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Renewable energy and energy security

Alternative pathway to fossil energy imports consumption in Finland

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ABSTRACT:
Renewable energy sources (RES) have an essential role in substituting traditional fossil fuels, oil, natural gas, and coal. Besides being considered a desirable target from the environmental conservation point of view, renewable energy deployment can additionally offer an effective tool for improving energy security. Many countries, including Finland, import fossil energy from concentrated energy sources. Therefore, the deployment of renewable energy can diversify the energy supply and reduce the dependence on fossil energy imports. Even though the subject is widely acknowledged, empirical analysis of the effects is not so far broadly available, especially in the case of Finland.

This master's thesis discusses the role of RES in the energy security of Finland from the perspective of import dependence. The study empirically assesses the effects of renewable energy consumption on fossil energy imports consumption in the country between 2000–2020. The literature review covers an overview of energy supply and demand in Finland, as well as a recent development and future views of domestic renewable energy sources. Furthermore, the concept of energy security and the complexity of determining the issue, along with the energy security views of the country, are addressed. The literature review concludes with the theoretical framework on the relationship between renewable energy deployment and energy security. The empirical analysis utilizes time series regarding energy consumption in the country in 20 years period, sourced from the Official Statistics of Finland database. Multiple linear regression analysis is then applied to assess the effects of renewable energy sources' consumption on fossil energy imports consumption in the period. A series of regression diagnostic tests along with stability testing supports the correctness of the empirical models employed for the investigation.

Key findings first discover that RES consumption shows a declining effect on coal and oil consumption, but the development of natural gas import consumption is not explained by RES with the model used. The conclusion is drawn that renewable energy has been successfully utilized to decrease coal and oil imports consumption rather than natural gas imports. Further, findings underline, besides hydropower, decreasing effect of marginal RES alternatives combined (wind energy, solar power, liquid biofuels, and heat pumps) on coal and oil consumption in the country between 2000–2020. In addition, the role of direct electricity imports in compensating for fossil energy consumption reflects in the results. The findings of the study are largely parallel to previous literature in Europe and contribute to the evidence of RES enabling improvements in energy security.

KEYWORDS: Energy dependence, Energy imports, Energy security, Fossil fuels, Renewable energy sources, Security of energy supply

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TIIVISTELMÄ:
Uusiutuvalla energialla on keskeinen rooli perinteisten fossiilisten polttoaineiden, öljyn, maakaasun ja hiilen korvaamisessa. Sen lisäksi, että uusiutuvan energian käyttöä pidetään ympäristön kannalta vähemmän haitallisena vaihtoehtona, se voi olla keino energiaturvallisuuden parantamiseen. Monet Euroopan maat kuten Suomi, tuovat fossiilisia polttoaineita keskittyneistä energialähteistä. Uusiutuvan energian käyttöönotto voi hajauttaa energian tarjontaa ja vähentää riippuvuutta fossiilisesta tuontienergiasta. Asia on laajasti tunnistettu tutkimuskirjallisuudessa mutta empiiristä analyysia vaikutuksista etenkään Suomessa ei vielä ole kattavasti saatavilla.

Tämä taloustieteen pro gradu -tutkielma käsittelee uusiutuvan energian roolia Suomen energiaturvallisuudessa, fossiilisen tuontienergian ja tuontiriippuvuuden näkökulmasta. Tutkielman tavoitteena on empiirisesti analysoida uusiutuvan energian kulutuksen vaikutuksia fossiilisten polttoaineiden kulutukseen Suomessa vuosina 2000–2020. Kirjallisuuskatsaus esittelee energian tarjonnan ja kysynnän keskeiset piirteet sekä uusiutuvan energian käytön maassa. Lisäksi käsitellään energiaturvallisuuden määrittelyä sekä Suomen energiaturvallisuuden näkymiä. Näin muodostuu teoreettinen viitekehys uusiutuvan energian mahdollisista vaikutuksista energiaturvallisuuteen. Tutkielman empiirisessä analyysissä hyödynnetään Tilastokeskuksen tietokannasta kerättyjä aikasarja-aineistoja energiankulutuksesta 20 vuoden ajanjaksolta Suomessa. Lineaarista regressioanalyysia soveltamalla arvioidaan eri uusiutuvien energialähteiden vaikutuksia fossiilisten polttoaineiden tuonnin kulutukseen vuosina 2000–2020. Regressioanalyysin tulokset varmistetaan sarjalla diagnostisia testejä.

Empiiriset havainnot osoittavat uusiutuvan energian vähentävän vaikutuksen hiilen ja öljyn tuonnin kulutuksessa. Maakaasun tuonnin kulutuksen kehitystä ei kuitenkaan voida selittää käytetyssä mallissa uusiutuvan energian kulutuksella. Tulos viittaa siihen, että uusiutuvaa energiaa on onnistuneesti hyödynnetty vähentämään hiilen ja öljyn tuonnin kulutusta maakaasun kulutuksen sijaan. Muiden keskeisten havaintojen mukaan hiilen ja öljyn kulutukseen vuosina 2000–2020 on vaikuttanut vähentävästi vesivoiman lisäksi muut osuuksiltaan pienemmät uusiutuvat energialähteet yhdessä: tuulivoima, aurinkovoima, nestemäiset biopolttoaineet ja lämpöpumput. Uusiutuvan energian lisäksi tuontisähkön merkitys fossiilisen tuontienergian korvaamisessa näkyy tuloksissa. Löydökset ovat pitkälti samankaltaisia aiempien eurooppalaisten tutkimustulosten kanssa ja antavat osaltaan näyttöä uusiutuvan energian mahdollisista energiaturvallisuutta parantavista vaikutuksista.

AVAINSANAT: Energiaturvallisuus, Energiariippuvuus, Fossiiliset polttoaineet, Huoltovarmuus, Tuontienergia, Uusiutuvat energialähteet

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Abbreviations

CO_2	Carbon dioxide
GDP	Gross domestic product
HHI	Herfindahl –Hirschman index
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
MLR	Multiple linear regression
OLS	Ordinary least squares
OSF	Official Statistics of Finland
RES	Renewable energy source
SW	Shannon –Wiener index
TJ	Terajoules

1 Introduction

Fossil energy is often produced from concentrated sources since the fuel stocks are geographically unequally distributed and exist in limited geographical areas. Fossil energy imports to Finland mainly originate from the region of Russia. The supply base of energy essentially affects the energy security of a country, and energy security is traditionally approached from the perspective of the diversity of supply or energy source dependence. Fossil energy production is acknowledged as damaging to the environment, such that governments and countries seek to shift to carbon-neutral energy sources and production. Conversely, energy security has received less attention as a motivation for substituting fossil energy imports, even though this is a recognized driver among political decision-makers.

The motivation of this thesis arises from the increasing trend of the utilization of renewable energy sources (RES) and the drive to reduce fossil energy consumption. In addition to environmental issues, fossil fuel imports are a significant factor of energy import dependence among many European countries. Dependency on energy imports from concentrated supply sources poses a concern for energy security and even enables the use of an “energy weapon”. In the spring of 2022, the dependence on fossil energy imports inspired more serious discussion due to the Russo-Ukrainian War and, therefore, further increased geopolitical tension. Many European countries are in a sudden critical situation, seeking effective measures to substitute fossil energy imports.

The relationship between energy security and renewable energy has been discussed previously in the research literature, e.g., by Valentine (2011) and Valdes Lucas et al. (2016). Literature has furthermore explored energy security as a driver of renewable energy deployment (see Wang et al., 2018). In Finland, theoretical scenario analysis has been conducted to evaluate the potential effects of renewable energy on energy security by Aslani et al. (2014), and the energy security effects of fossil energy dependence have been discussed by Jääskeläinen et al. (2018). International organizations, such as International Energy Agency, have broadly analyzed energy security and fossil import dependence among countries (see IEA, 2014). An international analysis is also provided by World Energy Council (2021). Gokgoz & Guvercin (2018) and Marques et al. (2018) have, similar to this study, empirically analyzed the effects of renewable energy deployment on fossil energy consumption in Europe. Despite the vast body of literature on the topic, research gaps exist, especially in the case of Finland. The evaluation of the potential adverse effects of renewable energy deployment on energy security has achieved less attention in the literature. Besides, since the research topic is relatively new, there is an observed shortage of empirical research on the proven effects of RES on energy security. This thesis aims to contribute to the latter of these.

This study discusses the effects of renewable energy on energy security, particularly in the case of Finland. The research problem is to empirically assess the effects of the consumption of renewable energy on fossil energy imports consumption in Finland from 2000 to 2020. Therefore, energy security is approached from the perspective of fossil energy import dependence. The research problem is answered first by reviewing the relevant literature and constructing the theoretical framework. Then, econometric analysis applying multiple linear regression models is employed to assess the effects of RES consumption on fossil energy imports consumption in the country between 2000–2020.

The thesis proceeds as follows; First, chapter 2 covers an overview of energy demand and supply in Finland. Then literature review regarding the concepts and recent trends of renewable energy and energy security is presented in chapter 3, concluding with the essential connection between these two subjects. Chapter 4 presents the empirical analysis of the study and a discussion of the results. Finally, chapter 5 concludes with remarks on the thesis with the policy implications and suggested future research topics.

2 Energy demand and supply in Finland

This chapter describes the energy market in Finland in terms of energy consumption and supply. The chapter covers a review of energy consumption in Finland and the energy supply, which divides into domestic energy production and energy imported from foreign sources. The chapter also aims to describe country-specific characteristics and particular issues relating to energy demand and supply in Finland.

Total energy consumption in Finland in 2020 was 1.28 terajoules (Official Statistics of Finland, 2021). Energy consumption in Finland has varied between 2000–2020, but in the long-term trend, the country's total energy consumption has decreased slightly since around 2006 (see Figure 1). The continuously increasing renewable energy consumption as well characterizes the recent development of the energy market in Finland. On the contrary, the usage of fossil fuels has decreased since around 2010 (Figure 2).

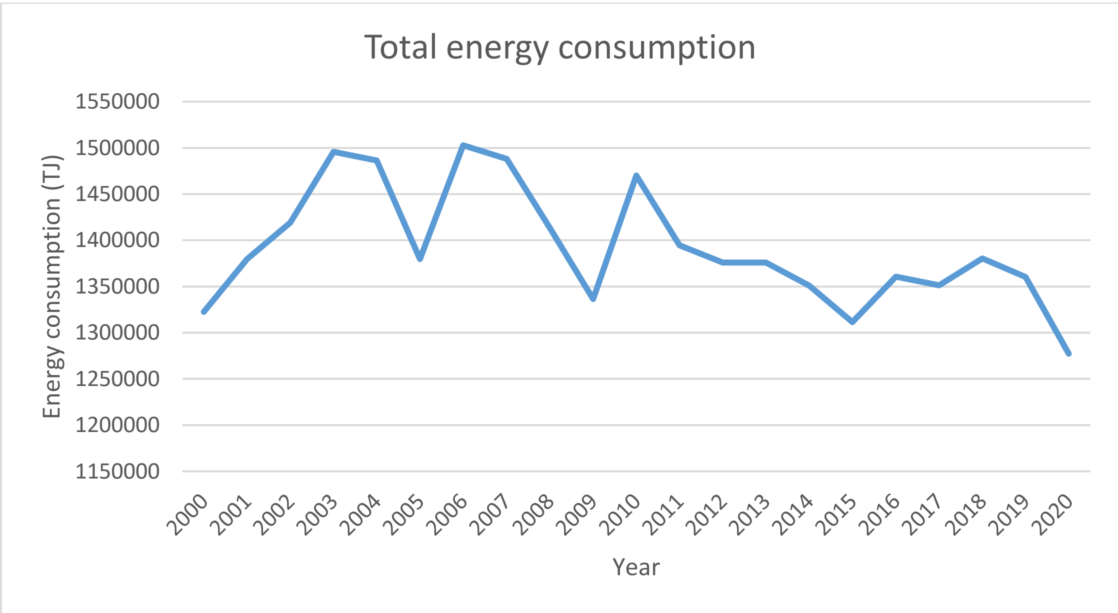

Figure 1. Total energy consumption in Finland 2000–2020 (OSF, 2021. Author's visualization).

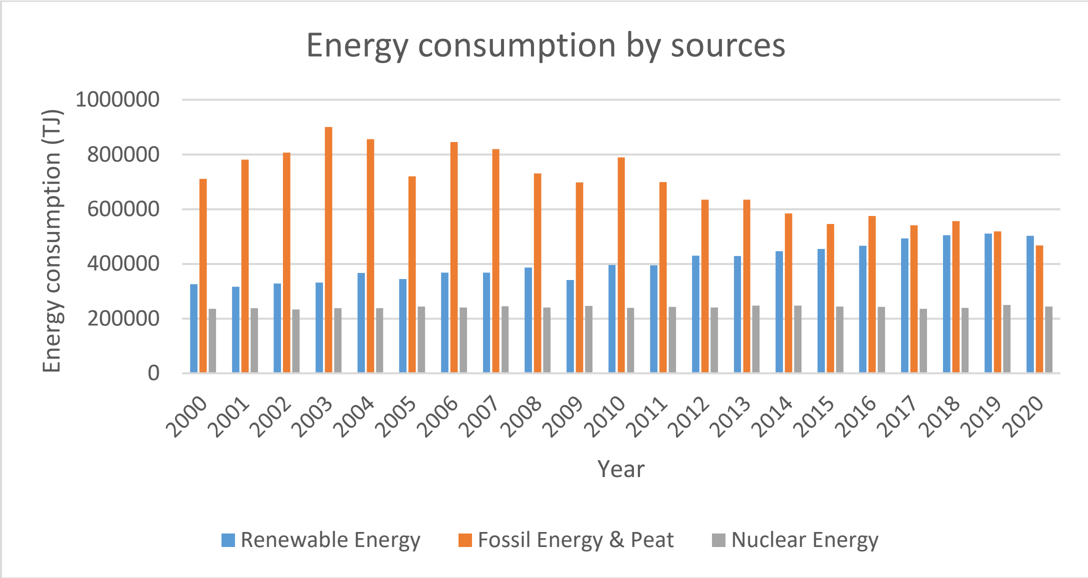

Figure 2. Energy consumption by sources 2000–2020 (OSF, 2021. Author's visualization).

Energy Consumption per capita in Finland reaches a high level compared to other European countries (Eurostat, 2022a; Tabasi et al., 2018, p. 127). Final energy consumption per capita in Finland counts as almost double the average final energy consumption in IEA bioenergy member countries (IEA, 2021). Finland's high energy consumption per capita has been explained by an energy-intensive industrial sector and cold climate in the country. Moreover, long distances and low population density are suggested as factors behind the country's high-level energy consumption (Tabasi et al., 2018). As Figure 3 describes, Finland's energy consumption per capita in 2020 was considerably over the average of EU-27 countries.

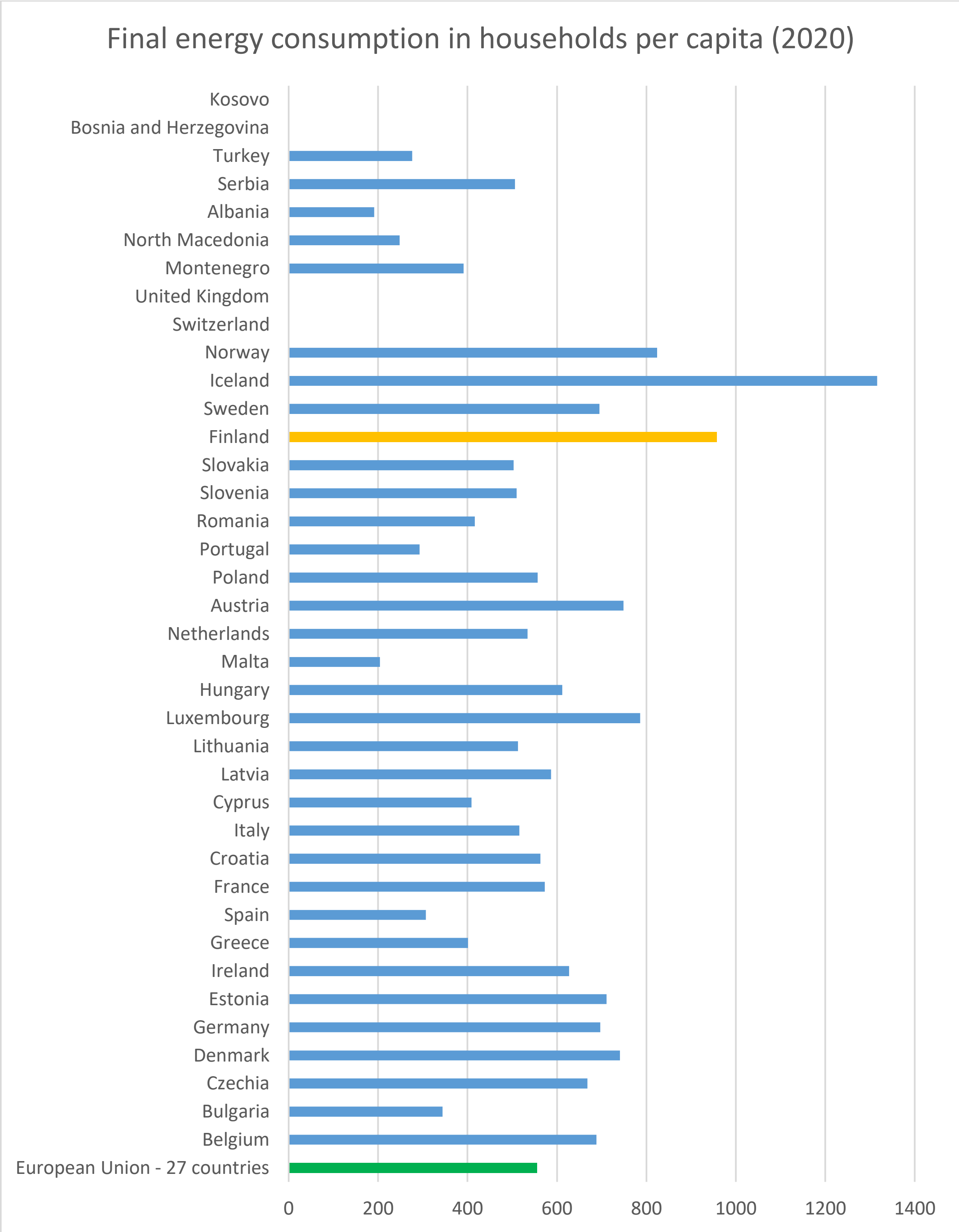

Figure 3. Final energy consumption in households per capita 2020 (Eurostat, 2022a. Author's visualization).

Energy intensity and *energy efficiency* are terms closely associated with energy consumption. Energy intensity or energy output ratio (1) is a ratio value used to measure the energy requirements of a driving economic variable such as GDP or value-added

(Bhattacharyya, 2019, p. 57). Energy efficiency, on the other hand, is a term closely related to energy intensity. Energy efficiency improvements are achieved when less input is consumed to maintain an equivalent economic activity level. Energy efficiency improvements have been determined as a strategic goal on behalf of the European Union's sustainable development, and energy intensity has a considerable role in improving energy efficiency. (Filipovic et al., 2015, p. 547).

$$Energy\ intensity = \frac{Total\ energy\ consumption}{GDP} \tag{1}$$

According to World Bank data (2022), Finland ranks among the energy-intensive countries in Europe, and the energy intensity level is higher than in other Nordic countries (see Figure 4). Energy intensiveness in Finland is raised by the combination of the cold climate, long distances, and the energy-intensive industrial sector, which consumes over half of the electricity consumed in Finland. On the contrary, Finland has no domestic fossil fuels recourses or uranium production for nuclear power plant fuel. These factors combined have historically made Finland highly dependent on imported energy. Energy imports in Finland consist considerably of fossil energy imports, such as oil and natural gas. Finland, therefore, imports a dominant amount of its primary energy from Russia. (Jääskeläinen et al., 2018, p. 2). Between 2000 and 2020, there has been a slight decline in energy intensity in Finland, as shown in Figure 5.

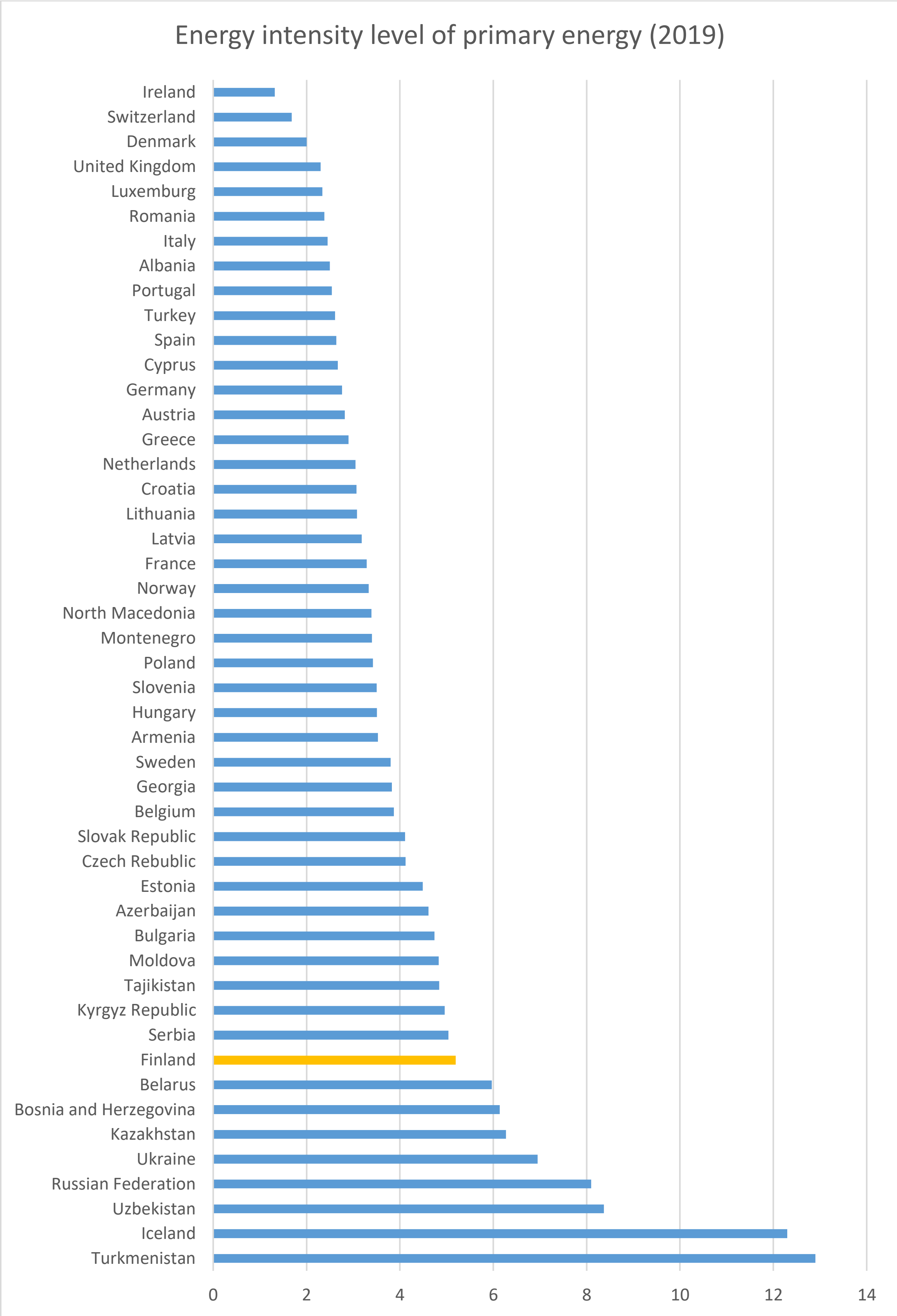

Figure 4. Energy intensity level of primary energy (2019) (World Bank, 2022. Author's visualization).

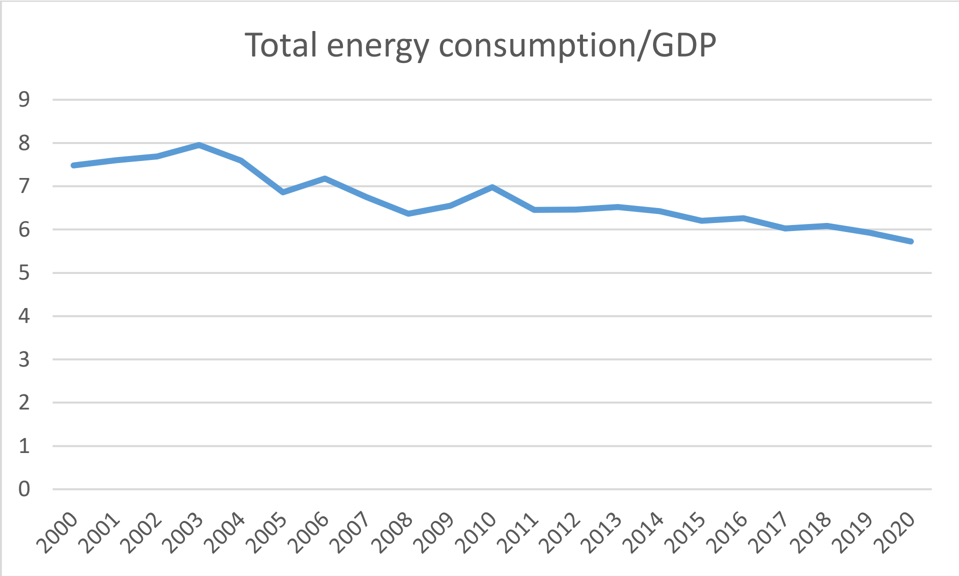

Figure 5. Energy intensity (total energy consumption/GDP) 2000–2020 (OSF, 2021. Author's calculation).

Drivers of energy consumption in Finland have been studied previously, e.g., Tabasi et al. (2018) investigated the relationship between selected economic variables; GDP, population growth and industrial growth rate, and total energy consumption in Finland. Their empirical model described a high correlation between the selected economic variables and energy consumption. According to the authors, the energy-intensive industrial sector and a cold-weather raise Finland's energy consumption to a high level compared to other European countries. The energy intensiveness of the industrial sector in Finland is illustrated in Figure 6, presenting the shares of different economic sectors from total energy consumption in 2020.

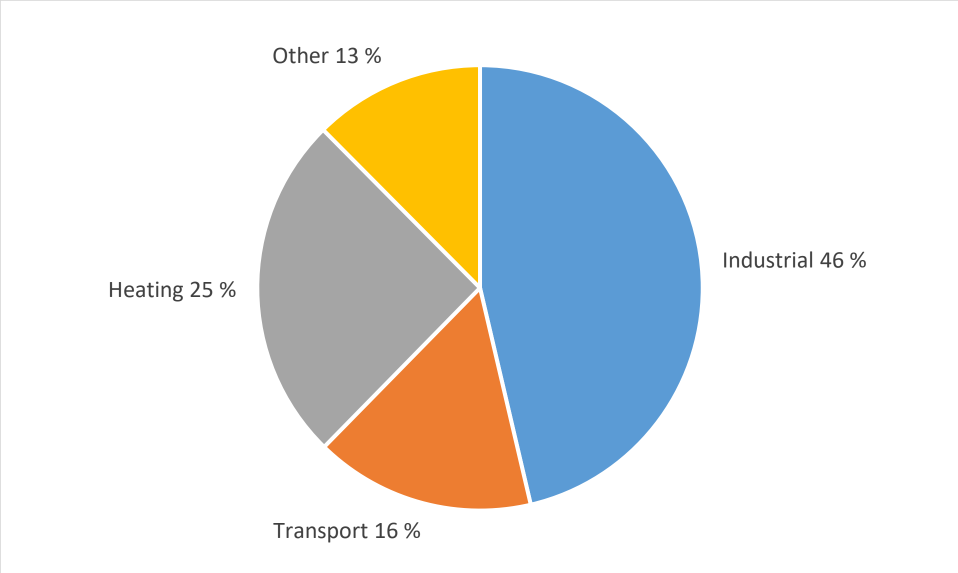

Figure 6. Energy consumption by sector 2020 (OSF, 2021. Author's visualization).

Energy consumption shares between economic sectors have remained relatively similar between 2000 and 2020 in Finland. According to Official Statistics of Finland (OSF, 2021), in the year 2020 industrial sector consumed 46 percent of the total energy consumption in the country. The industrial sector in Finland is energy-intensive in international comparison and consumes almost half of the total energy consumed in a country (IEA bioenergy, 2021). The industrial structure of Finland has historically developed on energy-intensive industrial forms, such as paper and forest industry and chemical production. Especially the forest industry has been among the key consumers of electricity in Finland. (Tabasi et al., 2018).

The transportation sector's share of total energy consumption was around 16 percent in 2020. (OSF, 2021). The transportation sector consumes especially petroleum products, but between 2000–2020, the increasing trend of renewable energy consumption has also slowly reached the transportation in Finland. Electricity consumption shares are relatively less significant in the transportation sector, but alternative renewable energy forms such as biofuels are more relevant in transportation. This development further makes it possible to increase the share of renewable energy in the transportation sector. Further planning is taking place to increase the sustainable energy utilization in the transportation sector in Finland, e.g., enabling more competently alternative transportation forms for private cars. Additionally, the quality of new cars brought to market expects to shift increasingly towards hybrid cars instead of petroleum engine vehicles. (Tabasi et al., 2018).

In the residential sector, energy is consumed mainly for heating space and maintaining different functions in buildings. In Finland, especially heating requires the leading share of energy consumed in the residential sector and energy consumed for heating supplies from the district heating system. (Tabasi et al., 2018). In an international comparison, the energy consumption of heating in the residential sector in Finland is also relatively significant due to the northern climate and higher domestic heating requirements (IEA bioenergy, 2021). In 2020, heating consumed around 25 percent of total energy consumption in Finland (OSF, 2021).

2.1 Domestic energy production

Domestic energy production in Finland relies mainly on wood-based bioenergy (biomass) and nuclear energy. Specifically, wooden biomass is a significant energy source in Finland, and the share of wood fuel production from total energy consumption was 28% in 2020 (OSF, 2021). Nuclear energy was adopted in Finland when energy company Fortum Power and Heat launched Loviisa nuclear plant reactors 1 and 2 in 1979 and 1981 (IAEA, 2020). Currently, Finland produces a significant amount of its electricity consumption with nuclear energy; approximately 28% of energy consumption in Finland covers via nuclear energy (IEA, 2021, p. 9). In Finland, nuclear energy production has remained stable since the early ’80s when the company TVO launched Olkiluoto nuclear powerplant’s second and latest new functioning reactor, Olkiluoto 2 (www.stuk.fi). There are four nuclear reactors currently operating in Finland, located in the cities of Olkiluoto and Loviisa.

The role of nuclear power expects to rise in the future in Finland due to the new nuclear reactor deployment in 2022. Olkiluoto 3 reactor construction work was finished in 2021 when the first experimental deployment of the reactor took place. Currently (2022), Olkiluoto 3 is under final preparation to produce electricity for the electric net. Deployment of the Olkiluoto 3 will increase the amount of electricity produced by nuclear energy in Finland to approximately 40 percent (www.tvo.fi). There are no domestic uranium resources in Finland, so nuclear power fuel uranium imports from foreign countries. Electricity produced via nuclear energy is considered a domestic energy production, but also the role of uranium imports is discussed briefly in the context of energy imports.

Finland's primary inclusively domestic energy resources are wood-based fuels (biomass), hydro power, and peat (IAEA, 2020). Peat is a substance developing in the wet biomass during the combination of different processes, such as biological and chemical. Peat forms in the ecosystem in the interaction between living and post-living materials and requires the appropriate environmental conditions and a significant amount of time. (Dai et al., 2020, p. 4). Peat differs from the other two significant domestic energy forms, wood fuels and hydropower, by being not defined as renewable energy. However, peat is not as well defined as a fossil energy form either. Although the peat is forming in biomass, the formation process is slow and typically requires thousands of years (Dai et al., 2020, p. 14). In Finland, peat contributed 3.4 percent of the total energy consumption in 2020 (OFS, 2021).

2.2 Energy imports

Due to the domestic energy production that is less than the total energy consumption of a country, Finland imports energy in different forms from several external sources. However, a significant share of imports is fossil energy imports, and almost all fossil energy used is imported from Russian sources. Fossil energy imports include oil, natural gas, and coal, all three conventional fossil energy forms. (Jääskeläinen et al. 2018, p. 11). In addition to the environmental concerns of fossil fuel usage, a political and geopolitical crisis like the Russo-Ukrainian war, which escalated in 2022, has raised the discussion on the dependency on fossil energy imports from Russia in a case of many countries. Political decision-makers in Finland are therefore compelled to pay increased attention to the issue.

Natural gas to Finland was inclusively imported from Russia until 2020, when the *Balticconnector* gas line between Estonia and Finland enabled natural gas imports in addition from Baltic countries (Lyyra et al., 2018.) Currently, besides Russian gas, natural gas imports also include a share of gas imports from Estonia, imported through the Balticconnector from Baltic countries, Lithuania and Latvia (Energiateollisuus, 2022). The Balticconnector gas line can be considered an improvement for the significant natural gas import dependence on Russia since the total share from natural gas imports was covered with Russian natural gas in 2016 before the Balticconnector project was deployed in 2019–2020 (Lyyra et al. (2018, p. 3). Importation of natural gas in Finland has been in decline between the years 2010–2017, as Figure 7 reveals.

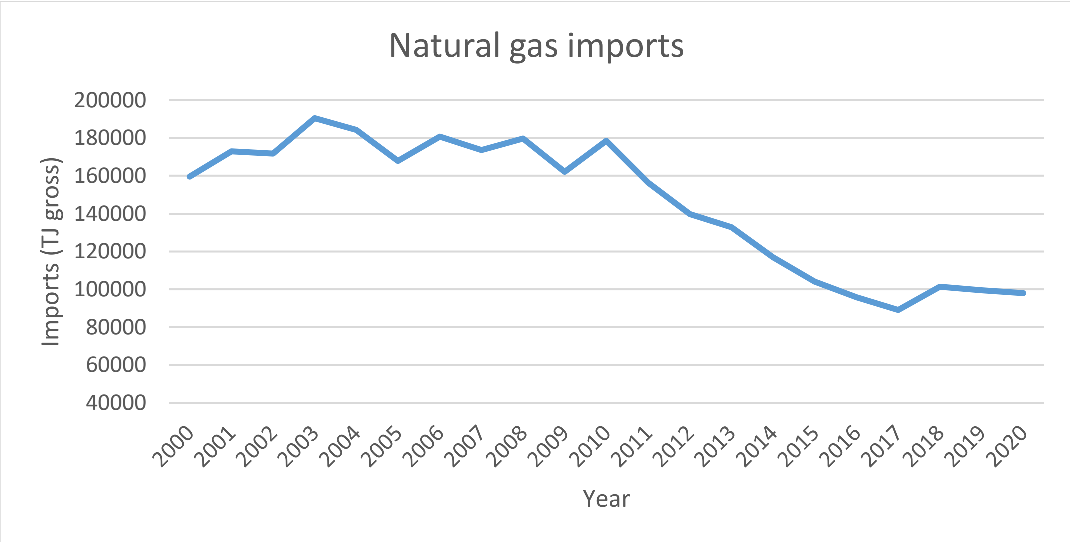

Figure 7. Natural gas imports 2000–2020 (IEA, 2022. Author's visualization).

The second fossil fuel mix imported to Finland is coal. The share of coal in electricity production in Finland has continuously decreased from 2000 to 2020 and further planning is taking place such that alternative energy sources could in future years, completely replace the usage of coal (Energiateollisuus, 2022). Around 50 percent of the coal imported to Finland comes from Russia, but other countries such as Poland and Australia contribute to the coal imports (International Trade Administration, 2019). Similar to natural gas, in coal imports, there has been a development toward a more diversified supply. Since, 2016, Russian coal imports still counted for 87 percent of coal importation in

Finland (Lyyra et al., 2018, p. 4). In addition, the declining development in coal imports is visible between 2000–2020 (see Figure 8).

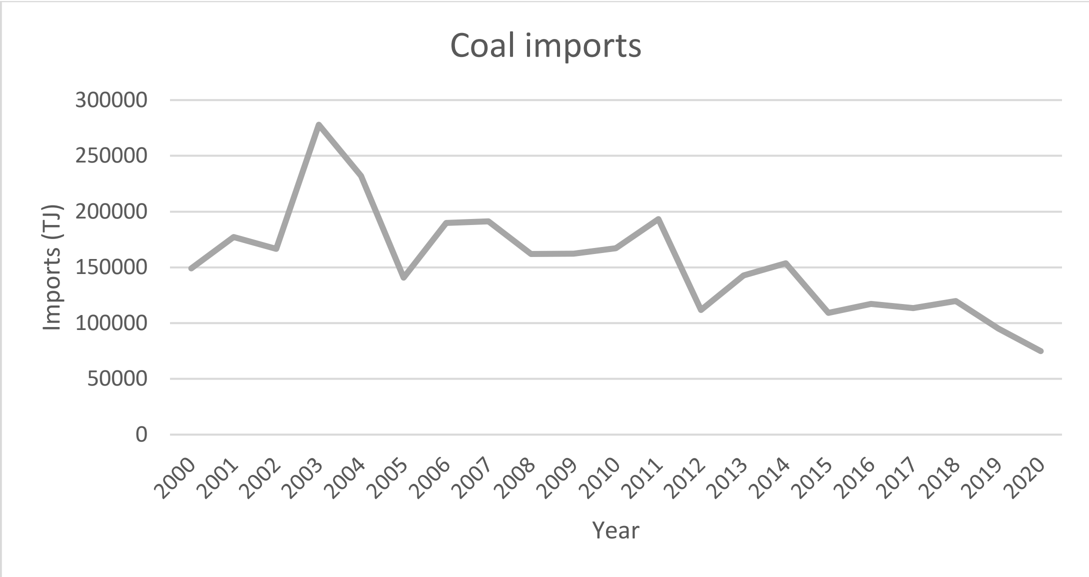

Figure 8. Coal imports 2000–2020 (IEA, 2022. Author's visualization).

Historically, oil products have been the most significant single fossil fuel import in Finland. Oil imports to Finland originate mainly from Russian sources. Neste refinery in Porvoo consumes almost inclusively Russian crude oil in their production (Energiateollisuus, 2022). Around 80 percent of all oil products are imported from Russia, primarily due to the more competitive pricing of Russian crude oil than alternative brent oil quality, e.g., from Norway (Lyyra et al., 2018. p. 3). Unlike natural gas imports and coal imports, the trend in oil imports does not show signs of a decline from 2000 to 2020, as shown in Figure 9 below. However, crude oil imports also account for the considerable amount of oil imported over the domestic consumption since Neste refinery uses Russian crude oil in their production. Therefore, the oil imports and oil consumption in Finland do not equal.

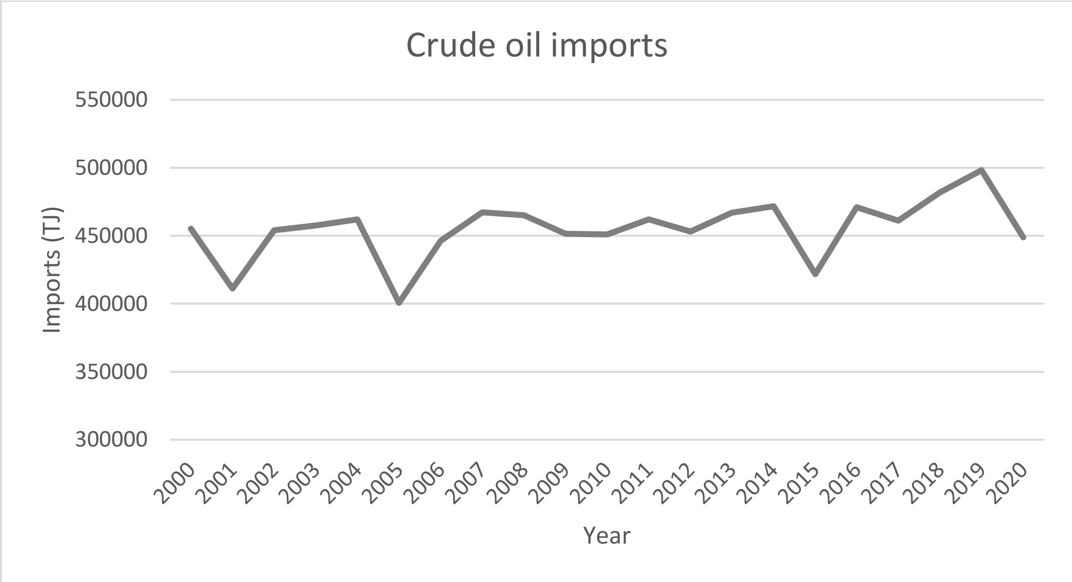

Figure 9. Crude oil imports 2000–2020 (IEA, 2022. Author's visualization).

Due to the significant role of nuclear energy in domestic electricity production, Finland also imports uranium used as a fuel for nuclear power plants. According to Finnish nuclear energy company Teollisuuden Voima (TVO), the uranium imports used as fuel in nuclear power plants are mainly imported from Kazakhstan, Canada, and Australia (www.tvo.fi).

Currently, in 2022, Finland imports a considerable share of wooden biomass used in energy production from Russia. There is no broad consensus (in spring 2022) on how the Russian counter-sanctions concerning the export of wood can affect Finland, but according to recent suggestions, the gap in wood imports from Russia is replaceable with wooden fuels from other sources (www.forest.fi). It can be assumed that this could be done with less effort than replacing fossil fuels imported from Russia since, unlike fossil fuel resources, Finland has a significant domestic wood-based energy source. This topic has arisen in discussion since the Russo-Ukrainian war and sanctions triggered by it in spring 2022.

Among the previously discussed energy imports, direct electricity is imported to Finland from external sources located in the neighboring countries. Finland imports electricity from neighboring countries, Sweden, Russia, and Norway. Depending on the year, a number of direct electricity has also been imported from Estonia across the Gulf of Finland. Direct electricity imports have remained constant in recent years (see Figure 10). Most of the direct electricity imports originate from Sweden, but electricity imports, in addition, include a less significant share of electricity imports from Russia. Measured by the share, Norway and Estonian imports have performed a less significant role than electricity imports from Sweden and Russia.

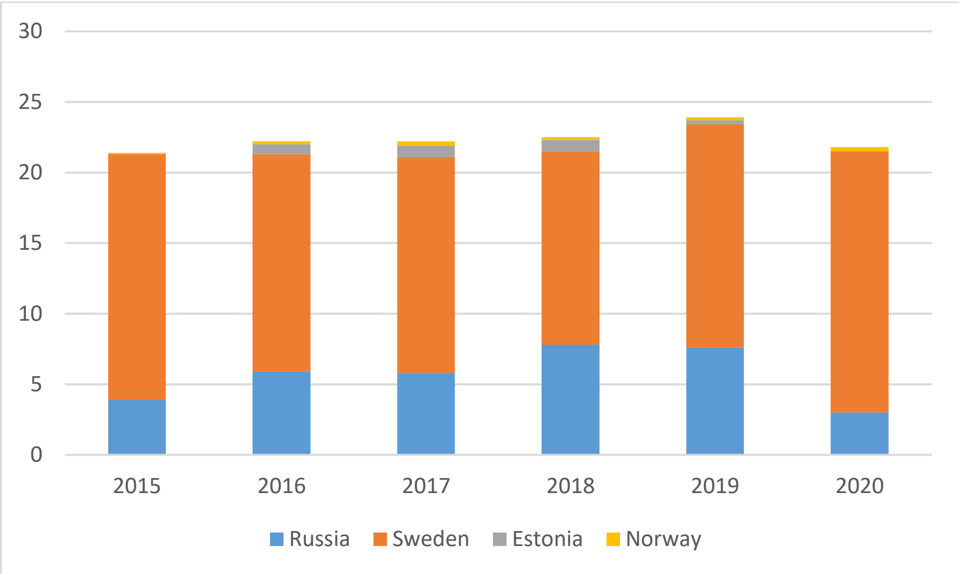

Figure 10. Direct electricity imports 2015–2020 (OSF, 2021. Author's visualization).

The Nordic countries Norway, Sweden, Finland, and Denmark developed an integrated system of the Nordic electricity market, *Nord Pool,* in the 1990s. At a later stage, Estonia, Lithuania, and Latvia have additionally become members of a joint power market system. The joint market cluster aims to advance securing a supply and balancing between the supply and demand of electricity in the member countries. Owners of the joint Nord Pool market are the national transmission system operators of the countries associated with the Nord Pool. (Halsnæs et al., 2021, p. 4). Russia is not a member country of the Nord Pool cluster but is integrated into the net with links in the border area of Finland and Russia (Jääskeläinen et al., 2018, p. 11).

In the future, the role of foreign electricity imports and the Nordic market cluster can be expected to rise in securing the energy supply security of Finland. The decarbonized electricity system will require diversified import capacities to assure the balance of supply and demand in the case of domestic production lacking a demand. An integrated Nordic electricity system can be an essential factor in ensuring a market-based demand and supply during a downfall in domestic electricity production. (Sitra, 2021, p. 133-134). Therefore, the joint Nordic electricity markets are suggested to have a vital role in integrating renewable energy on a large scale into the electricity system in the future in Finland (Ministry of Economic Affairs, 2019, p. 19-20).

3 Literature review

This chapter discusses the concepts of renewable energy and energy security. A literature review covers two essential topics in energy economics, and the connection between the subjects is examined. By exploring the relevant research literature around the topic, the conceptual framework for the empirical part of the thesis is constructed. The role of renewable energy expects to rise in Finland in the future and increasing renewable energy utilization is additionally a global trend. In Finland, future decarbonization objectives and aspirations of environmental improvement in energy consumption are high-level. According to e.g. (IEA, 2021), Finland has a national energy and climate strategy considered in every election period, and in 2019 Finnish Government announced ambitious aims to contribute to global mitigation of carbon dioxide, (CO_2) by achieving carbon neutrality till 2035 (EU 2050). Finland is targeting to be the first welfare state to reach fossil freedom and set objectives in addition include measures for increasing carbon sinks and stocks to support the path to reach carbon neutrality (p. 3).

Energy security concerns are currently under discussion in many countries in Europe. In the spring of 2022, the Russian–Ukraine War escalation, and therefore sanctions against Russia, have shown the dependency on Russian energy imports in several European countries, like Germany. Currently, there is ongoing planning on compensating the Russian energy sources since the broad consensus of western sanctions set for Russia requires a measure to decline the energy imports from the Russian region.

3.1 Renewable energy

A conventional way to categorize different energy forms is by dividing them into non-renewable and renewable energy sources. *Non–renewable energy* is an energy source from a finite stock of resources. Therefore, consumption in time decreases the possibility of consuming the energy source in the future time. (Bhattacharyya, 2019, p. 10). Fossil energy refers to energy forms that have been formed from post-living remains throughout the process, typically no less than millions of years, therefore considered non-renewable. Standard fossil fuels used in energy production are oil, gas, and coal. (Bhattacharyya, 2019, p. 177). On the contrary, energy from the source of constantly available flow of energy, such as wind power and solar energy, is defined as *renewable energy* (Bhattacharyya, 2019, p. 10).

The categorization of renewable and non-renewable energy forms can be straightforward in theory. However, in practice and energy policies, determining energy into renewable and non-renewables occasionally deals with controversial energy forms that have no clear status, or there is no broad consensus concerning the (political) definition. As discussed previously, in Finland, peat is an energy form that falls between strict categorization in a national energy policy. The issue of peat has been debated in Finland, and further discussion is still ongoing among the political decision-makers, tackling the issue of whether peat should define as a renewable or non-renewable energy form. Currently, peat is not categorized as a renewable energy source and is instead determined as "slowly renewing biomass" (www.yle.fi).

Renewable energy is an attractive alternative in substituting conventional fossil energy forms. In addition to mitigating the environmental impact of energy production, improving energy supply security is commonly recognized as an essential driver of renewable energy deployment in the literature. Energy security concerns about fossil energy are shared globally due to finite stocks of fossil energy, competition of supply, and political instability in geopolitical regions where significant fossil fuel stocks locate. These are all factors that might affect, e.g., the price volatility of energy. (Bhattacharyya, 2019, p. 229).

Despite the several appealing features of renewable energy sources, e.g., mitigation of the negative climate impact and contribution to energy supply diversity or self-sufficiency, adverse elements of renewable energy are also recognized. Some characteristic features of renewable energy forms can pose barriers to shifting from conventional fossil energy to renewable alternatives. Generally, issues, e.g., limitations for storing energy and the essential requirement for energy supply and consumption balancing in a time, are not usually compatible with renewable energy sources, such as wind power or solar energy, since this type of energy can be generated just when conditions are appropriate.

3.1.1 Renewable energy utilization in Finland

As a European Union member Finland has committed to the EU climate change mitigation goals, targeting carbon neutrality in the future years. In addition, Finland also has its own ambitious goals to implement an increasing amount of renewable energy production in the future years (Holma et al., 2018, p. 1433). Currently, Finland is among the frontier countries in renewable energy production in Europe. Share of renewable energy presents approximately 40 percent of the energy consumption in the country. Further, Finland seeks to achieve over 50 percent share during the 2020s. (Ministry of Economic Affairs and Employment of Finland, 2022).

The share of renewable energy, especially in electricity production in Finland, is significant. Approximately half of the domestic electricity production in Finland is produced by renewables, such as hydropower and bioenergy. (IEA, 2021, p. 9). The most significant share of renewable energy production is covered by wood-based fuels, which generated approximately 70 percent of renewable energy in Finland in 2020. Hydropower and wind energy were the second most significant single renewable energy source categories. (OSF, 2021). Figure 11 illustrates the shares of different renewable energy sources from Finland's total renewable energy consumption in 2020. For the development of different renewable energy sources in Finland from 2000 to 2020, see Figure 12.

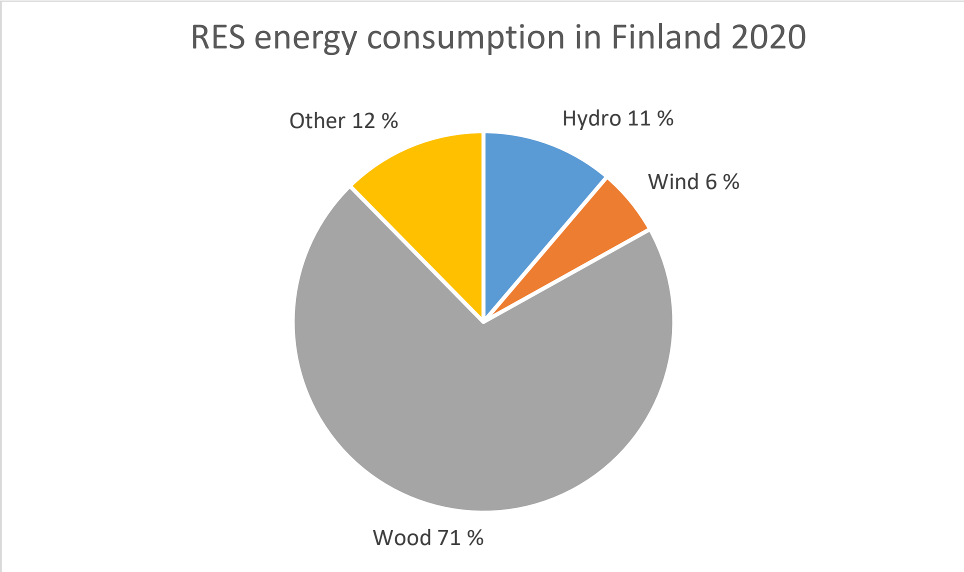

Figure 11. Renewable energy consumption 2020 (OSF, 2021. Author's visualization).

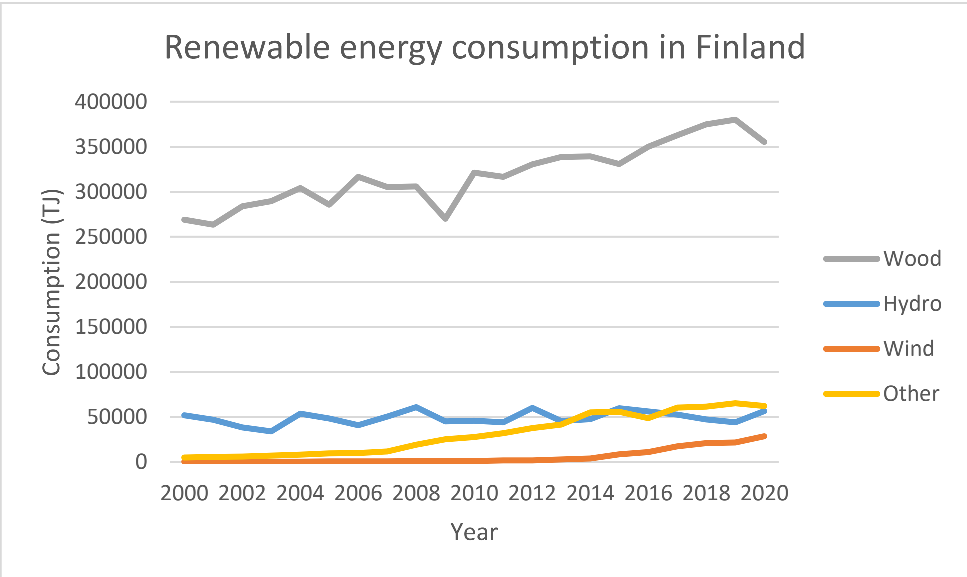

Figure 12. Renewable energy consumption 2000–2020 (OSF, 2021. Author's visualization).

The present high level of renewable energy production raises a question regarding the future possibilities and capacity of the implementation of renewable energy. Zakeri et al. (2015) have addressed the issue of a potential maximum limit on the degree of renewable energy implementation in the Finnish energy sector. Authors concluded in their analysis that without significant reforms in Finland, the renewable energy implementation of over 50% is not readily achievable. Higher shares of RES implementation in the future require improvements in energy efficiency and the flexibility between energy consumption and demand. Also, Sitra (2021) emphasizes the subject of the flexibility of the energy system in the analysis concerning reaching decarbonization targets with electrification in Finland. It is suggested by the analysis that both supply and demand-side flexibility must be met to achieve a carbon neutrality target in 2050 (p. 104). The following subchapters discuss the renewable energy applications utilized in energy production in Finland and briefly review the expected future developments of domestic renewable energy sources.

3.1.1.1 Bioenergy

Bioenergy is energy generated from organic sources, such as firewood, bark, sawdust, demolition wood, and similar biomass. Especially wood-based bioenergy has an essential role in energy production in Finland. In international comparison, Finland has been at the top of the energy producers in biomass utilization with Germany and Sweden (Aslani et at., 2013). Considering the high level of biomass utilization, bioenergy has a key role in the production of renewable energy in Finland, being the most significant single source of renewable energy covering over 70 percent of renewable energy production in Finland (www.bioenergia.fi; Ministry of Economic Affairs and Employment of Finland, 2019, p. 51).

Bioenergy has further advantages compared to other renewable energy resources. Unlike wind power or hydropower, bioenergy can be temporarily stored and therefore utilized more flexibly. Preferable features make bioenergy combined with other renewable energy resources a valuable addition to renewable energy sources. Storability enables improvements for characteristic problems of renewable energy, e.g., increasing the flexibility between the balance of demand and supply and improving the energy system reliability. (Hakkarainen & Hannula, 2019, p. 1403). The utilization of renewable energy hybrid systems (RES hybrids) has earned increasing attention in a discussion. With the desirable feature of storability, bioenergy can improve the critical flaws of most renewable energy sources. On the contrary, biomass is often available in limited amounts, and therefore the combination of other renewable energy sources and bioenergy can likewise improve the issue of limited availability of biomass. (Hakkarainen & Hannula, 2019, p. 1413).

According to Sitra (2021), bioenergy will likely have a vital role in the national decarbonization in Finland and in meeting the decarbonization objective. Besides traditional solid wood-based biofuels, other types of bioenergy, e.g., black liquor, industry by-products, liquid biofuels, biogas, biochar, and algae oil, can besides contribute to renewable energy production in the future (p. 74). Non-wood, alternative bioenergy forms can be used to compensate for the adverse impact of wooden bioenergy utilization, decreasing the carbon sink (Sitra, 2021, p. 77).

Since the most significant share of bioenergy utilization is covered by solid biomass or wood energy, bioenergy production in Finland is broadly integrated into the forestry and forest industry. Wood-based fuels have approximately covered approximately 25 percent of total energy consumption in Finland. (Ministry of Economic Affairs and Employment of Finland, 2019, p. 51). The recent development of further promotion of alternative biofuels in Finland has taken place from 2000 to 2020, and new bioenergy applications such as biodiesel and bioethanol were implemented in 2007 in Finland (IEA, 2021, p. 6). Also, biogas is an increasingly employed source of bioenergy in Finland since the development of biogas applications has been favorable between 2000 and 2020, and therefore biogas has an increasing role in the share of gas supply in a country (IEA, 2021, p. 8).

The biomass distribution in Finland varies unevenly, and seasonal limitations pose restrictions on biomass utilization in energy production. Concerning the limitations of biomass-based energy production, Aslani et al. (2013) addressed a particular concern for supply, cost, and quality. According to the authors, biomass is a less attractive investment to investors compared to other energy forms. Therefore, the competitiveness of biomass has been sought to improve, e.g., by taxation of other energy forms. The promotion of biomass by subsidies and taxation has increased in Finland, which has characterized the sector as a rapidly changing business environment. Potential improvements have been presented for future development, such as increasing the stability in the biomass industry. The authors as well underpinned the potential of developing more suitable applications of biofuels that could be used in the transportation sector, such as bio-oils and industrial alcohol, to support bioenergy employment in the future (Aslani et al., 2013, p. 508).

3.1.1.2 Hydropower

The hydropower infrastructure in Finland is relatively old, built mainly in the 1950s and 1960s. The main share of hydropower is generated from large-scale hydropower plants, and the hydropower infrastructure has been under improvements of automatization and maintenance, therefore ensuring the functionality even though new constructions have not been employed (Aslani et al., 2013, p. 508). Compared to other renewable energy sources, e.g., biomass and wind power, hydropower deployment has lacked in Finland, and most of the growth potential for future implementation has been suggested to be already used (Aslani et al. 2013, p. 509). Hydropower in Finland covered approximately 11% of renewable energy production in 2020 (OSF, 2021).

Concerning the future development, no significant changes are expected in the hydropower production in Finland also according to the Ministry of Economic Affairs and Employment of Finland (2019, p. 50). Although, small-scale hydropower plants have been suggested to potentially have additional benefits, e.g., tax exemption, that could be seen as an attractive feature for future investments in hydro power (Aslani et al. 2013, p. 509).

3.1.1.3 Wind power

Wind power production in Finland was employed first in 1992 and has attracted an increasing number of investments in the 2010s. According to Aslani et al., 2013, wind power has been one of the most rapidly expanding energy industries among European countries with suitable geographics. European countries rank at the peak of the total installed wind energy capacity globally (Aslani et al., 2013, p. 509). Modern wind power turbines can be installed flexibly offshore in addition to traditional onshore wind turbines. In the 2000s, wind power development still lagged in Finland in international comparison such that environmental, social, and economic barriers have been disrupting the development (Aslani et al., 2013, p. 509). Similarly, according to Panula-Ontto et al. (2018, p. 508), wind power capacity has been at a lower level in Finland than in other Nordic countries. Therefore, the potential for the future implementation of wind power is suggested to be substantial in Finland by the authors (p. 508).

Between 2000–2020, an increasing level of wind power was deployed in Finland, and from around 2014, wind energy consumption in Finland has been on an increasing trend (OSF, 2021). According to Sitra (2021)'s analysis, the role of wind power is suggested in the future to be a cost-efficient way to ensure the supply of non-carbon electricity in Finland. Considering two potential future electrification scenarios, the analysis concluded that supported by development improving both supply and demand-side flexibility, onshore wind energy can be a considerable cost-effective way to increase renewable energy production in Finland (p. 144).

Issues such as environmental impacts of wind turbine installations, land use restrictions, and noise pollution have raised a discussion concerning implementing wind power in Finland. Additionally, environmental restrictions, e.g., relating to the cold climate and long winter season, pose technological concerns to wind turbine installations in the country. Due to the high economical prices, wind power deployment has been more subsidized by policy tools to attract more new investments in wind energy in Finland. (Aslani et al. 2013, p. 511). Depending on the regulatory environment and subsidy policies expansion of wind power in the future, power generation can expand vastly by 2030 and is suggested possibly even more than double the production (Panula-Ontto et al., 2018, p. 508).

3.1.1.4 Other renewable energy sources

In addition to the discussed primary renewable energy sources, hydro power, wind power, and bioenergy, other renewable energy source applications are utilized in Finland for energy production. Other types of renewable energy include energy forms such as solar energy and heat pumps, employment of these types of applications have been increasing steadily in recent years in Finland, but the shares from total energy consumption are still less significant (OSF, 2021).

Solar energy production in Finland is currently a small-scale sector. According to Aslani et al. (2013), limitations to the implementation of solar energy are caused mainly by location, economic prices, and technical issues. Finland's geographical location causes its solar heat to occur less than in most countries of Europe. Especially in the wintertime, daylight and sunlight are barely present in Finland, and this is one of the essential issues limiting solar energy utilization in Finland. This also makes solar energy a less attractive renewable energy alternative than others, such as wind and hydropower. In addition, economic and technological factors such as expensive and experimental technologies of solar energy affect the attractiveness of solar energy implementation. However, solar energy can be seen as an attractive energy form in small-scale buildings, such as summer cottages, in Finland since the sunlight is more present in the summer and cottage culture is prevalent in Finland. (Aslani et al. 2013, p, 511-512).

Geothermal energy is an energy source consumed via heat pumps to utilize ground heat present in the ground base. Heat pump installations in Finland are used for heating residential spaces or water in households. New heat pump installations in Finland have increased over the years, and there is ongoing development toward scaling heat pumps for larger constructions like office buildings. (Aslani et al., 2013, p. 512; Sitra, 2021, p. 89). In the future, heat pumps, especially in district heating and buildings, most likely have an essential role in the Finnish energy market (Sitra, 2021, p. 13). Suggested barriers still exist for heat pump implementation. The prices of heat pump constructions can set a barrier to employing additional installations, even though the running costs of heat pumps are usually lower than alternative energy forms (Aslani et al., 2013, p. 512). Furthermore, it was recently reported in 2022 that the EU is planning the ban of F-gas, used in heat pumps till 2025 (European Commission, 2022; www.mtvuutiset.fi).

3.2 Energy security

Energy is a vital resource for a functioning economy and society. Since the first oil shock in the 1970s, the factor of energy security has been more broadly considered in the discussion. Since then, increased attention has globally been focused on the effort to increase the diversity in the energy supply (Bhattacharyya, 2019, p. 416). Energy security as a concept and the measurements of the factor can be approached from a wide range of perspectives with different emphases. In addition to an initially broad energy security framework, rising perspectives emphasizing alternative factors, such as environmental impact, have been gaining more attention in the literature.

The concept of energy security is a complex ensemble and under continuous evolvement. Despite the attention and broad body of literature around the topic, researchers have not achieved consensus on defining and measuring the factor of energy security (Jääskeläinen et al., 2018). Therefore, it is essential to review feasible approaches to defining the subject. There are alternative ways to define the issue, and this thesis approaches energy security from the perspective of imported fossil energy dependency. The approach has been selected since, throughout its history, Finland has been significantly dependent on foreign imported (fossil) energy (e.g., IEA, 2020). Increased geopolitical tension between western countries and significant fossil fuel exporter, Russia, has further emphasized the relevance of import dependency on energy security.

3.2.1 Concept and indicators

The concept of energy security can be approached from different perspectives. Traditionally, energy security concerns have been related to factors such as oil supply and energy prices. The development of energy systems evolving into more complex entities has also posed requirements to re-evaluate the concept and its priorities further. Today, energy security encompasses a wide range of factors that can, in one way or another, threaten a country's energy system. (Bhattacharyya, 2019, p. 416-417).

Despite the limitations of precisely defining the concept of energy security and, therefore, the lack of simple indicators for the issue, the research literature has suggested several alternative indicators that can be used in measuring energy security with different approaches. Different indicators for measuring energy security typically focus on factors relating to diversity of energy supply, energy self-sufficiency, or share of energy imports from total energy consumption. For example, Cherp & Jewell (2011) categorized energy security indicators as indicators of sovereignty, robustness, and resilience. One conventional approach to dividing different energy security indicators is whether they measure the concentration of the energy supply or the dependence on energy sources (Bhattacharyya, 2019, p. 421-422).

In the research literature, energy security is conventionally approached from the "four A's" perspective. According to this type of definition, energy security is divided into concerns of availability, affordability, accessibility, and acceptability. This basic *A-framework* has been widely considered with some modifications in the research literature. (Cherp et al. 2014, p. 416-417). In addition, today furthermore, alternative or complementary rising approaches are paying attention to additional essential factors, e.g., sustainability aspects, in defining energy security. These approaches aim to develop modern indicators that underline factors of sustainability and environmental impact in assessing energy security (Radovanović et al., 2017).

World Energy Council (2021) emphasizes particularly efficient usage of domestic resources and the diversification and decarbonization of the energy system in energy security consideration. Their *World Energy Trilemma Index*-approach considering energy equity, sustainability, and energy security, determines factors such as balancing current and future energy demand as well as the resilience to system-level shocks as a key factors of energy security (p. 8). In their assessment of energy security, several sub-indicators are considered to construct a more robust image of the resilience and reliability of the county's energy infrastructure and the country's ability to manage energy sources (p. 20).

Quantitative indicators can be used as a tool for evaluating energy security. *Herfindahl -index, HHI* (2), and *Shannon Wiener -index, SW* (3) are index tools generally used to measure the amount of concentration of a particular market. These tools can likewise be applied to measure energy security from a perspective of the concentration of sources in the energy supply. (Bhattacharyya, 2019, p. 422). *Fuel Mix* describes the combination of different sources used in a country and indicates the degree of diversification in the combination of energy used. Fuel mix can be captured in different energy consumption levels, e.g., concerning the primary energy sources, final energy consumption, or describing the mix in a particular economic sector. (Bhattacharyya, 2019, p. 421).

$$HHI = \sum_i x_i^2 \tag{2}$$

$$SW = -\sum_i x_i \, ln(x_i) \tag{3}$$

An alternative approach to investigating energy security is defining the issue from the perspective of dependency on imported energy. When choosing an approach of imported energy dependency to define energy security, the ratio value of imported energy to total energy consumption can be used as one indicator of energy security. Therefore, *the import dependence ratio* (4) describes the level of imported energy from total energy consumption. High dependency on imported energy can lead to several issues from the perspective of energy security, e.g., affecting the energy price and volume variation. (Bhattacharyya, 2019, p. 421).

$$Import\ dependece\ ratio = \frac{Net\ energy\ imports}{Primary\ energy\ supply} \tag{4}$$

In the research literature, the approach of energy dependency has been widely applied in assessing energy security (e.g., Wang et al., 2018). Still, despite the widespread use in the existing literature of import dependence as a proxy for energy security, the approach has additionally gained critiques. Investigating energy security only from the view of dependency sets limitations for the investigation. This type of narrow approach typically excludes other relevant energy security factors, such as the diversity of energy supply. (Valdes Lucas et al., 2016). However, this critique can be presented to most approaches to energy security since the concept cannot be defined simply and measured with one optimal indicator. Therefore, it is essential to understand the selected approach and its limitations when assessing energy security.

To conclude, it is rarely possible to measure the entire concept of energy security using simple indicators as presented above. For a more comprehensive investigation, combining different indicators is the preferable choice for the more precise analysis of energy security (Bhattacharyya, 2019, p. 423). Inevitably this thesis narrows the concept of energy security while concentrating on the fossil energy imports and import dependence approach. This selection is still selected for a reason. The primary focus is on the dependence on fossil energy imports since, in Finland, fossil energy is significantly supplied from one source, the Russian region. Further, the current international situation due to the Russian-Ukraine war and increasing geopolitical tension have driven several countries and governments to evaluate and assess their dependency on fossil energy imports.

3.2.2 Energy security in Finland

The energy security and the potential issues of Finland have been evaluated with varying results in the research literature. Aslani et al. (2012) concluded that despite the lack of own fossil fuel energy resources, Finland reaches a high level of energy security due to the successful diversification of energy supply sources in the country. The energy mix in Finland has been defined as diversified and balanced also by IAEA (2020). In international comparison, Finland has been ranked among the top performers in energy security due to the previously mentioned good level of diversity of the energy mix, which is further improved by the actions to decrease fossil energy consumption and, on the contrary, increase the utilization of RES alternatives. These measures have been presented to contribute to energy security performance and compensate for the modest utilization of domestic natural resources in energy production. (World Energy Council, 2021, p. 22). The previously discussed deficiency of a strict definition and a broad energy security framework is as well reflected in the results of an evaluation of energy security in Finland. Therefore, conclusions concerning energy security vary depending on the factors emphasized in the analysis.

Additionally, potential threats to energy security and negative scenarios in the case of Finland have been addressed in the literature. For example, the potential hazard of severe drought occurring in Nordic countries and, therefore, disruption in hydropower supply in Finland has been evaluated to cause a potential energy security threat since the significant share of hydropower in energy consumption in Finland. (Jääskeläinen et al., 2018). This type of concern can expect to become more relevant since the energy share provided by renewable energy sources, dependent on natural conditions like the weather, is expected to rise further in the future.

The effects of intense fossil energy trade between Russia and Finland have reasonably been investigated as an energy security threat. Jääskeläinen et al. (2018) explored Finland's dependence on energy imports from Russia. The authors aimed to investigate whether the dependency on Russian fossil fuel imports poses a potential threat to energy security in Finland. The authors evaluated energy security from the perspective of resilience, security of supply, and affordability but as well sought to consider the environmental impact of energy supply. The analysis concluded that no acute threat is caused by the dependency on Russian imports from the techno-economical perspective precisely. However, the analysis also suggested that the possibility of (geo)political tendencies, e.g., that could cause disruptions in the energy supply in Finland, cannot be excluded. Therefore, the possibility of an adverse effect on energy security due to dependency remains.

The European Union has, in many connections, addressed the energy security concern of import dependency on one significant foreign energy supplier in its member countries. After the 2006 and 2009 wintertime events, when severe disruptions in gas supply occurred in the European Union's eastern member countries, the EU has been aiming for objectives to seek measures to improve energy security and reduce its member countries' dependence on significant outside energy sources. (European Commission, 2014, p. 2). Several countries in Europe and in the EU depend on fossil energy, such as natural gas, imported from Russia. The Russia-Ukraine war that escalated in spring 2022 has further accelerated the policies driving to reduce dependency on Russian fossil fuels. The war and the sanctions against Russia and Russian countersanctions are likely to affect the energy trade significantly in the future (IEA, 2022).

The main factor increasing import dependence also in the case of Finland has been fossil energy imports and especially crude oil imports from Russia. During the years 2000–2012, there was a significant increase in crude oil imports from Russia, when the share of Russian oil increased by a 7% compound rate, from 43 % to 89% of total oil imports (IEA, 2014, p. 173). In addition to Russian oil imports there is a considerable dependency on natural gas imports from Russian natural gas sources, although the Balticconnector gas line between Estonia and Finland has improved the situation since 2020 (Lyyra et al., 2018.)

As it was discussed previously, the import dependence ratio can be used as a quantitative indicator to measure energy security from the perspective of the county's dependency on imported energy. The import dependence ratio of Finland and its development from 2000 to 2020 is captured below (Figure 13) to explore how the dependence on energy imports has developed in Finland during the period. The import dependence ratio is calculated by using the formula presented in chapter 3.2.1. According to International Energy Agency (IEA, 2022) statistics, net energy imports to Finland from 2000 to 2020 have declined over the period, and there can similarly be seen a slight decline in import dependence ratio, measuring net energy import to primary energy supply in the same period.

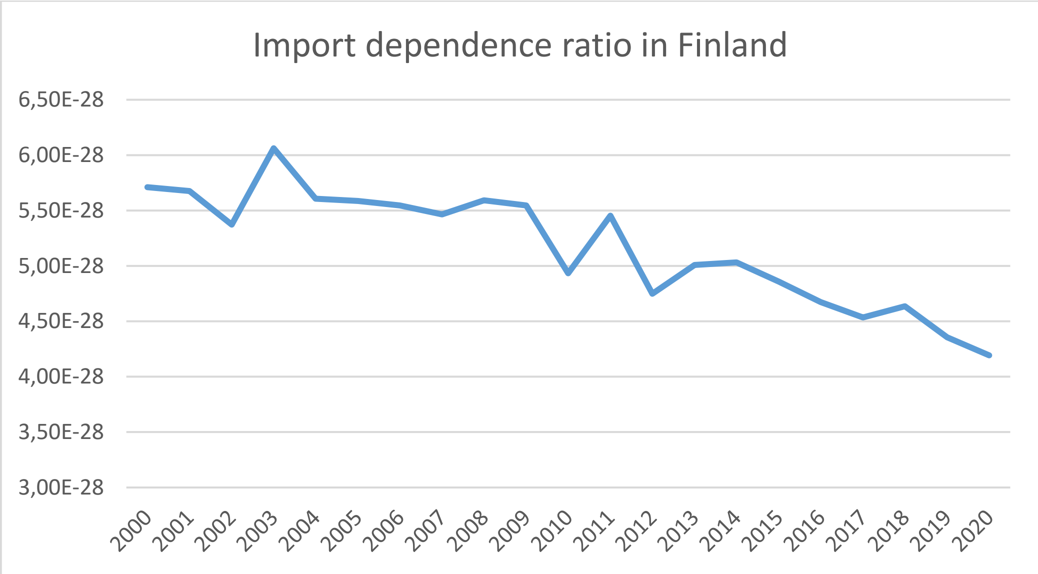

Figure 13. Import dependence ratio 2000–2020 (IEA, 2022. Author's calculation).

Despite the sign of positive progress in import dependence from 2000 to 2020, a significant share of energy consumption in Finland is still covered by Russian fossil energy imports. As can be seen below in Figure 14, in comparison to other Northern European countries, Finland imported significant shares of fossil energy exclusively from Russian sources in 2020. Eurostat's (2022b) statistics reveal that among the European Union 27 countries, when it comes to Russian energy imports, Finland compares to other Eastern European or former Soviet Union countries, such as Slovakia and Hungary, rather than other Nordic countries, Sweden, Norway, and Denmark. Figure 14 also shows that Finland imports Russian oil over domestic use (141, 2%) since the Russian crude oil is a significant resource for the oil company Neste refinery, operating in Porvoo.

	Total	Natural gas	Oil	Coal
European Union 27 countries (from 2020)	24,4 %	41,1 %	36,5 %	19,3 %
Belgium	24,3 %	7,9 %	46,1 %	35,8 %
Bulgaria	15,4 %	72,8 %	13,1 %	8,2 %
Czechia	23,7 %	86,0 %	35,7 %	1,7 %
Denmark*	21,1 %	52,4 %	27,6 %	86,3 %
Germany	31,1 %	58,9 %	35,2 %	21,5 %
Estonia*	21,4 %	86,5 %	279,4 %	0,1 %
Ireland	3,2 %	0,0 %	6,1 %	5,2 %
Greece	46,5 %	38,9 %	73,0 %	8,9 %
Spain	7,5 %	10,5 %	8,8 %	43,2 %
France	8,4 %	20,0 %	15,7 %	29,7 %
Croatia*	24,7 %	55,0 %	14,2 %	74,7 %
Italy	23,8 %	40,4 %	17,4 %	49,8 %
Cyprus	1,7 %	:	1,3 %	105,4 %
Latvia	31,0 %	100,1 %	25,5 %	95,6 %
Lithuania	96,1 %	50,5 %	202,7 %	69,1 %
Luxembourg	4,3 %	27,2 %	0,0 %	7,7 %
Hungary	54,2 %	110,4 %	57,4 %	11,3 %
Malta	7,5 %	0,0 %	8,7 %	:
Netherlands	49,0 %	35,8 %	70,5 %	50,3 %
Austria*	16,5 %	58,6 %	7,3 %	9,2 %
Poland	35,0 %	45,5 %	76,3 %	13,4 %
Portugal	4,9 %	9,6 %	6,0 %	0,0 %
Romania*	17,0 %	15,5 %	37,0 %	11,8 %
Slovenia*	17,6 %	81,0 %	24,9 %	0,8 %
Slovakia	57,3 %	75,2 %	159,4 %	26,6 %
Finland*	45,0 %	92,4 %	141,2 %	30,0 %
Sweden	8,5 %	13,9 %	32,5 %	22,7 %
Iceland	0,0 %	:	0,0 %	0,0 %
Norway	3,9 %	0,2 %	10,5 %	18,7 %

Figure 14. Imports from Russia in gross available energy in 2020 (Eurostat, 2022b. Highlighted by author).

3.3 Linking renewable energy and energy security

The connection and dynamics between renewable energy and energy security have become more relevant themes since the global concerns of environmental effects. Specifically, climate change and environmental pollution, have underlined the role of sustainable renewable energy in energy policy discussion. As a continuously growing and evolving segment, renewable energy can offer many countries a tool to diversify their energy mix, primary energy supply sources or improve self-sufficiency. Therefore, energy security can affect renewable energy policies, and on the contrary, renewable energy deployment affects energy security. Before proceeding to the empirical analysis of this thesis, the connection between renewable energy and energy security is discussed for further acknowledgment of the potential effects of renewable energy employment on energy security.

The relationship between energy security and renewable energy deployment has been described as a complex entity in the research literature, and the quality of the relationship depends on factors such as the engaged energy strategy and the approaches to defining energy security (Valdes Lucas et al., 2016, p. 1032). The research topic is relatively new, which can be seen, e.g., in the literature describing the relationship between renewable energy and security as an "emerging symbiosis”. Since the traditional relationship between fossil energy sources and energy security has increasingly been further substituted by increasing focus on the relationship between renewable energy and energy security. (Valentine, 2011).

In addition to the increasing concerns of environmental issues, energy supply security is among the key factors behind the global increase in awareness of the importance of renewable energy utilization (Gokgoz & Guverin, 2018). Deployment of renewable energy sources has been suggested as a solution to confront the issues arising from dependency on external fossil fuels import. A wide range of potential issues has been long acknowledged relating to dependency on external fossil energy imports, e.g., fluctuations in energy prices and high transportation costs. Renewable energy deployment can contribute to solving these kinds of issues. (Aslani et al. 2013, p. 505-506).

Energy security issues have been suggested as a remarkable factor behind further renewable energy deployment (Valdes Lucas et al., 2016, p. 1043). When renewable energy can function as a substitute for traditional energy sources such as fossil fuels, energy security concerns relating to fossil energy consumption can be an effective driver of renewable energy development. Therefore, energy security concerns can contribute to the further deployment of renewable energy. (Wang et al., 2018). From an economic perspective, additional advantages such as minimal fuel (operating) costs and significantly lower externality costs compared to traditional fossil fuels make renewable energy deployment a desirable option in the future also from the perspective of energy security (Aized et al., 2018).

Effects of renewable energy sources deployment on fossil energy imports have been assessed at the European Union level, and the substitution effect between renewable energy deployment and imported energy (fossil energy and direct electricity imports) has been captured, e.g., by Gokgoz & Guvercin (2018). Their empirical analysis described a negative dependency between the employment of renewable energy and fossil energy imports in the European Union countries. Therefore, the authors concluded by emphasizing the effect of renewable energy deployment on energy security. Additionally, other research approaches, instead of aiming to focus on the energy dependency decrease by renewable energy deployment, have been employed in the research. Emphasizing the improvements in the diversification of energy sources by renewable energy employment has similarly been a suggested approach instead of energy dependence (Valdes Lucas et al., 2016). This approach has been justified by stating that an energy strategy aiming to increase diversification would be more coherent and optimal than a strategy aiming to reduce energy dependency (p. 1043).

Several energy scenario analyses concerning renewable energy deployment and energy security effects in the future have been conducted previously in the literature. Lyyra et al. (2018) suggests that the energy security supply in Finland will likely improve in the future, supported by the continuous decline in imported fossil fuels from Russia. The decline in energy import dependency additionally decreases economic dependence on Russia and therefore lowers the risk of Russia using energy as an influence tool for Finland. Authors determined preserving fuel logistics and assuring the functionality of the electricity grid as the most crucial factors influencing the energy supply security of Finland under the future energy transition (p. 2). Authors suggested the measures such as substituting fossil energy imports with renewable energy, along with diversification of imports, to improve energy supply security in the future in Finland. Aslani et al. (2013) employed in their study three simulations of the potential scenarios with different levels of renewable energy deployment in Finland in the future. The correlation between the implementation of renewable energy and dependency on imported energy (natural gas) was described based on their energy dependency analysis.

In addition to the positive effects that renewable energy employment can have on energy security, RES deployment may as well create a series of new, adverse issues for energy security (Johansson, 2011). Energy security literature has traditionally addressed topics, for instance, geopolitics and dependence on fossil energy imports. The potential adverse effects of renewable energy deployment for energy security have been left unnoticed, and therefore a significant research gap concerning the possible adverse effects of renewable energy exists. (Johansson, 2011, p. 598). Further, the particular characteristics of renewable energy sources, differing from traditional fossil energy, enables a new type of issue that needs to be considered from the perspective of energy security. Contrary to fossil fuels, renewable energy consumption depends on varying, continuous energy flows rather than a predictable stock of energy. (Johansson, 2013, p. 598-599). Therefore, especially the issue of energy demand and supply balance in a time becomes a more relevant issue in renewable energy utilization.

Therefore, renewable energy deployment does not always inevitably improve energy security (Johansson, 2013). Dependency on any energy source is generally a factor that affects energy security. Potential improvements in energy security due to the deployment of renewable energy typically link to improvements in energy self-sufficiency or diversity in energy sources (decreasing the dependence on single sources). Similarly, dependency on renewable energy (imports) can adversely affect energy security by increasing energy dependency. (Johansson, 2013, p. 603). Lilliestam and Ellenbeck (2011) have addressed this type of concern also relating to the planning of *Desertec*[1]. A significant concentration of renewable energy and dependence on single sources could be used (like any other energy source) as an energy weapon if the dependency on RE sources achieves a considerably high level (Lilliestam & Ellenbeck, 2011).

To conclude a remark, the connection between energy security and renewable energy deployment is a complex entity, but several positive effects are broadly recognized. The quality of the relationship between renewable energy and energy security varies depending on the determination of the energy security approach, as well as the current level of energy security, e.g., the construction of the energy mix and level of import dependence. A broad consensus can be found that the deployment of renewable energy can diversify the energy supply and increase energy self-sufficiency. Moreover, renewable energy is an effective tool to subsidize the consumption of conventional fossil fuels, which in many countries are imported from foreign countries and centered sources. Therefore, the dependency on fossil energy imports can be reduced by employing alternative renewable energy sources.

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[1] *Desertec concept refers to a planning of energy cluster providing solar energy imports from North Africa to Europe.*

4 Empirical analysis

The theoretical framework of the empirical analysis is motivated by numerous previous research on the relationship between energy consumption and economic activity (see Kraft & Kraft, 1978). The selected empirical approach is influenced by Gokgoz & Guvercin's (2018) analysis in *"Energy security and renewable energy efficiency in EU"*, where the authors evaluated renewable energy deployment's effects on energy security by assessing the effects of RES on fossil energy consumption in panel data set of 28 European Union countries. Moreover, the approach of this analysis was selected since a significant share of fossil energy consumed in Finland is imported from Russia, and currently (2022), Finland, among many countries in Europe, is confronting the challenge of seeking alternatives for Russian energy imports, due to the Russian-Ukraine War and rising geopolitical tension.

The empirical analysis aims to investigate the effects of renewable energy consumption on the consumption of fossil energy imports in Finland between 2000 and 2020. The analysis, therefore, evaluates the energy security effects of increased renewable energy consumption in Finland, linked to fossil energy imports dependence. The assessment utilizes econometric modeling on the effects of renewable energy sources used in Finland, wood fuels, hydropower, and other renewables, on fossil energy imports (oil, natural gas, coal) in a combined time series data set covering the period of 20 years, 2000 to 2020.

4.1 Empirical method

Multiple linear regression analysis is applied for causal inference of the effects of the independent (regressor) variables on the dependent (response) variable. *The multiple linear regression model (MLR)* is an extension of the linear single variable regression model, allowing the use of more than one regressor variable in the analysis (Stock & Watson, 2020, p. 217). *Causal inference* of the response variable and regressor variables objectives to, based on the collected data, estimate the effect which changes in the independent variable cause in the dependent variable (Stock & Watson, 2020, p. 143). Regression coefficients in the regression models are estimated by *ordinary least squares estimates (OLS).* The ordinary least squares estimator chooses the coefficients in the regression models in a way that the regression line is as near as possible to the data observed. (Stock & Watson, 2020, p. 148). The mathematical equation of the multiple linear regression model in general form is presented below (5).

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \varepsilon_p \tag{5}$$

4.2 Data and variables

The secondary dataset utilized in the analysis constructs of time series datasets compiled from the Official Statistics of Finland (OSF) database. Official Statistics of Finland is a national database of Finland that collects the national statistics and is currently covering over 250 sets of different key statistics of Finland. Data sourced from the database are widely used, e.g., in social decision-making and legislative planning. (OSF, 2022). The time series data sets used in this analysis cover a period of 20 years from the years 2000 to 2020. Data contains information on energy usage by different energy sources in Finland during the period. In addition, data capturing the gross domestic product of Finland (GDP) in the period is retrieved from the OSF database.

Energy variables applied are selected based on the overview covering energy consumption and supply in Finland, along with the previous research literature and economic theory. A total of 11 variables are used in the analysis. Dependent variables are specified as *fossil*, *oil*, *natgas,* and *coal*. Independent variables used are *wood*, *hydro*, *resother*, *nuc*, *electimp*, *other*. Furthermore, *GDP* is incorporated as a control variable. Dependent variables describe the share of fossil energy imports (*fossil*) total from energy consumption. Additionally, dependent variables are incorporated to individually describe natural gas (*natgas*), coal(*coal*), and oil (*oil*) imports from energy consumption in Finland.

Independent variables capture two primary renewable energy sources in Finland, wood fuels (*wood*) and hydropower (*hydro*). In addition, (*resother*) captures less significant (by share) alternative renewable energy sources. This includes wind power, solar energy, heat pumps, and liquid biofuels. The variable *nuc* is a share of nuclear energy from the energy consumption in Finland since a significant part of electricity in Finland is produced by nuclear energy. Also, considering the essential role of direct electricity imports in Finland, *electimp* is incorporated to include the effect of net electricity imports to Finland. Variable *other* involve other energy forms than aforementioned, e.g., peat. *GDP* is the real GDP of Finland during the period. (Effect of inflation has been excluded using a GDP price index and capturing GDP with constant prices). An overview of the initial variables is provided in Table 1 below.

Table 1. Variable specifications.

Variable	**Definition**
fossil	Fossil energy imports consumption (oil, natural gas, coal) (TJ)
oil	Oil imports consumption (TJ)
natgas	Natural gas imports consumption (TJ)
coal	Coal imports consumption (TJ)
nuc	Nuclear energy consumption (TJ)
electimp	Direct net electricity import consumption (TJ)
other	Other energy forms consumption (peat, reaction heat of industry, hydrogen, other.) (TJ)
GDP	Real GDP, constant prices year 2015 (€)
wood	Wood fuels consumption (black liquor, wood fuels in industry and energy production, small scale combustion of wood) (TJ)
hydro	Hydropower consumption (TJ)
resother	Other renewables consumption (wind, solar, liquid biofuels, heat pumps, other) (TJ)

4.3 Descriptive statistics

Descriptive statistics of the data sets used in this empirical analysis are described in Table 2 below. Descriptive statistics presents the observations, mean, standard deviation, and minimum and maximum values. Further, skewness and kurtosis of the variables are besides reported in the table.

Table 2. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
fossil	21	611900	108599	424474	797755	-.0451106	1.859471
oil	21	333713.8	36943.77	268085	382563	-.1905448	1.591149
natgas	21	122026	35885.14	65967	169200	-.3653042	1.531724
coal	21	148741.3	43764.47	70363	241436	.3996726	2.551011
nuc	21	241478.5	4423.472	233398	249981	.0511583	2.185389
electimp	21	50650	16138.22	17467	73532	-.4558094	2.609543
other	21	83051.52	18683.99	52507	114175	.1878905	1.663616
GDP	21	208408.4	15354.4	176738.3	229523.4	-.6740563	2.411624
wood	21	318740.1	34565.08	263443	380002	.0887664	2.04006
hydro	21	49047.62	7172.3	34038	60874	-.066848	2.45963
resother	21	37132.19	29973.12	5251	90662	.526047	1.827337

4.4 Estimation models

Guided by the overview of energy consumption in Finland between 2000–2020, the following multiple linear regression models are constructed to assess the effects of RES on fossil energy imports consumption, plus considering alternative energy sources. Regression models are applied to examine the quality and statistical significance of RES variables (*wood*, *hydro* & *resother*) on the consumption of fossil energy imports in Finland (*fossil*, *oil*, *natgas*, *coal*). Alternative energy sources considered in the models are nuclear energy (*nuc*), direct energy imports (*electimp*), and peat & other (*other*). Multiple linear regression models are presented next in equations 6-9.

$$fossil_t = \alpha_t + \beta_1 wood_t + \beta_2 hydro_t + \beta_3 resother_t + \beta_4 nuc_t + \beta_5 electimp_t + \beta_6 other_t + \beta_7 GDP_t + \varepsilon_t \tag{6}$$

$$oil_t = \alpha_t + \beta_1 wood_t + \beta_2 hydro_t + \beta_3 resother_t + \beta_4 nuc_t + \beta_5 electimp_t + \beta_6 other_t + \beta_7 GDP_t + \varepsilon_t \tag{7}$$

$$natgas_t = \alpha_t + \beta_1 wood_t + \beta_2 hydro_t + \beta_3 resother_t + \beta_4 nuc_t + \beta_5 electimp_t + \beta_6 other_t + \beta_7 GDP_t + \varepsilon_t \tag{8}$$

$$coal_t = \alpha_t + \beta_1 wood_t + \beta_2 hydro_t + \beta_3 resother_t + \beta_4 nuc_t + \beta_5 electimp_t + \beta_6 other_t + \beta_7 GDP_t + \varepsilon_t \tag{9}$$

Where t is the time-period (i.e., t = 2000, 2001, 2002, ..., 2020), α is the intercept, β is the coefficient estimate, and ε is the error term.

4.5 Unit root testing for time series

General restriction in using economic time series data in statistical modeling is non-stationarity and unit root of time series. Therefore, before proceeding to the regression analysis, pre-empirical testing of data is performed, and the time series used in estimation models are tested for unit root to confirm stationarity. For unit root testing, two tests are used to verify the results. Tests for unit root used are the *Dickey-Fuller test* (Dickey & Fuller, 1979) for unit root and the *Phillips-Perron test* (Phillips, & Perron, 1988). Testing confirms that most of the retrieved time series are non-stationary in level. Therefore, first difference transformations are applied for the times series to ensure they can be used in the estimation models. Mathematical equations of the Dickey-Fuller test (10) and Phillips-Perron test (11) for unit root are presented below, and the results for unit root testing are reported in Table 3.

$$\Delta y_t = \alpha y_{t-1} + \chi_t' \delta + \varepsilon_t \tag{10}$$

$$H_0: \alpha = 0$$
$$H_1: \alpha < 0$$

$$\Delta y_t = \beta y_{t-1} + \varepsilon_t \tag{11}$$

$$H_0: \beta = 0$$
$$H_1: \beta < 0$$

Table 3. Unit root testing results.

Variable	**(DF)** Level	**(PP)** Level	**(DF)** Δ	**(PP)** Δ	**Conclusion**
fossil	-0.464 (0.8988)	0.062 (0.9634)	-5.380^{***} (0.0000)	-5.709^{***} (0.0000)	I(1)
oil	0.250 (0.9749)	0.499 (0.9848)	-4.773^{***} (0.0001)	-4.793^{***} (0.0001)	I(1)
natgas	-0.108 (0.9487)	-0.092 (0.9503)	-4.905^{***} (0.0000)	-4.881^{***} (0.0000)	I(1)
coal	-1.776 (0.3926)	-1.493 (0.5370)	-5.730^{***} (0.0000)	-6.809^{***} (0.0000)	I(1)
nuc	-3.554^{**} (0.0067)	-3.542^{**} (0.0070)	-7.962^{***} (0.0000)	-8.170^{***} (0.0000)	I(0)
electimp	-2.112 (0.2397)	-1.990 (0.2909)	-5.882^{***} (0.0000)	-6.402^{***} (0.0000)	I(1)
other	-1.450 (0.5583)	-1.368 (0.5977)	-4.598^{***} (0.0001)	-4.716^{***} (0.0001)	I(1)
GDP	-2.018 (0.2789)	-2.042 (0.2686)	-3.722^{**} (0.0038)	-3.660^{**} (0.0047)	I(1)
wood	-1.491 (0.5381)	-1.344 (0.6087)	-7.009^{***} (0.0000)	-7.516^{***} 0.0000	I(1)
hydro	-3.857^{**} (0.0024)	-3.815^{**} (0.0028)	-5.635^{***} (0.0000)	-6.651^{***} (0.0000)	I(0)
resother	1.224 (0.9962)	1.957 (0.9986)	-4.767^{***} (0.0001)	-6.651^{***} (0.0000)	I(1)

(DF) for the Dickey-Fuller test. (PP) for Phillips-Perron test. Level refers to initial values before differencing and Δ to values after first differencing.
Test statistics Z(t). MacKinnon approximate p-value for Z(t) in parenthesis.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Unit root testing results confirm that time series have no unit root after differencing, and data sets after first differencing can be used in regression analysis. After ensuring the time series fulfills the requirements of stationarity, multiple linear regression analysis is employed for estimation, and the results are presented in Table 4.

4.6 Regression analysis

Table 4. Regression analysis results.

	Model 1 fossil	**Model 2** oil	**Model 3** natgas	**Model 4** coal
wood	0.936**	0.205	0.0503	0.662*
	(3.31)	(2.10)	(0.38)	(2.51)
hydro	-1.451*	0.289	-0.171	-1.556**
	(-2.67)	(1.54)	(-0.67)	(-3.07)
resother	-2.837**	-1.304**	-0.182	-1.424
	(-3.07)	(-4.07)	(-0.42)	(-1.65)
nuc	-0.299	0.418	-0.254	-0.496
	(-0.34)	(1.36)	(-0.61)	(-0.60)
electimp	-1.608***	0.245	-0.385	-1.471**
	(-4.23)	(1.86)	(-2.14)	(-4.15)
other	1.270*	0.702***	0.149	0.427
	(2.79)	(4.45)	(0.69)	(1.01)
GDP	-0.431	-0.333	0.395	-0.457
	(-0.48)	(-1.06)	(0.92)	(-0.54)
_cons	-2542.0	-802.7	-3231.1	1264.6
	(-0.47)	(-0.43)	(-1.26)	(0.25)
N	21	21	21	21
R^2	0.9308	0.8461	0.6124	0.8833
Adj. R^2	0.8936	0.7632	0.4037	0.8205
Prob > F	0.0000	0.0002	0.0447	0.0000

t statistics in parentheses
* *p < 0.05*, ** *p < 0.01*, *** *p < 0.001*

After estimating the regression models, the eventual regression equations are given as follows (Model 1 (12), Model 2 (13), Model 3 (14), and Model 4 (15)).

$$-2542.0 + 0.936_{wood} - 1.451_{hydro} - 2.837_{resother} - 0.299_{nuc} - 1.608_{electimp} + 1.270_{other} - 0.431_{GDP} + \varepsilon_t \tag{12}$$

$$-802.7 + 0.205_{wood} + 0.289_{hydro} - 1.304_{resother} + 0.418_{nuc} + 0.245_{electimp} + 0.702_{other} - 0.333_{GDP} + \varepsilon_t \tag{13}$$

$$-3231.1 + 0.0503_{wood} - 0.171_{hydro} - 0.182_{resother} - 0.254_{nuc} - 0.385_{electimp} + 0.149_{other} + 0.395_{GDP} + \varepsilon_t \tag{14}$$

$$1264.6 + 0.662_{wood} - 1.556_{hydro} - 1.424_{resother} - 0.496_{nuc} - 1.471_{electimp} + 0.427_{other} - 0.457_{GDP} + \varepsilon_t \tag{15}$$

4.6.1 R-squared and statistical significance

R-squared (R^2) and *adjusted R^2* of the regression model can be used to investigate if the independent variables likely cause the variation in the dependent variable. R^2 is calculated as the ratio value of the explained sum of squares to the total sum of squares and therefore is a ratio value between 0-1 (Stock & Watson, 2020, p. 153). Higher R^2 values near 1 suggest that the regression model is more accurate in describing the issue and that the variation in the dependent variable is more likely explained by the changes in the independent variable (Stock & Watson, 2020, p. 263). Adjusted R^2 can be as a more precise measure of fit in a multiple linear regression model since the R^2 tends to increase by adding variables in the model. Adjusted R-squared corrects the effect and therefore offers more precise information on the fit in the multiple linear regression model (Stock & Watson, 2020, p. 223).

Examining the R^2 values of the model discover that the adjusted R^2 of model 1 is 0.8723. This is the highest value of the models employed and suggests that in model 1 (*fossil*), independent variables explain 87 percent of the variation in the dependent variable. Investigation of the additional models 2-4 reveals lower R-squared values compared to the general model 1. Model 2 (*oil*) adjusted R^2-value is 0.7632 (76%). Model 3 (*natgas*) performs weakest with 0.4037 (40%) adjusted R-squared value. The final model 4 (*coal*) has the second-highest adjusted R-squared value of 0.8205 (82%). Based on the R-squared values of the models, the evaluation suggests that the general model 1 (*fossi*l) explains the issue more than additional models. However, the model 4 (coal) additionally performs well with over 82% adjusted R^2.

Inspecting the statistical significance of the models is an additional tool used to evaluate the model performance. Prob > F indicates values of 0.0000 to general model 1 (*fossil*) and model 4 (*coal*). In model 2 (*oil*) value is 0.0002, and model 3 (*natgas*) as well reveals the lowest results in terms of Prob > F. The value of 0.0447 states the null hypothesis can be rejected at the 5% significance level but not at 1%.

Inspection of the explanatory variables' statistical significance suggests that since *nuc* and *GDP* are not significant in any standard significance level in any models, they could be removed from the models and do not explain the fossil energy imports consumption. Removing non-significant variables could furthermore correct the R-squared of the models. Further investigation is required to understand these results. Model 3 (*natgas*) weak performance indicates that the model explaining natural gas imports with alternative energy variables fails to explain the issue more than alternative models employed.

4.6.2 Regression diagnostics

A series of diagnostic tests for estimations are conducted to ensure that the used models do not suffer from statistical issues, e.g., heteroskedasticity and serial correlation. Tests used for heteroskedasticity are *White's test* (White, 1980) and *Breusch-Pagan/Cook-Weisberg test* (Breusch & Pagan, 1979). *Breusch-Godfrey test* (Breusch, 1978) is used to detect a serial correlation between the residuals in the models. To ensure results of no serial correlation, also *Durbin-Watson's t-statistics* (Durbin & Watson, 1950) is examined.

Results of the Durbin-Watson d-statistics can have values between 0 and 4. A value near 2 indicates no serial correlation (see Table 5 for results).

Table 5. Test results for heteroskedasticity and serial correlation.

Model	**White's test**	**Breusch-Pagan/Cook-Weisberg**	**Breusch-Godfrey LM-test**	**Durbin-Watson d-statistic**
Model 1	21.00 (0.3971)	0.00 (0.9610)	0.000 (0.9899)	1.777878
Model 2	21.00 (0.3971)	0.10 (0.7489)	0.326 (0.5682)	2.050258
Model 3	21.00 (0.3971)	0.06 (0.8114)	0.033 (0.8555)	2.02874
Model 4	21.00 (0.3971)	0.00 (0.9521)	0.016 (0.8980)	1.824192

Chi2 and (Prob > chi2) reported in White's test, Breusch-Pagan/Cook-Weisberg test, and Breusch-Godfrey test. Durbin-Watson test results report a d-statistic.

White's test results show that the null hypothesis of constant variance cannot be rejected in any standard significance levels. Therefore, according to White's test, no heteroskedasticity is indicated. Similarly, Breusch-Pagan test results support the previous result of no severe heteroskedasticity in the estimation models. According to Breusch-Pagan test statistics, the null hypothesis of the constant variance cannot be rejected in any standard significance levels. Results, therefore, ensure the previous result of no heteroskedasticity in estimations.

Breusch-Godfrey test results indicate no serial correlation in the models since the null hypothesis (no serial correlation) cannot be rejected in any standard significance levels. Further, the Durbin-Watson test for autocorrelation provides values of around 2 in all models, supporting the result from the previous test that there is no severe autocorrelation biasing estimations.

For potential multicollinearity, *variance inflation factor (VIF)* values are investigated. VIF (16) is used to measure the correlation and the strength of correlation between the explanatory variables in a regression model. Variance inflation factor values 1-5 are interpreted as an indicator of an appropriate level, moderate correlation between the variables, and a sign of no severe multicollinearity in the model. On the other hand, a VIF value greater than 5 (or 10) would be considered an indicator of severe possible multicollinearity and is generally considered to require further investigation of the possible multicollinearity. Results for VIF-test are presented below in Table 6.

$$VIF_j = C_{jj} = (1 - R_j^2)^{-1} \tag{16}$$

Table 6. Results of VIF-test for multicollinearity.

Variable	VIF	1/VIF
Δother	2.66	0.376589
ΔGDP	2.13	0.468634
Δwood	1.88	0.532725
Δelectimp	1.85	0.540946
Δhydro	1.78	0.561878
Δnuc	1.49	0.670941
Δresother	1.11	0.897301
Mean VIF	1.84	

Variance inflator factor values for the models meet the requirements for the conclusion that there is no severe multicollinearity among the independent variables. VIF-values of all variables used are <5, which can be considered a positive result for no multicollinearity. In addition, the correlation matrix (Table 7) shows no significant correlation between explanatory variables.

Table 7. Correlation matrix.

Variable	Δwood	Δhydro	Δresother	Δnuc	Δelec-timp	Δotherp	ΔGDP
Δwood	1.0000						
Δhydro	-0.0265	1.0000					
Δresother	-0.0718	-0.0529	1.0000				
Δnuc	-0.3803	-0.3876	0.0053	1.0000			
Δelectimp	-0.1657	0.0205	0.1832	0.1627	1.0000		
Δother	0.5066	-0.3061	-0.1717	-0.1080	-0.4926	1.0000	
ΔGDP	0.4982	0.2223	-0.2128	-0.1732	0.1305	0.3670	1.0000

Lastly, stability tests are performed for all models. *A cumulative sum test (CUSUM)* for parameter stability as well as a *cumulative sum test of squares (OLS CUSUM)* are conducted to ensure the stability of coefficients in the models over time. The following figures (15-22) present the results of stability tests. Results can be visually interpreted as a positive sign of stability since the line exists in the shaded area. Results confirm that the mean of all regression models is stable at a 5 percent significance level. The series of diagnostic tests conducted with the stability tests strongly support the conclusion that there are no statistical problems in the data and estimation models applied.

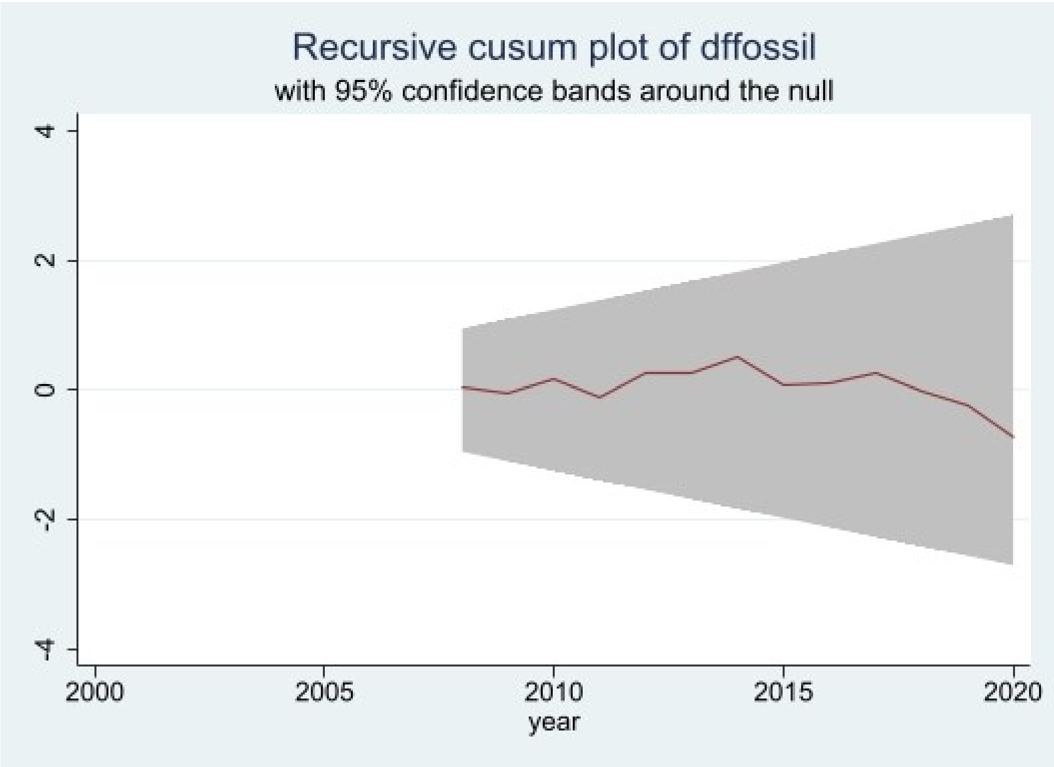

Figure 15. CUSUM plot, model 1.

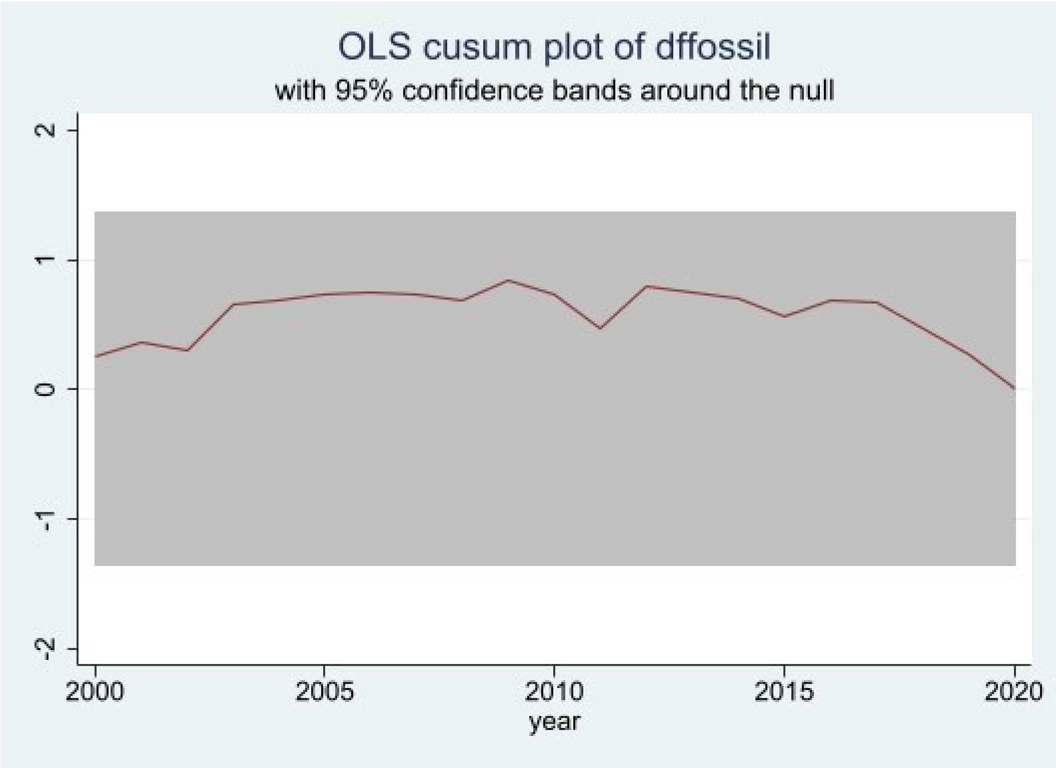

Figure 16. OLS CUSUM plot, model 1.

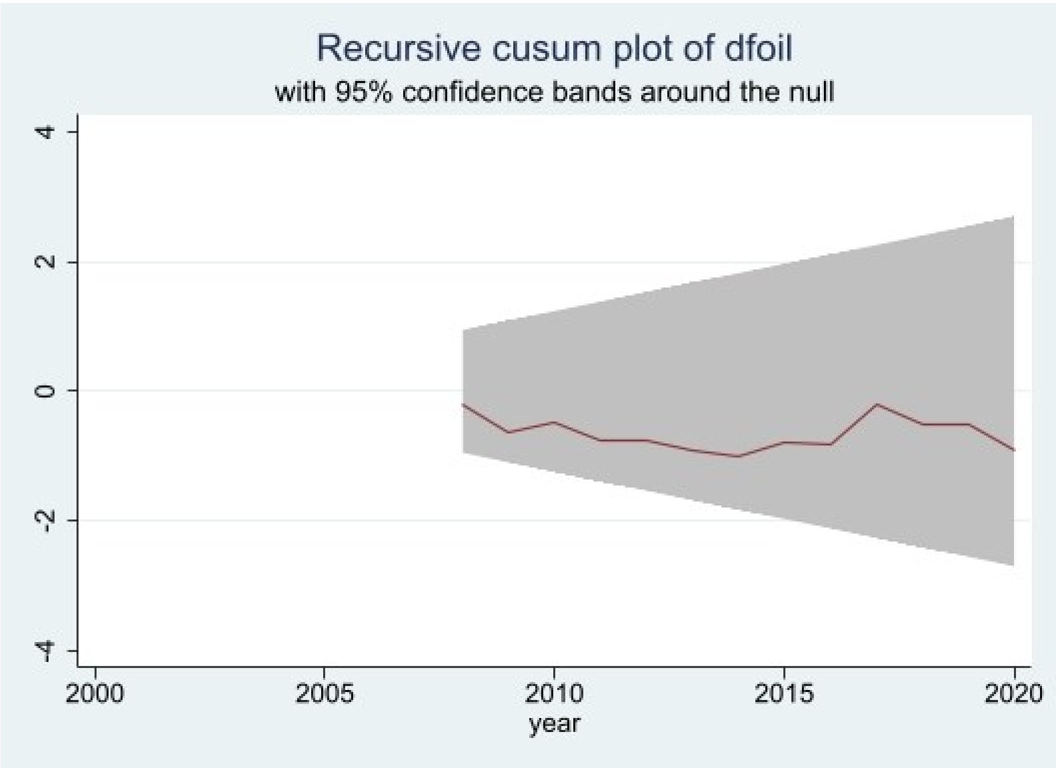

Figure 17. CUSUM plot, model 2.

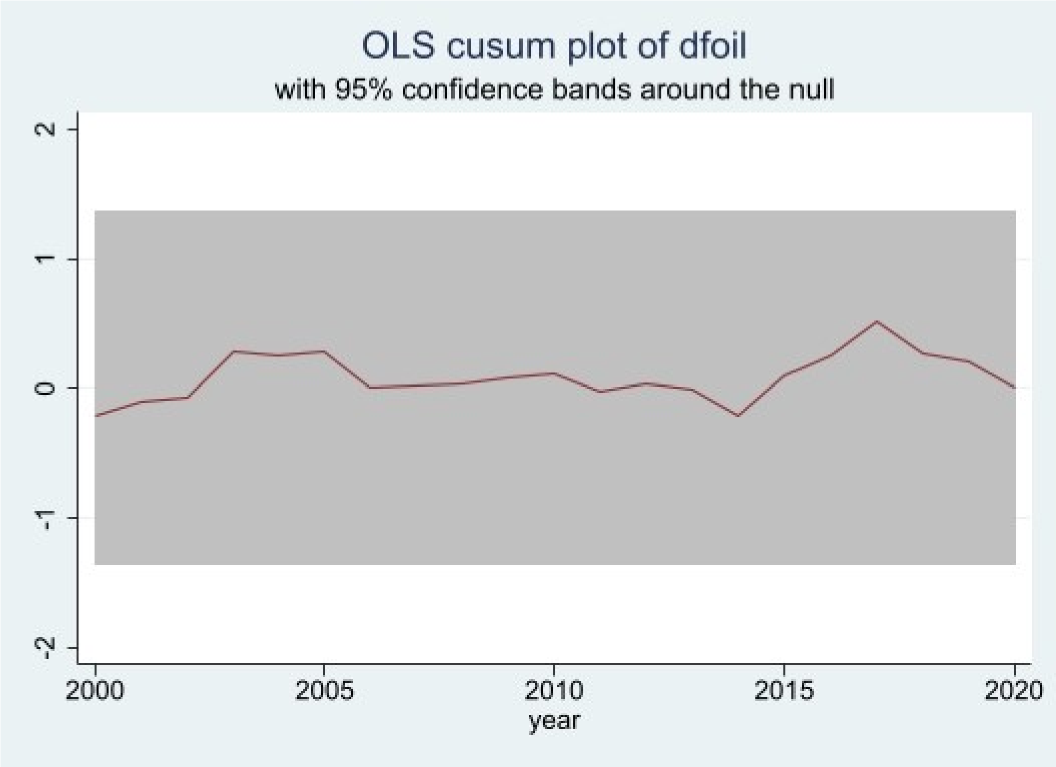

Figure 18. OLS CUSUM plot, model 2.

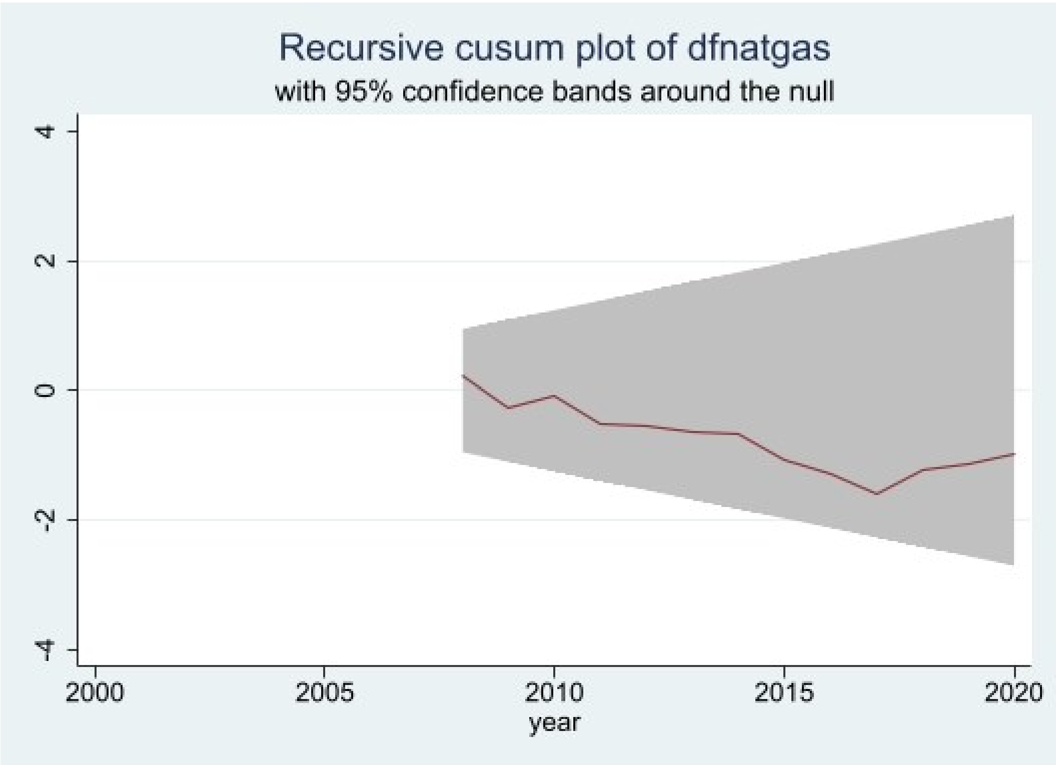

Figure 19. CUSUM plot, model 3.

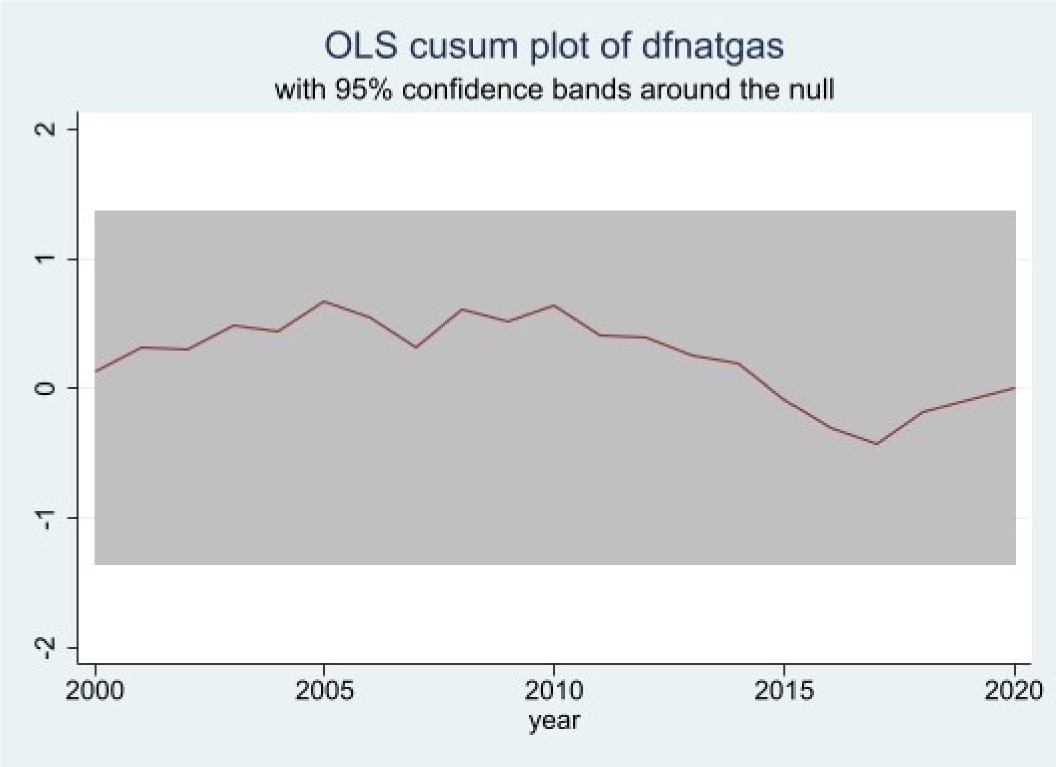

Figure 20. OLS CUSUM plot, model 3.

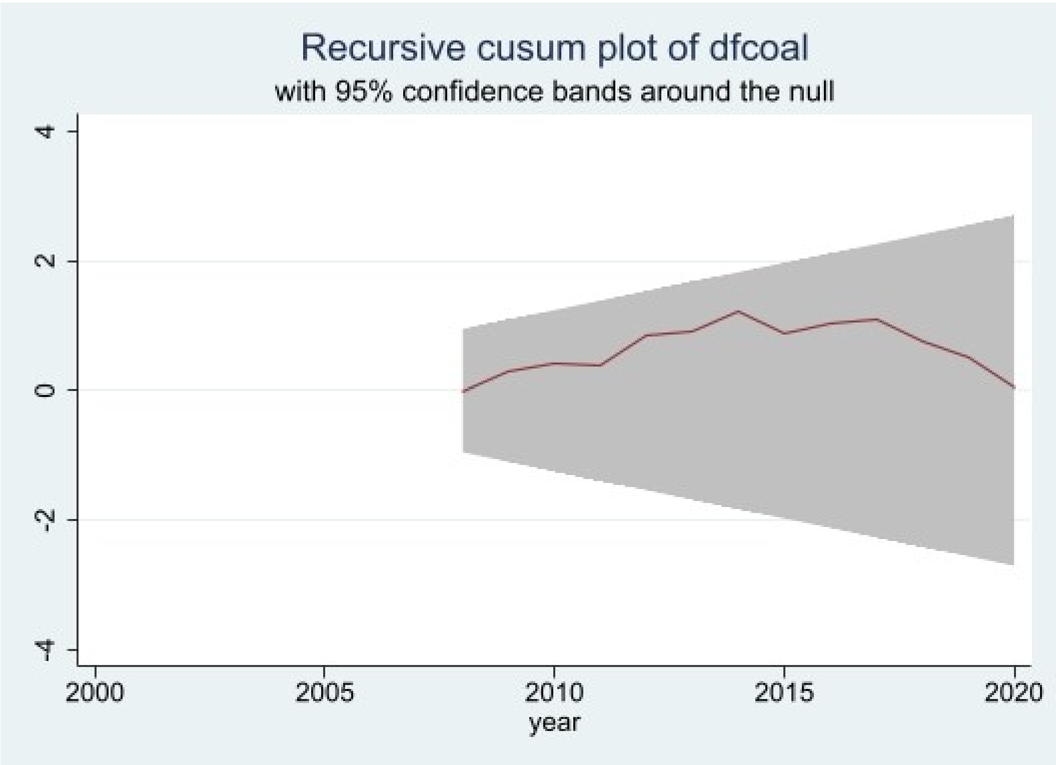

Figure 21. CUSUM plot, model 4.

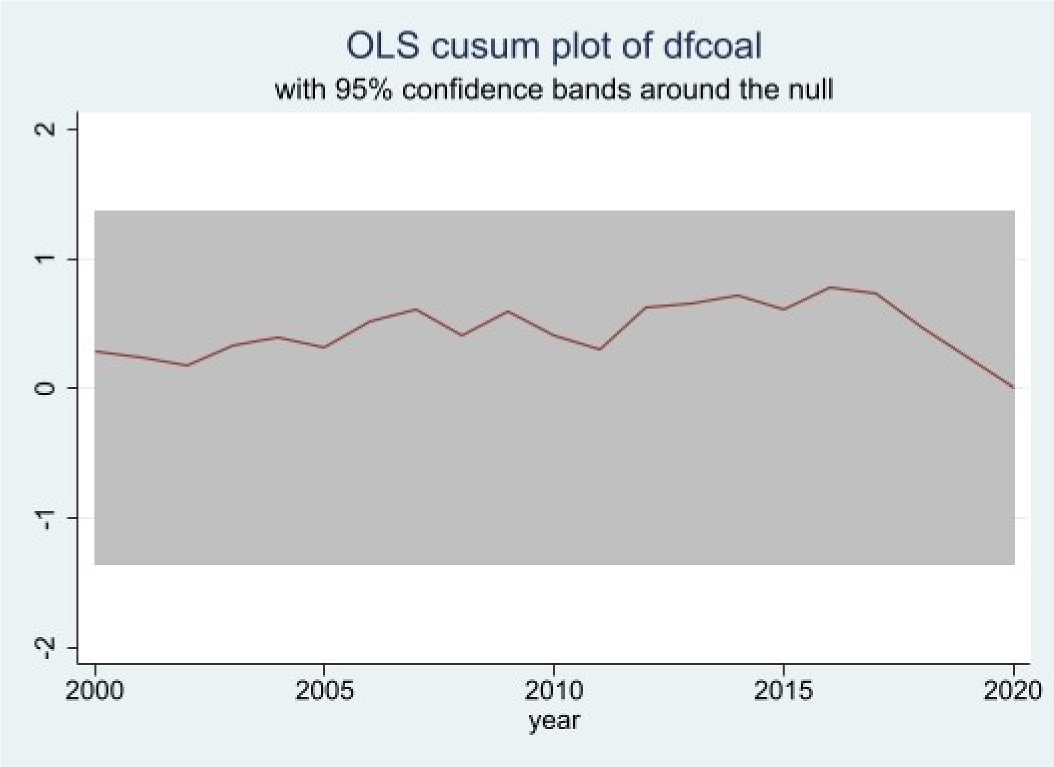

Figure 22. OLS CUSUM plot, model 4.

4.7 Discussion

Empirical analysis reveals that based on models 1 (*fossil*), 2 (*oil*), and 4 (*coal*), renewable energy sources show a statistically significant declining effect on the consumption of fossil energy imports in Finland from 2000 to 2020. The result is supported by a theoretical framework considering the development of Finland's energy supply between 2000–2020. Results are, moreover, the same directional and consistent with recent research relating to the effects of RES on fossil energy consumption (see Gokgoz & Guvercin, 2018; Marques et al., 2018). In model 3 (*natgas*), explanatory variables did not show statistical significance. Therefore, natural gas consumption could not be explained by alternative energy variables, although Gokgoz & Guvercin (2018) additionally captured the decreasing effect of RES on natural gas, besides oil and coal. Model 3 result proposes that between 2000-2020, RES has not been utilized to reduce natural gas imports consumption, unlike it is for oil and coal imports.

In model 1, *hydro* and *resother* have negative regression coefficients, the result being significant at the 5% significance level. This indicates that in the general model, explanatory RES variables *hydro* and *resother* (wind, solar, liquid biofuels, and heat pumps) have produced a decline in response variable *fossil*. Therefore, implying that the utilization of the aforementioned renewable energy sources has contributed to scaling down the use of fossil energy imports in the country. The finding is moreover supported by Gokgoz & Guvercin's (2018) results since they demonstrated the negative effect of RES on fossil imports among EU countries. Marques et al. (2018) similarly presented a declining effect of renewable energy, solar, and hydropower on fossil fuels.

Surprisingly, RES variable *wood* has a positive regression coefficient, implying that *wood* has not contributed as *hydro* and *resother* in decreasing *fossil.* Though, this finding is similar to previous results of Marques et al. (2018), which concluded that bioenergy showed no significance in declining fossil energy consumption. Besides the RES variables, variables *electimp* and *other* are significant in model 1. The negative coefficient of *electimp* denotes the decreasing effect of direct electricity import on fossil energy imports consumption, as can be expected. Alternative energy variable *other* (e.g., peat) has a positive coefficient instead, proposing alternative energy forms have not been employed by reducing fossil energy imports consumption as RES and electricity import.

Model 2 discovers a negative regression coefficient on *resother*, implying a negative effect on *oil*. The result is statistically significant at a 1% significance level and is consistent with model 1 findings. Likewise, Gokgoz & Guvercin (2018) found a similar effect of RES on oil imports. The *other* variable has a positive coefficient, and the result is significant at a significance level of 0.1%, revealing a similar effect to *oil* as on *fossil*. Unlike in model 1, *wood* and *electimp* do not show statistical significance in model 2. Non-significance of *electimp* is theoretically supported since direct electricity imports are not the optimal substitute for oil imports, considerably utilized in sectors such as transportation.

In model 4, RES variables *wood* and *hydro*, in addition to *electimp*, show statistical significance at a 5% significance level (or lower). Therefore, showing similar effects on *coal* as on *fossil* in model 1. Similarly, in this model, *wood* has a positive regression coefficient while *hydro* and *electimp* have negative coefficients instead. Unlike in model 1, *resother* is not significant. The findings are a reflection that coal imports consumption between 2000–2020 has been in decline, and renewable energy alternative hydropower along with direct electricity imports has been successfully utilized to compensate for coal imports consumption. Gokgoz & Guvercin (2018) and Marques et al. (2018) likewise concluded the negative effect of RES on coal consumption. Though, Marques et al. (2018) findings emphasized other renewables instead hydropower in reducing coal consumption.

Reverse results of wood fuels compared to other RES can linkage to wood fuels in Finland differing from other RES alternatives considerably. Wood fuels dominate total energy consumption, while alternative renewables are more marginal by shares. The recent development of bioenergy has aimed to develop other applications along with wood combustion, e.g., liquid biofuels and biogas. The reverse effect, however, proposes that wood combustion has not been used in Finland to cut fossil fuels in the period, as is the alternative RES. The result seems contradicted since the wood fuels have increased between 2000-2020 and fossils, on the contrary, decreased. Still, the finding is similar to Marques et al. (2018), where the authors concluded no effect of bioenergy on fossil consumption among European countries.

More marginal RES alternatives, wind power, solar energy, heat pumps, and liquid biofuels, have been developed further from 2000 to 2020 to support the path to decarbonization in Finland. Therefore, it is not surprising that other RES revealed a significant declining effect on fossil imports. Finding supports that the usage of wind power, solar energy, heat pumps, and liquid biofuels has successfully contributed to the decline in fossil energy imports in Finland between 2000–2020. The share of hydropower production from energy consumption shows no sign of an increase in the period; hence hydropower's significance and negative effect in the models indicate that even though new hydropower capacity has not been installed in Finland in the period, the energy produced by with existing capacity has been efficiently utilized to scale down fossil energy import consumption.

Significant results concerning electricity imports in models 1 and 4 propose that besides RES, direct electricity imports have been compensating for fossil imports consumption in Finland. The effect is underpinned particularly in the coal imports consumption. The result is consistent with the energy supply development in Finland since the declining trend in coal consumption and the impact of joint Nordic electricity markets, Nord Pool, which has an important role in energy supply. Findings, therefore, support the previous conclusions in the literature that the Nord Pool market cluster is likely to have an essential role in decarbonization in Finland in the future (Ministry of Economic Affairs, 2019, p. 19-20; Sitra, 2021, p. 133-134).

Results for GDP and nuclear energy appear surprising based on insight and theoretical framework. Economic growth relates to energy consumption (Kraft & Kraft, 1978), and GDP is found to relate to energy consumption as well in Finland (see Tabasi et al. (2018). The reason for the result requires further investigation beyond this analysis. Nuclear energy is in a vital role in energy production in Finland, and therefore it could be reasonably expected to present a significance in affecting fossil fuel imports consumption. The effect of nuclear energy in reducing fossil fuel consumption is also presented by Gokgoz & Guvercin (2018). Non-significance can nevertheless have support from the energy supply development in Finland. Additional nuclear reactors have not been launched between 2000–2020. Due to the constant nuclear energy level during the period, nuclear energy possibly does not explain changes in fossil energy import consumption. The effects of nuclear energy on fossil energy import consumption in Finland could be assessed after the deployment of the Olkiluoto 3 reactor, expected to launch in 2022 and increase nuclear energy production substantially.

5 Conclusions

In this thesis, first, an overview of energy consumption and supply in Finland and the development of renewable energy in Finland were covered. Characteristics of energy consumption in Finland, such as the energy intensiveness of the economy and high energy consumption per capita, were as well discussed. Despite the energy-intensive economy, the share of RES from energy consumption is high, and Finland is among the top countries in Europe implementing renewable energy and targeting further deployment. Finland's energy mix is evaluated as diversified in the literature, enabling a high level of energy security despite the lack of domestic (fossil) energy resources. Although the import dependence ratio of Finland shows a mild decline between 2000–2020, the share of fossil energy imports, particularly from Russia, is considerable in Finland compared to other Nordic countries. The theoretical framework of the relationship between renewable energy and energy security was explored based on relevant literature, and the approach of energy dependence on fossil energy imports was selected to empirically evaluate the effects of RES on energy security.

Empirical analysis assessing the effects of renewable energy consumption on fossil energy imports consumption in Finland between 2000-2020 discovered that renewable energy sources had been utilized to decline fossil energy imports, especially coal consumption. Results, therefore, support that renewable energy employment in Finland has also enabled improving effects on the country's energy security. The findings were similar to the previous empirical research literature in Europe. Since natural gas consumption was not explained with renewable energy, the conclusion is that RES alternatives have been employed to decrease coal and oil imports rather than natural gas.

Particularly hydropower and more marginal by shares, wind power, solar energy, heat pumps, and liquid biofuels combined appear to be utilized to compensate for fossil energy imports in the period. Surprisingly, as the most considerable RES by a share, wood fuels did not show a declining effect on fossil imports consumption in this analysis. In addition to renewable energy alternatives, findings discovered that direct electricity imports had the same directional effect on fossil energy consumption, therefore underlining the importance of electricity imports in compensating for fossil fuel consumption. Nuclear energy and GDP did not appear as significant in the analysis. The result of nuclear power gets support from energy development in the country since new nuclear energy capacity has not been implemented during the period.

5.1 Policy implications

Policy implications of the thesis support the deployment of renewable energy to substitute fossil energy imports and decrease fossil energy import dependency in Finland. Finland is targeting carbon neutrality in 2025, before the EU target 2035. Geopolitical tensions are likely to affect the import of fossil energy from the Russian region in the future. These factors underpin the need for developing alternative energy forms to substitute considerable shares of fossil energy imports. Since, despite the decline, fossil imports from Russia are at a high level in Finland compared to other Nordic countries. In addition to traditional domestic renewable energy source hydropower, other alternative applications, wind power, solar energy, heat pumps, and liquid biofuels further development can support the transition to carbon-neutral energy production and compensate for fossil energy imports in Finland. Therefore, contribute to energy security in addition.

Alternative biofuels that could be utilized in the sectors that do not benefit from current main RES alternatives (e.g., transportation sector) development is in an essential role since the transportation sector is a considerable consumer of fossil fuels. Besides, electrification development does not seem likely to affect the transportation sector in the near future. Even though the share of coal imports decreased continuously from 2000 to 2020, the oil imports show no significant decline in the period. This development underlines the necessity for liquid biofuel alternatives to compensate for the fossil energy intensiveness of the transportation sector. Additionally, substituting natural gas imports with suitable alternative renewable energy sources should be promoted since RES showed no declining effect on natural gas import consumption.

Direct electricity imports' effect on compensating for fossil imports was highlighted in the analysis, and the joint Nord Pool electricity market's role is essential in the decarbonization of energy production in Finland, similarly according to previous literature. Therefore, the development of the joint market structure between the Nord Pool countries and the national flexible electric grid systems further development enables the effective implementation of green electricity in the future and supports the path to scaling down fossil fuel consumption.

5.2 Limitations of the study and suggested future research

This study as well has limitations. The thesis selects the approach of energy dependency for energy security. Selection is necessary to define the research problem. On the contrary, it excludes other essential layers of energy security from the investigation. The used empirical method is a simplification model for the complex research problem. It does not count dynamic effects or long-period development precisely. Performance between estimation models varied, and more precise and advanced models could be further employed to investigate the relationship between RES and energy security in Finland. Implementing more advanced models that can correct the weakness of this kind of modeling, only capturing the dependency between variables, is strongly encouraged.

In addition, the potential adverse effects of increasing renewable energy deployment on energy security are left beyond investigation. These issues were briefly addressed in chapter 3.3, where it was discussed that deploying alternative renewable energy may pose new adverse issues to be solved from the perspective of energy security. Moreover, this is a considerable research gap around the topic since the discussion regarding the effects of renewable energy deployment is asymmetric, focusing mainly on the potential positive effects of further implementation.

Besides the aforementioned, future research is suggested regarding the potential of marginal alternative renewable energy applications, such as heat pumps and liquid biofuels. Further applications of this kind of renewables can be essential in sectors that do not benefit from current main renewable applications, e.g., the transportation sector. Furthermore, empirical research concerning the effects of RES and different renewable energy forms on energy security is important since the research topic is relatively new, and the shift towards decarbonization is an ongoing phenomenon. Finally, current geopolitical tensions due to the Russian-Ukraine War has led to a situation where also Finland is driven to seek alternative pathways to compensate for Russian fossil energy imports on an accelerated schedule. Therefore, the effects of the suddenly changed geopolitical environment affecting the energy trade and requirements for alternative energy policies could be investigated.

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