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Faculty of Business Economics

Master of Management

Master's thesis

The impact of the energy crisis on the EU's renewable energy transtition

Minh Ngoc Nguyen

Thesis presented in fulfillment of the requirements for the degree of Master of Management, specialization Data Science

SUPERVISOR :
dr. Sumit MAHARJAN

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2023
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Acknowledgments

This dissertation marks the culmination of my Master of Management journey at Hasselt University, a path paved with invaluable experiences and guidance. Eight months and much research was what it took me to finish this dissertation. However, I could only have done this with all the support I received. Through this preface, I express my deepest gratitude to the individuals who have guided, supported, and encouraged me through this incredible journey of writing this dissertation.

First, I sincerely thank my promoter, Dr. Sumit Maharjan, and my supervisor, Dr. Alessandro Martulli. Your guidance from day one and insightful feedback has improved the quality of my work and significantly enriched my academic journey. I have learned a lot about doing research from learning from you. Your mentorship has inspired me, and being one of your advisees was my greatest pleasure.

I would also like to thank the professors and teaching assistants of the Master of Management - Data Science program at Hasselt University. You are the most dedicated and supportive professors I have ever met. Thank you for your invaluable knowledge and support throughout the academic year.

On a personal note, I owe a debt of gratitude to my father, mother, and brother. Thank you for supporting me, for believing in me, and for giving me the opportunity to study in Belgium. I am also grateful to my friend, Dung Hoang, for your love and support during this journey.

I hope this Master's dissertation contributes to the existing body of knowledge on the renewable energy transition from an economic perspective and provides valuable insights for further research on this subject.

Nguyen Minh Ngoc
Hasselt University
May 2024

Abstract

Triggered by the current conflicted worldwide geopolitical situation and the internal dependency on energy imports, both imposed a new challenge for the EU in 2022: an energy crisis. By June 2023, EU household gas prices surged 53.3% year-on-year and 97.2% compared to 2018. From 2020, to combat climate change and enhance energy security, the European Union has pursued a renewable energy transition, central to the European Green Deal, aiming for climate neutrality by 2050. Despite ambitious investments and policy commitments, the transition faces significant obstacles, exacerbated by the recent energy crisis. Therefore, it calls for a deep analysis of how these major energy and economic shocks affect the short-term renewable energy transition in the EU to reevaluate the current transition and learn how to deal with future energy disruption. This study examines the impact of the 2021-2023 energy crisis on the renewable energy transition in the EU27, focusing on macroeconomic effects, environmental factors, renewable energy supply-demand market, and policy responses. Through a quantitative descriptive analysis of secondary data, the research identifies the negative influences of the energy crisis on the EU's GDP and export volume, which were even more severe than the impacts COVID-19 had on the economy. The study finds that the crisis led to an immediate increase in non-renewable energy supply, especially LNG, while decreasing the renewable energy consumption in the electricity sector right at the moment the crisis happened. However, it facilitated a resilient, albeit slower, growth in renewable energy consumption in the electricity and heating and cooling sector as the EU balanced its energy demand and adapted to the current situation. Also, Member States with different renewable energy adoption rates adapt to the energy crisis differently based on their capabilities. Financial incentives and regulatory policies, particularly within the REPowerEU plan, were crucial in accelerating the renewable energy transition; however, they worked better with already established sectors. However, the current goal of renewable energy share of the EU is somewhat too ambitious given the current economic and political condition.

The research underscores the importance of diversifying energy sources, enhancing infrastructure, and implementing flexible policies to ensure energy security and sustainability. It was also worth noticing that the current policies and action packages may not be enough for the EU to reach the ambitious goal of renewable energy adoption in the short term. Recommendations for policymakers include continued investment in renewable energy capacity, improved regulatory frameworks, and strategies to reduce dependence on non-renewable energy sources. These findings provide valuable insights for future energy policy decisions and highlight the need for preparedness and sustainable growth in renewable energy in the face of potential crises.

Tables Of Contents

List Of Abbreviations

Abbreviation	Definition
EU	European Union
GDP	Gross Domestic Product
EKC	Environmental Kuznets Curve
RED	Renewable Energy Directive
RPS	Renewable Portfolio Standard
EU27	27 countries in the European Union of: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden

Chapter 1: Introduction

The world has never been the same since the COVID-19 pandemic, which has reshaped the entire global socio-economic condition. COVID-19 affects all industries around the world, but the energy sector is one of the industries that has suffered the most severe consequences of the pandemic, especially in areas that are already susceptible to socio-economic changes, like Europe. After two years of fighting and recovering from the COVID-19 pandemic, the European Union faces a new worry: the energy crisis since the Russia - Ukraine conflict. The energy crisis is defined as a price rise of energy resources or a tremendous shortfall in the supply of energy resources. Usually, it refers to a shortage of electricity, oil, natural gas, and other natural resources. (Naseem, 2015). By the end of June 2023, EU household gas prices reached 0.984 euro per kilowatt-hour, an increase of 53.3% compared to the same period last year and 97.2% compared to 2018 - which was when Europe had not been affected by the results of the COVID-19. (Eurostat, 2023).

The causes of the energy crisis in Europe can be divided into two leading causes: objective causes and subjective causes. Regarding objective causes, the pandemic has disrupted economic activities and changed energy-intensive activities across the entire region, directly affecting the supply-demand relationship of energy in Europe. Due to lockdown policies, travel restrictions, and reduced production at factories during the pandemic, demand for energy decreased in manufacturing-related sectors. Meanwhile, residential energy use increased significantly when people had to stay at home for long periods, leading to excessive use of electrical and heating equipment in the house. The second objective cause all lies in the Ukrainian-Russian conflict that has lasted for the last two years and Russia's use of gas supplies as both a physical weapon and a political weapon on the EU as they reduced the natural gas deliveries to Europe. This gas supply - critical for heating, industrial processes, and power generation - has been cut by more than 80% in 2022 compared to early 2021. Wholesale electricity and gas prices have surged as much as 15-fold since early 2021, with severe effects on households and businesses. The price of electricity in the EU household and non-household price is directly linked to the cost of imported gas from Russia, which led to the skyrocketing energy price in the EU. Therefore, LNG has become the most important energy import to substitute the scarce energy source in Europe.

Regarding internal causes, first, gas energy sources in EU countries largely depend on imported energy sources. 62.55% of Europe's energy sources in 2022 depend on imports, mainly from the US, Russia, and Qatar. 40% of natural gas pipelines, 27% of oil, and 46% of coal in the EU are imported from Russia (Eurostat, 2023). The EU aimed to reduce this dependency by introducing the 10-point plan to bring down the use of oil and to reduce the dependence on imported energy swiftly. They also concluded new contracts for LNG with various countries, such as Algeria, Australia, Nigeria, Norway, Qatar, Azerbaijan, Egypt, and Israel. The next reason is that, due to the effects of the economic recession across Europe, many renewable energy projects have had to be temporarily delayed or changed plans due to capital constraints, impacting the timeline for achieving renewable energy targets. Many developers of hydrogen projects are facing challenges in accessing subsidies to support hydrogen initiatives due to the slowing funding stream and the lack of clarity in subsidy processes.

To combat climate change, promote sustainable economic growth, and improve energy security by being less reliant on external sources, the European Union has been pursuing a renewable energy transition. From the content of the European Green Deal, energy is the central focus for the transition towards climate neutrality by 2050. Renewable energy transition means switching from fossil fuels to renewable sources, improving energy efficiency in major industries, and encouraging the use of clean technologies. The European Commission promises that the investment for renewable energy in the EU will reach 396 billion euros annually from 2021 to 2023 and between 520 and 575 billion euros annually until 2050. This spending is channeled through the Recovery and Resilience Facility, cohesion policy funds, the Modernisation Fund, and several others (Agnieszka Widuto, 2023). The Green Deal also stated that the EU will target the reduction of at least 55% of net greenhouse gas emissions by 2030, equalling the 1990 level. However, the transition to renewable energy in the EU still has many obstacles that cannot be resolved in the short term. These problems became even more serious due to the energy crisis post-COVID-19 period and the geopolitical conflict worldwide. According to the European Environmental Bureau, the biggest problem hindering the transition to renewable energy is that capital for renewable energy systems is quite limited because European countries still use gas and oil as their main energy sources. Combined with the energy crisis since the Russia-Ukraine conflict, the authorities chose the short-term solution of importing gas from sources other than Russia instead of investing in long-term renewable energy projects. Fossil fuels are also the main energy source used for heating in Europe, and a complete switch to using renewable energy will cause electricity prices to skyrocket as 20 out of 27 European countries receive subsidies for fossil heating. In addition, administrative procedures and bureaucracy are also issues affecting the transition to renewable energy because European countries all have different procedures for approving the use of renewable energy, as they process information at different speeds depending on digitalization capabilities. According to the United Nations Environment Program report in 2022 about Renewable Global Status, renewable energy share in Europe was 22.1% in 2022, much higher than the figure of 12.5% worldwide. However, this number was achieved thanks to the successful implementation of renewable energy in Sweden, Finland, and Latvia, while 12 countries in the EU have yet to achieve a share of 20%.

Currently, there are many studies researching factors affecting the transition of renewable energy globally and in the region. These studies are especially interested in factors that have long-term effects, such as GDP, income level, or government decisions, such as policies, subsidies, and action programs. These studies are mostly constructed with data recorded over a long period, thereby showing the direction of the influence of those factors on renewable energy consumption and the transition from traditional energy to renewable energy. However, major energy and economic shocks can cause the factors affecting renewable energy transition to change in the short term. Limited studies were found on this issue. Some studies investigated the change in energy structure during the economic crisis in 2008, but the scope of these studies was only in a few countries or small regions. In the latest research, the impact of the COVID-19 epidemic on renewable energy consumption and renewable energy shifting became popular because of the urgency and uncertainty it brings to the government, investors, and consumers. Some studies have also shown the connection between energy or economic crises with energy consumption and the shift in energy type preference. However, the scope of these studies is on a global scale. Therefore, this study will focus on the impact of the energy crisis 2021-2023 on renewable energy transition in the EU27 region through economics, energy market, and policies. The studies also provide recommendations for the governments to make effective policy decisions on renewable energy transition to combat the current situation and prepare for crises that may occur in the future.

Chapter 2: Literature Review: Drivers of renewable energy consumption

1. Macroeconomic factors

1.1. GDP

Trying to find the perfect balance between using energy effectively to stimulate economic growth and controlling environmental degradation has long been a debate among researchers. Most of the theories and studies that determine the factors that affect energy consumption in general and renewable energy consumption are based on one of the most famous economic environmental concepts, the Environmental Kuznets Curve (EKC). The EKC concept was first introduced by Beckerman (1992) to explain the effect of economic growth on environmental degradation. He states that there is clear evidence that economic growth leads to environmental deterioration in the early stages. Still, in the end, the best and only way to attain a sustainable environment in most countries is to become rich. It means that at the beginning of an economic development phase, usually, a country must use natural resources to produce goods and services and that there will be waste accumulation due to economic activities, which leads to a positive relationship between GDP or income and environmental degradation. But with more remarkable economic growth, a country can limit the use of nature in industrialization, which results in reduced environmental consequences.

The relationship between renewable energy consumption and GDP has different degrees of significance among developed and developing countries. Still, in line with the EKC concept, most indicate a significant positive relationship. In research by Chontanawat, J (2006), causality is found from energy consumption to GDP and GDP to energy consumption for both the non-OECD group (developing countries) and the OECD group (developed countries). The results are true for both renewable and non-renewable energy consumption. Still, the causality is far more intensive for the group of developed countries. It is suggested that the causality is weak only in impoverished nations as these countries' economies are agriculture-based and might be less independent regarding energy deployment. Wang & Wang (2020) studied only the impact of renewable energy and found that increased renewable energy consumption can promote GDP growth and that the relationship is non-linear for OECD countries, which means the more these countries increase their renewable energy consumption, the more significant the effect of renewable energy consumption on GDP growth. Al-Mulali (2014) shows that for every type of energy, whether from fossil fuels or renewable energy, there is a positive correlation between energy consumption and GDP growth in the long run. However, non-renewable energy seems to have a more significant effect on all economic sectors when compared to renewable sources. The unidirectional relationship between GDP and renewable energy use is also proven by Domac et al. (2005) and (Chien & Hu, 2008), as macroeconomic efficiency can be achieved by expanding businesses and new employment opportunities in the renewable energy industry.

Divided by region, that same effect is also recognized in Asia in the studies by Yuan (2010) in China, Bayar (2014) in Asia developing countries, and Shakeel (2014) in South Asia. They all show a bidirectional relationship between electricity consumption and GDP growth: greater electricity consumption leads to a growth in GDP, and higher GDP can raise electricity consumption. However, the relationship is more short-term. Regarding the relationship between renewable energy consumption and GDP growth in China, Qi et al. (2014) stated that GDP growth has a unidirectional positive relationship with renewable energy use. This is because high economic growth can lead to higher energy demand and prices, creating favorable conditions for renewable energy adoption. Meanwhile, a slow-growing economy will depend on existing sources of non-renewable energy, such as fossil fuels, and restrict the use of renewable energy since this source becomes much less competitive in price. A study of renewable energy use and GDP in Turkey using the Granger causality finds that real GDP has a unidirectional effect on renewable energy consumption. It suggests that renewable energy demand management policies will not have a negative impact on economic growth (Ocal & Aslan, 2013). In the USA and Latin America, renewable energy consumption is strongly linked with economic activities and economic growth (Campo, 2013), and high-quality energy, such as renewable sources, is more efficient when used to produce an additional unit of the country’s wealth (Stern, 2004). Akintande et al. (2020) studied the most populous countries in Africa and found that an increase in GDP can lead to an increase in renewable energy consumption. Therefore, the government should focus on good governance and invest in economic activities to promote the use of renewable energy.

In Europe, it is suggested that the link between renewable energy consumption and GDP growth exists in the long and short run. Still, the result differs among countries based on their primary sources of energy (Caraiani et al., 2015; Menegaki, 2014; Pirlogea & Cicea, 2012). Caraiani et al. (2015) find that the short-run relationship between renewable energy consumption and GDP only exists for Hungary, Poland, and Turkey at a 1% significance level as they depend on coal consumption. However, Yu et al. (2014) and Huang et al. (2008) find no direct relationship between these countries. Acaravci & Ozturk (2010) used the F-test for the cointegration test and found that there is a long-run relationship between renewable energy consumption and real GDP per capita in Denmark, Greece, Italy, Switzerland, Portugal, Germany, and Iceland. Saint Akadiri et al. (2019) state that there is a long-run equilibrium relationship between renewable energy consumption and economic growth by examining the data set from 1995 - 2015 of EU-28 countries. The study found that a 1% increase in renewable energy consumption can increase GDP by 0.071% in the long run, but in the short run, that 1% increase will decrease GDP by 0.008% due to the cost impact of renewable energy sources. This finding is in line with the result of Marques et al. (2010), which states that the effect of GDP growth on renewable energy demand is positive and statistically significant for all EU countries; however, the effect is negative for non-EU members.

From the literature, it is evident that GDP growth and renewable energy consumption have a bidirectional impact. This can be explained by the fact that the higher GDP growth and GDP per capita, the country's citizens will have a better income level, which can help them to bear the high cost of renewable energy compliance, as well as better social and economic welfare can be achieved to promote sustainable energy development.

1.2. Trade openness

Trade openness is an important macroeconomic variable that refers to the degree of engagement of a country in international trade. Trade openness is often measured by the ratio of net trade to the country's gross domestic product, or the trade balance of the country. Energy and trade openness are closely linked, as exporting and importing goods require energy. Also, trade openness allows emerging countries to import advanced energy technologies. To examine the impact of the energy crisis in the EU, trade openness is also worth taking into account since the EU experienced the highest-ever trade deficit of €432 billion in 2022 (Eurostat, 2023). Currently, only a few studies are available regarding the causal relationship between renewable energy consumption and trade openness. Most of the existing literature uses renewable energy consumption as part of the total energy use to determine the relationship between trade openness and energy consumption, but they all yield different results. Overall, there are three dominant flows of findings in the existing literature about trade openness and renewable energy consumption.

The first flow stated that there is unidirectional causality from trade openness to renewable energy consumption in some nations. Studying the effects of trade openness and other macroeconomic variables in 23 European countries on renewable electricity production sources (combustible renewable energy, waste generation, hydropower, nuclear energy) using the Granger causality test, Al-Mulali (2014) found that trade openness can improve renewable energy generation and boost non-polluted industries in general. Basak Gul Akar (2016) used the system-GMM method to study the required determinants of renewable energy consumption in Balkan countries from 1998 through 2011. The researcher suggests that trade openness can positively affect renewable energy consumption in Balkan countries. Using the panel Granger-causality test, Odhiambo (2021) found a unidirectional causality from total export to renewable energy consumption in sub-Saharan African countries. Still, if both export and import are considered, no causality is found, even in the short-term or long-term. Nepal et al. (2021) also used the Granger test to examine the role of trade openness in providing energy security in India. They find that renewable energy consumption is caused by trade openness and other variables such as foreign direct investment and environmental sustainability in the long run. In the USA, Dogan and Turkekul (2016) found a long-run unidirectional causality relationship between trade openness and renewable energy consumption by using the VECM Granger causality test. According to the finding of Shahbaz et al. (2017), which studied the same case in the US from 1960 to 2016, there is also a one-way causality from trade openness to biomass energy consumption in the country.

While the first stream favours the causality of renewable trade openness and energy consumption, another second stream of the existing literature focuses on the opposite of how renewable energy demand can influence trade openness. However, this finding has only been found in a few studies. Considering the case of BRICS nations, Sebri & Ben-Salha (2014) use the ARDL approach and conclude that trade openness promotes renewable energy consumption positively. Trade openness helps BRICS countries benefit from sustainable energy transfer, which enables them to invest in the renewable energy sector. In Iran, a short-term causality from trade openness and renewable energy consumption is also found using the ARDL boundary test and VECM Granger causality test SK Yzadi (2014).

Between the two strands, there is an another strand believes a bidirectional relationship exists between the two factors. A study of 25 OCED countries using the Pedroni panel cointegration test and Granger causality test suggests that there is a bidirectional relationship between renewable energy and both export and import volumes of these countries in both short term and long term (Ben Jebli et al., 2015). Tiba & Frikha (2018) also explore the relationship between renewable energy consumption and trade openness in 12 high-income countries and 12 middle-income countries and find that there is a difference in the significance of the relationship between renewable energy consumption and trade openness, as well as total energy consumption and trade openness among countries. Among high-income countries, Canada and Sweden have a significantly positive relationship for total energy consumption. At the same time, Portugal and Spain record a negative impact of trade openness on energy consumption. The rest of the countries find no relationship between trade openness and energy demand. For developing countries, the significance of trade to energy consumption is even smaller, as the only country where the authors find a positive relationship is Brazil. In those 24 countries, a bidirectional relationship between renewable energy consumption and trade openness is found in the long run in Sweden, China, and the UK. The hypothesis that a long-run bidirectional relationship between trade openness and renewable energy is also confirmed by Dogan & Seker (2016) as the researcher studied that relationship in 23 top-level renewable energy-consuming countries using the Pedroni, Kao, and LM bootstrap panel cointegration test. Shahbaz et al. (2014) concluded that a cointegration relationship exists between trade openness and renewable energy consumption in high, middle, and low-income countries. This relationship is an inverted U-shape in high-income countries, implying that at the beginning, a 1% increase in trade openness raises renewable energy consumption by 0.86%. Still, after a threshold level, trade openness can cause a decline in renewable energy consumption due to the adoption of new technologies. On the other hand, in low and middle-income countries, the relationship is U-shaped as trade openness decreases renewable energy consumption at first, but then the renewable energy consumption will increase thanks to a country's trade openness.

2. Environmental factors

An extension of the existing EKC concept, the environment-growth-renewable energy nexus, has been widely used to assess the potential of renewable energy development in cutting the carbon footprint. Much literature supports the idea that CO2 emissions can positively affect renewable energy consumption in the long run and that renewable energy somewhat impacts carbon emissions. However, the results vary across different countries and periods. Some studies even find a bidirectional relationship between the two variables.

Salim & Rafiq (2012) studied the determinants of renewable energy consumption in Brazil, China, India, Indonesia, the Philippines, and Turkey and found that, except for the Philippines and Turkey, the carbon emission level has a positive effect on renewable energy consumption in the long run. To be specific, an increase of 1% in CO_2 emission leads to a 0.033% increase in renewable energy consumption. In Brazil and China, a bidirectional relationship between renewable energy consumption and pollutant emission levels is found in the short run. Using the vector error correction model and the Granger causality test to examine the relationship between CO_2 emissions and multiple other variables in Tunisia in the period of 1980 - 2011, a unidirectional causality running from CO_2 emissions to renewable energy is found in the short run. A bidirectional relationship is found in the long run (Jebli and Youssef, 2017). In Nordic countries, Irandoust (2016) indicates a causal relationship running from renewable energy to CO_2 emissions in Denmark and Finland, while in Sweden and Norway, a bidirectional causality relationship is found even though the degree of significance levels differ across countries. This suggests that the increasing use of renewable energy sources can mitigate CO_2 emissions in Denmark and Finland. Still, in Sweden and Norway, carbon dioxide emissions can also help to boost the demand for renewable energy. It is also suggested that there is a significant relationship between technological innovation and renewable energy in these countries since Nordic nations have the highest technical index in alternative energy, but no causality between renewable energy and GDP was found. Farhani & Shahbaz (2014) studied 10 Middle Eastern countries and North African countries (MENA region) from 1980 to 2009 using the Fully Modified Ordinary Least Squares and Dynamic Ordinary Least Squares. He shows that there is an unidirectional causality running from renewable energy consumption and output to CO_2 emissions in the short run. Still, in the long run, this is a bidirectional causality.

A study Saharan Africa's ten largest electricity generators found that there is a long-run relationship between carbon dioxide emission level and renewable energy consumption, as well as real income, non-renewable energy consumption, and trade openness. In which the researchers stated that CO_2 emissions with respect to renewable energy have an elasticity of 0.34%, which indicates the increase in renewable energy consumption can help to slow down the process of environmental degradation (Inglesi-Lotz & Dogan, 2018). The same unidirectional relationship running from carbon dioxide emission level to renewable energy demand was also found in a study in China, but only in the short run. The study concluded that CO_2 emission can cause renewable energy consumption at a significant level of 5%, which means an increase in the level of CO_2 can promote the use of renewable energy since the government will take energy measures to prevent environmental degradation (Chen et al., 2019). Omri & Nguyen (2014) also studied the case of China and found that CO_2 emission is one of the determinants of renewable energy consumption. The higher the carbon dioxide level, the more favorable conditions will be set to promote renewable energy. Sadorsky (2009) studied the determinants of renewable energy consumption in G7 countries by using the FMOLS and DOLS methods. The study found that CO_2 levels have a positive impact on promoting the use of renewable energy in most countries at various levels, but the most significant results were observed in the case of France and the UK, which a 1% increase in carbon dioxide emissions per person can bring renewable energy consumption per capita by 5.23%. However, a negative relationship was found in Japan. Some other studies also found this negative relationship between CO2 emissions and renewable energy consumption. For example, Bilgili et al. (2016) used 17 OECD countries' annual data from 1977 to 2010 to test the validity of the EKC concept and suggest that CO2 emissions are negatively correlated with renewable energy consumption. Study the case in Europe, Marques et al. (2010) also found a negative relationship between carbon dioxide emissions and renewable energy deployment, which means the higher the emission level, the smaller the commitment to renewable energy development.

Some studies indicate that renewable energy, in both the short run and the long run, does not affect CO2 emissions. By examining the group of 19 developed and developing countries from 1984 to 2007 using the panel error correction model, Apergis et al. (2010) suggest a long-run statistically significant negative relationship between nuclear energy consumption and emission. Still, there is a positive relationship between renewable energy consumption and emissions. The study found that nuclear energy can reduce CO2 emissions in the short run. Still, renewable energy does not reduce the emission level due to the lack of technology to produce massive amounts to meet the demand. This conclusion is also supported by studies in the USA from 1960 to 2007 and in France from 1960 - 2003 that there is a unidirectional causality running from nuclear energy consumption to CO2 emission (Iwata et al., 2010), but no causality from renewable energy to CO2 emission is found as renewable energy consumption has not reached a certain level where it can have a significant effect on the environment at the time of study (Menyah & Wolde-Rufael, 2010). A study by Payne (2012) finds no causal relationship between CO2 emission and renewable energy consumption in the US from 1949 to 2009. The study suggests that an unexpected shock to CO2 emission can positively affect renewable energy demand. However, with the Autoregressive distributed lag cointegration approach, a long-run negative unidirectional relationship running from renewable energy use and CO2 emission in Algeria from 1980 to 2012 is found. However, the study is still in favor of renewable energy generation, which cannot significantly contribute to CO2 emission due to insufficient level of generation (Bélaïd & Youssef, 2017).

3. Non-renewable energy prices

Other types of non-renewable energy, such as fossil fuels like oil, are some of the most likely substitutes for renewable energy. The demand for oil and natural gas energy will depend on the global price of these fossil fuels. Therefore, an increase in oil prices will result in a lower demand for non-renewable energy. In this case, countries will seek alternative energy sources that are less expensive and more efficient, such as renewable energy. Many studies have used oil prices as a determinant of renewable energy consumption. However, some have shown that the correlation is not always significant and positive.

A study in Central American countries from 1980 to 2010 found a unidirectional correlation between coal and oil prices and renewable energy consumption. An increase of 1% in coal price leads to a 0.153% in renewable energy consumption per capita, and an increase of 1% in oil prices can increase renewable energy consumption even further by 0.285% per capita (Apergis & Payne, 2014). Studying the 53 most renewable energy-consuming countries, Ponce et al.

(2020) found a statistically significant positive relationship between non-renewable energy prices and renewable energy consumption in both middle-high-income countries and low-middle-income countries. Though it promotes the use of clean energy sources, the increase in non-renewable energy prices does not reduce the consumption of non-renewable energy. In the OECD, between 1990 and 2017, a study also found that the price of non-renewable energy is positively related to renewable energy consumption. More specifically, a 1% increase in non-renewable energy price can cause an increase of 0.829% in renewable energy consumption in the long run and 0.422% in the short run (Li et al., 2020). A newer study found that an increase in oil prices can increase renewable energy consumption in developed and developing countries by around 2.5%. However, the positive relationship is more powerful in non-democratic countries but is less significant in democratic countries (Chen et al., 2021). In the United States - the world's largest crude oil-consuming country, researchers also found that a rise in oil prices can increase the use of renewable energy. Lower crude oil prices can reduce the attractiveness of renewable energy consumption, both in the long run and in the short run (Sahu et al., 2022).

On the other hand, a famous study by Sadorsky (2009) concluded that oil prices have a significantly negative impact on renewable energy consumption in G7 countries. The same finding was further supported by Omri & Nguyen (2014), who found that oil prices can even have a significantly negative impact on renewable energy consumption in middle-income countries as well as on the global scale, but have no significant effect in both high-income and low-income countries. This was potentially due to the ability to avoid the oil price risk through appropriate energy conservation policies of high-income countries or switching to cheaper fossil fuels such as coal in low-income countries. When examining the effects of oil price shocks in South Asian countries, Munhasir & Muntaha (2020) were also in favor of the idea that raising crude oil prices by 1% can lead to a decrease of around 2.35% to 3.59% in renewable energy consumption, especially in oil-importing countries. However, if oil price hikes reach a level of USD 136 per barrel (USD 2016 base price), then a 1% increase can actually facilitate renewable energy consumption by 0.1% - 0.14%. Also, in an oil-exporting country such as Russia, the researchers came to the same conclusion that oil prices can negatively affect renewable energy consumption (Karacan et al., 2020).

4. Renewable energy policies

Many countries worldwide have used policies to encourage investment in renewable energy and increase renewable energy consumption. Renewable energy policies can be divided into two main types: those based on financial incentives and those based on the Renewable Portfolio Standard (Safwat Kabel et al., 2019). Financial incentives are defined as offers that help make renewable energy systems more accessible and cheaper to purchase (Ciarreta et al., 2017), helping consumers and businesses overcome price barriers and reduce risks while investing in renewable energy projects (Hogg & Regan, 2010; Cox, 2014). Renewable Portfolio Standard is a requirement for consumers, retailers, or producers to increase the use of renewable energy to a certain target in their portfolio to encourage the use of renewable energy (Jager et al., 2011).

The main financial incentives applied to renewable energy are tax incentives, loans, and feed-in tariffs. Studying tax exemption, rebates, and lower tax rate policies in EU-27 countries, Cansino et al. (2010) point out that tax incentive policies have a positive impact on the green energy transition, but there is no one-size-fits-all approach to tax incentives for promoting green electricity. Implementing tax incentives in the EU can promote renewable energy transition at a continental scale but might face challenges due to the adoption abilities of member-state countries. Therefore, these policies must be implemented continuously in the medium or long term. El-Karmi & Abu-Shikhah (2013) point out the importance of financial incentives in a case from Jordan. In particular, financial incentives are an effective tool to increase investment in renewable energy technology. However, these incentives must be combined with other economic incentives because tax rates have little impact on renewable energy projects' return rate and net present value. Therefore, it is recommended that attention should be given to indirect taxation and exemption for renewable energy investors. Bobinaite & Tarvydas (2014) agree that feed-in tariff incentives play a crucial role in encouraging renewable energy consumption, and financing instruments for the renewable energy sector are different for developing countries and developed countries and the level of development of the renewable energy sector. In particular, developed countries can receive funds from the government, banks, venture capital funds, private equity funds, pension funds, and sovereign funds. In contrast, developing countries' renewable energy funds depend on governments, multilateral development banks, regional development banks, and commercial banks.

Many other researchers have also studied the Renewable Portfolio Standard as a central tool for increasing renewable energy consumption and generation. Joshi (2021) examines the impacts of the Renewable Portfolio Standard (RPS) on renewable electricity capacity and consumption using renewable energy data from 47 states in the USA between 1990 and 2014 and found that RPS positively influences non-hydro renewable energy use. The same finding was found in the case of China’s renewable energy sector, as RPS can effectively reduce carbon emissions and positively affect renewable energy promotion (Yan et al., 2022)

In Europe, renewable energy policy first appeared in 1991 when Germany introduced the first feed-in tariff for renewables. Since then, the transition to renewable energy has been included in EU policies and economic goals and is continuously updated to suit the region's situation. The Renewable Energy Directive (RED) and The European Green Deal are two of the most important policies. They all combine financial incentives and renewable portfolio standards as the main tools to control the transition to renewable energy.

The first notable renewable energy policy and one of the legal frameworks that paved the way for future EU renewable energy policies is the Renewable Energy Directive (RED). RED's main goal is the development of clean energy across all sectors of the EU economy, supporting cooperation between EU countries towards this goal (European Commission, 2023). In 2010, RED set an ambitious target to reduce greenhouse gas emissions in the EU by at least 20% by 2020, increase the share of final renewable energy consumption to at least 20%, and achieve energy savings of at least 20%. European Union member states must ensure that 10% of transport energy consumption comes from renewable energy. From there, RED aims to ensure energy security in the EU, cope with climate change, and reduce dependence on foreign fossil energy resources. RED also offers many mechanisms for member countries to achieve this lofty goal, such as support schemes, guarantees of origin, joint projects, cooperation with third countries, and biofuel sustainability criteria. Since RED was introduced, the share of renewable energy consumption in the EU increased by 10.5%, from 12.5% in 2010 to 23% in 2022, with the leading countries of Sweden (66%), Finland (47.9%) and Latvia (43.4%) (Eurostat, 2023).

In December 2018, the RED was revised and became the national law of EU countries in June 2021 to speed up the transition process. In particular, the target for the share of renewable energy consumption was increased to 32%, and at the same time, the share of renewable fuels in transport is increased to 14% by 2030. Next, to cope with changes after the COVID-19 pandemic and political instability around the world, in October 2023, a target of share of renewable energy is revised to 42.5% by 2030. The target for the transportation energy consumption of renewables is also to increase to 29% by 2030, thanks to the greater use of advanced renewable fuels. In addition, 5% of newly installed renewable energy capacity will be from innovative technologies by 2023. Many other targets are also set for each specific industry, mainly focusing on increasing the proportion of renewable energy consumption by 1.6% each year. Member states must set their national targets for renewable energy use to contribute to the overall EU target. These are called the National Renewable Energy Action Plans (NREAPs). These targets are established based on each country's circumstances and potential for renewable energy deployment. The new directive will support this process by speeding up the licensing time for renewable energy plant projects such as solar energy and wind turbines to 12 to 24 months.

EU countries agreed on the European Green Deal in November 2019. This Agreement focuses mainly on energy, global climate change, and environmental issues. The deal aims to achieve climate neutrality by 2050 under the Paris Agreement. The European Green Deal has set many ambitious targets, of which the most important are three main issues: reducing net greenhouse gas emissions by 55% compared to 1990 by 2030, planting at least 3 billion new trees in the EU, and becoming the first climate-neutral continent by 2050. The European Green Deal also offers many solutions and specific timelines to achieve this goal. These solutions focus mainly on transforming the energy system because 75% of the EU's greenhouse gas emissions come from energy production and use.

The most prominent solution of the European Green Deal is REPowerEU. REPowerEU was implemented in May 2022 to help the EU save energy, produce clean energy, and diversify its energy supply, thereby ensuring energy security, coping with energy attacks from Russia, and contributing to the renewable energy transition. First, REPowerEU diversifies the EU's energy supply by establishing agreements with other third countries for pipeline imports, investing in Liquefied Natural Gas (LNG), strengthening relationships with renewable hydrogen exporting countries such as Namibia, Egypt, and Kazakhstan, and other natural gas exporters such as Egypt and Israel. Initially, the EU's calculations yielded results when Russian imported pipeline gas in the EU decreased from 41% in 2021 to 8% by the end of 2022 (Eurostat, 2023). Next, to preserve the necessary energy sources for production and consumption, the EU has increased gas reserves to over 90% while reducing gas consumption across Europe by at least 15%.

In conclusion, the drivers of renewable energy consumption focus on macroeconomic factors such as GDP, trade openness, environmental considerations, non-renewable energy prices, and renewable energy policies. The EKC theory has been a central framework, suggesting a positive relationship between GDP and renewable energy consumption, particularly in developed countries. Trade openness has emerged as another significant macroeconomic factor influencing renewable energy consumption. However, the relationship varies between nations. CO2 emissions used to measure the quality of environmental factors have also been identified as drivers of renewable energy consumption. Non-renewable energy prices play a crucial role in shaping renewable energy consumption patterns. Renewable energy policies, including financial incentives and Renewable Portfolio Standards, have promoted renewable energy consumption worldwide, with some studies highlighting their positive impact on renewable energy uptake. However, the drivers of renewable energy consumption in previous literature reviews were focused on a longitudinal period without considering the shocks of, for example, economic or energy shocks.

Chapter 3: Methodology

1. Quantitative descriptive analysis

This study will analyze the impact of the energy crisis on the renewable energy transition in EU27 countries through descriptive analysis of the collected data mentioned above. This descriptive analysis will transform the raw data into understandable and readable formats, which are charts and tables. Using this method, data can be presented and interpreted to find the change in patterns in the energy crisis period. Thus, the patterns can give valuable insights into the renewable energy transition amidst the energy crisis. These visualizations also facilitate clear communication of the research findings to stakeholders and policymakers.

To analyze the data, besides visual presentation, text description is also used to describe the data, therefore providing a comprehensive view of the data. The text description will include trends found in the data, patterns within the same dataset and different datasets to find their relationships and the key developments observed in the data. Statistical analysis is also used to quantify and summarize the raw data. This includes mean calculation and percentage change calculation by month, by quarter, and by year. These mean values provide insights into the average trends and magnitudes of various factors affecting the renewable energy transition amidst the energy crisis.

In order to assess the effectiveness of policies implemented during the energy crisis, a statistical test, named the T-test, is also used to compare the means of the two periods, before and after the policies. The t-test, also known as t-statistic or sometimes t-distribution, is a popular statistical tool used to test differences between the means (averages) of two groups or the difference between one group's mean and a standard value (Qualtrics, 2024). In this case, the T-test is applied to compare the average values of electricity generation from solar energy and hydrogen energy from two periods: before and after implementing energy policies during the energy crisis. The T-test helps provide a clear statistical basis to see if the policy led to significant differences in the usage of renewable energy in electricity generation. Therefore, we can evaluate the effectiveness of the policy in reducing reliance on non-renewable energy sources and boosting renewable energy usage. The T-test is suitable for this policy evaluation as it fits the relatively small sample size of the monthly electricity generation chosen. The T-test is also sensitive to the changes in value, and the results are straightforward to interpret.

2. Data collection

The research problem was analyzed based on the indicators available for economic growth, trade openness (import and export), environmental and energy indicators, and renewable monitoring indicators gathered from Eurostat and the International Energy Agency of 27 EU countries. In order to evaluate the trends in renewable energy transition in EU27, several statistical data were collected, and then a database was created in MS Excel. The following indicators were taken into account:

Impact on	**Category**	**Indicators**	**Data Details**	**Time Period**
Economy and trade	Economic Indicators	GDP growth of EU27 countries	Quarterly data	2018 - 2022
	General Trade Indicators	Export turnover Export turnover year-on-year growth Trade balance of EU27 countries	Quarterly data	2018 - 2022
	Energy Trade Indicators	Gas import volume to EU27 countries by partner and Russia, including crude oil and petroleum products, natural gas, solid fuels, electricity	Monthly data	2018 - 2022
	Energy Indicators	Electricity and gas price for household consumers by band (tax and levies excluded)	Bi-annually data	2018 - 2022
Environment	Environmental Indicators	Air emissions account for greenhouse gases	Monthly data	2018 - 2022
Renewable energy transition	Non-renewable energy supply	Energy supply by primary sources, thousand tonnes of oil equivalent	Annually data	2011 - 2022
	Non-renewable energy demand	Final energy consumption by primary sources, thousand tonnes of oil equivalent	Annually data	2011 - 2022
	Natural gas import volume	Pipeline gas and liquefied natural gas (LNG) import volume, annual data	Annually data	2013 - 2022

	Renewable energy investment cost	Solar PV and onshore wind investment cost estimates for newly contracted projects under high commodity prices	Annually data	2015 - 2022
	Renewable Energy Adoption Indicators	Percentage of renewable energy use in electricity and heating and cooling	Annually data	2004 - 2023
Policies and actions	Effectiveness of policies	Changes in electricity generation from solar energy and hydrogen energy	Monthly data	2018 - 2023

The study period is mainly from 2018 to 2022, in order to deeply analyze and find the change in patterns during the energy crisis period. However, data from 2011 to 2022 is also collected for a general analysis of the renewable energy transition in Europe. The subject “EU27” represents twenty-seven countries in the European Union, which include Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czechia (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Greece (GR), Spain (ES), Ireland (IE), Lithuania (LT), Luxembourg (LU), Latvia (LV), Malta (MT), the Netherlands (NL), Germany (DE), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Sweden (SE), Hungary (HU), and Italy (IT).

3. Research question

This study analyzes the impact of those factors from a pre-energy crisis and post-energy crisis perspective. The research aims to investigate the impact of the energy crisis in Europe on the factors that influence renewable energy consumption. The proposed research questions are:

(1) How does the energy crisis impact the overall economic growth in EU countries?

(2) How does the energy crisis impact renewable energy consumption in EU countries?

(3) What energy policies were implemented during the energy crisis in EU countries?

(4) What lessons are learned and outlook for renewable energy deployment in EU countries?

Chapter 4: Empirical Results

1. Impact of the energy crisis on the overall macroeconomics in EU countries

Before the COVID-19 pandemic and the energy crisis began, Russia was the EU27's largest partner in natural gas imports, especially natural gas pipelines. According to Figure 1, in 2018, natural gas imports from Russia accounted for about 9% to 14% of the entire amount of natural gas imported into the EU27 each month, estimated at an average of 11.2% per month. However, by July 2022, Russia strategically exploited this dependency of the EU27 on its natural gas supply to address political issues stemming from the Russia-Ukraine conflict. This was evidenced by Russia's gradual reduction of gas volume exports to the EU27 via the Nord Stream 1 pipeline. Consequently, significant disruptions were observed in the EU27 energy market during the third quarter of 2022. In Figure 1, it can be seen that July 2022 recorded a decrease in the amount of natural gas imported from Russia. From the monthly natural gas imports from Russia at 6,000 million cubic tonnes to 7,600 million cubic tonnes, the figure drops to only 2,000 million cubic tonnes to 3,000 million cubic tonnes from July 2022 to December 2022, a 3-fold decrease. Therefore, the share of Russian natural gas imports to EU27 dropped to a record low of only 4-5% per month. As a result, by the end of 2022, the total amount of natural gas imported into the EU27 in December 2022 also decreased sharply by 16.8% compared to the same period in 2021, causing a shortage of energy supply for consumers and production, leading to an energy price crisis at the end of 2022 shown in Figure 2.

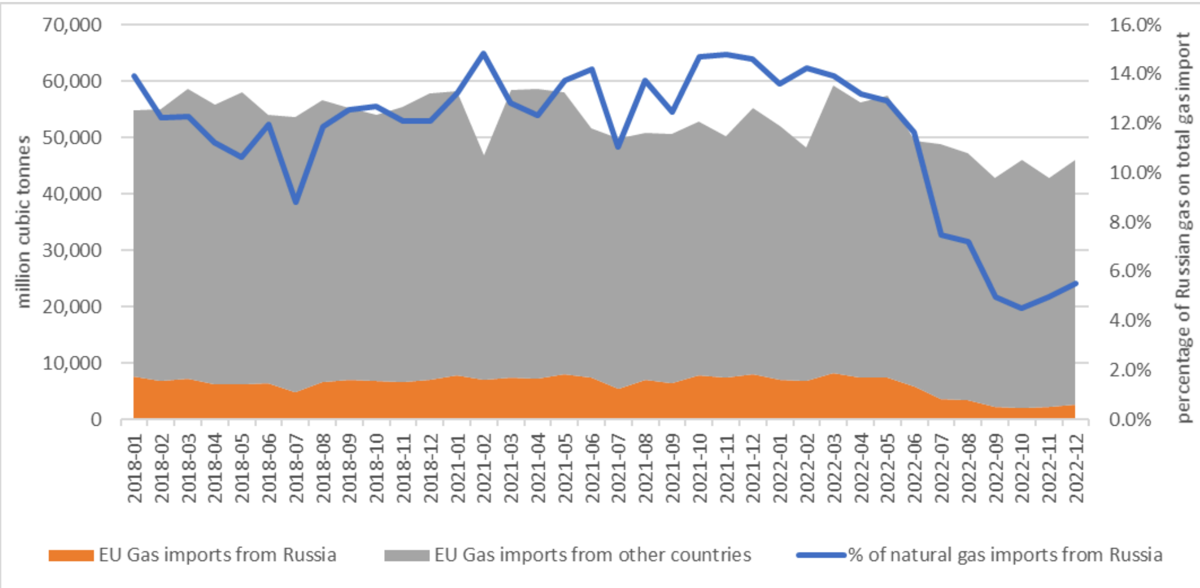

Figure 1: Gas imports to EU27 by partners, monthly data (Eurostat, 2024), (Data code: nrg_ti_gasm)

Figure 2: Dutch TTF Gas price (euros per megawatt hour) from Jun 2019 to April 2024 (Barchart, 2024)

Before 2018, electricity and natural gas prices in the EU27, excluding tax and levies factors, only fluctuated slightly according to the inflation rate. Electricity prices for household consumers in the DA band (consumption less than 1,000 kWh) averaged €0.273 per kWh from 2018 to the first half of 2021. Gas prices fluctuated quite similarly and were stable at an average of €0.076 per GJ (data is for band D1 - consumption less than 20 GJ) from 2018 to the first half of 2021. However, starting from the second half of 2021, when global supply chains showed disruption and conflict began to heat up between Russia and Ukraine, the energy market responded to the risk of partial or total gas cuts from Russia. Compared to the first half of 2021, electricity prices in the first half of 2022 increased by 26.7% to €0.347 per KWh (DA band). Natural gas prices in the first half of 2022 reacted even more violently, increasing by 41.0% year-on-year, reaching €0.898 per GJ (band D1). When the official information about cutting the supply of natural gas from Russia was announced, electricity prices in the second half of 2022 continued to increase sharply to €0.385 per KWh (band DA), an increase of 110.9% compared to the first half of 2022 and increased by 136.9% year-on-year. Due to the direct impact of supply disruptions, natural gas prices in the second half of 2022 increased to a record level of €0.136 per GJ (band D1), an increase of 51.3% compared to the first half of 2022 and 155.1% over the same period in 2021.

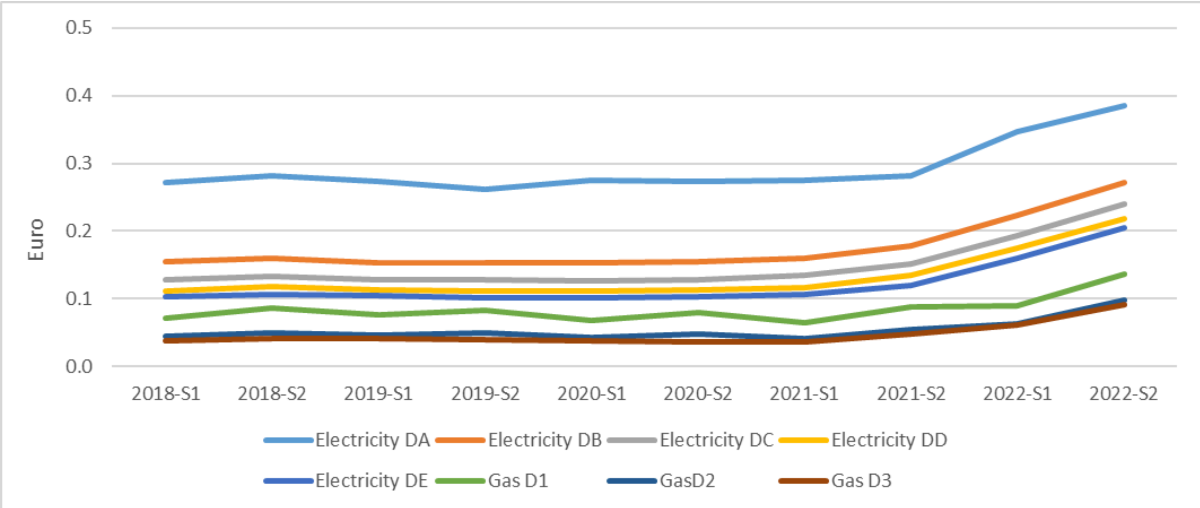

Figure 3: EU27 Electricity and gas price for household consumer by band, bi-annually data (tax and levies excluded) (Eurostat, 2024), (Data code: nrg_pc_202; nrg_pc_204)

The average quarterly GDP growth of EU27 countries over the previous year reached about 3.55% in 2018. By the end of 2019, the total GDP of the entire EU27 reached 3,545,255 million euros. The trade balance remained stable at 125,052 million euros per quarter, with export turnover growing steadily from 2018 to 2019. In 2020, especially in the second quarter, the EU economy encountered a big shock from the Covid-19 epidemic. GDP and export growth plummeted to negative growth from the first quarter of 2020 and lasted until the end of the third quarter of 2020 due to lockdown policies to respond to the pandemic. Despite using budgetary easing and economic supporting measures during the pandemic, the real GDP of the EU27 still decreased by 5.7% in 2020 compared to the previous year.

In 2021, thanks to vaccine programs and the gradual easing of restrictions, the EU's GDP grew 5.4% y-o-y. In 2022, EU27 recorded full-year GDP growth at 3.61% y-o-y. However, this growth largely owes itself to the momentum of the economic rebound after the low GDP growth rate in the COVID-19 period. By the end of 2022, when the energy crisis began to erupt across Europe, the region's economy and commodity exports showed clear abruptions. Combined with disrupted global supply chains, high inflation rates, and tightening monetary policies, the economy stagnated from 2022 to 2023, with GDP growth in 2023 at only 0.5% y-o-y. It can be seen that the energy crisis that started in July 2022 has directly affected the economy of the EU27. If in the first and second quarters of 2022, quarterly GDP growth increased by 2.2% on average, compared to the previous quarter, and by 9.5% over the same period last year, the third quarter of 2022 only recorded an increase of 1.5% compared to the previous quarter and 7.9% over the same period in 2021. The energy crisis continued until the fourth quarter of 2022, with quarterly GDP growth only increasing by 1.7% over the previous quarter and 7.9% over the same period last year. Import-export activities were extremely severely affected. In the third quarter of 2022, EU27 export growth only reached an increase of 3.4% compared to the previous quarter, much lower than the average increase of 4.6% in 2021. By the fourth quarter of 2022, quarterly export growth had decreased to a negative figure of -0.63% compared to the previous quarter. The EU27's quarterly exports from 2018 to 2022 only recorded negative growth twice: one was during the pandemic lockdown period, and the other was when the energy crisis began to break out. The quarterly trade balance was also affected, recording a low of only 36,940 million euros, lower than during the COVID-19 lockdown period.

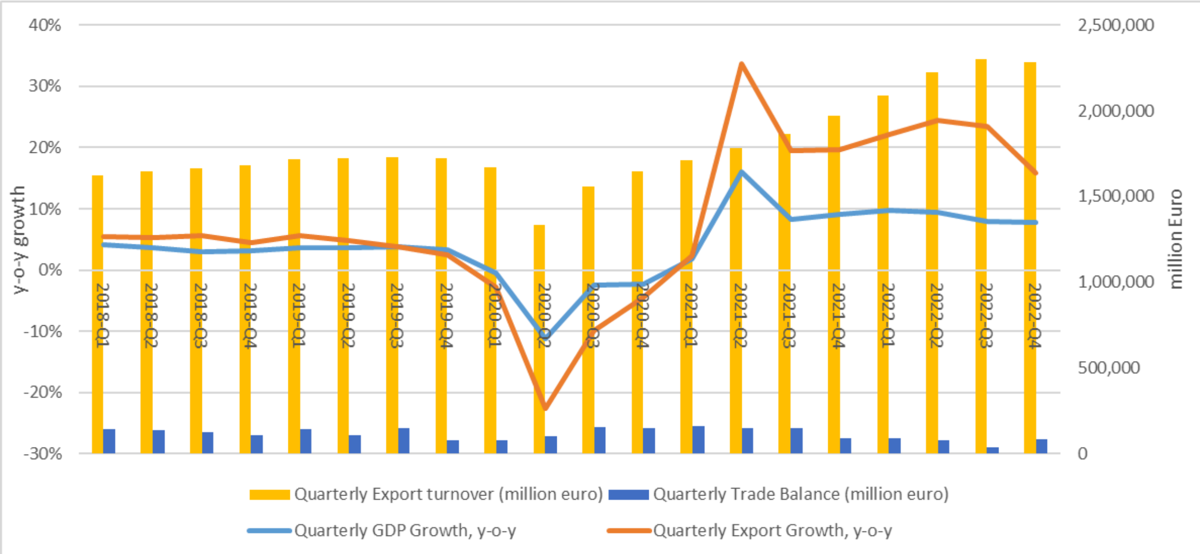

Figure 4: EU27 GDP growth and trade indicators, quarterly data (Eurostat, 2024), (Data code: namq_10_exi; namq_10_gdp)

In conclusion, the energy crisis sparked by Russia's diminished supply of natural gas exports to the EU27 resulted in disruptions to the region's energy market, a significant supply shortage, and a sharp escalation in energy prices by the end of 2022. This crisis, compounded by the lingering effects of the COVID-19 pandemic, imposed an economic strain on the EU27, leading to lagging GDP growth rates and slowing exports. The crisis emphasized the EU27's vulnerability to external energy dependencies and the urgent need for diversified energy sources and resilient energy policies.

2. Impact of the energy crisis on greenhouse gas emissions in EU countries

In general, greenhouse gas emissions in the EU27 have continuously decreased since 2010. In terms of air emissions account for greenhouse gas emissions, from a high of 1,168,889 thousand tonnes in the first quarter of 2011, greenhouse gas emissions have decreased continuously, averaging 1.74% year-over-year from 2011 to 2015 and 1.07% from 2016 to 2019. By 2020, due to the tremendous impact of the COVID-19 epidemic, greenhouse gas emissions from air emissions decreased sharply by 9.09% compared to 2019. However, along with the economic recovery in 2021, greenhouse emissions from air emissions increased by 5.96% compared to 2020. This increase has caused the average air emission per capita in EU27 in 2021 to increase to 2.05 tonnes, an increase of 5.4% compared to 2020 but still 4.9% lower than 2019.

In 2022, according to Figure 5, the amount of greenhouse gas emissions in the first quarter increased slightly by 1.7% compared to the same period in 2021. However, since Russia began to gradually reduce the amount of natural gas exported to the EU in the second quarter of 2022 and completely cut off in August 2022, greenhouse gas emissions in the second quarter, third quarter, and fourth quarter of 2022 all decreased compared to the same period in 2021, at 0.2%, 0.9% and 5.8% respectively. In the fourth quarter of 2022, the activities that saw the most significant reductions in greenhouse gas emissions were electricity, gas, steam, and air conditioning supply (-9.2%), manufacturing (-9.0%), and construction (-9.2%). The only three sectors that saw an increase compared to last year were mining and quarrying (+3.3%), waste supply (+2.4%), and transportation and storage (+2.1%). Thanks to this reduction, air emissions account for greenhouse gas emissions per capita in 2022 decreased to 2.01 thousand tonnes, the lowest level ever since 2020. Thus, the energy crisis impacts greenhouse gas emissions from all economic activities, especially energy-intensive sectors such as manufacturing, power generation, and transportation. The decrease in greenhouse gas emissions in the electricity, gas, steam, and air conditioning supply also emphasizes the transition from non-renewable to renewable resources to generate these necessities in the EU27 countries.

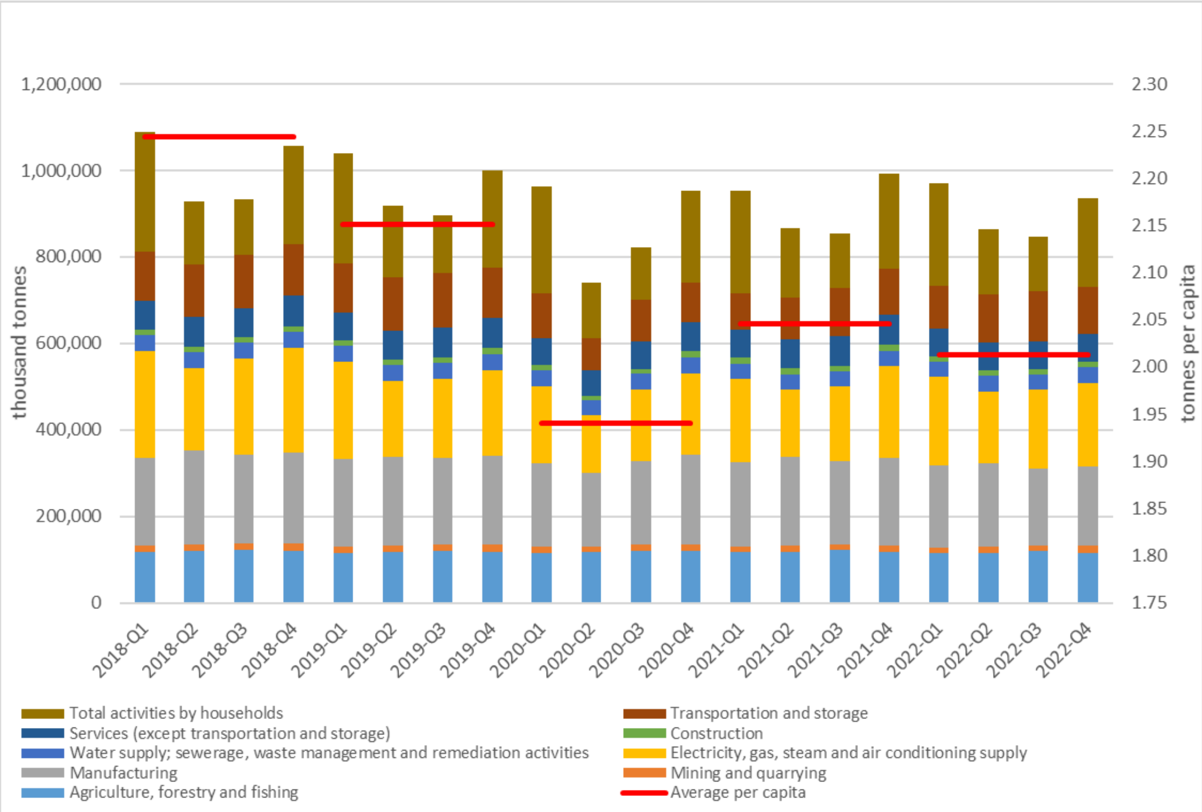

Figure 5: Air emissions account for greenhouse gases, monthly data (Eurostat, 2024), (Data code: env_ac_aigg_q)

3. Impact of the energy crisis on renewable energy transition in EU countries

3.1. Impact on the renewable energy supply

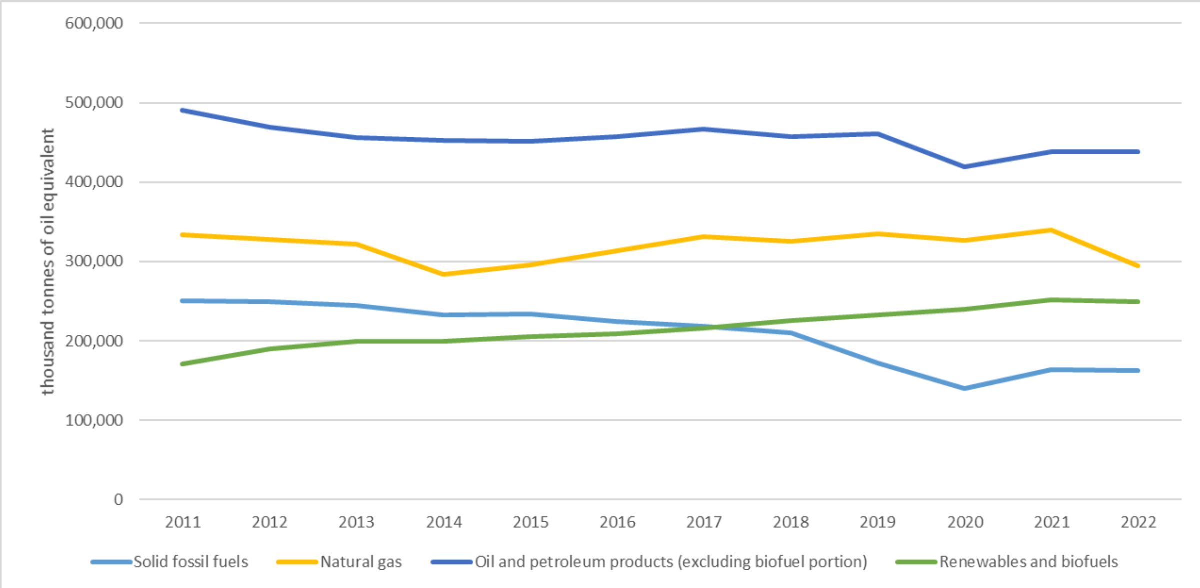

Figure 6: Total energy supply by primary sources, thousand tonnes of oil equivalent (Eurostat, 2024), (Data code: ten00122)

According to Figure 6, solid fossil fuels supply in 2011 - 2019 shows a general decreasing trend over the years thanks to the EU27's policies gradually eliminating dependence on polluting fossil fuels and the development of renewable energy generation. From 2011 to 2019, there was a notable decline in consumption, dropping from 250,502 to 171,825 thousand tonnes of oil equivalent, which decreased 31.5%. The oil and petroleum products supply has decreased slightly over the past 12 years but remains high and plays an essential role in the EU energy system. If, on average, in 2011-2020, the supply of solid fossil fuels decreased by 6.0% per year, then the supply of oil and petroleum products only decreased by an average of 1.7% per year. In 2022, both solid fossil fuels and oil supply remained stable, as EU countries have quickly sought energy trade partners other than Russia to make up for the increase in energy imports with this country.

While the two non-renewable energy sources mentioned above have both tended to decrease over the past decade, the natural gas supply in EU27 generally remains relatively stable over the years until a sharp decrease of 13.2% y-o-y in 2022 due to the impact of supply disruption from Russia. Figure 7 shows that the import volume of both natural pipeline gas and liquefied natural gas (LNG) in 2022 increased compared to the previous year. To cope with the energy shortage caused by the energy crisis, the EU has increased cooperation with other countries to ensure adequate imports of natural pipeline gas and replace natural pipeline gas with LNG. With the advantage of easy transportation and more energy-dense than natural pipeline gas, LNG became the type of natural gas that the EU focused on importing in 2022, with import volume increasing by 70.1% compared to 2021. Meanwhile, the volume of natural pipeline gas imports increased slightly to 8.3%. As mentioned above, LNG imported into the EU mainly comes from the US, Norway, North Africa, and Azerbaijan. It is expected that LNG supply worldwide and the amount of LNG imported into the EU will continue to increase rapidly, thanks to increased production capacities of LNG exporters. On the EU side, Member States are increasing LNG import capacity by constructing many LNG regasification and port terminals to ensure a steady supply and prepare for supply interruptions that may occur if the war between Russia and Ukraine continues to drag on. Specifically, the EU's LNG import capacity has increased by 40 bcm in 2023 and is expected to increase by 30 bcm in 2024 (Eurostat, 2023). However, the EU's natural gas supply generally declined in 2022 due to a sharp decline in domestic production, mainly from the reductions in the Netherlands - the EU’s largest gas producer. Specifically, at the Groningen gas field, natural gas production decreased by up to 2 bcm, equivalent to a reduction of 30% in the first 9 months of 2022 (IEA, 2022).

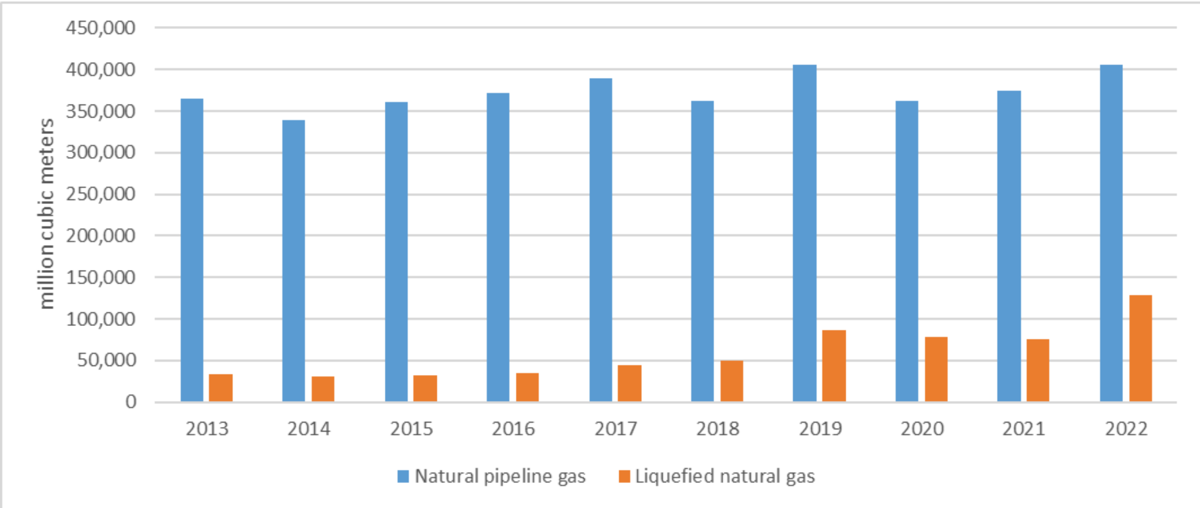

Figure 7: EU27 pipeline gas and liquefied natural gas (LNG) imports volume, annual data (Eurostat, 2024), (Data code: nrg_ti_gas)

If, over the past decade, the non-renewable energy supply has decreased gradually, the renewable energy supply has grown steadily, except for a slight decrease in 2022. From 2011 to 2021, the EU's renewable energy supply increased by 4.0% per year on average. In particular, in 2011 and 2021, the growth rate of the EU's renewable energy supply increased dramatically, at 10.6% and 5.2%, respectively, thanks to the announcement of renewable energy policies such as RED in 2010 and the European Green Deal in 2020. This growth has helped renewable energy surpass solid fossil fuels and become the EU's third most significant energy source. 2022 is the only year to record negative renewable energy supply growth since 2011, with a decrease of 1.3% compared to 2021. Even though in 2022, the combined energy generated by solar energy, onshore wind, and offshore wind increased by 14%, hydro generation dropped by 17% due to the drought in the summer. The decrease in the overall renewable energy supply was also caused by high investment costs for renewable energy projects and supply chain difficulties, which directly affect the price of materials for these projects.

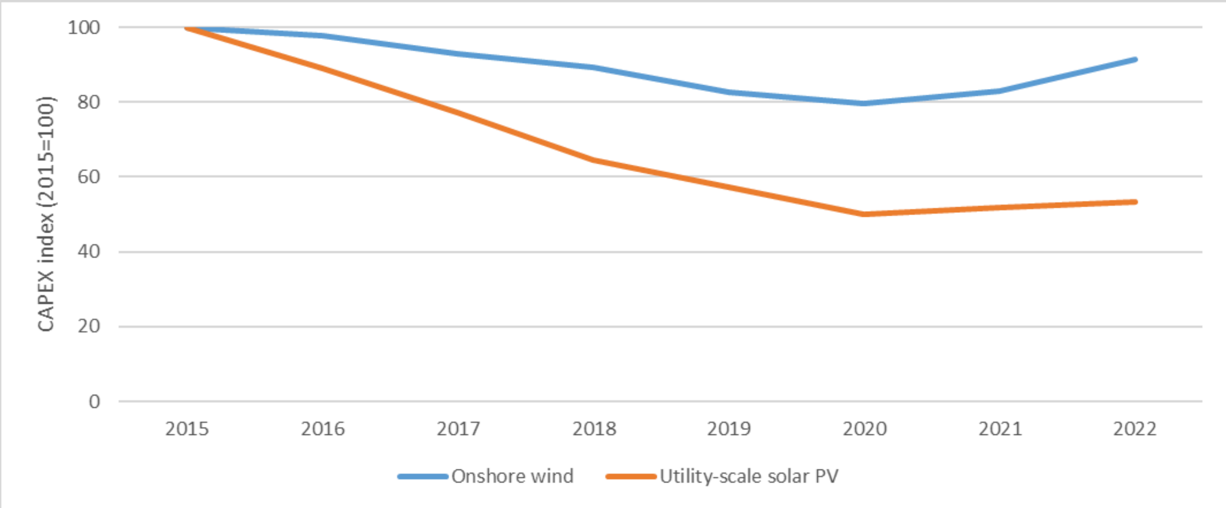

Figure 8: Solar PV and onshore wind investment cost estimates for newly contracted projects under high commodity prices (IEA, 2022)

Overall, the change in energy supply sources pattern over the past 11 years in the EU shows a declining trend in the supply of solid fossil fuels. Meanwhile, renewable energy supply continues to grow steadily and become a critical energy source in the EU. This suggests reducing reliance on coal in favor of cleaner energy sources. Despite efforts to promote renewable energy, oil and petroleum products, and natural gas, supply remains relatively stable, indicating continued reliance on these sources. At the same time, natural gas and oil are still the two largest energy sources in the EU's energy reserves. When the energy crisis occurred, in the case of 2022, with the supply of coal and natural gas, the EU promptly found new sources of supply for these two non-renewable energy sources instead of quickly promoting renewable energy supply. This is because of two main reasons: (1) renewable energy projects need resources and time to complete and put into operation, while the EU needs to find an immediate solution that can solve the energy shortage problem, and (2) natural gas, LNG, solid fossil fuels are energy sources that can be quickly imported and solve the energy problem for the EU.

3.2. Impact on the renewable energy consumption

Based on the collected data, the consumption of solid fossil fuels decreased steadily from 2011 to 2022 thanks to the restriction on the consumption of solid fossil fuels. During the energy crisis, from 18,842.853 tonnes of oil equivalent in 2021, solid fossil fuels consumption notably dropped to 16,294.287 tonnes of oil equivalent in 2022, a 13.5% y-o-y decrease. This was even higher than the y-o-y decrease of 12.5% in 2019 when COVID-19 affected the whole European economy and much more significant than the average annual decrease of 3.4% from 2011 to 2021. This sharp decrease is due to the peak in coal prices due to the impacts of coal supply disruptions from Russia. Natural gas, the second-largest non-renewable energy source in terms of consumption in the EU27, fluctuated over the years 2011-2021 but generally maintained a stable level even during COVID-19. However, natural gas consumption decreased sharply by 13.1% in 2022 due to supply disruption and rising prices. As shown in Figure 3, natural gas prices in 2022 increased 155.1% over the same period in 2021. Meanwhile, from 2011 to 2021, natural gas consumption always remained balanced, with an increase of about 0.8% per year. Oil and petroleum products rebounded in 2021 and 2022 from a sharp decline during the Covid-19 pandemic, with 4.9% and 2.1% increases, respectively. It can be seen that the increase in oil and petroleum products in 2022 is much lower than in 2021. Despite recording continuous growth within two years, annual consumption of oil and petroleum products by the end of 2022 is still about 4.1% lower than in 2019, before the COVID-19 pandemic occurred. Overall, the energy crisis has directly affected the prices of non-renewable energy sources, reducing the demand for these types of energy. The sharpest drop in consumption belongs to natural gas - the commodity most affected by the energy conflict between Russia and the EU. If calculating the total consumption of solid fossil fuels, natural gas, oil, and petroleum products, the amount of non-renewable energy consumption in 2022 decreased by 4.1% compared to 2021, indicating a negative impact of the energy crisis on non-renewable energy consumption.

Meanwhile, the consumption of renewables and biofuels has increased steadily over the years, exhibiting an upward trend. This sustained growth reflects ongoing investments in renewable energy infrastructure, policy support for clean energy initiatives, and technological advancements in renewable energy technologies. During the energy crisis, from 111,077,259 tonnes of oil equivalent in 2021, renewable energy consumption decreased slightly by 0.6% yet remained high at 110,265,191 in 2022. However, this slight decrease is due to a 2.6% decrease in electricity consumption in EU countries. Amidst the difficulties caused by the energy crisis, renewable energy consumption is still stable, proving the importance of renewable energy in production and the lives of EU citizens.

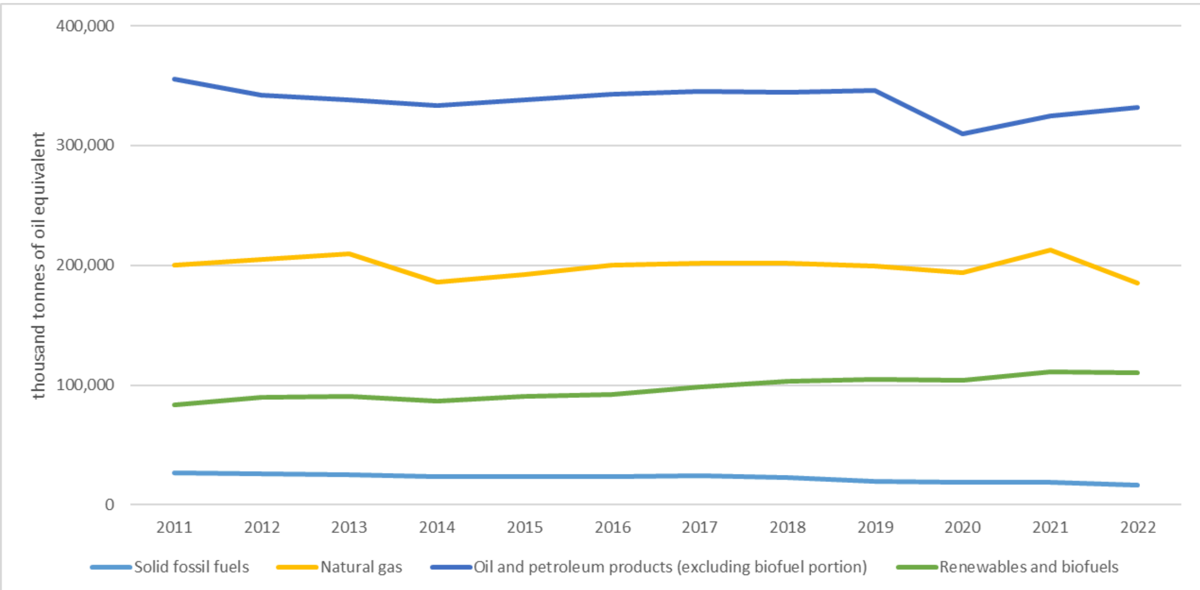

Figure 9: Final energy consumption by primary sources, thousand tonnes of oil equivalent (Eurostat, 2024), (Data code: ten00123)

Looking at the in-depth data on the share of renewable energy in the final energy consumption of EU27 countries in Figure 10, renewable energy accounted for only 9.6% of the total energy consumption of EU27 in 2004. After 18 years, this figure rose to 23.0% in 2022. Except for

2021, the only year that saw a slight decrease of 0.5%, the share of renewable energy consumption continuously increased, reflecting the transition to a cleaner energy source. Compared with 2021, the EU27's share of renewable energy consumption in 2022 increased by 5.0% y-o-y, higher than the annual growth rate in the period 2013-2019. The minimum and maximum share of renewable energy in the EU27 also continuously increased in the period 2004-2021. The minimum value rose from 0.1% in 2004 to 13.1% in 2022, demonstrating an increase in the lowest level of renewable energy share over time. Likewise, the maximum value increased from 38.4% in 2004 to 66.0% in 2022, reflecting a higher level of renewable energy penetration. In 2022, compared to 2021, the maximum share of renewable energy increased by 5.3%, and the minimum value increased by 11.7%, much higher than the increase of 4.3% and 9.5%, respectively, in 2021 compared to 2020. However, in 2021, the gap between the maximum and minimum share of renewable energy was 51.0%, while the gap in 2022 was 52.9%. Only 10 countries had a share of renewable energy above the EU27 average, while 17 countries had a share below the average. Among these 17 countries, there were 5 countries with a share of renewable energy below 15%. Thus, the energy crisis of 2022 facilitated the increase in the share of renewable energy consumption in EU27. However, the widening gap between the minimum and maximum values suggests the variability in the adoption of renewable energy and the ability to respond quickly to energy crises from renewable sources across EU27 countries.

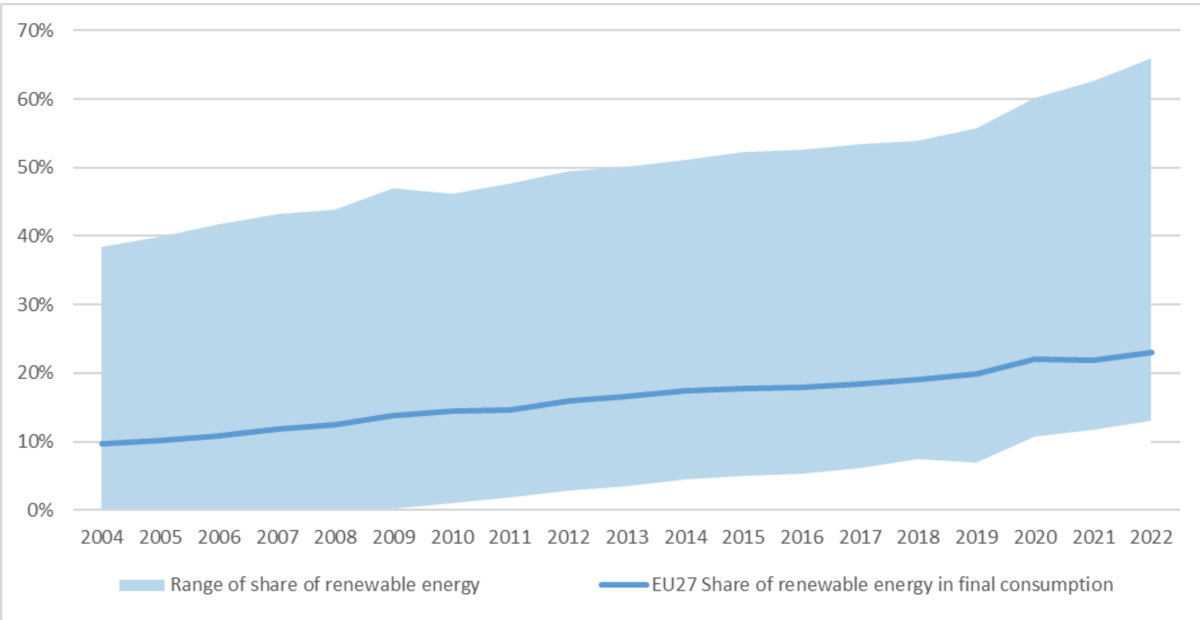

Figure 10: Percentage share of renewable energy in final energy consumption in EU27 countries, annual data (Eurostat, 2024), (Data code: nrg_ind_ren)

To calculate the overall renewable energy share in final energy consumption, the renewable energy share in electricity generation, heating and cooling, and transportation is used. As electricity and heating and cooling are the most prominent activities in using energy, this analysis uses these two sectors to analyze the impact of the energy crisis on renewable energy consumption.

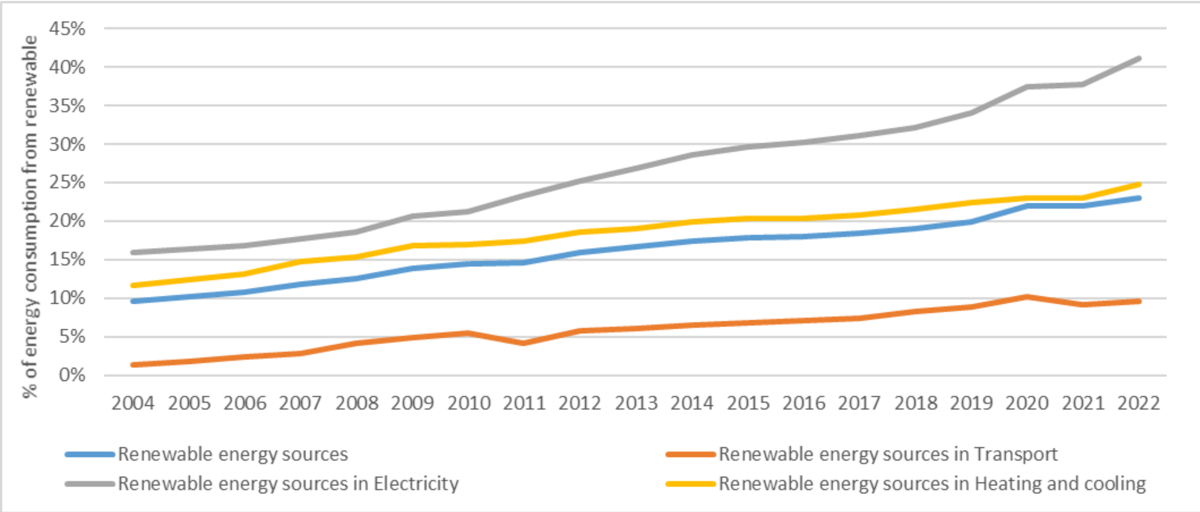

Figure 11: Percentage share of renewable energy sources in activities, annual data (Eurostat, 2024), (Data code: nrg_ind_ren)

According to Figure 11, electricity generation was the activity with the largest share of energy from renewable sources in 2022, at 41.2%. From 15.87% in 2004, renewable energy share in electricity generation increased by an average of 5.5% per year between 2004 and 2022. Among them, four years saw the most robust increase: 2009 (11.5%), 2011 (9.5%), 2020 (9.7%) and 2022 (9.1%). These years witnessed instability in the global economy and the EU region, such as the economic crisis in 2008-2010, the Covid-19 pandemic, and the energy crisis in 2022. During these times of crisis, when trade stagnates and prices of energy types on the market experience many fluctuations, countries in EU27 were more reliant on renewable energy sources available for electricity generation.

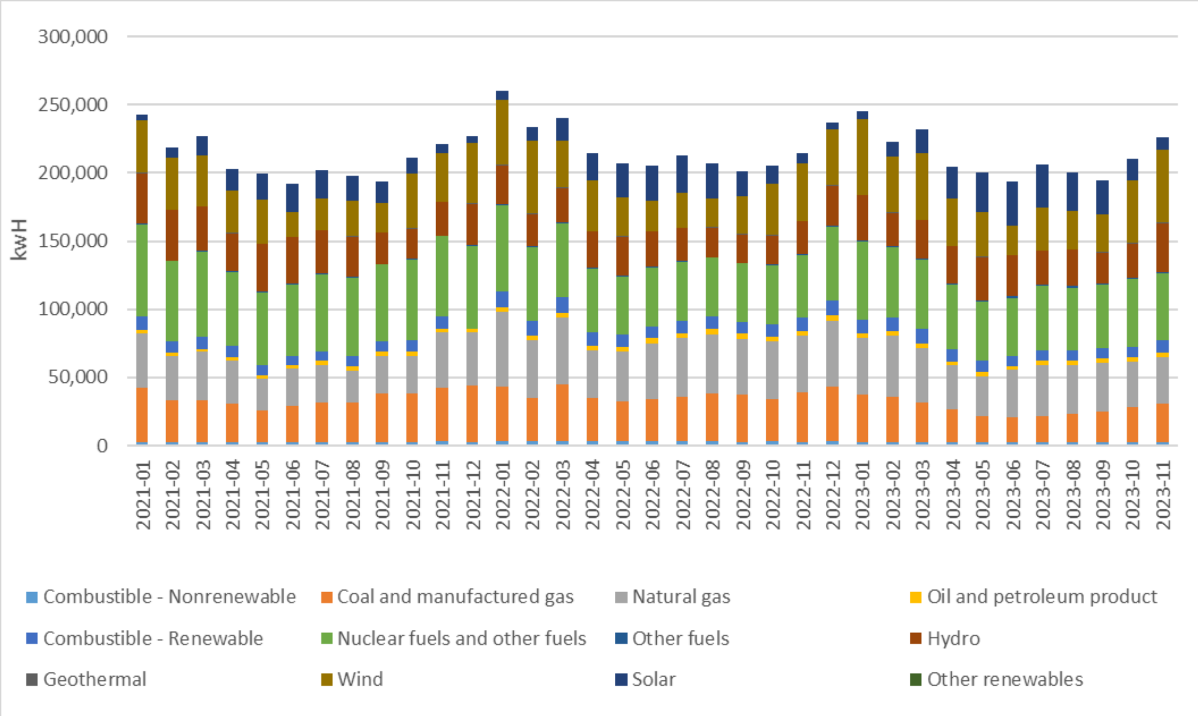

Figure 12a: Net electricity generation by source of energy, monthly data (Eurostat, 2024), (Data code: nrg_cb_pem)

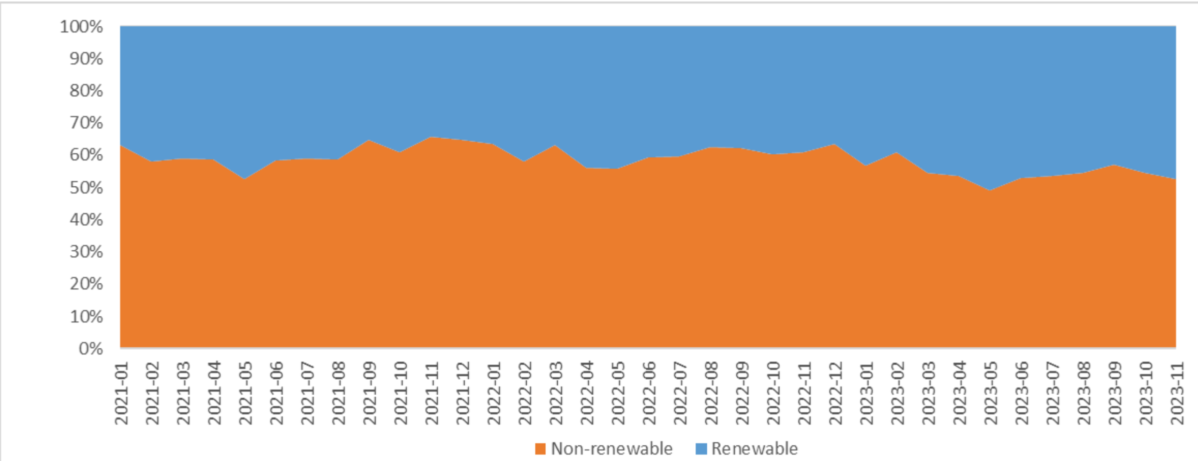

Figure 12b: Proportion of net electricity generation by renewable energy and non-renewable energy, monthly data (Eurostat, 2024), (Data code: nrg_cb_pem)

To see more clearly the change in the use of renewable energy in electricity production, Figures 12a and 12b depict the change in the priority of energy sources in electricity generation before, during, and after the peak of the energy crisis. In 2021, the energy source that produced the most electricity in EU27 countries was nuclear fuels, with 695,994 kWh, accounting for 27.5% of total electricity generated. Although an energy source emits low carbon emissions, nuclear fuels are non-renewable, requiring finite materials (uranium) mined from specific locations. Ranked second on this list is coal and manufactured gas, accounting for 15.3% of all electricity produced. Right behind these two non-renewable energy sources are wind power (15.2%), natural gas (14.9%) and hydrogen (14.3%). On average, in 2021, the amount of electricity produced from non-renewable energy accounts for 60.4%, and renewable energy accounts for 39.6%. From March to August, the amount of electricity produced from renewable energy accounts for a high proportion of about 41% to 47%, mainly thanks to the increase in solar energy in the summer months.

In 2022, when natural gas and coal prices began to increase rapidly from February, and the energy crisis began to erupt in August, electricity generation by energy source changed. Nuclear fuels continued to produce the most electricity, but much less than in 2021, at 577,583 kWh, down 17% compared to 2021, accounting for 21.9% of total electricity in EU27. Natural gas jumped to second place with 518,170 kWh, an increase of 37% compared to 2021, accounting for 19.6% of all electricity production. Wind ranked third in the source of electricity generation, accounting for 15.9%. Fourth was coal and manufactured gas with 15.8%, and fifth was hydrogen with 11.3%. Except for nuclear fuels, which decreased slightly compared to all months in 2022, electricity generation from the rest of non-renewable sources in 2022 increased compared to 2021, with the most robust increase belonging to natural gas (+37%) and oil and petroleum products (+30%). These two sources saw a continuous increase in all months compared to 2021. In particular, electricity from natural gas increased sharply from August 2022 due to the EU's policy to cope with the shortage of pipeline gas using LNG. Electricity from this source also made up for the shortage of non-renewable combustibles and coal in the last four months of the year.

However, on the more positive side, overall electricity generation from renewable energy sources also significantly improved. In 2022, Europe faced its worst drought in at least 500 years, pushing hydro generation to its lowest level since at least 2000. Therefore, electricity generated from hydro and geothermal was down compared to all months of 2021. For 2022, electricity generated from hydro energy decreased by 18%, and geothermal decreased by 1%. Electricity from renewable combustible and solar energy also saw growth compared to 2021. However, it can be seen that the growth was more considerable from January to August, before the energy crisis happened. Overall, in 2022, the electricity generation from renewable combustibles increased by 13%, and solar increased by 27%. This was the most significant increase ever recorded in solar energy consumption for electricity generation (Ember, 2023). Wind power fluctuated throughout the year, generating 9% more electricity than in 2021.

Regarding the ratio of electricity generated from non-renewable and renewable energy, the ratio was 59.6% and 40.4% in July 2022 and leaned more towards non-renewable energy, with the ratio being 62.6% and 37.4% in August 2022. On average, in 2022, this rate was 60.5% and 39.5% (the rate in 2021 was 60.4% and 39.6%). It can be seen that although overall, renewable energy consumption for electricity increased during the year of the energy crisis, non-renewable energy was still the immediate source of energy used to cope with the energy shortage, specifically natural gas and oil. However, after solving the energy shortage, consumption quickly stabilized and returned to its original rate by equivalently increasing the use of renewable energy.

	Combustible - Nonrenewable	Coal and manufactured gas	Natural gas	Oil and petroleum product	Nuclear fuels	Other fuels
2022-01	15.1%	2.4%	35.1%	37.3%	-6.5%	0.8%
2022-02	10.2%	3.9%	31.8%	34.6%	-6.7%	-8.5%
2022-03	38.4%	34.4%	38.3%	53.7%	-12.4%	4.7%
2022-04	11.5%	13.8%	9.5%	30.6%	-12.6%	6.0%
2022-05	21.2%	29.0%	52.3%	34.5%	-19.5%	3.8%
2022-06	17.2%	20.2%	46.6%	33.2%	-19.0%	-2.3%
2022-07	9.2%	13.1%	56.6%	20.2%	-22.7%	-0.5%
2022-08	13.7%	19.7%	88.6%	23.2%	-24.7%	-12.5%
2022-09	7.6%	-1.5%	46.7%	22.4%	-24.4%	2.9%
2022-10	5.3%	-12.4%	55.0%	16.9%	-26.7%	14.0%
2022-11	-2.9%	-8.2%	1.9%	15.9%	-20.9%	-1.1%
2022-12	13.7%	-1.7%	22.9%	47.0%	-11.1%	-17.6%

Figure 12c: Year-on-year percentage change in monthly net electricity generation from non-renewable sources, comparing data from 2022 to 2021 (Eurostat, 2024), (Data code: nrg_cb_pem)

Month	Combustible - Renewable	Hydro	Geothermal	Wind	Solar
2022-01	18.7%	-21.5%	2.9%	22.6%	59.3%
2022-02	22.0%	-37.3%	1.3%	41.9%	31.8%
2022-03	27.6%	-23.6%	-0.2%	-6.8%	21.9%
2022-04	19.4%	-5.5%	-0.4%	22.4%	20.7%
2022-05	23.2%	-18.4%	0.7%	-13.5%	30.7%
2022-06	36.4%	-23.2%	-4.9%	25.4%	20.8%
2022-07	26.0%	-24.7%	-3.5%	13.4%	30.7%
2022-08	17.0%	-26.8%	-1.1%	-17.6%	35.4%
2022-09	15.2%	-8.3%	-3.6%	27.5%	15.9%
2022-10	8.1%	-5.5%	-2.8%	-6.0%	18.2%
2022-11	8.6%	-2.5%	-1.2%	17.7%	30.8%
2022-12	22.3%	-3.1%	-1.1%	-7.4%	8.0%

Figure 12d: Year-on-year percentage change in monthly net electricity generation from renewable sources, comparing data from 2022 to 2021 (Eurostat, 2024), (Data code: nrg_cb_pem)

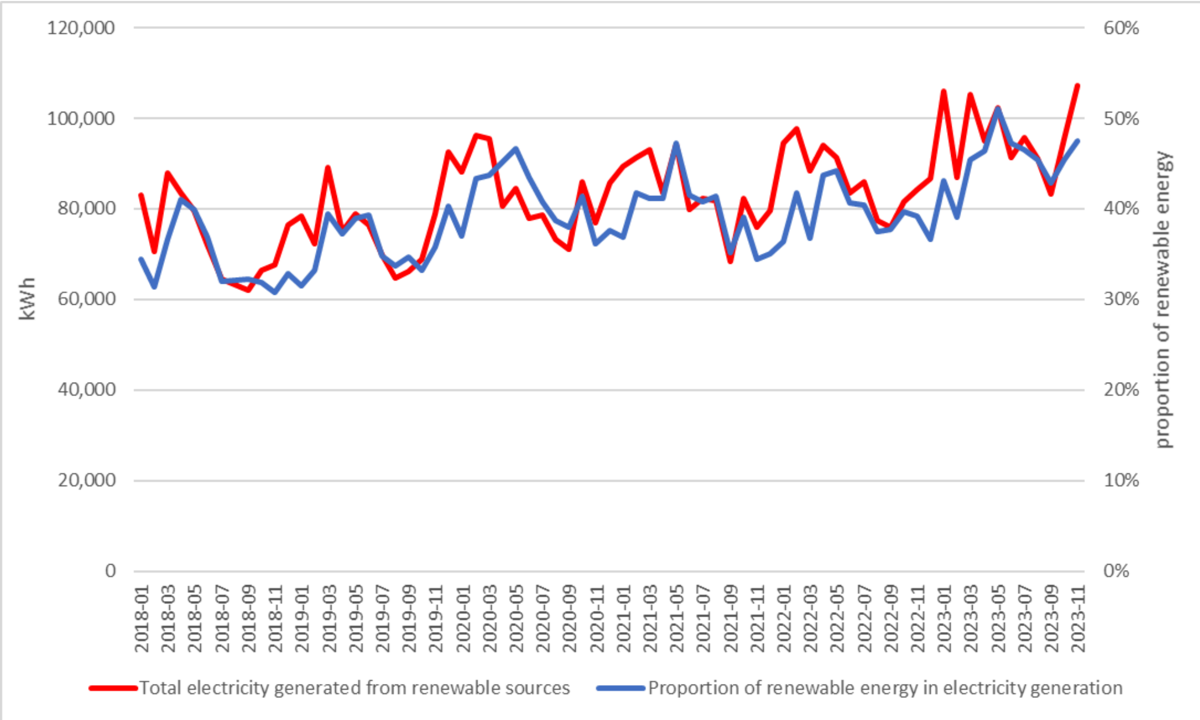

Figure 13: The transition from non-renewable to renewable energy in electricity generation from 2018 to the end of 2023 (Eurostat, 2024), (Data code: nrg_cb_pem)

The impact of the energy crisis on the increase in renewable energy consumption for energy generation was more apparent in 2023 when demand gradually stabilized. In the first 11 months of 2023, nuclear fuels produced the most electricity, accounting for 22.8%. Wind has surpassed natural gas and has become the energy source that produces the second most electricity, accounting for 17.9% of all electricity production, while natural gas accounted for 17.4%. Hydro moved to fourth place with 13.2% of all electricity produced. On average, in the first 11 months of 2023, the proportion of electricity generated from renewable energy accounted for 45.5%, an increase of 4.9% compared to 2022. Even in May 2023, for the first time, renewable energy became the primary energy source for electricity production in EU27, accounting for 51% of electricity produced.

It can be seen that the energy crisis has a negative impact on renewable energy consumption in electricity generation right at the moment it begins because countries need to seek alternative available energy sources immediately to compensate for the shortage that Russia created in the EU energy market. However, after a few months, as EU countries focused on improving infrastructure and developing policies to increase renewable energy consumption, renewable energy consumption increased rapidly, thereby reducing EU dependence on imported energy sources, mainly non-renewable. The energy crisis has been a lever to help speed up renewable energy transitioning in EU27, accelerating the share of renewable energy in electricity generation to equivalent to non-renewable energy consumption in this field.

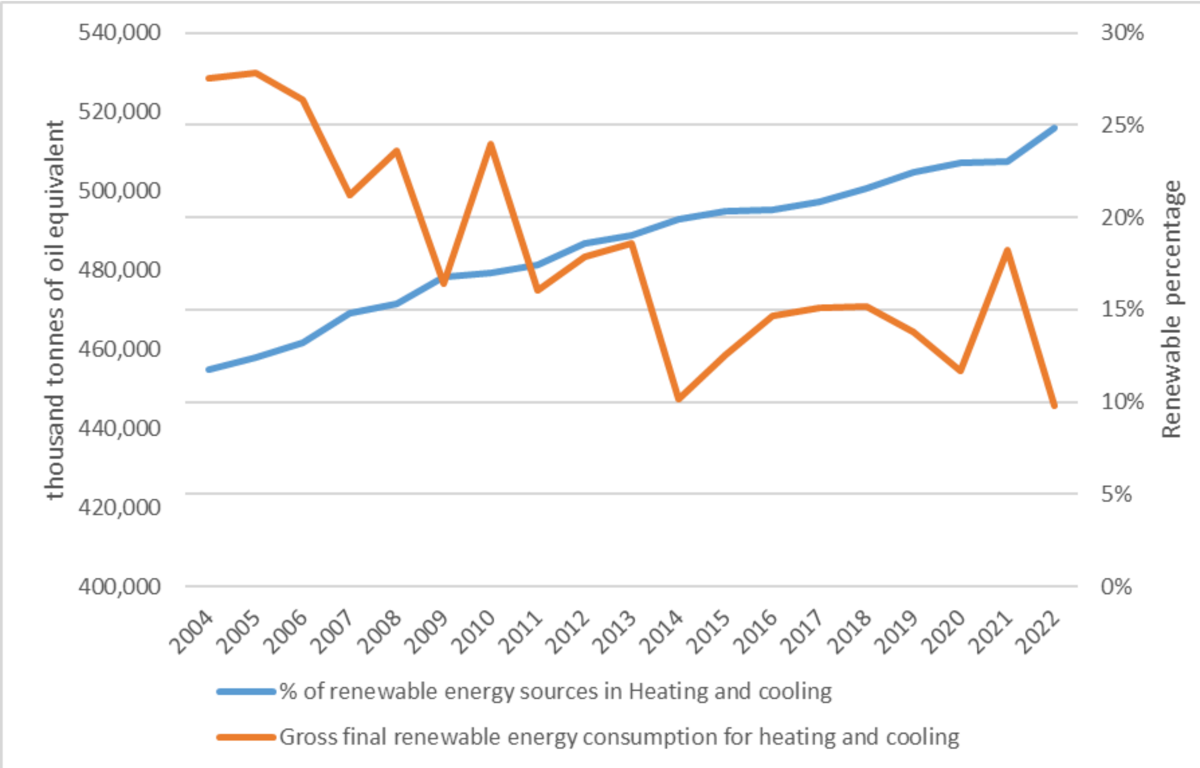

Figure 14: Renewable energy consumption for cooling and heating, annual data from 2004 to 2022 (Eurostat, 2024), (Data code: nrg_ind_urhcd; nrg_ind_ren)

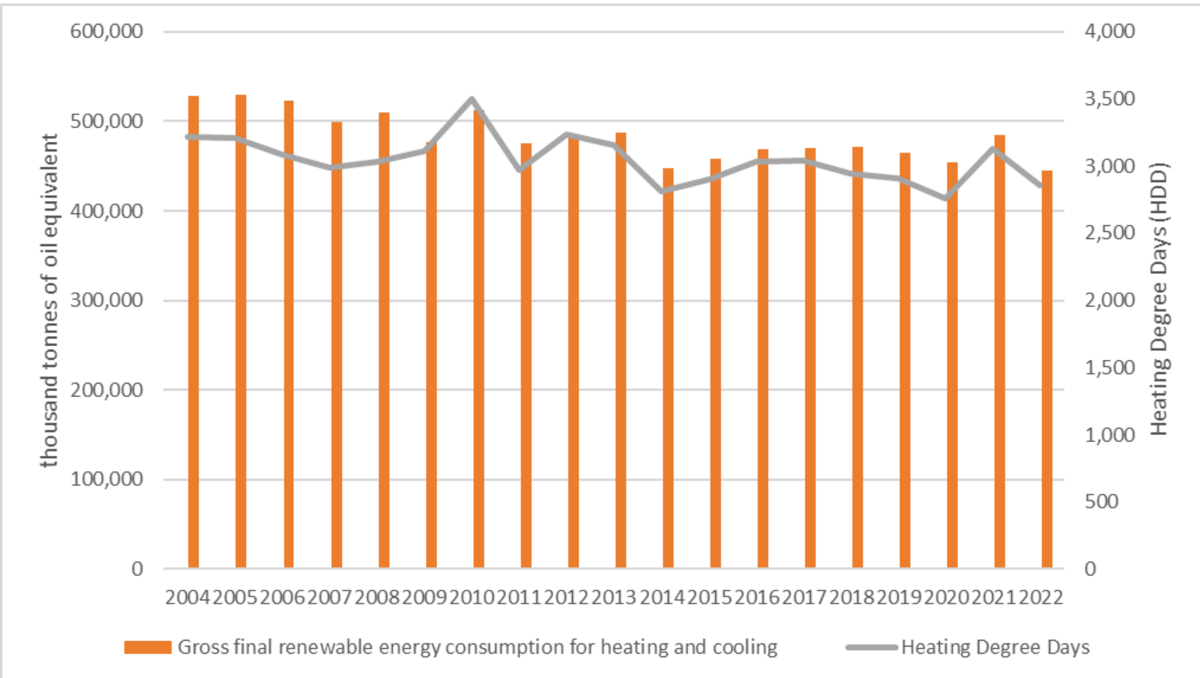

Figure 15: Renewable energy consumption for cooling and heating and Heating Degree Days, annual data from 2004 to 2022 (Eurostat, 2024), (Data code: nrg_ind_urhcd; nrg_ind_ren)

Looking at the change in the share of renewable energy use in heating and cooling, there is a gradual increase in the use of renewable energy sources. In 2004, only 11.7% of EU27's energy for heating and cooling came from renewable sources. After 19 years, this has grown to 24.8% in 2022, indicating an annual increase of 0.69% from 2004 to 2022. Similar to the electricity sector, the share of renewable energy use in heating and cooling also increased more significantly in periods that witnessed instability in the global economy and the EU region. Specifically, the years with the highest growth in the share of renewable energy in heating and cooling were 2007 and 2009 (+1.6% and 1.5%), the global economic crisis, and 2022 (+1.8%), Europe's energy crisis. In these periods, Member States of the EU27 faced high energy prices and turned to renewable energy sources to stabilize the supply of energy needed for their heating and cooling purposes. In 2022, also with timely policies from EU governments to rapidly increase the share of renewable energy in this sector and a more ambitious goal for the usage of renewable energy for heating and cooling. Looking at the gross final renewable energy for heating and cooling, the figure decreased over the past two decades. This is most likely due to the reduction in Heating Degree Days shown in Figure 15. Heating Degree Days is a metric used to calculate the demand for heating a building based on the total degrees in a period that the average daily outdoor temperature is lower than 18°C. Therefore, the lower gross renewable energy consumption from 2004 to 2022 is due to climate change, which increases the average temperature in winter, rather than a reduction in the use of renewable energy in heating.

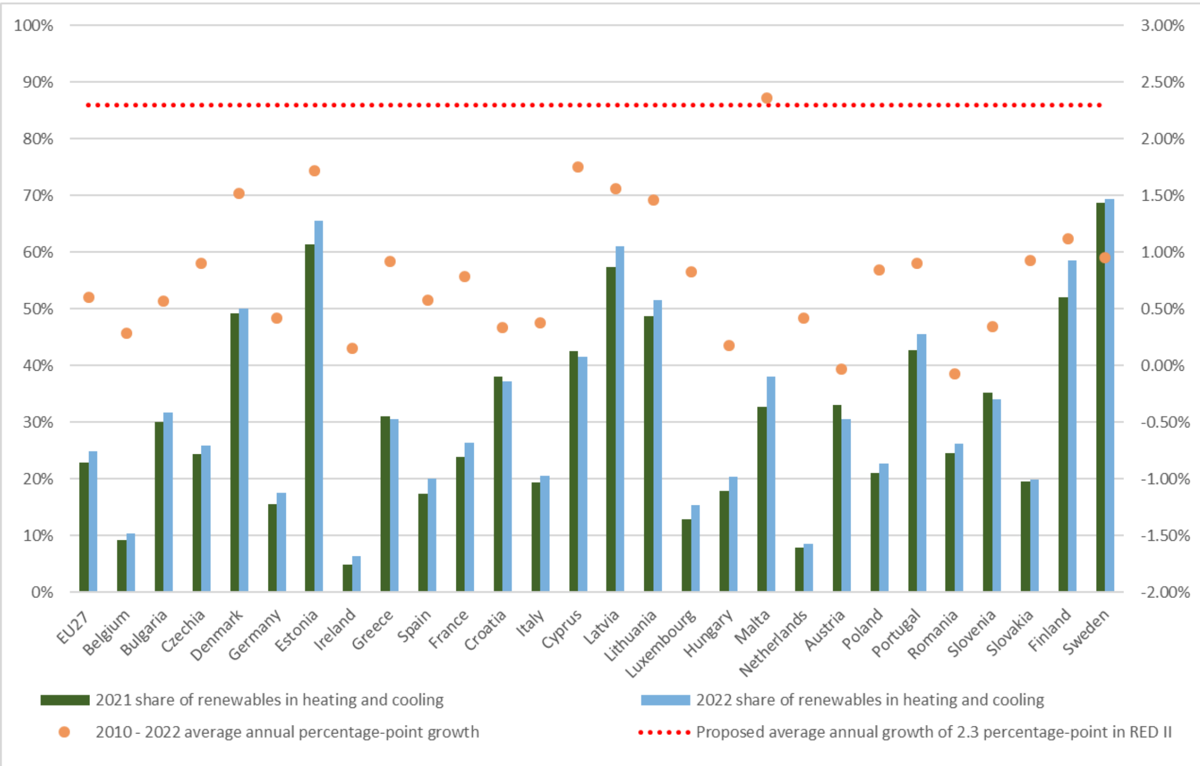

Figure 16: Share of renewable energy consumption for cooling and heating in 27 EU countries (Eurostat, 2024), (Data code: nrg_ind_ren)

The data in Figure 16 shows the share of renewable energy consumption in heating and cooling for 27 EU countries before and during the 2022 energy crisis, as well as its average annual growth rate since the first policy regarding renewable energy was introduced in 2010. During the energy crisis, most countries saw an increase in renewable energy consumption for heating and cooling in 2022 compared to 2021, except for Greece (-0.5%), Croatia (-0.8%), Cyprus (-1.0%), Austria (-2.4%) and Slovenia (-1.2%). These countries are highly vulnerable to climate risks, and renewable energy production was somewhat affected by unexpected weather changes in 2022. Also, their capacity for renewable energy production is still limited and blocked by inadequate legislation. These Member States, except for Cyprus, also witnessed relatively low annual growth rates in the past 13 years. The annual growth rate in renewable energy in heating and cooling for Greece was 0.9%, Croatia was 0.3%, Austria was 0.0%, and Romania even witnessed a negative growth rate of -0.1%. Meanwhile, Estonia, Latvia, Malta, and Finland increased their share of renewable energy in heating and cooling by 3.6-6.5% just from 2021 to 2022, showing their dedication to being at the forefront of sustainable heating and cooling practices. It is worth noting that three out of four countries have already been in the top Member States with the highest share of renewable energy for heating and cooling (Estonia in 2nd, Latvia in 3rd, Finland in 4th). Countries with an already high share of renewable energy adapt better to unexpected changes in the supply of energy, given that their infrastructure is more established, combined with sustainable and robust renewable energy legislation to support the generation and consumption of renewable energy, in this case, for heating and cooling.

Regarding the annual growth rate of the share of renewable energy in heating and cooling, 12/27 countries witnessed a lower growth than the EU27 average of 0.6% per year, while 15 exceeded this growth, and only 7 Member States had an annual growth rate of more than 1.0%. Only Malta managed to get an average annual growth rate of 2.4%, which met the proposed growth of 2.3% in the RED II target. Therefore, the proposed annual growth rate of renewable energy in heating and cooling is somewhat very ambitious, given the differences in technology abilities, as well as the existing base of infrastructure and policies for renewable energy development among Member States. Achieving this target requires more substantial efforts from national governments and the EU to incentivize the transition towards renewable energy, especially for countries with a lower share of renewable energy in heating and cooling.

4. Policies and actions implemented during the energy crisis

The main and central plan implemented during the energy crisis was the REPowerEU plan, which aims to diminish the EU's dependence on Russian fossil fuels and natural gas. The plan also focuses on diversifying the EU's energy portfolio in order to cope with future disruptions of energy. This plan includes (1) saving energy, (2) diversifying supplies, (3) quickly substituting fossil fuels by accelerating Europe's clean energy transition, and (4) smartly combining investments and reforms (European Commission, 2022). Multiple actions and plans have been launched and implemented since the RePowerEU plan began in May 2022. Instead of analyzing these measures chronologically, this research will categorize them into financial incentives and renewable portfolio standards incentives to see the connections between financial, regulatory, and strategic elements.

4.1. Financial Incentives

Financial incentives implemented within the REPowerEU plan package mostly focus on reducing renewable energy technologies' financial burden and investment barriers. The IPCEI Hy2Tech and the European Solar PV Industry Alliance are two of the most prominent initiatives. IPCEI Hy2Tech was announced on 15 July 2022, and it aims to develop advanced hydrogen technologies to cut carbon emissions in multiple industries, especially the manufacturing and transport sectors. This was the first ever important Project of Common European Interest in the hydrogen sector. Since there was no established hydrogen market in Europe, companies and Member States hesitated to invest in such risky technologies. It seeks to significantly increase the EU's hydrogen production capabilities, reducing dependence on fossil fuels and promoting greener energy alternatives. In order to achieve this, hydrogen technologies, including electrolyzer, fuel cell efficiency, and hydrogen storage, will be developed by multiple companies in the Member States to reduce the number of raw materials and optimize the manufacturing, transportation, and distribution of hydrogen. End-users of hydrogen products such as trucks, trains, and ships will also be developed to promote the use of hydrogen energy. The total investments under the IPCEI Hy2Tech are expected to be 14.2 billion euros, with €5.4 billion in state aid and €8.8 billion from private investments, including 35 companies across 15 Member States.

Another renewable energy sector that the EU focuses on is the solar photovoltaic manufacturing sector. With the European Solar PV Industry Alliance, which was established on December 9 2022, the EU aims to diversify the energy sector and mitigate the supply risk by reaching a manufacturing capacity of 320 GW by 2025 and supporting the installation of 600 GW of solar capacity by 2030. This is also aligned with the REPowerEU plan and will deliver €60 billion of new GDP per year in Europe and the creation of more than 400,000 new jobs. The initiative will work on mapping investment opportunities and creating project pipelines of bankable projects in order to attract private investments. It also simplifies the permitting process for new solar energy projects and supports the sustainable development of the sector, which will stimulate the investment of solar PV projects.

Overall, these plans all focus on increasing the EU’s local manufacturing capacities of hydro and solar PV energy in order to reduce reliance on fossil fuels and energy imports. They also reduce the regulatory processes that are hindering the establishment of new renewable energy projects and attract private investment in these fields. Finally, they aim to protect consumers from spikes in energy prices and ensure long-term sustainability and energy efficiency in Europe.

To analyze the effectiveness of these initiatives on the overall renewable energy transition, the hydro and solar energy consumption for electricity generation was used to determine the effect.

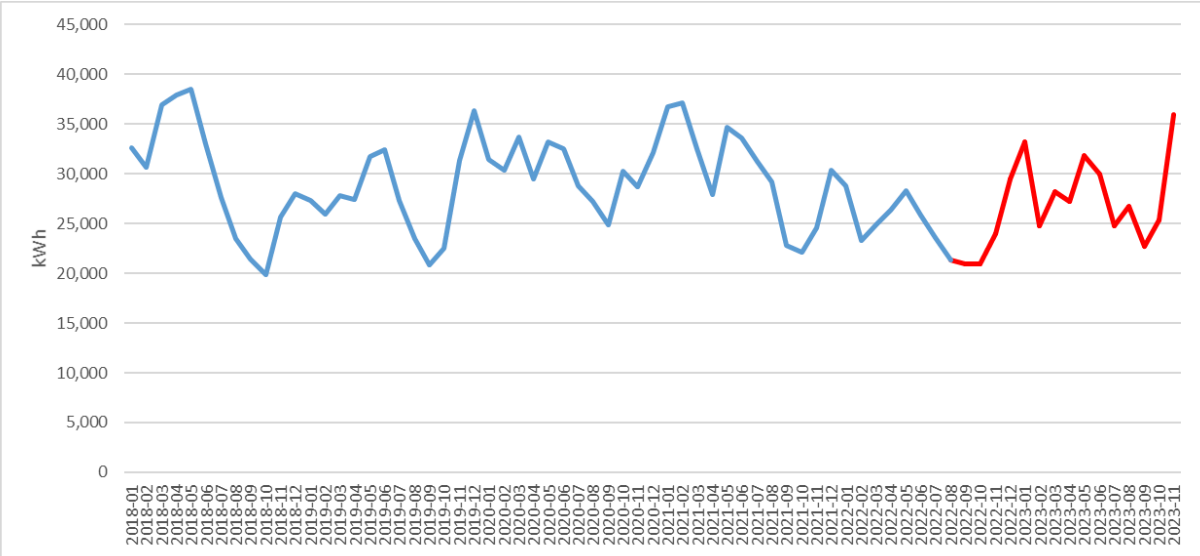

Figure 17: Change in electricity generation from hydro energy before and after IPCEI Hy2Tech was implemented (Eurostat, 2024), (Data code: nrg_cb_pem)

Electricity generation from hydropower exhibits a seasonal pattern, with peaks in spring (March to May) and troughs in the summer to early winter (August to December), as hydropower is influenced by rainfall. To analyze the impact of the initiative, a t-test was performed to compare the mean hydropower generation before and after August 2022. The result shows that the mean electricity generation from hydropower after August 2022 is lower than before due to a decrease in the average electricity generation from hydro post-initiative. However, with a p-value of 0.76, we do not have enough evidence to address the impact of the IPCEI Hy2Tech on hydropower consumption. This decrease is likely due to the worst drought in 200 years in Europe rather than the initiative's impact.

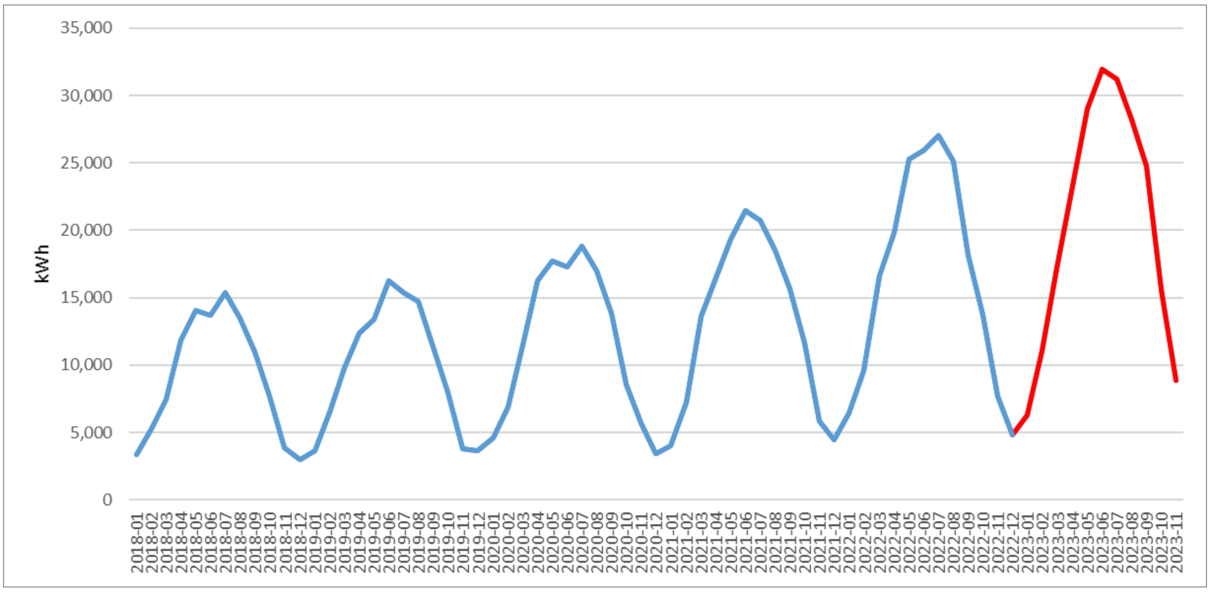

Figure 18: Change in electricity generation from solar energy before and after the Solar PV Industry Alliance was implemented (Eurostat, 2024), (Data code: nrg_cb_pem)

The higher peaks and troughs in the electricity generation from solar energy indicate growth in overall solar energy production. However, after December 2022, when the initiatives were implemented, the following months showed exceptionally high value. Using a T-test, a significant increase in the mean electricity generation from solar energy after the implementation of the policy (M = 20,677.53) compared to before (M = 12,166.98), with a p-value of 0.02. This significant p-value implies that the initiative likely had an effect on increasing solar energy generation.

Within the two financial incentives, the Solar PV Industry Alliance had a significant effect on the renewable energy transition in Europe, thanks to the detailed policies from investment incentives and regulatory incentives. IPCEI Hy2Tech also provided good baseline policies to establish the European hydro market. However, due to the weather conditions in Europe in 2022 and the current status of the local hydrogen market, no significant impact of this policy was found on hydrogen consumption on electricity generation.

4.2. Renewable Portfolio Standards

The Renewable Portfolio Standards are the second category of policies implemented during the energy crisis. Through regulations and actions to boost the adoption of renewable energy, the EU aims to increase renewable energy use to a certain level while, at the same time, reducing the percentage of non-renewable consumption and decreasing the amount of greenhouse gases from these energy sources.

First, under the European Green Deal, the EU agreed on stronger legislation to accelerate the rollout of renewable energy. This agreement has raised the EU's target for renewable energy consumption in 2030 to a minimum of 42.5%, increasing by 10.5% compared to the previous target of 32%. Negotiators also agreed that the EU would aim to reach 45% of renewables by 2030. Through this action, the EU has shown a commitment to faster deployment of renewable energy and to meet the target of the Fit for 55 package, which is to reduce the EU's greenhouse gas emission by 55% by 2030. If the EU can do this successfully, it can reduce the energy price within the Member States while gaining energy security and independence from foreign sources of fossil fuels. The agreement includes targets for renewable energy across various sectors to reach this overall objective of 42.5% by 2030. Renewable energy consumption in buildings by 2030 will reach a benchmark of 49%. In the transport sector, the target is 29%, including a combined sub-target of 5.5% for advanced biofuels and renewable fuels of non-biological origin and a minimum level of 1% for renewable fuels of nonbiological origin. They also include the indicative target of a 2.3-percentage-point average annual increase in the share of renewables in heating and cooling during the periods of 2026-2030 and an average annual increase of 1.9 percentage points in the industry during the periods 2024-2027 and 2027-2030.

In order to reach this target, from the figure of 23.02% in 2022, the EU needs to increase its overall renewable energy consumption by a total of 19.48% from 2022 to 2030 to meet the target of 42.5%, which is approximately 2.435% per year. Therefore, with an indicative target of a 1.9% annual increase in the share of renewables in the industry, it might not be possible for the EU to reach this goal in 2030. With the 2022 level annual increase of 1.09%, the EU will also not be able to reach the target of 42.5% share of renewable energy in 2030.

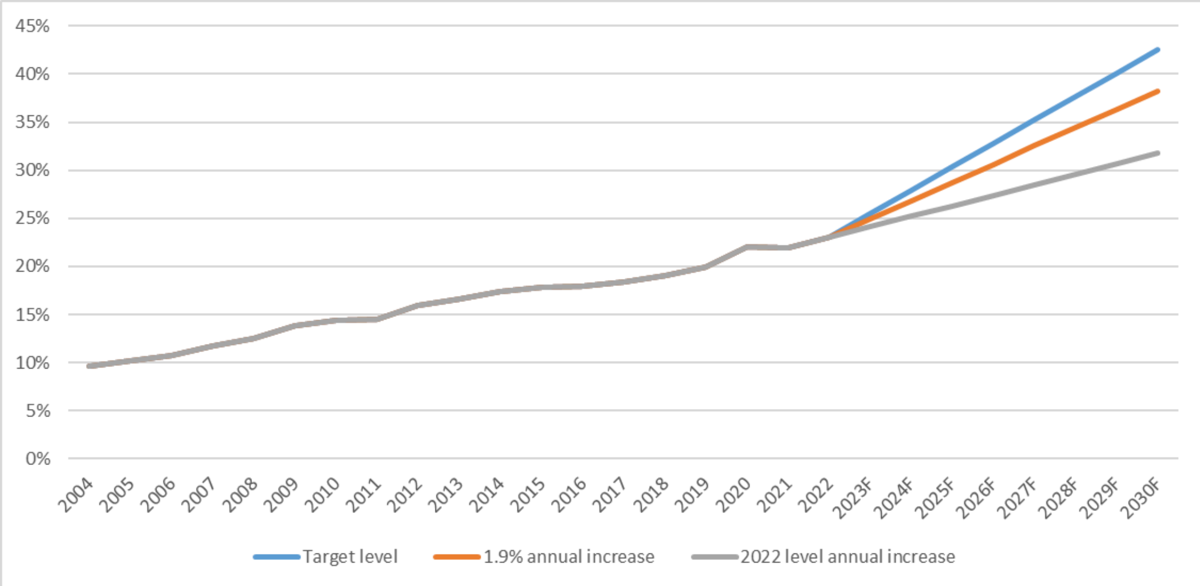

Figure 19: Forecast of share of renewable energy in EU by 2030 with three scenarios (Eurostat, 2024), (Data code: nrg_ind_ren)

The EU also introduced many measures to support Member States in reaching this objective. For example, the REPowerEU supported integrating energy systems in the hydrogen and biofuels sector. On November 9, 2022, the EU proposed an Emergency Regulation for renewable energy permitting, which streamlines the process for solar and wind projects, which aims to quickly increase renewable energy production and reduce dependence on energy imports.

Apart from these solutions, the EU, within the REPowerEU and the European Green Deal, also discussed other efforts to reduce gas demand during winter, establishing relationships with other countries to diversify their LNG imports and mitigating methane emissions in the oil and gas industry. First, the EU established demand reduction measures for gas in July 2022 to reduce gas use in all Member States by 15% between 1 August 2022 and 31 March 2023. This measure applies to consumers, public administrations, households, power supplies, and all industries. To help the Member States in reaching this 15% reduction, a European Gas Demand Reduction Plan was set out. These actions include substituting gas with other fuels and saving energy. The measure also helps Member States identify and prioritize the most critical components of the economies that need to focus on energy. This safeguards against potential energy supply disruptions, mainly due to political tensions. On the other hand, the EU also adopted new legislation requiring EU gas storage to be kept at a capacity of 80% to secure the supply for winter. Next, the EU diversified away from Russian gas imports by deepening its relationship with energy-exporting countries such as Norway, Egypt, and countries in the Eastern Mediterranean region. These energy partnerships are not just for immediate needs but are planned to continue beyond 2030, ensuring a long-term supply. In the first half of 2022, non-Russian LNG imports rose by 21 billion cubic meters (bcm) compared to last year.

Non-Russian pipeline imports also grew by 14 bcm from Norway, Azerbaijan, the United Kingdom, and North Africa (European Commission, 2023). Finally, with the Global Methane Pledge Energy Pathway in June 2022, the EU, the United States, and 11 other countries aimed to accelerate methane emissions reductions in the oil and gas sector by at least 30 percent by 2030 from 2020 levels. Countries and supporting organizations announced nearly $60 million in dedicated funding to support the implementation of the Pathway.

In conclusion, through the REPowerEU plan with a robust framework and detailed action, the EU aimed to reduce the dependency on Russian energy and accelerate the renewable energy transition. Regarding financial incentive measures, the Solar PV Industry Alliance has boosted solar energy consumption with a significant increase in electricity generation from solar power. This suggests that the policy was effective in enhancing solar energy input and output, thanks to the detailed regulatory policies and the existing favorable infrastructure for developing the solar energy sector. The IPCEI Hy2Tech initiative, despite a substantial financial commitment (€14.2 billion), has not had a significant impact on hydrogen energy consumption for electricity. The decrease in output is more likely linked to environmental factors rather than policy efficacy. The effect of the policy might be more impactful in the future when the hydrogen market is more established through all the measures mentioned in the initiative. However, the initiative will set a solid foundation for the hydrogen market to grow in the long term, which will change the consumption pattern in the future. Regarding Renewable Portfolio Standards, the revised targets under the European Green Deal aim to increase the EU's renewable energy consumption to an ambitious level of 42.5% by 2030. Achieving this goal will require an annual increase in the EU’s renewable energy share of at least 2.435%, higher than the annual increase target of 1.9% and double the current growing rate of 1.09% in 2022. Therefore, reaching this target by 2030 might be challenging without further robust measures and consistent annual increases.

Chapter 5: Discussion: Lessons learned and outlook for renewable energy transition in the EU

This research on the impact of the energy crisis on the economy, the environment, and renewable energy, which includes the renewable energy supply and consumption in Europe, has uncovered several key lessons about the current situation of the renewable energy transition and how Europe reacted with uncertainty and vulnerability in the energy market.

First of all, the diversification of energy sources and energy suppliers is crucial for the security of the energy market, and there should be preparation for unpredictable shocks in the energy market. The main reason behind the European energy crisis is the over-reliance on Russian non-renewable energy sources, including fossil fuels and natural gas. Therefore, a sudden cut from this one energy source can disrupt the whole energy supply of EU countries, impacting the whole economy, which can be seen in the group's GDP growth and trade balance. The sharp rise in energy prices also demonstrated how sudden shortages can trigger inflation and economic downturns. The EU also needs to prepare for the shocks, not only in the energy market but also for the whole economy, since geopolitical shocks can negatively impact the market. This preparation includes ensuring energy reserves, diversifying energy sources, and creating more sustainable energy policies to withstand crises.

Secondly, robust renewable energy infrastructure is the key to ensuring a swift renewable energy transition, especially during the energy crisis. The need for a resilient infrastructure for renewable energy is clearly shown when the EU faces several challenges in switching from non-renewable energy to renewable energy in a short period to address the shortage in the energy supply. As the current infrastructure is insufficient to produce alternative energy for non-renewable sources, especially gas and oil, the EU immediately needs to import LNG from other countries to secure the sudden drop in supply. This import strategy helps with the diversification of suppliers. However, it is detrimental to the transition to renewable energy in the EU. In Member States that have a sluggish growth in the share of renewable energy, for example, Austria, Croatia and Slovenia, the research showed that it is much harder for them to turn directly to renewable energy in a crisis. Meanwhile, this transition is stronger in countries with already high renewable energy penetration, like Finland, Malta, and Estonia. In the crisis, the EU immediately provided policies to promote the rapid investment and development of renewable energy projects. However, since these projects need time to complete and start operating, this is more of a long-term than an immediate solution. By continuing to invest in renewable infrastructure, not only production but also storage and grid integration, the EU can achieve a more sustainable growth of the renewable energy market, which can instantly respond to the need for clean energy, as well as keep the energy reserved for the times in need.

Thirdly, by combining financial incentives and renewable portfolio standards, the EU’s REPowerEU policies have set the ground for further improvement in the renewable energy transition. However, to reach the ambitious goal, these policies must be more flexible and responsive to unexpected events to maintain their effectiveness. The best response to the energy crisis within the REPowerEU package is that the EU and its Member States have addressed renewable energy as the central pillar to deal with the energy shortage from Russia. They also tackled the pain points of renewable energy projects in the EU, which are the bureaucratic procedures in permit-granting, by speeding up these processes in renewable energy projects. At the same time, the EU also proposed measures to gradually reduce the consumption of fossil fuels and other non-renewable energy sources. These gradually decreasing measures included energy-saving efforts by consumers and producers and financial incentives for energy efficiency upgrades. However, when facing the energy shortage, the EU immediately implemented measures to drastically increase its LNG import, emphasizing gas's importance to the EU's energy market. With LNG import contracts running beyond 2030 and even longer, the EU's transition to renewable energy can face difficulties. Meanwhile, the continuously growing supply of LNG will create an abundance of non-renewable energy, pushing the price of gas downwards and creating an even more favorable price, which can discourage fast-growing economies in the EU27 from adopting renewable energy. With financial incentives for renewable energy sectors, policymakers should consider the establishment of the sector since these policies are more significant for sectors that have already received attention and investments rather than non-established sectors with no existing market. Moreover, in order to meet the goal, the EU needs to provide more solutions and encourage policies for other renewable sector, such as geothermal energy or renewable combustible energy, since solar PV and wind capacity expansion are not sufficient to reach the REPowerEU goal for 2030 (International Energy Agency, 2023).

Finally, the key to the swift transition to renewable energy is the reduction in non-renewable energy, not only in supply but also in demand. As the fossil fuels and natural market is so stable, in the energy crisis, just one cut in supply can disrupt the market with price spikes. During the Covid-19 times, energy prices dropped mainly due to reduced demand. Meanwhile, from 2021, when the economy recovered from the COVID-19 pandemic, energy demand increased to keep up with the growing economic activities, which led to an increase in non-renewable energy prices. Therefore, implementing renewable energy requires strong policies to reduce demand for non-renewable energy, as well as the societal will to change and restrict demand. The EU has already implemented policies to reduce energy use in household cooling and heating, such as replacing old gas heating systems with new ones using electricity or renewable energy and imposing a 15% reduction in gas and fuel demand in 2022. This should continue, and more actions should be aimed at promoting and educating the public on reducing energy usage, particularly non-renewable energy, while introducing more policies to encourage energy saving and replacing renewable energy in companies and households. These can include phasing out the existing subsidies for fossil fuels, creating favorable conditions for end-users to purchase renewable energy-using equipment, prioritizing the use of renewable energy in the public sector, and increasing awareness for citizens.

Regarding the overall energy market, from January to April 2024, the gas price has decreased considerably compared to the previous year and remained stable for the past four months. Even though the price is still higher than the 2020 level - before the energy crisis began, it is safe to say that the European energy crisis has begun to subside and is moving toward resolution. With the high gas storage and new agreements with LNG exporters from the RePowerEU policies, it is also less likely for the EU to experience such a similar energy shock in the short term, at least until 2030, when these policies change or end. However, given the current unstable situation among countries in the Middle East - the EU’s main LNG exporters, the natural gas market in Europe still faces the risk of LNG delivery disruption and requires close monitoring from policymakers.

Many researchers have agreed that the renewable energy sector in Europe will continue to improve over the next decades thanks to new projects continuously being implemented and the EU government's interest in promoting the transition to renewable energy. However, the EU will encounter many challenges to replicate the double-digit level increase in solar energy generation in the past three years, as there are existing issues related to legislative barriers and the gloomy economic outlook (SolarPower Europe, 2023; Wood Mackenzie, 2024). First, the EU economic growth is lagging below expectations due to high inflation. Lower household consumption, weak investment growth, and stagnant manufacturing activities have pushed the GDP growth outlook of the EU to 0.9% y-o-y in 2024 and 1.7% y-o-y in 2025 (European Commission, 2024). As a capital-intensive industry that requires a lot of initial investment capital, difficulties in the general economic situation can sharply reduce the attractiveness of renewable projects to investors. Meanwhile, projects waiting to be licensed or under construction may be delayed due to a lack of capital, leading to these projects being delayed for many years. However, this could be eased if the European Central Bank introduced solutions to reduce interest rates at the June 2024 meeting. Next, renewable energy permit-grant procedures have not yet been accelerated to the pace agreed in the Renewable Energy Directive and RePowerEU. Therefore, this is an opportunity to help the EU accelerate renewable energy production to achieve the 42.5% renewable energy share target by 2030. However, it can also be a major barrier to developing the renewable energy sector.

The EU's dependence on Chinese renewable energy technologies is also worth attention to in the future. China accounted for about 75% of the global manufacturing capacity for solar modules as of 2021, while Europe accounted for only 3% (International Energy Agency, 2023). The Chinese manufacturing industry now provides the EU with cheap solar energy technologies and raw materials for producing renewable energy. China supplies around 90% of the EU’s solar panel needs and over 90% of the EU’s demand for rare earth permanent magnets and battery-grade lithium (McWilliams et al., 2024). This will soon expand to the wind power sector, with wind turbines being mass-produced in China and exported to the EU. In the long term, if the EU fails to implement the Green Deal Industrial Plan aimed at securing the necessary materials for a quick shift to renewable energy, it risks becoming dependent on a single source for the supply of key technologies.

Chapter 6: Conclusion

Despite leaving behind many consequences in economics, politics, and even citizens' trust, the EU energy crisis has unraveled many existing problems that need to be resolved in the EU energy market that were previously disregarded. At the same time, this crisis also helps the EU realize the importance of quickly transitioning to renewable energy and the power of ensuring energy security from within. Even though it has passed the most stressful period of the energy crisis, the EU still has much work to do to quickly develop the renewable energy sector to achieve the set goals as well as ensure balance in the long-term energy supply and demand. The findings are highlighted as follows:

(i) The energy crisis, exacerbated by Russia's diminished supply of pipeline gas, has had negative macroeconomic impacts on the EU27 region. Natural gas imports from Russia dropped to 2,000 - 3,000 million cubic tonnes from July 2022 to December 2022, a 3-fold decrease compared to the 2018-2021 level, which led to a decrease of 16.8% in gas imports compared to the same period in 2021. Combined with the lingering effects of the COVID-19 lockdown period, the sudden cut shook the EU's energy market, which was dependent on Russian energy imports, leading to a noticeable slowing GDP growth rate and lagging export turnover. EU27's GDP growth in Q3 2022 was only 1.5% compared to the previous quarter, and the slow growth continued to linger throughout 2023. The export growth was 3.4% in Q3 2022, much lower than the average increase of 4.6% in 2021. By Q4 2023, quarterly export growth had decreased to a negative figure of -0.63% compared to the previous quarter, which marked the second time from 2018-2022 that the EU27 recorded a negative growth in exports.

(ii) Greenhouse gas emissions reduced significantly and continuously during the energy crisis by 0.2%, 0.9%, and 5.8% during the second, third, and fourth quarters of 2022. Thanks to this reduction, air emissions account for greenhouse gas emissions per capita in 2022, which decreased to 2.01 tonnes, the lowest level ever since 2020. Sectors that witnessed the most significant reduction in greenhouse gas emissions were those that are energy-intensive and heavily dependent on natural gas and non-renewable energy sources such as electricity, gas, steam, and air conditioning supply, manufacturing, and construction. Conversely, sectors that are less dependent on natural gas, such as mining and quarrying and waste supply, experienced an increase in greenhouse gas emissions. These shifts can be useful for policymakers in generating new policies to help the EU27 achieve a more sustainable reduction in greenhouse gas emissions.

(iii) Although non-renewable energy sources have gradually decreased in the EU's energy portfolio, the region's energy supply is still heavily dependent on these sources, especially natural gas. When the energy crisis happened, the EU immediately implemented actions to ensure sufficient non-renewable supply, especially LNG. This was shown by the increase of 70.1% in LNG volume imports and 8.3% in natural pipeline gas imports in 2022 compared to 2021 figures. Meanwhile, renewable energy supply witnessed the first negative growth rate of -1.3% in a decade due to unfavorable weather conditions and high investment costs. In 2022, renewable energy supply decreased by 1.3% compared to 2021, while the average annual growth rate of renewable energy supply was 4.0% from 2011 to 2021. The crisis has shown the reliance on immediate solutions of non-renewable energy in the EU and suggested future challenges in shifting away from oil and gas. The shortage has also unraveled the weak-to-adapt renewable energy infrastructure in the region, underscoring the need for capacity building and resilience in existing renewable energy projects.

(iv) During the energy crisis, the total consumption of non-renewable energy sources decreased by 4.1% compared to 2021 due to the peak in prices. In which, solid fossil fuels consumption decreased by 13.5% y-o-y, and natural gas consumption decreased sharply by 13.1% y-o-y due to the increase of 155.1% y-o-y in prices. Conversely, renewable energy and biofuels have displayed a resilient and upward trajectory in consumption despite a slower growth in 2022 attributed to a reduction in overall electricity consumption in the EU. Compared with 2021, the EU27's share of renewable energy consumption in 2022 increased by 5.0%, higher than the annual growth rate in the period 2013-2019. Even though the EU's share of renewable energy increased in 2022, a wider renewable adoption gap among Member States of 52.9% in 2022 compared to 51.0% in 2021 was observed. This gap and the fact that only 10 countries had a share of renewable energy above the EU27 average suggests a variability among Member States' ability to respond to the energy crisis through renewable sources.

(v) In line with the increasing dependence on non-renewable supply, the electricity generation sector immediately turned to gas and oil to cope with the energy shortage during the crisis. Except for nuclear fuels, which decreased slightly compared to all months in 2022, electricity generation from the rest of non-renewable sources in 2022 increased compared to 2021, with the most robust increase belonging to natural gas (+37%) and oil and petroleum products (+30%). The ratio of electricity generated from non-renewable and renewable energy was 59.6% and 40.4% in July 2022 and leaned more towards non-renewable energy, with the ratio being 62.6% and 37.4% in August 2022. However, a few months after regaining balance from the shock, renewable energy consumption in electricity generation rapidly increased to almost the same proportion as non-renewable energy. In 2023, wind surpassed natural gas and has become the energy source that produces the second most electricity, accounting for 17.9% of all electricity production. Hydro moved to fourth place with 13.2% of all electricity produced. On average, in the first 11 months of 2023, the proportion of electricity generated from renewable energy accounted for 45.5%, an increase of 4.9% compared to 2022. Overall, non-renewable energy was the immediate source of energy used to cope with the energy shortage because countries need to seek alternative available energy sources immediately to compensate for the shortage that Russia created in the EU energy market. However, as EU countries focused on improving infrastructure and developing policies to increase renewable energy consumption to cope with the crisis, renewable energy consumption increased rapidly, thereby reducing EU dependence on imported energy sources, mainly non-renewable.

(vi) The share of renewable energy use in heating and cooling in the EU increased significantly in the unstable periods of the economy, such as in the global economic crisis (+1.5%) and the EU energy crisis in 2022 (+1.8%). The different rates of employing renewable energy consumption in heating and cooling among Member States suggest that countries with established renewable energy infrastructure and a high share of renewable energy consumption, such as Estonia, Latvia, and Finland, adapt better to shocks in the energy market. With existing capacities and favorable policies from the EU government, these countries have rapidly increased the share of renewable energy by 3.6-6.5% just from 2021 to 2022. Meanwhile, countries with sluggish growth in the share of renewable energy find it difficult to adapt their renewable energy consumption to the shortage of non-renewable energy. However, given that only Malta managed to meet the proposed growth of the RED II target, the proposed annual growth rate of 2.4% in renewable energy in heating and cooling is very ambitious for the EU27.

(vii) Financial incentives that the EU proposed worked better for the renewable energy sector that is already established and is less risky or confusing for investors, for example, in this case, the solar photovoltaic sector. Thanks to these incentives, monthly electricity generated from solar significantly increased by 69.9% (M after policy = 20,677.53 compared to M before policy = 12,166.98), with a p-value of 0.02. This significant p-value implies that the initiative likely had an effect on increasing solar energy generation. The effect was not found in the case of the hydrogen sector, which was similar to the result of the study by Joshi (2021). With the Renewable Portfolio Standards policies, more robust policies that are tailored to different Member States are needed to reach the ambitious target in 2030. In order to reach the target of 42.5% renewable energy consumption, from the figure of 23.02% in 2022, the EU needs to increase its overall renewable energy consumption by 2.435% per year, which is much higher than the annual increase target of 1.9% and the 2022 level annual increase of 1.09%. Moreover, the policy to import LNG immediately and continously can be detrimental to the future EU energy market.

The research has provided several key findings about the energy crisis's impact on the renewable energy transition in the EU and how the EU coped with the shortage of energy. However, there are some limitations that should be acknowledged and addressed. First of all, the data used for research is purely based on secondary data sources, which can be biased or inaccurate, especially for the latest figures. The secondary data sources also limit the research from exploring the long-term development of renewable energy after being supported by actions and policies from the government, which may lead to an incomplete analysis. The next limitation is the methodological constraint of using descriptive statistics and T-test analysis. This methodology helps find key insights by exploring the change patterns in renewable energy deployment; however, it cannot address the correlation between the drivers of renewable energy and the use of green energy. Finally, by using the EU27 data as the central figure for the analysis, this research might not be able to cover the impact of the energy crisis on the Member States' renewable energy sector, given that they all have different levels of renewable energy technology, economic status, and infrastructure. Future research can further explore whether the drivers of renewable energy consumption maintain the same directional correlation in the short term and long term after the energy crisis. It can also examine whether the REPowerEU plan is equally effective among all Member States.

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Appendix

1. Result of T-test: Change in electricity generation from hydro energy before and after IPCEI Hy2Tech was implemented

Independent groups t-test

Group Statistics

	Group	N	Missing Count	Missing Count (Group Column)	Mean	Standard Deviation	Standard Error Mean
Electricity_generation_from_hydro	Before policy	55	0	0	29,022.0282	4,676.6143	630.5945
Electricity_generation_from_hydro	After policy	16	0	0	26,688.7199	4,488.8954	1,122.2239

Levene Test

The Levene Test is used to test for the equality of variances.

	F	df 1	df 2	p-Value
Electricity_generation_from_hydro	0.0883	1	69	0.7672

Independent Groups Statistics

Confidence Interval (CI) Probability: 95.0%

Differences are reported of the groups: Before policy - After policy

	Variance Assumption	t	df	p-value (2-tailed)	Mean Difference	Standard Error Difference	CI (Lower Bound)
Electricity_generation_from_hydro	Equal variances assumed	1.7717	69	0.0809	2,333.3082	1,316.9632	-293.9615
Electricity_generation_from_hydro	Equal variances not assumed	1.8126	25.2681	0.0818	2,333.3082	1,287.259	-316.4255

2. Result of T-test: Change in electricity generation from solar energy before and after SolarPV Industry Alliance was implemented

Independent groups t-test

Group Statistics

	Group	N	Missing Count	Missing Count (Group Column)	Mean	Standard Deviation	Standard Error Mean
Electricity_generation_from_solar	Before policy	60	0	0	12,166.9824	6,458.638	833.8066
Electricity_generation_from_solar	After policy	11	0	0	20,677.531	9,298.8613	2,803.7122

Levene Test

The Levene Test is used to test for the equality of variances.

	F	df 1	df 2	p-Value
Electricity_generation_from_solar	5.2771	1	69	0.0246

Independent Groups Statistics

Confidence Interval (CI) Probability: 95.0%

Differences are reported of the groups: Before policy - After policy

	Variance Assumption	t	df	p-value (2-tailed)	Mean Difference	Standard Error Difference	CI (Lower Bound)
Electricity_generation_from_solar	Equal variances assumed	-3.7375	69	0.0004	-8,510.5486	2,277.0977	-13,053.2343
Electricity_generation_from_solar	Equal variances not assumed	-2.9095	11.8314	0.0133	-8,510.5486	2,925.0701	-14,893.8165