is able to improve the productivity of renewable energy to a level comparable to fossil fuel in the long run, growth should be just as well-off as with fossil fuel. Ultimately, given the economy's likely reliance on renewable energy, greater capital devoted to its production and improved productivity will boost consumption and output, while mitigating the effects of a potential fossil fuel price spike. (Barretto, 2018, p.207.)

Court et al. (2018) come to similar conclusions in their model, which tries to connect the ideas between endogenous growth theory and biophysical economics perspectives. This means that their model is subject to the physical limits of the real world. For example, technological progress, which is defined as the efficiency of converting primary energy to useful energy, has an upper bound, as thermodynamics imposes that perfect conversion is impossible. Although technological progress is otherwise endogenous the upper bound is given as an exogenous parameter. (Court et al., 2018, p.37.)

Similarly to Barretto (2018) the model highlights the importance of the ability to use energy as efficiently as possible, as the main conclusion of the paper is that the final energy converting efficiency (i.e. the upper bound of technological progress) hast to be sufficiently high to have a smooth transition from non-renewable energy to renewable energy, that does not negatively affect economic growth. Otherwise, the model predicts an unanticipated non-renewable energy peak, occurring at a low level of renewable energy production, causing a surge in economic output, followed by a decline. (Court et al., 2018, p.52.)

To conclude, these models present the possibility of renewable energy having a negative effect on economic growth in the short-term, if technology is not able to adapt quickly enough. To be more precise the possible economic downturn in these models is not caused by renewable energy consumption as such, but rather by depletion of non-renewable resources combined with the lower efficiency of renewable energy. These findings differ from Arbex and Perobelli (2010), however they do not give definitive conclusions instead the outcomes rely on how technology is able to adapt.

2.4. Hypotheses on the nexus between renewable energy and economic growth

As mentioned before there are four main hypotheses on the connection between energy consumption and economic growth: growth, feedback, conservation and neutrality (Apergis & Payne, 2012, p.734). These hypotheses can be tested using empirical methods however, it is also useful to understand the thoughts and rationale behind the hypothesis. Therefore, in this section I will briefly discuss some of the ideas behind each hypothesis drawing on previously presented theoretical frameworks.

Firstly, the growth hypothesis states that energy consumption is a fundamental driver of economic growth (Apergis & Payne, 2012, p.734). In this, view energy is an essential input in the economy's production function and an increase in energy consumption leads to higher economic output. This idea is backed up by the model by Arbex and Perobelli (2010), where energy, particularly renewable energy, is explicitly included in the production function, and the increase in renewable energy consumption leads to economic growth. Additionally, in the long term the model implies faster growth with increasing renewable energy consumption as it decreases the drag put on growth by the diminishing non-renewable sources. Moreover, the endogenous growth models by Barretto (2018) and Court et al. (2018) also give support to this perspective, as energy is an important factor in the economy's production function. However, in these models increasing renewable energy does not always lead to higher growth, as differences in efficiency compared to fossil fuel may also affect the outcome.

Secondly, the feedback hypothesis is based on the interconnected relationship between energy consumption and economic growth, meaning that economic growth leads to higher energy consumption, while energy consumption, in turn, fuels further growth (Apergis & Payne, 2012, p.734). This hypothesis is also supported by the endogenous growth models by Barretto (2018) and Court et al. (2018). In these models, economies initially rely on non-renewable energy. However, as the economy grows the technology behind renewable energy improves and renewable energy consumption starts to increase, this in turn further accelerates economic growth. This process creates a self-reinforcing cycle, well demonstrated by the growing speed at which renewable energy consumption grows in Barretto's (2018) model, aligning with the core idea of the feedback hypothesis.

Next, the conservation hypothesis, states that growing energy consumption is a result of economic growth, meaning that reducing energy consumption may not necessarily have a negative effect on growth (Apergis & Payne, 2012, p.734). In other words, as the economy grows, so does its need for energy. However, simply increasing or decreasing energy consumption alone does not directly influence economic growth. Rationale behind the conservation hypothesis can be explained through technological improvements. For example, in the Stiglitz (1974a) model, technological change and capital accumulation keep the economy on a stable growth path, when natural resources, such as oil, are slowly reducing. In other words, technological advancements enable the economy to maintain at least the same level of output with using less resources (i.e. energy), which is in line with the core idea of the conservation hypothesis.

Finally, the neutrality hypothesis rests on the idea that energy consumption has a minimal effect in the economic growth process (Apergis & Payne, 2012, p.734). This view is assumed in basic neoclassical models, such as Solow (1956) which, do not explicitly include energy as a factor in the production function. Instead, economic growth is primarily driven by technological progress. Since energy is not a key determinant of growth, increasing total energy consumption or renewable energy consumption should have little to no effect on economic growth, unless it influences other factors such as labour.

3. Empirical Literature

In this section I will present some of the relevant empirical literature surrounding the nexus between renewable energy and economic growth. The literature is broad and spans over a variety of different countries and regions, but it has not yet found a consensus on the relationship between renewable energy consumption and economic growth. This is evidenced by the fact that there is support for all aforementioned hypotheses on energy consumption and economic growth.

One reason for the variation between findings is the different methodologies and data used across studies. It is also important to note that even though some of the research claims to test for causality, establishing true causation is complex and often uncertain. For example, the Granger causality test, which it often used, examines whether one time-series is useful in forecasting another, rather than providing a direct causal link (Verbeek, 2017, p.363). Therefore, I will use terms such as *connection* and *relationship* instead of causality when presenting the results of these tests.

This section is divided into two parts. Firstly, 3.1 Overview of Empirical research, where I present some of the most relevant studies around renewable energy consumption and economic growth. Second 3.2 Summary of Empirical Findings, where I shortly discuss and wrap up the empirical literature, its implications and possible shortcomings.

3.1. Overview of Empirical Research

Apergis and Payne have done a lot of research on the topic of renewable energy and economic growth. Overall, the methodology they use remains relatively consistent between papers. They utilize cointegration tests, panel error correction models and granger causality tests to establish the relationship between the variables. Moreover, in each of their studies the model is estimated using the fully modified ordinary least squares (FMOLS) method. The inputs are real GDP, renewable electricity consumption, gross fixed capital formation and total labour force. (Apergis & Payne, 2010a, 2010b, 2011, 2012.) The methodologies used in these studies are often used as a base in more recent papers as well.

Apergis and Payne (2010a) study 13 countries in Eurasia[3] from 1992 to 2007, Apergis and Payne (2010b) observe twenty[4] OECD countries from 1985 to 2005 and Apergis and Payne (2011) examine six countries in Central America[5] from 1985 to 2005. These papers are interesting, since they are all able to produce similar results even though the countries studied differ in their energy mix. For example, due to the vast amounts of oil and natural gas in Russia, the majority of energy consumption in Eurasia originates from fossil fuels, whereas there is no natural gas production or consumption and limited oil refining in Central America (Apergis & Payne, 2010a, p.1392, 2011, p.343). Using the FMOLS estimation technique and the Granger causality test, the authors find support for the feedback hypothesis in each of the studies. Additionally, they produce the following statistically significant estimates: a 1% increase in renewable energy consumption increases real GPD by 0.195%, 0.074%, 0.76% and 0.244% for Eurasia, Eurasia excluding Russia, OECD countries and Central America respectively (Apergis & Payne, 2010a, p.1394; 2010b, p.658; 2011, p.345).

Furthermore, Apergis and Payne (2012) add to the earlier papers with a study of a much larger panel of 80 countries. This study differs from the previous ones with the addition of non-renewable energy to the model, however they are still able to produce similar results. The panel causality test indicates a bidirectional connection between renewable energy consumption and economic growth as well as between non-renewable energy consumption and economic growth, thus supporting the feedback hypothesis. Additionally, the model estimates that a 1% increase in renewable energy consumption increases real GDP by 0.371%. (Apergis & Payne, 2012, p.735-736.)

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[3] Eurasia defined as: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan. The study excludes Lithuania and Turkmenistan due to unavailable data.

[4] Countries studied: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Iceland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and the United States.

[5] Central America defined as: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. The study excludes Belize due to unavailable data.

Inglesi-Lotz (2016) follows the econometric methodology of Apergis and Payne (2010b) in her study on the impacts of renewable energy consumption on economic growth. However, the study differs a bit as it uses a fixed effects estimation instead of FMOLS. She uses data from 30 OECD countries from 1990 to 2010. The research is interesting since it has two variables representing renewable energy consumption in the economic growth process: total renewable energy consumption in kiloton of oil equivalent and the share of renewable energy consumption in the total energy mix as a percentage. (Inglesi-Lotz, 2016, p.60.) The study presents similar effects using both proxies: a 1% increase in total renewable energy consumption increases GDP by 0.105% and a 1% increase in the share of renewable energy consumption increases GDP by 0.089%. She is also able to produce similar results when economic growth is measured as GDP per capita instead of GDP. Additionally, the cointegration test points to a long-run equilibrium relationship between GDP and renewable energy consumption, no matter which proxies are used. (Ingelsi-Lotz, 2016, p.61.)

Also Kasperowicz et al. (2020) use a similar production model and econometric strategy as Apergis & Payne (2010b) as a base for their study on the relationship between renewable energy consumption and economic growth. However, they use a dynamic ordinary least squares (DOLS) method as well as FMOLS in their estimation. (Kasperowicz et al., 2020, p.1087-1089.) The study finds that there is a long-run equilibrium relationship between renewable energy consumption and economic growth in 29 European countries[6] from 1995 to 2016 (p.1087 & 1091). Additionally, the panel estimation using DOLS and FMOLS produce similar and statistically significant results with minor differences in the magnitudes of the estimated coefficients. The estimates state that a 1% increase in renewable energy consumption increases GDP by 0.158% and 0.159% when analysed using DOLS and FMOLS, respectively. (Kasperowicz et al., 2020, p.1091.)

[6] Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxem-bourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, United Kingdom, Iceland, Norway

Similarly, Saidi and Omri (2020) show the effect of renewable energy consumption on economic growth in fifteen countries[7] that consume a lot of renewable energy over the 1990-2014 period. The model uses GDP per capita as its dependent variable and renewable energy consumption, gross fixed capital formation and labour as its independent variables. (Saidi & Omri, 2020, p.3-4.) Using the FMOLS technique there appears to be a positive and significant effect between renewable energy consumption to economic growth for the panel of countries studied. The authors report that a 1% increase in renewable energy consumption leads to an increase of 0.22% in economic growth. Additionally, the country specific results indicate that there is a positive and significant connection between the two variables for 8 of the 15 countries, highlighting the possible differences between countries. (Saidi & Omri, 2020, p.6.) Furthermore, the authors use the vector error correction model (VECM) Granger test to further investigate the connection between renewable energy consumption and economic growth. They find a bidirectional connection between the two variables in the long run, thus supporting the feedback hypothesis. On the other hand, in the short-term they find evidence for the conservation hypothesis. (Saidi & Omri, 2020, p.7.) However, it is important to note that the study uses combustible renewables and waste as the proxy for renewable energy. Combustible renewables comprise of solid biomass, liquid biomass and biogas, therefore a large part of renewable energy sources, such as hydropower, wind power and solar power are ignored in the study (World Bank, n.d.).

Madaleno and Nogueira (2023) find similar results in how renewable energy consumption affects economic growth in European countries as Inglesi-Lotz (2016) and Kasperowicz (2020). However, they use a different model with more variables, which is formatted as follows: economic growth is the dependent variable while renewable energy, carbon emissions, fixed assets, human capital, research and development (R&D), foreign direct investment, labour force and international trade are the independent variables. Similar to Inglesi-Lotz (2016) the paper uses the percentage of renewable energy consumption in the total energy mix as its proxy for renewable energy consumption. (Madaleno & Nogueira, 2023, p.5 & 8.) Using a fixed effects model, the authors find that a 1% increase in renewable energy consumption increases economic growth by 0.119%.

[7] Includes Brazil, Canada, China, Denmark, France, Germany, Italy, India, Japan, Poland, Portugal, Spain, Sweden, the UK and USA

Furthermore, they also estimate the model without carbon emissions, which in turn indicates that a 1% increase in renewable energy consumption increases economic growth by 0.092%. (Madaleno & Nogueira, 2023, p.10.)

However, not all studies find a positive effect between renewable energy consumption and economic growth, one of these studies is Ocal and Aslan (2013). The authors investigate the connection in Turkey from 1990 to 2010 using an Autoregressive Distributed Lag (ARDL) approach and the Toda-Yamamoto causality test. The model uses GDP as its dependent variable while the independent variables are renewable energy, total labour force and gross fixed capital formation. It is notable that this study only uses combustible renewables and waste percentage of total energy as its proxy for renewable energy consumption. (Ocal & Aslan, 2013, p.497-498.) The estimated coefficients indicate a negative relationship between renewable energy consumption and economic growth, namely, a 1% increase in renewable energy consumption decreases GDP by 0.30%. Additionally, the Toda-Yamamoto causality test indicates a connection from economic growth to renewable energy consumption, thus backing the conservation hypothesis. (Ocal & Aslan, 2013, p.498.)

Tugcu et al. (2012) use a classical Cobb-Douglas type production function, where economic growth is a function of renewable energy consumption, non-renewable energy consumption, capital and labour. In addition, they do a separate analysis with an augmented Cobb-Douglas production function, where human capital and R&D are also added to the model. The authors use the models to study the effects of renewable and non-renewable energy on economic growth in G7[8] countries for the 1980-2009 period. The study uses an Autoregressive Distributed Lag (ARDL) approach with the following variables: real GDP, real gross fixed capital formation, labour force, total number of full- and part-time students enrolled in public and private tertiary education, the combined number of patent applications filed with the European Patent Office (EPO) and under the Patent Co-operation Treaty (PCT), renewable energy consumption, and non-renewable energy consumption, measured as the total energy use from coal, natural gas, and petroleum. (Tugcu et

[8] G7 countries: USA, Germany, France, Italy, United Kingdom, Canada and Japan

al., 2012, p.1945.) Moreover, the authors adopt the causality test developed by Hatemi-J (2012) to test the connection between renewable energy and economic growth (Tugcu et al., 2012, p.1948). The interesting thing about the study is that the two models produce different results. First, using the classical function the authors find a bidirectional connection for all the countries, which points to the validity of the feedback hypothesis. On the other hand, the augmented production function produced mixed results. For example, while the authors do not find a connection between renewable energy consumption and economic growth for France, Italy, Canada and the USA, they do find support for the feedback hypothesis for England and Japan and the conservation hypothesis for Germany. (Tugcu et al.,2012, p.1949.) These results highlight the effect that different model specifications can have on the results. Additionally, they also highlight the possibility of country specific factors affecting the results.

Another study that highlights the differing results between countries is Alper and Oguz (2016). They use model function, similar to the classical model used by Tugcu et al. (2012), which they also estimate using the ARDL method. The paper studies Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Poland, Romania and Slovenia from 1990 to 2009 and the results indicate a positive impact from renewable energy consumption to economic growth. However, the results are statistically significant only for Bulgaria, Estonia, Poland and Slovenia. The estimations state that a 1% increase in renewable energy consumption leads to 0.086%, 0.106%, 0.060% and 0.051% increase in economic growth in Bulgaria, Estonia, Poland and Slovenia respectively. (Alper & Oguz, 2016, p.956-957.) Additionally, the study uses the asymmetric causality test by Hatemi-J to further investigate the relationship between renewable energy consumption and economic growth. These results however point to no relationship between renewable energy consumption and economic growth for Estonia and Slovenia even though the regression estimates were positive and significant. The test supports the neutrality hypothesis also for Cyprus, Hungary and Poland, while the conservation hypothesis is supported for Czech Republic. The authors find evidence for the growth hypothesis only in Bulgaria. (Alper & Oguz, 2016, p.957.) However, it is important to note that this study also only uses combustible renewables and waste as the proxy for renewable energy, which, as noted above, ignores a majority of renewable energy sources.

The study by Bhattacharya et al. (2016) also underlines the importance of national context in determining the relationship between renewable energy consumption and economic growth. The study examines 38[9] of the world's top renewable energy consuming countries from 1991 to 2012. The authors use a simple production function, where renewable energy, non-renewable energy, capital and labour are the drivers of growth. (Bhattacharya et al., 2016, p.735-736.) Using FMOLS and DOLS estimations, the panel level results show a positive and significant relationship between renewable energy consumption and economic growth. More precisely, a 1% increase in renewable energy consumption is associated with a 0.109% increase in economic growth according to the FMOLS estimate, with DOLS producing a very similar result. (Bhattacharya et al., 2016, p.738.) However, when applying country-specific time-series analysis, the results vary. Most countries still show a positive and significant relationship between the two variables. However, India, Ukraine, Israel and the United States show negative elasticities, while some show no statistically significant relationship, providing evidence for the neutrality hypothesis. The authors argue that possible reasons for differences between the countries could be due to their energy mixes or ability to adopt renewable energy into the production process. (Bhattacharya et al., 2016, p.739-740.)

As some of the studies have already noted, the neutrality hypothesis is also prevalent in the literature. Menegaki (2011) contributes to this with her paper which studies 27 European countries during the period from 1997 to 2007. Her dependent variable is GDP per capita, and the independent variables are, percentage of renewable energy in gross inland energy consumption, final energy consumption in 1000 tons of oil equivalent and greenhouse emissions in carbon dioxide equivalents. (Menegaki, 2011, p.259.) The study uses a random effects model, in addition the author implements a panel error correction model to determine the Granger causality between renewable energy consumption and economic growth (Menegaki, 2011, p.261). The study does not find a connection between renewable energy consumption and economic growth thus providing evidence for the neutrality hypothesis. However, the author argues that the neutral relationship

[9] Includes: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, Denmark, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Kenya, Republic of Korea, Mexico, Morocco, the Netherlands, Norway, Peru, Poland, Portugal, Romania, Slovenia, South Africa, Spain, Sweden, Thailand, Turkey, Ukraine, the United Kingdom & the United States.

between the two variables could be due to the early stages of development of renewable energy. (Menegaki, 2011, p.262.)

Subsequently, Ozcan and Ozturk (2019) have also found evidence for the neutrality hypothesis. They study the relationship between economic growth and renewable energy consumption in 17[10] emerging countries from 1990 to 2016. Similar to Apergis and Payne (2010a, 2010b, 2011) the paper uses the following model: the dependent variable is GDP, and the independent variables are renewable electricity consumption, total labour force, and real gross fixed capital. (Ozcan & Ozturk, 2019, p.31.) The authors use a bootstrap panel causality test developed by Konya (2006) to examine the Granger causality between the variables (Ozcan & Ozturk, 2019, p.34). In terms of the results, the authors find no evidence for a relationship between renewable energy consumption and economic growth in any of the countries except Poland, where evidence for the growth hypothesis is found. Thus, the paper presents evidence for the neutrality hypothesis. In addition, similarly to Menegaki (2011), the authors theorize, that the results could be due to the renewable energy sector not being well developed and it could begin to boost economic growth once it reaches a certain threshold level. (Ozcan & Ozturk, 2019, p.35.)

This threshold argument is tested by Chen et al. (2020), in their study of 103 countries during the 1995-2015 period. Similar to Apergis and Payne (2012) the authors assume a production function where economic growth comes from capital, labour, renewable energy and non-renewable energy. The authors then apply a general method of moments (GMM) technique for linear estimation and a dynamic panel error correction threshold model for non-linear estimation. (Chen et al., 2020, p.4-5.) The idea behind the threshold model is that if countries use lower amounts of renewable energy the relative cost compared to fossil fuels could be higher, thus the effects of renewable energy consumption may not lead to significant effects in economic growth. Therefore, the authors apply the threshold model, which allows them to test if the relationship between renewable energy consumption and economic growth differs when renewable energy consumption is above or below

[10] Includes: Brazil, Chile, China, India, Indonesia, Egypt, Greece, Hungary, Malaysia, Mexico, Peru, Philippines, Poland, South Africa, South Korea, Thailand and Turkey

a certain level. Additionally, the authors divide the sample into two groups of countries: OECD and non-OECD. Furthermore, they also do separate tests where the countries are divided into developed and developing countries. (Chen et al., 2020, p.9.)

In terms of the results, the authors find that a 1% increase in renewable energy consumption increases economic growth by 0.036% in OECD countries, when using the linear model. In contrast, they do not find significant effects for non-OECD, developing, developed or the whole sample of countries. As for the non-linear model the authors find that renewable energy affects economic growth positively if renewable energy consumption, is above 13,427 or 14,716 million kilowatt-hours for the whole sample of countries and non-OECD countries respectively. In these cases, a 1% increase in renewable energy consumption increases economic growth by 0.151% and 0.313% for the whole sample and non-OECD countries respectively. The authors also find similar results for developing countries. However, the authors find neutral effects for developed countries regardless of the level of renewable energy consumption. Moreover, they find that the linear model is better for the sample of OECD countries thus backing the findings of Apergis and Payne (2012) and Inglesi-Lotz (2016). (Chen et al., 2020, p.7-9.) Overall, the study highlights that different methods can affect the results and that the effects can change considerably depending on the area being analysed. It also seems that the level of renewable energy consumption can affect how economic growth reacts to renewable energy consumption.

Building on this idea, Raifu et al. (2025) explore how varying levels of renewable energy consumption and economic growth influence the dynamics between the two. Specifically, they study 35 OECD countries from 1990 to 2020 using Granger-causality tests. (Raifu et al., 2025, p. 5-6.) For the full sample of countries, the authors find a bidirectional relationship between economic growth and renewable energy consumption, with renewable energy exerting a stronger influence on economic growth. However, results vary when countries are grouped by levels of economic growth and renewable energy consumption. For example, in countries with high economic growth, the analysis reveals a unidirectional connection from renewable energy to economic growth, whereas in countries with lower economic growth the relationship is bidirectional. Similarly, countries with lower levels of renewable energy seem to exhibit a bidirectional connection between renewable energy and economic growth. Interestingly, however, countries with higher levels of renewable energy display no Granger- causality between the two variables. (Raifu et al., 2025, p.8.) These findings further underscore the importance of context. Especially, the absence of Granger-causality in countries with high renewable energy usage may be relevant for this thesis, as the Nordic countries rank among the global leaders in renewable energy consumption.

3.2. Summary of Empirical Findings

The empirical literature on the relationship between renewable energy consumption and economic growth reveals a complex and context dependent relationship. Using a variety of different methodologies researchers have sought to examine this relationship. A significant amount of the studies find a bidirectional connection between the two variables giving strong support to the feedback hypothesis. This has been especially emphasised in the works of Apergis and Payne (2010a, 2010b, 2011, 2012) along with studies using similar panel-based techniques.

However, the results are far from definitive. Several studies also find unidirectional relationships, lending support to the growth and conservation hypotheses, while others find no statistically significant relationship, supporting the neutrality hypothesis. This variety of findings suggests that national context, policy environments and energy structures all play an important role in the relationship between these two variables, a point also emphasized in studies, such as Bhattacharya et al. (2016). As a result, it is important to study diverse geographical and economic settings to deepen the understanding of the relationship between renewable energy consumption and economic growth. This also highlights the relevance of this thesis, as, to the best of the author's knowledge, there is no prior research focusing specifically on the Nordic countries and their distinctive energy mix.

Overall, while there is broad empirical support for the positive relationship between renewable energy consumption and economic growth, findings vary depending on countries analysed and modelling techniques among other factors. This diversity reinforces the need for careful empirical design and further research in different regional and institutional settings.

4. Trends in Renewable Energy and Economic Growth

This section provides an overview of the trends and developments of renewable energy consumption and economic growth. By providing historical and contemporary data, I aim to give insights relevant to the study. Thus, by illustrating not only the growth trajectory of renewable energy consumption and economic growth, but also broader patterns such as the evolving energy mix and regional differences, this section uncovers a broader understanding of the context in which the study is framed. The section is divided into two parts: 4.1. Renewable Energy and 4.2. Economic Growth. Together these parts provide a comprehensive overview of the context in which the study is based, setting up the scene for subsequent sections.

4.1. Renewable Energy

As mentioned previously, the study focuses on the Nordic countries for the period from 2000 to 2019. For this reason, the trends and development presented in this section will also focus on this area and time. However, to make the analysis more insightful, the section will also be comparing the Nordics to other regions and put everything into the context of the whole world.

As a starting point it is important to examine the development of renewable energy consumption in the Nordics. In other words, has the consumption of renewable energy increased over the period of 2000-2019? Unfortunately, due to data availability I have not been able to obtain exact data on energy consumption. To address this, I have used total energy supply as a proxy, which is defined as all the energy produced and imported into a country, minus exports and storage (IEA, 2024). Therefore, making it a valid proxy for consumption, as the main difference is that energy consumption also considers energy lost in the transformation process or during transmission.

Figure 1 illustrates the development of renewable energy supply in the Nordic countries. The data used in the figure is from the IEA's World Energy Highlights 2024 dataset. Additionally, the data

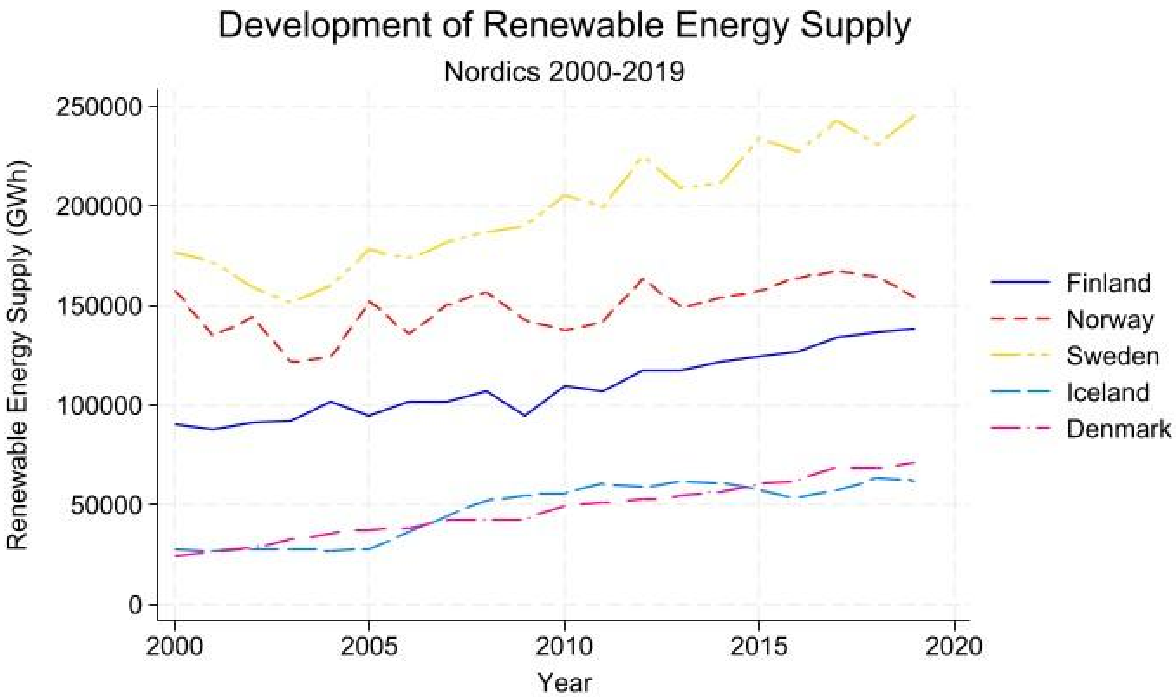

Figure 1. Renewable Energy Supply Nordics

was originally in petajoules but has been converted to gigawatt hours using conversion factors supplied by the IEA (2025).

The graph illustrates a positive trend in renewable energy supply in the Nordics throughout the 21^{st} century, with Sweden leading the pack. Finland reflects this development with steady growth from about 90 000 gigawatt hours to 138 000 indicating a growing reliance on renewables. The biggest growth in renewable energy has been in Denmark and Iceland, where the supply has grown 189% and 122% respectively. However, the outlier of the group is Norway with a 2% decrease in the supply of renewable energy during the period. This could be due to the already high levels of supply at the beginning of the period. To get a more comprehensive picture of the development, it is also good to analyse the development of renewable energy in the context of all energy usage. For this analysis the percentage of renewable energy in total energy consumption is a good indicator as it provides a clearer perspective on how renewable energy fits in with the broader

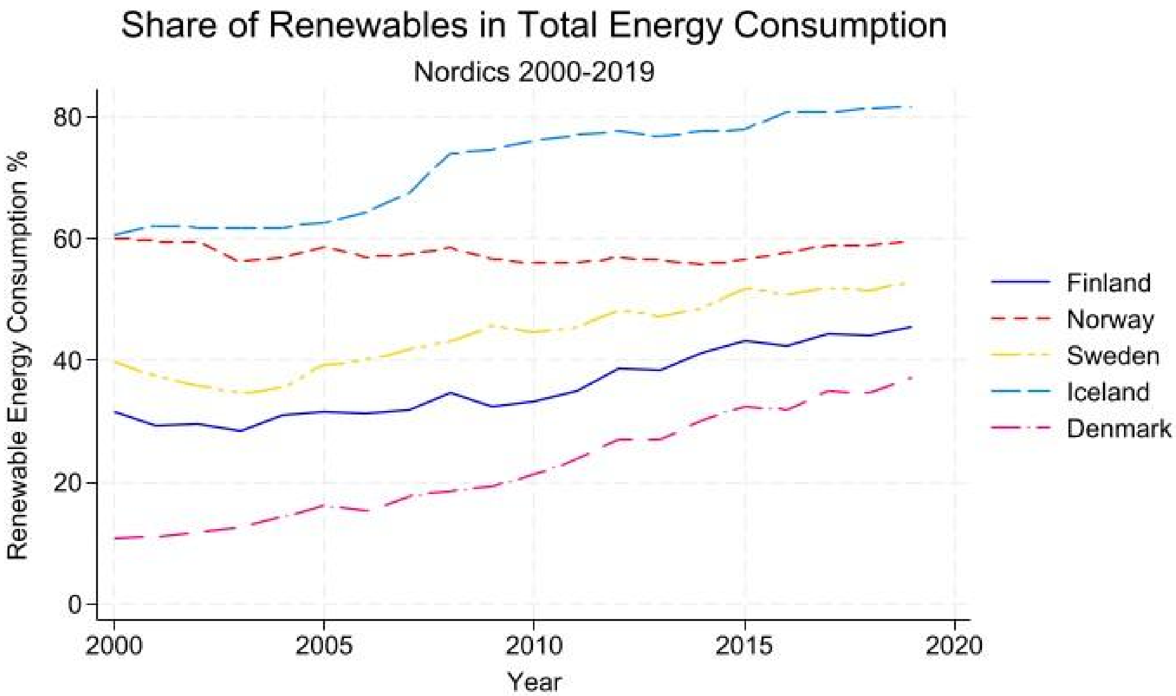

Figure 2. Share of Renewables in Energy Consumption Nordics

energy landscape. Figure 2 visualises this by showing the share of renewable energy in total energy consumption.

The data for figure 2 comes from the World Bank's WDI -database. The data is comparable with the first figure even though it is from a different dataset. This is because the World Bank uses the IEA as one of its sources for the data. Unfortunately, the data from the IEA is behind a paywall so I could not access it as the primary source. It is also good to notice that the data is for energy consumption instead of supply as in the previous graph.

Figure 2 confirms the positive trend of renewable energy consumption and dependency. Moreover, it clearly shows the rapid rise in renewable energy in Denmark and Iceland, especially the dramatic increase in Iceland between 2005 and 2010 is highlighted. Overall, the graph illustrates the high usage of renewable energy in all Nordic countries, with Iceland and Norway leading the way, likely

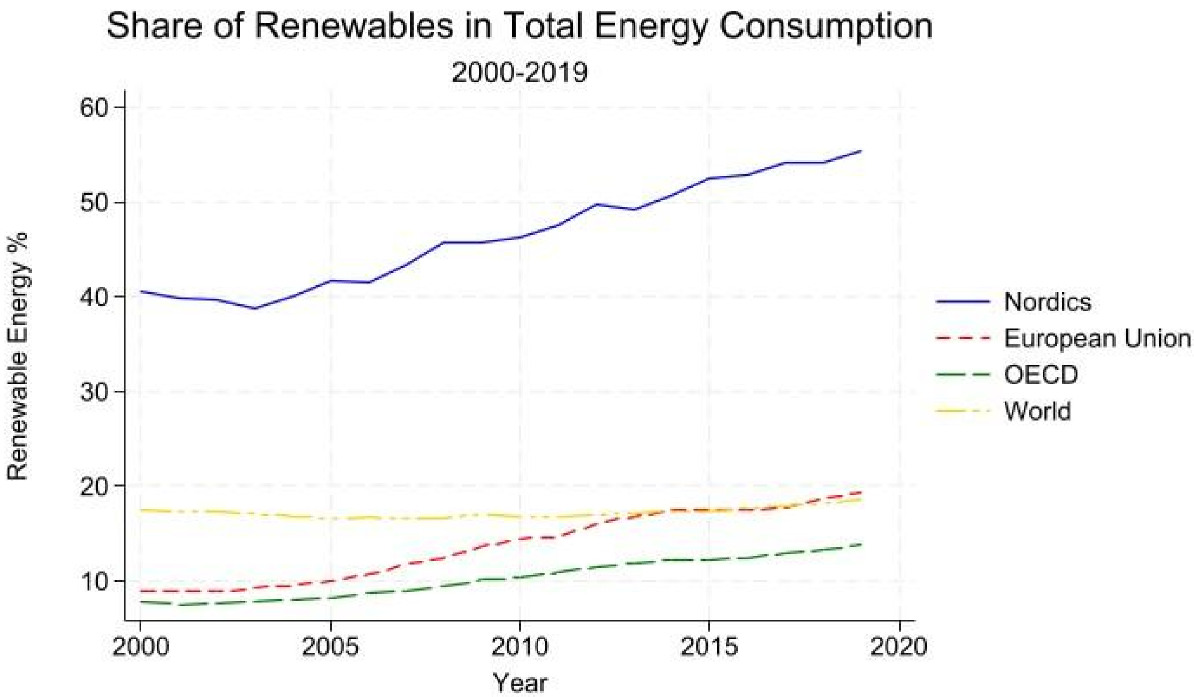

Figure 3. Share of Renewables in Energy Consumption by Region

due to their vast access to hydropower. To put these figures into perspective comparing the Nordics with other regions is useful, it also helps assess whether similar patterns exist elsewhere. Figure 3 does this by comparing the share of renewable energy in total energy consumption in the Nordics with other regions.

The WDI -database provides aggregated data for different regions, which has been used in figure 3. An exception is the Nordics which was not readily available in the database. Therefore, the reported values are averages calculated by the author. However, this does not make a big difference as the aggregation method used by the World Bank is also averages, albeit weighted.

Figure 3 highlights the speciality of the Nordic countries. Even though the trend is positive in OECD countries and the European Union, they are nowhere near the Nordic countries. Of course, there are only five Nordic countries making the comparison to 27 EU or 38 OECD countries

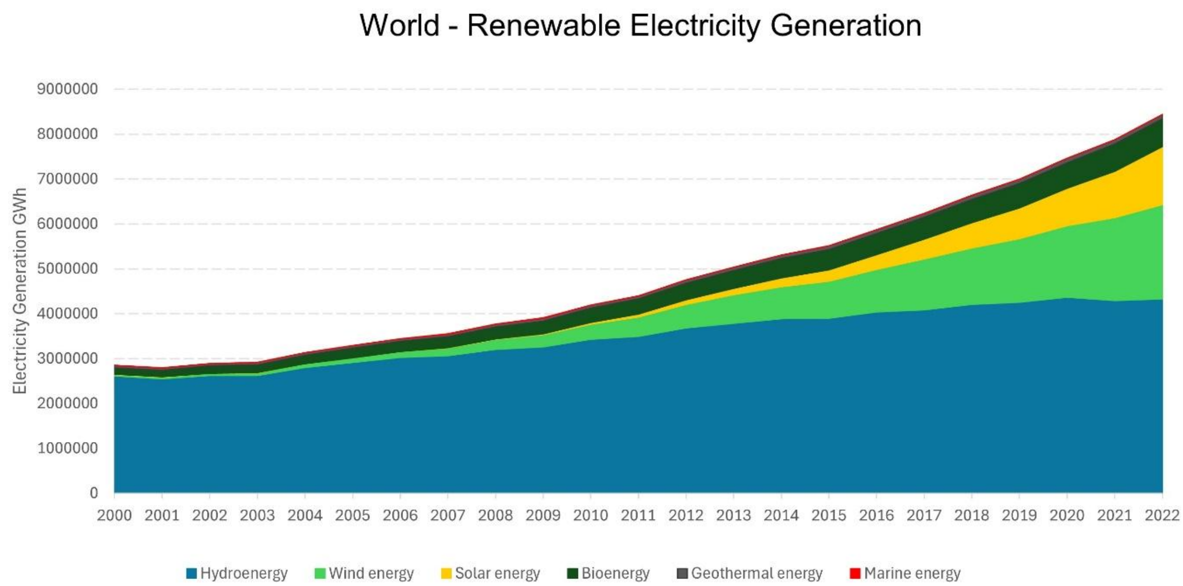

Figure 4. Renewable Electricity Generation

somewhat skewed. However, even when comparing the Nordic average to individual countries, few come close. For example, Germany, a country known for its ambitious energy transition policy, which has driven large-scale solar- and wind power adoption, only had a 17.10% share of renewables in total energy consumption in 2019, whereas the average across the Nordics was 55.40% in the same year (World Bank, n.d.).

To further illustrate the development of renewable energy consumption it is also useful to analyse the energy mix. The energy mix shows how much of each type of energy source is used in energy consumption. Due to data availability, I have chosen to illustrate the renewable energy mix through the lens of electricity generation. This ignores the energy used in heat generation and transportation, but it nevertheless gives an idea on how the mix of energy sources has developed over time. This in mind it is good to point out that especially bioenergy use is higher, as it is often used for heating as well as electricity generation.

Figure 4, which is based on the data from the International Renewable Energy Agency's (IRENA) Renewable Energy Statistics 2024 report, clearly shows the growing usage of renewable energy in electricity generation. From 2000 to 2022 electricity generated from renewable sources almost tripled, reflecting a growing global reliance on clean energy. In terms of the energy sources hydropower has remained the dominant source of energy throughout the period. However, its growth rate has been moderate, whereas wind and solar energy have expanded significantly in recent years, with annual growth rates of 21% and 37% respectively. Other sources also contribute to global electricity generation, though at a smaller scale. On the other hand, there are differences between countries and areas. For example, while bioenergy plays a relatively minor role on a global scale, in Finland it accounts for about 40% of renewable electricity generation (IRENA, 2024). This is why it is also important to look at different regions' and countries' energy mixes.

The trends illustrated in Figure 5 and Figure 6 align with the global development, although regional and national differences are evident. In particular, with the exception of Denmark, the Nordics exhibit a strong reliance on hydropower, whereas in Europe its share is decreasing, more rapidly.

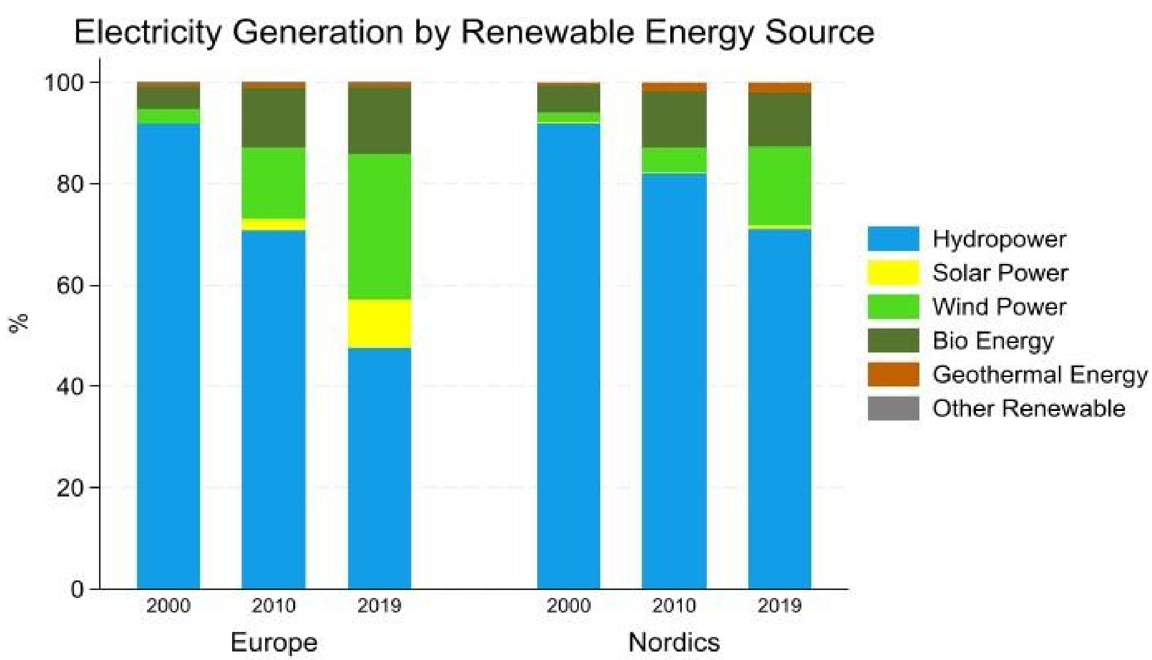

Figure 5. Energy Mix by Region

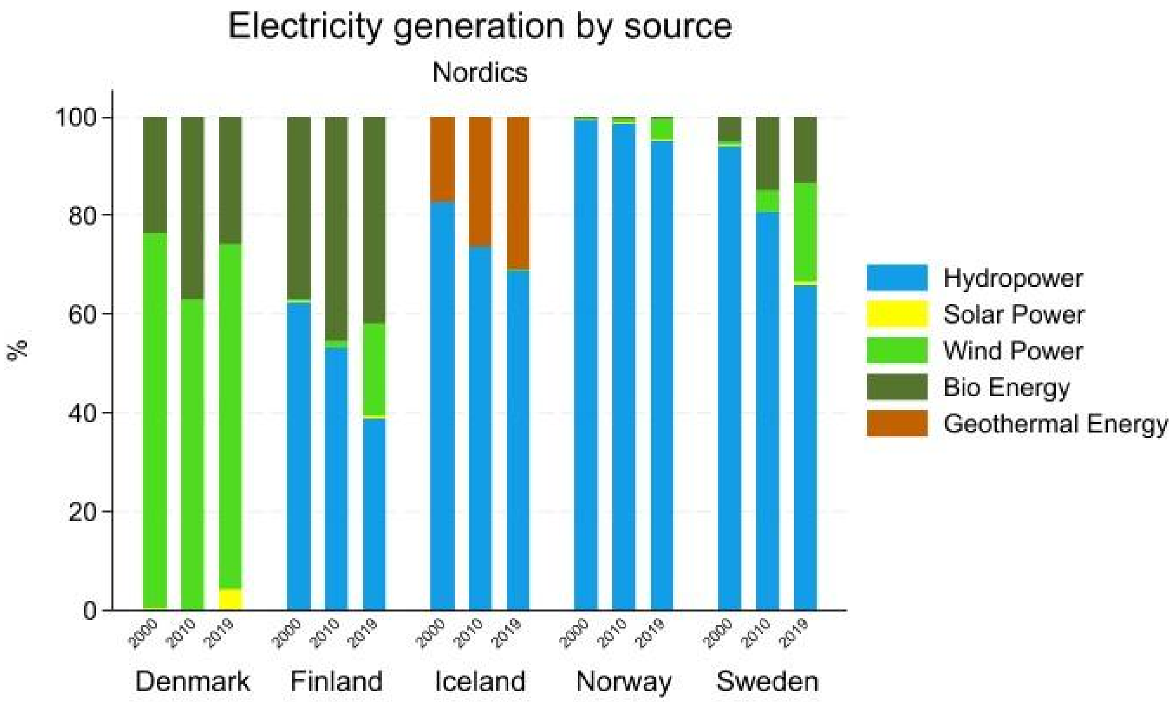

Figure 6. Energy Mix Nordics

Furthermore, even though the Nordics are in many ways similar, some national differences emerge. For example, Finland and Denmark stand out with their relatively high share of bio energy, while Iceland stands out with its high share in geothermal energy. Moreover, Denmark differentiates itself from the other Nordic countries with a lack of hydropower.

Overall, the Nordic countries are front runners in the consumption of renewable energy. With plentiful access to renewable sources, particularly hydropower, they have been able to adopt high shares of renewables in energy consumption, placing them well above global and European averages. While hydropower remains the dominant source in the region and globally, recent years have seen wind and solar power becoming ever more prevalent.

4.2. Economic Growth

This part will briefly illustrate and analyse the development of economic growth in the Nordic countries from 2000 to 2019. Additionally, it will, try to see if there is some kind of connection between economic growth and renewable energy before analysing it in more depth in section 5.

Figure 7 illustrates economic growth in the Nordic countries through the lens of GDP per capita, using data obtained from the World Bank's WDI-database. It shows that Finland has the lowest GDP per capita, whereas Norway has the highest throughout the period. Additionally, all the Nordics show similar trends with dips in economic growth around 2008-2010 and then varying degrees of growth after that. The dips are due to the financial crisis which affected economies worldwide. These kinds of crisis can affect the analysis, so it is important to take them into account and evaluate their effects on the analysis.

In terms of growth, the Nordic countries show gradual growth, with annual growth rates around 1%, apart from Norway which only poses an annual growth of 0.6%. However, as the financial crisis plays a major role in the development of economic growth during this period, it is also useful to look at growth rates pre and post crisis. Here we see that some countries have had quite different growth trajectories before and after the crisis. For example, Finland had a 2.3% annual growth in GDP per capita from 2000 to 2008 but after the crisis it has only managed an annual growth rate of 0.7% and is yet to reach the hights of 2008 in 2019.

Overall, the economic growth in the Nordic countries has been quite slow. Given this establishing a strong positive relationship between renewable energy and economic growth might prove challenging. However, this does not rule out the possibility of this relationship or alternatively the relationship could be negative. Therefore, further analysis is needed to better understand the relationship between the two variables. The next section will aim to do this with statistical analysis.

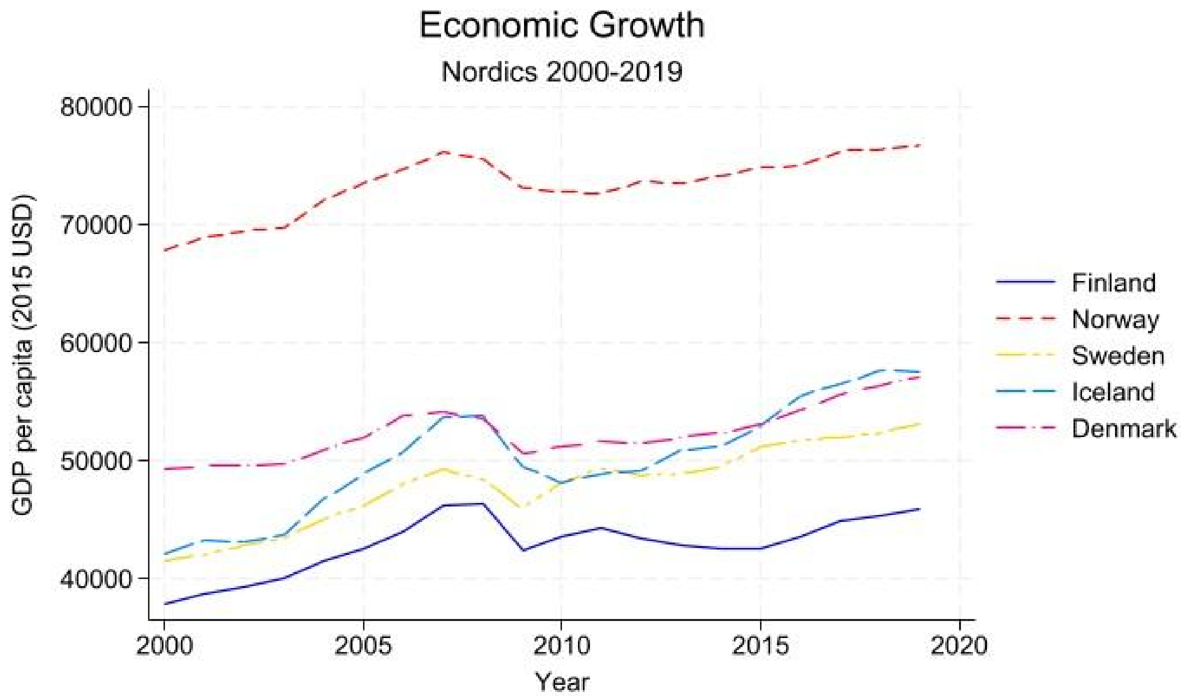

Figure 7. Economic Growth in the Nordics

5. Empirical Study

5.1. Data

The data in this section was collected from multiple sources. Initially it was combined in Excel and then further analysed using Stata. The dependent variable is GDP, while the main independent variable of interest is renewable energy consumption. The control variables include capital stock, labour and non-renewable energy consumption. The dataset covers the five Nordic countries, Finland, Sweden, Norway, Denmark and Iceland for the period 2000-2019.

As mentioned in the previous section, exact data on renewable energy consumption was not available due to data limitation and paywalls. Therefore, the proxy for renewable energy consumption is renewable energy supply. The main difference between these two measures is that energy consumption considers energy lost in the transformation process or during transmission, while supply reflects total energy provided. The same approach was done for similar reasons for non-renewable energy as well. Despite this, I will refer to these variables as consumption throughout the rest of the thesis to align with the research question.

The data for renewable and non-renewable energy was gathered from the IEA's 2024 World Energy Highlights dataset. For clarity, non-renewable energy in this context includes coal, crude oil, oil products and natural gas.

GDP, which is used to proxy economic growth, is measured as the total annual gross domestic product for each country, rather than the change in GDP (growth rate). To better capture growth, GDP is transformed into natural logarithmic form. This is also applied for all the other variables, meaning that coefficients can be interpreted as elasticities.

Capital stock refers to the estimated total value of physical assets available in the country, including buildings, machinery and infrastructure, rather than just annual investments. This distinction is important as capital stock better reflects the productive capacity of an economy over time. Both GDP and capital stock were obtained from the Penn World Table database.

Finally, the data on labour force was gathered from the World Bank's World Development Indicators database. Labour force comprises of people ages 15 and older who supply labour, it includes people who are employed and people who are currently unemployed but seeking work, as well as first-time jobseekers. (World Bank, n.d.)

Overall, these variables comprise a well-balanced panel dataset, with no missing values. Table 1 displays the summary statistics of the non-log transformed values of the variables used in the analysis. This includes number of observations, means, standard deviations and the minimum and maximum values for each variable. The GDP and capital variables are measured in millions of 2017 USD, while the energy variables are reported in petajoules (PJ).

Table 1. Summary statistics

Variable	Obs	Mean	Std.dev	Min	Max
Renewable Energy (PJ)	100	397.1	221.5	88.9	884.2
GDP (mil 2017 USD)	100	255 306.6	144 954.1	10 017.6	532 053.7
Labour Force	100	2 666 115	1 530 244	169 448	5 551 799
Capital (mil 2017 USD)	100	1 014 263	617 627.4	56 147.39	2 380 619
Non-renewable energy (PJ)	100	542.8	276.8	24.5	942.1

5.2. Econometric model and methodology

The econometric methodology used in this thesis follows the works done by Apergis and Payne (2012) and it has a basis in the theoretical works presented earlier. The complete regression model is as follows:

$$Y_{it} = a_i + \beta_1 RE_{it} + \beta_2 K_{it} + \beta_3 L_{it} + \beta_4 NRE_{it} + \varepsilon_{it},$$

where Y is economic growth, RE is renewable energy consumption, K is capital, L is labour as the number of employed people in the country, NRE is non-renewable energy consumption, α_i is the intercept term, which accounts for unknown parameters and finally ε_{it} is the error term. To ensure robustness the model will be estimated using various specifications, including and excluding different variables. Additionally, the data will be transformed into natural logarithm form, so that estimates can be interpreted as elasticities, as in Apergis and Payne (2012). The log-transformed variables will be depicted using lowercase letterings.

The thesis uses panel data, meaning that individuals, in this case countries, are observed at several points in time. Using this kind of data has several advantages compared to cross-section or time-series data sets. For example, as Hsiao (2003, p.3-7) lists: 1. Panel data usually has a lot of data points, which reduces collinearity between explanatory variables and increases degrees of freedom, thus improving the efficiency of the econometric estimates. 2. A panel setting allows for the analysis of questions that cannot be addressed through cross-sectional or time series data. 3. Panel data provides a way to solve or reduce omitted variable bias by utilizing time and individual variation of the data. 4. A panel setting can simplify the computation and interpretation of econometric estimates. 5. Panel data can generate more accurate predictions for individual outcomes than time-series data alone.

Especially the ability to reduce or solve omitted variable bias is interesting for the thesis, as it is likely that the bias will be present in the simple regression used to model the nexus between economic growth and renewable energy consumption. Omitted variable bias arises, when the model omits a variable that affects the outcome variable y and correlates with the explanatory variable x_j (Verbeek, 2017, p.146). However, if the omitted variables are constant over time, panel data estimators can consistently estimate the effect of the observed explanatory variables that do vary over time (Verbeek, 2017, p.386).

This thesis considers two possibilities to combat the unobserved effects, fixed effects (FE) and random effects (RE) estimations. Additionally, the presence of unobserved effects is not taken for granted, meaning that pooled ordinary least squares (pooled OLS) is also considered. If there is no unobserved heterogeneity among the cross-sectional units, the pooled OLS estimation is applicable and produces consistent estimators for the slope parameters.

In terms of the methods that take unobserved effects into account, the random effects estimation allows for unobserved heterogeneity, however, strong exogeneity assumptions and assumptions on the correlation structure of errors are needed. Firstly, it assumes strict exogeneity, which states that the idiosyncratic error at each time is uncorrelated with the explanatory variables in all time periods. Next, it assumes orthogonality between the unobserved effects and each explanatory variable. Under these assumptions the random effects estimation is consistent and asymptotically efficient. Fixed effects estimation, on the other hand, allows for arbitrary correlation of unobserved heterogeneity with observables. This makes it more robust as it can estimate the slope parameters consistently even in the presence of time-constant omitted variables. However, it cannot distinguish between time-constant independent variables and time-constant unobserved effects, meaning that these kinds of variables cannot be studied. (Verbeek, 2017, p.384-393.)

In practice, the decision between the methods is done by statistical tests on the regressions. First, an F-test is used to test between the pooled OLS and FE regressions. The null hypothesis of the test is that the intercepts do not differ, i.e. $a_i = a_0$ for all i, and the alternative hypothesis is that $a_i \neq a_0$ for at least one i. Rejecting the null hypothesis implies that there is a significant unobserved effect, meaning that the pooled OLS returns unreliable test statistics. Next, if the null hypothesis of the F-test is rejected, the Hausman test is applied to test between the FE- and RE-estimators. The Hausman test basically compares the slope parameters, β, of the two estimators under the null hypothesis that either of them is consistent, while the alternative hypothesis is that only the FE-estimator is consistent (Mátyás et al., 2008, p.81).

After confirming the best estimator, I will move onto concerns about stationarity. Since the dataset has only five cross sectional units and 20 time periods, the panel resembles the usage of multiple time-series rather than a typical large-N short-T panel. Due to this it is important to examine whether the variables used can be treated as stationary or not. When a variable is stationary the limiting distribution of its estimator will approximate to normal as the time periods increase, allowing for valid inference using standard statistical tests. However, if data are non-stationary, standard estimators will have non-standard distributions leading to invalid test statistics. (Hsiao, 2003, p.298.) More importantly, if the two variables are non-stationary and not cointegrated, running a regression on them may produce spurious results (Phillips & Moon, 1999, p.1058). Therefore, if non-stationarity is found I will proceed to test for cointegration. Series are said to be cointegrated if a linear combination of several I(1) series is stationary (Verbeek, 2017, p.353). If cointegration is confirmed, the thesis will continue the analysis using the estimator confirmed earlier.

Stationarity will be tested using Im-Pesharan-Shin (2003) and Fisher type tests, whereas cointegration will be tested using Pedroni's (1999, 2004) panel cointegration test. Both stationarity tests are based on the augmented Dickey Fueller regression

$$\Delta y_{it} = \phi_i y_{i,t-1} + z_{it}' y_i + \epsilon_i,$$

where y_{it} is the variable being tested, $z_{it}' y_i$ is the panel specific mean and linear time trend, if it is included, ϕ_i is the unit root and ε_{it} is the error term. The null hypothesis in both tests is H_0: $\phi_i = 0$ for all i and the alternative hypothesis are H_a: $\phi_i < 0$ for a fraction of all i, in the IPS test, and for at least one i in the Fisher-type test. (StataCorp, 2025, p.624-627.)

The Pedroni (1999, 2004) panel cointegration test is based on a panel data model where each of the explanatory variables is an I(1) series. The Pedroni method uses different types of tests for whether the error term, e_{it}, is non-stationary. In essence the tests differ in how they pool and test the error terms. If the error terms are stationary there is cointegration. The null hypothesis of the Pedroni test is that there is no cointegration, thus rejecting the null hypothesis implies that e_{it} is stationary and there is cointegration. As with the unit root tests the Pedroni panel cointegration test also allows for panel specific means and time trends. (StataCorp, 2025b, p.74-78.) (See Pedroni, 1999, 2004, for more details on the test statistics.) Moreover, the test provides two types of statistics, panel and group. The panel tests follow a within-dimension approach, which includes four statistics. These statistics essentially pool the autoregressive coefficients across countries when testing the stationarity of the estimated residuals. In contrast, the group tests adopt a between-dimension approach, that averages the individual autoregressive coefficients from unit root tests conducted separately for each country. The group method provides three statistics. (Apergis & Payne, 2010a, p.1393-1394.)

5.3. Empirical Results

The regression analysis will be done by adding one parameter at a time to observe how individual variables affect the results. However, to avoid being overwhelmed by a battalion of F-, Hausman- and cointegration results, the focus will be on two main models:

Model 1

- Dependent variable: GDP
- Explanatory variables: renewable energy supply, capital, labour

Model 2

- Dependent variable: GDP
- Explanatory variables: renewable energy supply, capital, labour, non-renewable energy

As discussed, I will begin the analysis by confirming the best estimator using the F-test and the Hausman test. Firstly, the null hypothesis for the F-test, that intercepts do not differ, is rejected in both models as the p-values are smaller than 0.001 in each case. This implies that there are significant unobserved effects in both models, meaning that the fixed effects estimation is preferred over pooled OLS. Next, to determine whether fixed effects or random effects should be used, the Hausman test is conducted. Given the structure of the panel data the *sigmamore* option is applied to compute a more efficient variance estimate. This option essentially tells Stata to use the estimated error variance from the more efficient estimator, i.e. the random effects estimator. (StataCorp, 2025a p.1086.) The tests yielded chi-square statistics of 19.29 and 90.14 with three and four degrees of freedom, respectively. The p-values are less than 0.001 in both cases therefore, the null hypothesis is strongly rejected in both models, confirming fixed effects as the preferred estimator.

Next, the stationarity of the variables is tested using both Im-Pesharan-Shin (2003) and Fisher type tests. Since, the Nordic countries have strong economic and policy linkages there is a possibility of cross-sectional dependence. Therefore, applying the *demean* option in panel unit root testing is justified to mitigate bias from potential cross-sectional dependence. (See StataCorp, 2025b, p.612-628, for more details.) Both tests are applied to each variable, first without and then with the linear time trend parameter. For variables where the null hypothesis cannot be rejected the tests are repeated in first differences. The IPS test allows for a different lag structure for each time series, so the lag structure for these tests is chosen so that it minimizes the Akaike information criterion (AIC). This cannot be done for the Fisher tests, so the lag structure is set to the nearest whole number of the average number of lags used in the IPS test.

Table 2 displays the results of the Im-Pesharan-Shin and Fisher-type ADF panel unit root tests. All variables appear non-stationary when no time trend is included. When a linear time trend is added renewable energy consumption, and non-renewable energy consumption become stationary under both tests. However, GDP, labour and capital remain non-stationary, and are identified as I(1) processes, as differencing them once makes them stationary according to both tests. Therefore, as non-stationarity is confirmed for some variables the thesis proceeds to test for cointegration.

Table 2. Results for unit root tests

	Im-Pesharan-Shin			Fisher-type ADF (inverse Chi-squared)		
V	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
gdp	1.91	-0.31	-4.25***	2.92	10.23	40.43***
	(0.20)	(0.80)	(0.20)	(0.00)	(1.00)	(0.00)
re	0.61	-2.20**		6.32	45.88***	
	(0.80)	(0.40)		(1.00)	(0.00)	
k	1.00	0.12	-3.44***	4.04	12.04	33.32***
	(0.60)	(1.00)	(0.40)	(1.00)	(1.00)	(0.00)
l	3.51	-0.65	-2.77***	0.75	13.70	32.34***
	(0.40)	(1.00)	(0.40)	(0.00)	(1.00)	(0.00)
nre	0.95	-1.97**		8.68	18.92**	
	(0.00)	(0.20)		(0.00)	(0.00)	
Trend	No	Yes	No	No	Yes	No
1^{st} diff	No	No	Yes	No	No	Yes

Notes: (1) Significance codes are the following: 0.1 "*", 0.05 "**", 0.01 "***". (2) Number of lags reported in parenthesis. (3) Variable names are in lowercase letters to indicate log transformations.

The Pedroni panel cointegration test is also run with the *demean* option for the same reasons as for the unit-root tests. Additionally, the test is applied with the group and panel specifications for both models specified above. Table 3 presents the results for both models and all specifications. In all specifications at least one of the test statistics is significant at the 5% level. Especially the modified Phillips-Perron t-statistic shows consistent significance across all specifications, providing evidence for cointegration. Although model 1 does not indicate cointegration quite as strongly, the consistent and strong evidence from the more comprehensive model suggests that we can proceed to the regression analysis without substantial concern of spurious results.

Table 4 presents the results of the fixed effects regressions estimating the relationship between GDP and renewable energy consumption, with control variables being added one by one. A final specification is run where only statistically significant variables are included. As noted earlier, all variables are log-transformed, allowing the coefficients to be interpreted as elasticities.

Table 3. Pedroni cointegration results

	Model 1		Model 2	
	Group	**Panel**	**Group**	**Panel**
Modified variance ratio		-1.49*		-2.46***
Modified Phillips-Perron t-stat	2.10**	1.92**	2.96***	2.26**
Phillips-Perron t-stat	0.58	1.00	1.90**	-1.27
ADF t-stat	0.19	0.60	1.68**	-1.15

Notes: Significance codes are the following: 0.1 “*”, 0.05 “**”, 0.01 “***”.

Firstly, the coefficient for renewable energy consumption is consistently positive and statistically significant at the 1% level across all model specifications, indicating a robust positive relationship with GDP. The magnitude of this effect decreases as additional control variables are included in the model, suggesting that a part of this initial effect can be explained by other drivers of growth. Specifically, a 1% increase in renewable energy consumption is associated with a 0.131% increase in GDP when all variables are included in the model. However, this effect reduces to 0.123% when the model incorporates only statistically significant variables.

Next, capital has a positive and significant effect when first added to the model. Interestingly however, the effect becomes insignificant once labour is included. Labour, on the other hand, indicates a consistently strong positive relationship with GDP, with estimates ranging from 1.487 to 1.579. Also, the addition of labour significantly improves the model’s explanatory power, as evidenced by the sharp increase in R^2 and adjusted R^2 values from below 0.7 to over 0.9 once labour is included. This strong and important role is in line with traditional economic theory, which emphasises labour as a critical driver of economic growth. Interestingly, the model’s constant shifts from positive to negative once labour is included, further highlighting the critical role that labour plays in economic growth.

Table 4. Fixed effects regression results

	(1) gdp	(2) gdp	(3) gdp	(4) gdp	(5) gdp
re	0.365***	0.215***	0.112***	0.131***	0.123***
	(11.61)	(5.76)	(5.55)	(5.44)	(6.62)
k		0.196***	0.0278	0.0341	
		(5.80)	(1.39)	(1.67)	
l			1.513***	1.487***	1.579***
			(16.31)	(15.82)	(19.75)
nre				0.0412	
				(1.44)	
_cons	9.884***	8.124***	-10.81***	-10.88***	-11.46***
	(54.14)	(23.79)	(-9.21)	(-9.31)	(-10.57)
N	100	100	100	100	100
R^2	0.589	0.698	0.922	0.924	0.921
adj. R^2	0.567	0.679	0.917	0.918	0.916

Notes: (1) Significance codes are the following: 0.1 "*", 0.05 "**", 0.01 "***". (2) t-statistics are reported in parenthesis. (3) Lowercase lettering indicates log-transformed variables

Finally, the coefficient for non-renewable energy is positive but not statistically significant, suggesting that non-renewable energy might play a less direct role in driving economic growth, compared to renewable energy in the Nordic countries. Additionally, as already mentioned, the model indicates high values for R^2 and adjusted R^2, especially once labour is included. This suggests that a large amount of the variance in GDP is explained by the included variables, which reinforces the validity of the estimated relationships.

These findings are broadly consistent with the earlier literature on the relationship between renewable energy consumption and economic growth. For example, many papers, that report a positive effect, report elasticities between 0.1 and 0.3 percent, which aligns closely with the estimates presented in this thesis. This consistency with prior literature strengthens the external validity of the results.

Moreover, since the elasticities do not significantly differ from those found in other countries, the relatively high consumption of renewable energy in the Nordic countries does not appear to significantly amplify the effects. However, definitive conclusions on this cannot be made, as the magnitude of the effects can be influenced by a variety of different factors, such as economic region, time period, market maturity and other structural characteristics.

On the other hand, the result that non-renewable energy does not have a statistically significant relationship with GDP contrasts with previous studies. For example, Apergis and Payne (2012, p. 735), using a panel of 80 countries, find that non-renewable energy has an elasticity of 0.384, which is significant at the 1% level. A possible explanation for this could be in the specific characteristic of the Nordic countries, where renewable energy accounts for a large share of total energy consumption. The high reliance on renewables possibly reduces the marginal contribution of non-renewable energy to economic output. In contrast the panel of 80 countries used by Apergis and Payne (2012) includes many countries which are still heavily dependent on fossil fuels and non-renewable energy plays a central role in economic growth.

Overall, these findings support the idea that there is a positive relationship between renewable energy consumption and economic growth in the Nordic countries. However, the findings cannot be directly interpreted as evidence for any of the four main hypothesis on economic growth and energy consumption, as the direction of the results is not clear. In this regard, the results can be consistent with the growth, feedback or conservation hypotheses as they indicate a relationship but do not establish whether renewable energy drives growth or vice versa. On the other hand, the results do seem to reject the neutrality hypothesis as it assumes no relationship between energy consumption and economic growth.

Importantly, the results do not find a negative relationship. This suggests that increasing renewable energy usage should not hinder economic growth, meaning that policy makers can promote the usage of clean energies, without the worry of adverse effects economic growth.

6. Conclusions

This thesis aimed to investigate the relationship between renewable energy consumption and economic growth in the Nordic countries. Motivated by the growing need for sustainable economic policies, the study explored whether renewable energy contributes positively to economic output. Moreover, the Nordic countries provided a unique empirical setting with their global leadership in renewable energy adoption, strong environmental policies and relatively homogenous economic structures, allowing for meaningful regional comparison. To guide the analysis, the study was grounded in established theoretical frameworks and supported by a growing body of empirical literature examining the energy-growth nexus.

The theoretical relationship between the two variables is complex and context dependent. Conclusions drawn from the theoretical models often rely strongly on assumptions and changing them can have a significant effect on the results. For example, Barretto (2018) shows that transitioning from non-renewable to renewable energy can have either negative or positive effects on the economy, depending on factors such as the pace of renewable energy development and the initial efficiency gap between the two energy sources. This complex relationship is mirrored in the empirical literature, where results are varying and there is no clear consensus on the relationship between renewable energy consumption and economic growth. Empirical results often differ depending on the econometric methodology applied and the specific economic context under analysis. This underlines the importance of this study, which to the best of the author's knowledge, is the first specifically focusing on the Nordic countries.

To analyse the relationship between renewable energy consumption and economic growth in the Nordic countries, the thesis applied a fixed effects panel regression model, using data from 2000 to 2019. Due to the time-series nature of the panel dataset, stationarity and cointegration tests were conducted to mitigate the possibility of spurious regressions.

The main finding is that renewable energy consumption has a positive and statistically significant connection with economic growth across all model specifications. Specifically, a 1% increase in renewable energy consumption is associated with a 0.131% increase in GDP when all variables are included in the model. This is in line with previous research where estimated elasticities usually range between 0.1 and 0.3 percent, which strengthens the validity of the results.

On the other hand, since the estimates remain in the usual range found in the literature, it appears that the relatively high consumption of renewable energy in the Nordics does not amplify the effects. However, this high usage of renewable energy may help explain why non-renewable energy does not have a significant impact on economic growth, contrasting with findings from many other countries where non-renewable energy often shows a strong positive effect (see e.g. Apergis & Payne, 2012).

While these findings support the idea of a positive relationship between renewable energy consumption and economic growth, the analysis does not establish a direction between the two variables. Therefore, the results can be consistent with the growth, feedback or conservation hypothesis, as they indicate a relationship but do not establish if growth drives renewable energy consumption or vice versa. Despite this the results do seem to reject the neutrality hypothesis for the Nordic region, as it assumes no relationship between energy consumption and economic growth.

These findings suggest that increasing renewable energy consumption should not hinder economic growth. This implies that policy makers can promote the usage of renewable energy in order to achieve sustainable development goals, without the worry of adverse effects on economic growth.

However, as renewable energy technologies and economies continuously evolve, ongoing research is needed. Applying more advanced econometric techniques, such as vector error correction models or Granger causality tests, could also provide further insights into the nexus between renewable energy consumption and economic growth, in the Nordic countries. Moreover, future research could examine sector-specific effects or consider regional variations between countries to better tailor energy policy to economic needs. Overall, this thesis contributes to the growing body of research supporting the compatibility of environmental sustainability and economic development in advanced economies.

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