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THE IMPACT OF BIOFUEL PRODUCTION AND CONSUMPTION ON ECONOMIC EXPANSION IN THE EUROPEAN UNION

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The aim of this dissertation is to obtain a doctoral (PhD) degree in the scientific field of "Management and Business" (Major: Accounting and Finance).

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1. INTRODUCTION

1.1. Research background

Energy is a crucial part of economic progress as it is a key part of many production and consumption activities. One of the most important things for economic growth is energy. From a practical viewpoint, energy use drives financial development, economic growth and industrial productivity, and it is a key part of how any modern economy works (BHATTACHARYYA, 2019; GRIFFIN & STEELE, 2013; SAIDI, 2023; SCHWARZ, 2022; VARUN ET AL., 2009; WANG ET AL., 2021). In recent years, the energy demand has been soaring internationally (JIANG ET AL., 2023; ROBLES-IGLESIAS ET AL., 2023; SAHA ET AL., 2022). Also, energy prices are increasing daily (MACDONALD-SMITH & WIGGINS, 2022; WRIGLEY, 2022). This skyrocketing demand for energy and the soaring oil price have prompted energy-consuming nations to focus more on developing alternative energy sources (OLÁH, 2005; SULE ET AL., 2022). Biofuels are one of the most prominent alternatives to fossil fuels.

Biofuels are supported and encouraged due to their renewable and ecological benefits. There are two main categories of energy: fossil fuels and renewable resources. Renewable energy sources include the sun, biomass, wind, hydro, nuclear, geothermal, etc., while fossil fuels include oil, coal, and natural gas. As the need for energy throughout the world increases, energy scarcity has emerged as the primary obstacle to the growth of the global economy (DEMIRBAS, 2017). Incorporating biofuels will lessen a nation's dependency on conventional petroleum imports from other nations, mitigate the effects of oil price swings, boost the economy, and reduce carbon emissions. In addition, biofuels stimulate new businesses while concurrently boosting global economic activity.

As an integral part of the ‘bio-economy’ and as a source of renewable energy, biofuels have the potential to greatly enhance the safety of our energy, economic soundness, and the quality of our environment. Biomass is any dry organic matter that may be burned to produce heat or electricity; examples include wood waste, grass clippings, and farm byproducts (DEMIRBAS, 2008; THE ROYAL SOCIETY, 2008). The biofuels industry directly supported nearly 400,000 employments, with a total of 1.9 million jobs supported by the industry in the United States. By 2030, the advanced biofuel industry will have contributed $113 billion to the economy. There would be a $300 billion impact on economic activity as a whole (BIO, 2022).

Bioenergy plays a crucial part in the EU's markets for renewable energy and has the potential to significantly impact a low-carbon economy. Because they have a lower carbon footprint than other products, bio-based products are a desirable option for lowering glasshouse gas emission (BANJA ET AL., 2019). European Union is working with high importance on producing more biofuels and reducing their dependency on crude oil. That is why, EU countries' governments take different initiatives. For example, as the plenary of the European Parliament sets to vote on the revision of the Renewable Energy Directive, whether the EU will maximise the use of sustainable biofuels remains of paramount importance. There are several reasons why the EU should improve its biofuel efforts. Here are some examples, such as reducing the dependency on crude oil, promoting food security throughout the EU, fighting against adverse effects of climate change, and meeting climate targets (EU BIOFUELS CHAIN, 2022). EU commission's RePowerEU proposal also supports promoting European energy security and ensuring the sustainable domestic production of biofuels, promoting circular economy and carbon neutrality. According to one report of European Commission, 85% of Europeans think that the EU has to lessen its reliance on Russian oil and gas as soon as feasible (REPOWEREU, 2023), whereas biofuel is one of the most alternative solutions. Biofuel also have some very increasing importance in EU economy because of several forces such as rural development, energy security, investment, energy independence, and so on. Biofuel development in the EU is a relatively recent phenomenon, with significant progress made over the past 15 years since 2005. However, the current decade is the most important period for biofuel development. It is worth noting that although we refer to the EU as a single economic zone, not all countries within the region have made significant contributions to the development of biofuels (HASAN & JUDIT, 2022). Overall, biofuel also plays important roles in overall sustainability (CADILLO-BENALCAZAR ET AL., 2021)

Several studies found that the production and consumption of biofuels have a significant impact on economic growth. For example, HARTLEY ET AL. (2019A) revealed that expanding the bioethanol business to focus on a single product might boost economic growth without compromising food safety. NAKAMYA (2022) demonstrated that biofuels have the potential to provide a novel framework for alleviating poverty and promoting economic growth in economies that are heavily dependent on agriculture as their primary source of revenue. MEYER ET AL. (2013) mentioned biofuel as one of the major economic forces for the Brazilian economy. Some other studies also emphasize both production and consumption of biofuel as an importance force of financial development and economic growth (ARIMA ET

AL., 2017; BANDYOPADHYAY ET AL., 2009; DATTA, 2022; DEMIRBAS, 2009; ENGLISH ET AL., 2008; FORAN, 2001; FORAN & CRANE, 2000; GEHLHAR ET AL., 2012; MOSCHINI ET AL., 2012; SAIDI, 2023; WANG ET A., 2021; EREN ET AL., 2019).

Considering the high significance of energy economics, I specified bio-economy as the study area of my thesis. More particularly, I focus on the ‘bio-economy’ referred to as the biofuel economy. Focusing on the key theme I use keywords such as "biofuel," "biofuels," "biodiesel," "bioethanol," "bio-economy," "bioeconomy". Considering the key theme of this research, I focus first on bibliometric research to show how biofuel relates to economic circumstances. In this section, particularly, I focus on "biofuel," "biodiesel," and "bioethanol" as key study focus. In the second stage, I study the empirical impact of the production and consumption of biofuels on economic growth in the European Union as study area. More particularly, biofuel production (includes bioethanol and biodiesel production) and biofuel consumption (includes bioethanol and biodiesel consumption).

1.2. Research gaps and questions

Although there are many studies on the relationship between biofuels and economic growth, most of them do not have any empirical support. Consequently, empirical research on the contribution of biofuel production and consumption to economic growth is lacking. Also, the relationship between bioeconomy and financial development is not greatly explored in the literature. Considering the EU as a study area, there is still a lack of literature. There is little research on the economic significance of biofuels in the EU. Very few studies have shown the empirical impact of biofuels on EU views. Therefore, the lack of empirical research on the relationship between EU biofuel production and consumption, financial development, and economic growth is considered a gap in this study. Also, to the best of my knowledge from the literature, no study showed the influence of both production and consumption of biofuels on economic growth in a single platform. Therefore, this lack of integration of the influence of both production and consumption of biofuels on economic growth in a single platform is also considered as a lack for this study. Moreover, the impact of bioeconomy on financial development, and vice versa is still need more attention. The above research gaps motivate this study to specify the research questions. Considering the above significance and gaps of this research, I specify five research questions (RQ) in the following section:

- *RQ1: How does the production of biofuels impact on economic growth in the EU?*
- *RQ2: How does the consumption of biofuels impact on economic growth in the EU?*
- *RQ3: How does the degree of impact of biofuel production differ from its consumption in the EU?*
- *RQ4: How does biofuels, financial development, and economic growth cause each other in the EU?*
- *RQ5: How does bio-economy impact financial development, and vice versa?*

The answer of these five research questions is experimented in the finding section separately. Also, the output of these five questions are discussed in the discussion sections.

1.3. Research objectives

The main theme of this study is biofuel and economic growth in the EU. This theme helps to specify the gaps in this study. This study identifies five research objectives based on research gaps and research questions.

- *First objective* - to examine the empirical impact of biofuel production on economic expansion in the EU.
- *Second objective* - to investigate biofuel consumption's empirical impact on EU economic expansion.
- *Third objective* - to explore the relative importance of the impact of biofuel production on biofuel consumption in the EU.
- *Fourth objective* - to investigate the causal relationship between biofuel variables, financial development, and economic growth.
- *Fifth objective* – to investigate impact of bio-economy on financial development, and vice versa.

1.4. Research hypotheses

Research hypothesis formulation is one of the most important issues of any empirical study. Considering the significance, this study assumes five hypotheses. These hypotheses will significantly help to accomplish the objectives of this study. The hypotheses are mentioned in the following sections.

Hypothesis 1		*Biofuel production has a significant positive impact on EU economic growth.*
Hypothesis 2		*Biofuel consumption has a significant positive impact on EU economic growth*
Hypothesis 3		*Biofuel production has a higher significant positive impact compared to biofuel consumption on EU economic growth.*
Hypothesis 4	4A	*Biofuel production causes financial development and EU economic growth.*
	4B	*Biofuel consumption causes financial development and EU economic growth.*
Hypothesis 5		*Biofuel production and consumption has positive impact on financial development, and vice versa.*

All hypotheses are experimented here in this study as separate sections. Also, the findings are compared with the existing literature in the findings section of specific regression outcome. Finally, the output of both hypotheses is discussed in the discussion section in the later sections of this study.

1.5. Research design

In this research, an extensive analysis has been carried out to examine various previous scholarly works that have explored the concepts of biofuels, biofuel production, biofuel consumptions, and overall bioeconomy and its impact on EU economy. I design the research considering the concepts of this study. Initially this research was designed based on number of steps.

Step 1 – After an initial review of the existing literature on the sustainable biofuel economy, I initially specify a general area of research.

Step 2 – the field of study designated now is specific, so I start exploring an extended literature review from three different aspects. First, I explore the current state of the EU bioeconomy (please see section *2.2 – Present landscape of bioeconomy in the EU*), and second, I try to conduct a bibliometric review of a sustainable biofuel economy (please see section *2.3 – Bibliometric review on Sustainable biofuel economy*), from which I find important links between biofuels and the economy. In the third phase, I focus on the empirical literature focusing on the impact of biofuels on economic growth (please see the empirical findings of this study).

Step 3 – I specify the study area, EU, the research gap based on study area, research question focusing on study gap, objectives aligning with research gap & questions, and finally hypotheses formation.

Step 4 – I specify the methodological structure of the study based on previous literature.

Step 5 – Based on methodology and estimated model, I collect secondary data and processed for the experiment analysis.

Step 6 – Using the collected data, I experiment with the specified models from the methodology section.

Step 7 – After finalizing the experiment and getting the output in hand, I analyze the output of the study.

Step 8 – After the findings and analysis, I evaluate the study hypotheses that I assumed in the third step.

Step 9 – After evaluating research hypotheses, I address research gaps, questions, and research objectives based on experimental output.

Step 10 – Finally, I start writing the thesis report according to university pre-specified doctoral thesis regulation and structure.

The step-by-step research design is mentioned in Figure 1.

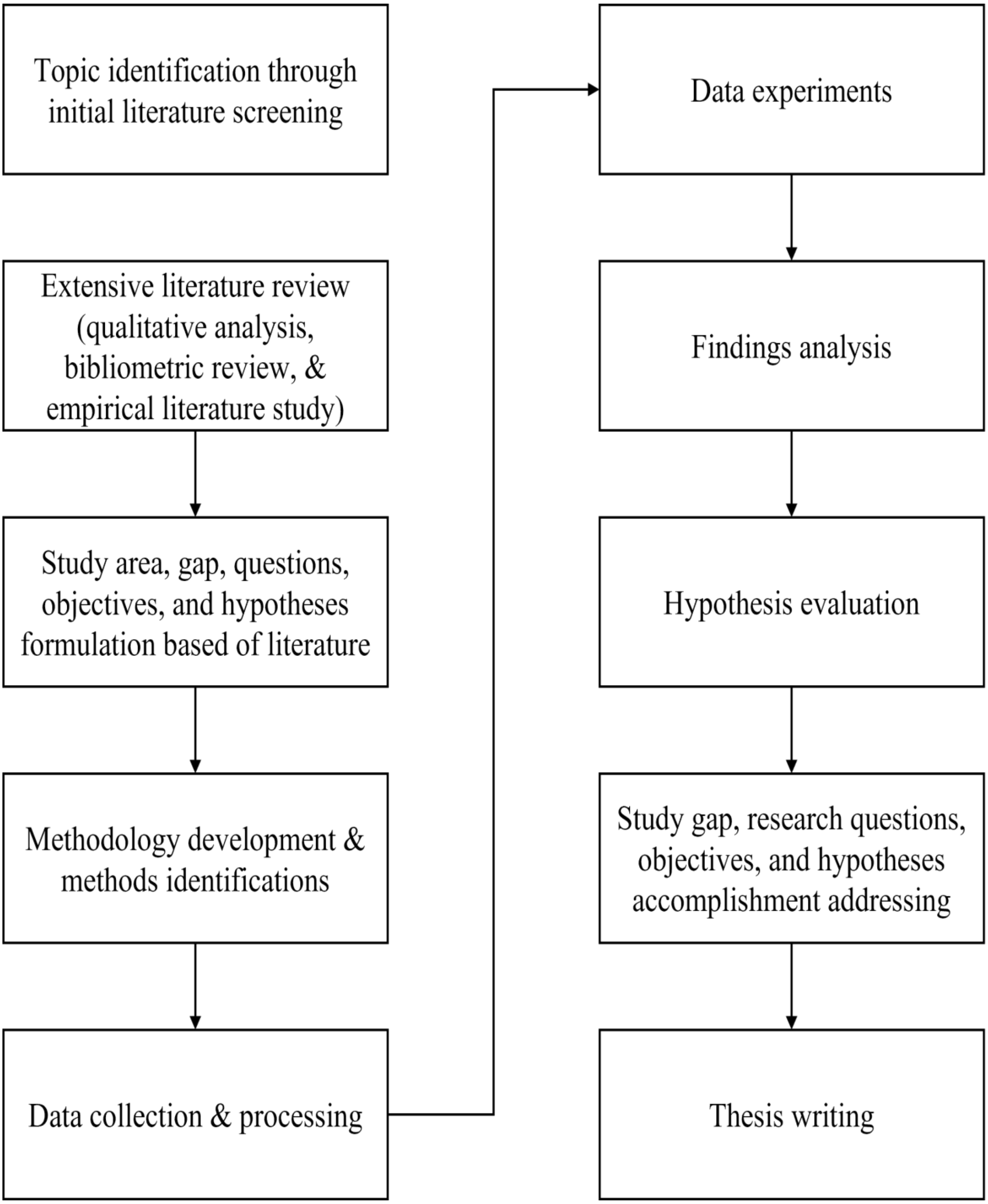


Figure 1: Research design

Source: Author’s illustration (2022)

1.6. Structure of the dissertation

This thesis is presented in a structured way. There are six key sections of the thesis. These are the introduction, literature review, data and methodology, findings and analysis, conclusion and policy implications, and novel findings and contributions.

In the first section, Introduction, this study presents the study background and significance, the research gap, five research questions, five research objectives, five study hypotheses, research design, and finally, the structure of the thesis. This section mainly gives the overall significance and aims of the study.

In the second section of the dissertation, the literature review, this study includes four sub-sections. First sub-section, this study discusses the definition of biofuels, explore the generations of biofuels, and different types of biofuels, and benefits and disadvantages of biofuels. Second sub-section, the present status of biofuel production and consumption in the European Union. More particularly, EU biofuel production, the consumption of ethanol feedstock, the share of most renewable energy consumption, and the contribution of biofuels for transport in the EU. This section helps to understand the overall EU bioeconomy scenario. Third sub-section, the bibliometric findings on biofuels. More precisely, yearly scientific output, national scientific output and collaboration, top-cited nations, most-used sources, top-relevant phrases, research priorities and the expansion of the biofuel economy, co-occurrence evaluation, and conceptual structure map. This section helps to understand the overall dimensions of bioeconomy and in what aspect biofuels connect economy. Fourth sub-section, the hypotheses of the study. Here, the first hypothesis is assumed from the previous literature on the production of biofuel's impact on economic growth. The second hypothesis is assumed from the previous literature on the consumption of biofuel impact on economic growth. The third hypothesis is biofuel production has a higher significant positive impact compared to biofuel consumption on EU economic growth. The fourth hypothesis is assumed from the previous literature on the causality between production and consumption of biofuel and economic growth.

In the third section, this study presents the data and methodology. The first section presents how and what types of data were used in this study and the measurement of the study variables. The second section presents the model construction of the study. The third and fourth section include the methods of unit root test and panel cointegration tests. Fifth, this study presents which panel regressions are used to investigate the output of the study in the sixth section.

In the fourth section, the findings and analysis are presented. Particularly, the findings and analysis section also have six subsections. The first section presents the descriptive statistics (description of the production and consumption of variables, descriptive statistics, and unit root tests). The second section shows the output of hypothesis 1 (impact of biofuel production on economic growth). Third, third section shows the output of hypothesis 2 (impact of biofuel consumption on economic growth). Fourth, investigation of both production and consumption of biofuels in a single model (Hypothesis 3). Fifth section presents the panel granger causality relationship (Hypothesis 4). Section six presents nexus relationships between biofuel production and consumption, financial development, and economic growth (Hypothesis 5). Finally, seventh section presents the hypotheses evaluation of the study.

In the fifth section, conclusions and policy implications, presents conclusion, limitations of the study, future research directions, and policy implications.

In the sixth section, I present novel findings and contributions. There are six novel contributions of this study. These contributions are aligned to the questions, objectives, and hypotheses of the study.

After the sixth section, I present the list of figures, tables, references, list of publications, statements, acknowledgments, and an appendix of the study. In the appendix, I present all the extensions and detailed findings of the study.

2. LITERATURE REVIEW

2.1. Introduction to biofuels

2.1.1. Definition of biofuels

In the 1970s, efforts were made to lower carbon dioxide emissions by investing in the commercial production of biofuels, which had enormous potential as a replacement for fossil fuels. In 2010, more than 100 billion gallons of biofuels were generated, demonstrating the industry's rapid expansion (PAUL ET AL., 2018). Biofuel refers to any kind of fuel produced from biomass, which can include material from plants or algae as well as animal waste products (JHA ET AL., 2022; LAKNER ET AL., 2021; POPP ET AL., 2021; ROBERTS & PATTERSON, 2014; ROBERTS & SMAGALA, 2022; PARAVANTIS, 2022; YOGEESWARI, ET AL., 2023, PRIYA ET AL., 2023). Biofuel is manufactured from feedstock material and can be easily renewed (VENKATESWARAN ET AL., 2022; MALODE ET AL., 2021). Biofuel is recurrently asserted as a cost-effective and environmentally safe alternative to petroleum-based fuels, especially in the context of growing crude oil prices and more serious concern for fossil fuels' adverse impact on global climate change (SARWER ET AL., 2022). Biofuel has a good future perspective in the context of producing a higher volume of biofuels with low-cost products (BARKER, 2016; AMBAYE ET AL., 2021).

2.1.2. Generations of biofuels

Biofuel technology can be categorised into a variety of technical generations. There are four generations of biofuels. Following the literature (OFORI-BOATENG, 2022; PHILLIPS, 2022; BARKER, 2016; CLARK & PAZDERNIK, 2016; KNOTHE, 2012; PAUL ET AL., 2018), this study briefly discussed three generations of biofuels in the following sections.

- *First-generation biofuels:* Sugar, vegetable oil, and starch, which are obtained mostly from food crops, are used to produce traditional biofuels. This category encompasses the great majority of biofuels now produced in commercial volumes. First-generation biofuels are generated on a large scale and have good decarbonization ratios due to their a low carbon footprint as compared to corresponding fossil fuels. This allows them to be used in place of fossil fuels in the same applications.

- *Second-generation biofuels:* The second generation of advanced biofuels is made from different crops, but those crops aren't used for food and waste lignocellulose. For the manufacturing process of the second-generation biofuels to work, enzymes and fermentation are needed. When compared to fossil fuels, the development of biofuels can result in a reduction in carbon dioxide emissions in the atmosphere of up to 90 percent, which makes the production of biofuels of the second generation an attractive endeavour.
- *Third-generation biofuels:* Third-generation biofuels are produced from algae, sometimes called algae biofuels. The third-generation algae biofuels are mainly made from photosynthetic algae. In the domain of genomics, the third generation intervenes directly in the production of biomass, assisting in the growth of plants with characteristics that are more advantageous for the conversion of bioproducts.
- *Fourth-generation biofuels*: Produced using plant materials, such as trees that have undergone genetic modification. The elimination of carbon dioxide in the atmosphere is going to be the primary focus of the fourth generation. Plants that have been genetically modified to take in (and store) more gases in their trunks, branches, and leaves than their ancestral ancestors are responsible for the capture of carbon. The transformation of carbon-containing biomass into fuel and gases takes place here (with the aid of second-generation methods). Because of this, not only are they considered to be renewable sources of energy, but they are also considered to be carbon-negative sources of energy. This is because the process of removing CO_2 from the environment results in a drop in the amounts of this gas that are present in the air.

2.1.3. Types of biofuels

According to SINGH ET AL. (2022), bioenergy technologies are attempting to generate next-generation biofuels derived from wastes, cellulosic biomass, and resources based on algae. Currently, the most prevalent biofuels are ‘ethanol’ and ‘biodiesel’, representing the first generation of biofuel technology. There are different types of biofuels, such as biogas, wood, biodiesel, bioethanol, methanol, and butanol (AMSPEC, 2021; MARTÍN-JUÁREZ ET AL., 2017; MORONE & COTTONI, 2016; RINKESH, 2022; SANCHEZ-RAMÍREZ ET AL., 2016). According to the *US Office of Energy Efficiency & Renewable Energy (n.d.)*, the most prevalent biofuels are ethanol and biodiesel, representing the first generation of biofuel technology. That is why this study describes bioethanol and biodiesel in the following section.

(i) *Fuel Ethanol* - Ethanol is a renewable fuel that derives from a wide variety of plant components (RAJESWARI ET AL., 2022; TRINDADE, 2016; LU, 2016; TOWLER, 2014). Corn and sugarcane are two examples of crops frequently used in ethanol production (MORONE & COTTONI, 2016; RINKESH, 2022). On the other hand, Cellulosic ethanol technology makes it possible for ethanol to play a more prominent role in the future fuel market by reducing the controversy surrounding the influences of crop ethanol on cereal stocks and food prices. Cellulosic ethanol technology also makes it possible for ethanol to play a more prominent role in the present fuel market (ZHANG ET AL., 2021). The majority of ethanol categories are produced from plants' starches and sugars, particularly corn starch in the United States. However, FIREW ET AL. (2022) claimed that energy research and development are working hard to develop technologies that will enable the use of cellulose and hemicellulose, the inedible fibrous materials that make up the majority of plant matter. Fermentation is the typical process that is used to transform biomass into ethanol. To make ethanol during the fermentation process, microorganisms, such as bacteria and yeast, metabolize the sugars found in plants.

(ii) *Biodiesel* - Biodiesel is used in energy compression-ignition (petroleum) engines, much as petroleum-derived diesel (RAJESWARI ET AL., 2022; SHIMASAKI, 2020; WANG, 2019). Animal fats and vegetable oils are combined to produce biodiesel. Alcohol is another component used in the production of biodiesel. Additionally, plant and animal fats are utilised as a supplement (AMRIYA TASNEEM ET AL., 2022; MORONE & COTTONI, 2016; RINKESH, 2022). The Renewable Fuel Standard's biomass-based diesel and total advanced biofuel requirements are both satisfied by biodiesel. Biodiesel is not the same as renewable diesel, sometimes known as "green diesel" (ASLAM ET AL., 2022).

(iii) *Biogas* - Biogas is mostly made of methane gas, despite being created by the anaerobic decomposition of biomass (PANT ET AL., 2023; ZVIRIN ET AL., 1998; YADAV ET AL., 2023; OLUDHE ET AL., 2013). Most agricultural businesses utilise biogas, which is now packaged in gas cylinders for residential use (RINKESH, 2022). Municipal garbage or waste, animal manure, food waste, plant material, and sewage are among the waste materials that can be converted into biogas. In most cases, biogas is used for vehicles purpose and as an alternative to natural gas (NATIONALGRID, n.d.).

(iv) *Methanol* - Methanol is also used as an alternative source of traditional energy with a high potential for the economy (OLÁH, 2005; OTT ET AL., 2012). Olah (2005) mentioned that as an alternate energy source would lead to the prospect of a "methanol economy" to decrease oil and gas reserves. Methanol, an alcohol that is comparable to ethanol, is used as a clean fuel for car engines, especially racing cars, all over the world. Methane and methanol have very different chemical structures, with methane being a gas and methanol being a liquid. Biomass is converted to methanol by gasification at incredibly high temperatures and in the presence of a catalyst (RINKESH, 2022).

(v) *Biobutanol* - Biobutanol is seen as a good replacement for traditional petroleum-based fuels because it has more energy per molecule and has the same chemical structure as gasoline (NAWKARKAR ET AL., 2022). Although biobutanol is less widespread than biodiesel and ethanol, it is the most promising biofuel. Though biobutanol is similar to biodiesel, biobutanol is generated from algae or bacteria rather than plant or animal fats (AMSPEC, 2021). Biobutanol is made from microalgae biomass, so it is becoming a more advanced biofuel, likely, it will eventually replace bioethanol (MARTÍN-JUÁREZ ET AL., 2017). Biobutanol also has high economic and environmental potential (SANCHEZ-RAMÍREZ ET AL., 2016).

2.1.4. Advantages and disadvantages of biofuels

Biofuels have both benefits and disadvantages. After studying the CAMPOS (2023), GUITARRA (2023), MAGALHÃES (2020), RAÍZEN SUSTAINABILITY AND CORPORATE COMMUNICATION TEAMS (2021), this study mentions the benefits and disadvantages in the following sections. In light of the possibility that oil reserves may be depleted, biofuels present an opportunity to diversify energy sources while also mitigating the effects of global warming. Using biofuel has a number of benefits, the most important of which are as follows:

- Low levels of carbon dioxide released into the atmosphere.
- Decreased contributions to warming the planet and the greenhouse effect.
- There are wide variety of plants that can serve as raw material for the manufacturing of biofuels. Sugarcane is one example of reduced carbon emissions in the atmosphere, with a production that is 90% lower compared to other energy sources.
- Have a diverse and onward portfolio that includes what the market is seeking for - in addition to providing security because it comes from virtually limitless sources.

- Boost employment opportunities throughout the industrial chain.
- Eliminate dependency on fossil fuels.
- Acquire a market advantage by manufacturing and/or marketing a product that uses renewable resources.
- Contribute to the improvement of the nation's trade balance as a result of exports.

One of the motivations for increasing production of biofuels is the recent uptick in the price of oil. However, there are several disadvantages of biofuels. The specific disadvantages of biofuels are mentioned in the following section.

- Large-scale intense agricultural farming.
- Rates of deforestation in natural regions have been on the rise.
- The development of monocultures utilising a variety of plant species.
- Influence on the environment, particularly on the land, air, and water, caused by plantations.
- The effect that plantations have on the environment, specifically the land, air, and water.
- Increase in the amount of water used and the inputs used in plantations.
- Influence on the worldwide decline in the amount of food produced.

Also, the manufacturing of biofuel relies on gases that hasten the process of global warming, despite the fact that biofuel itself contributes a negligible amount of carbon dioxide to the environment (SEARCHINGER ET AL., 2008; PLEVIN ET AL., 2010; FARGIONE ET AL., 2008; PUKKALA, 2014; CHERUBINI ET AL., 2011; SEARCHINGER, 2010). As a result of their dependence on cultivation, the products are dependent on intensive farming practises, and the planting of these crops typically takes place in previously wooded areas, in particular tropical forests. Intensive farming is one of the leading contributors to both the depletion of biological variety and the consumption of water resources. The fact that the inputs required for biofuels represent bigger benefits for producers makes it more attractive to reduce the amount of land dedicated to food production.

2.1.5. Increase the utilisation of biofuels in the economy

The utilization of biofuels is one of the important issues in the economy. There are various ways to help improve biofuel utilization. The first one that I want to focus on is R&D that can help improve the overall efficiency of biofuel production. R&D will also support the development of efficient technologies to reduce the cost of biofuel production. Another way to increase biofuel utilization is to develop production infrastructure, such as building infrastructure, improving storage facilities, developing pipelines, processing plants, etc. Since biofuels have a major impact on the overall economy, collaborative projects with other countries are also important. Not all countries are equally technologically advanced. Therefore, technology transfer can have a major impact on the development of the biofuel economy. Government policies and incentives for the sector are also important to increase the utilization of biofuels in the economy. Since the high production cost is one of the pressing issues, the government can implement lower tax policies, different subsidies, and mandatory requirements for biofuel consumption. The government can also provide flexible policies for financial institutions to increase investment in biofuel production projects. These regulations may aid in the development of a stable market for biofuels, increasing their parity with fossil fuels and enticing investment in their production and usage.

2.1.6. Challenges of biofuels development

Biofuel development also faces number of challenges such as (i) production cost of biofuels are high in some cases compared to fossil fuels. The higher cost of production affects the consumer price of the fuels. Higher consumer price ultimately motivate consumer to use the fossil fuel thereby biofuels face very strong competition in the marketplace. (ii) The competitive market always requires low-cost and efficient production technologies. Efficient technologies, which produce biofuels with lower production cost, is also a matter of high development cost. Thereby, cost of technology development is also one of the influential challenges that works as obstacle of the development of biofuel economy. (iii) Higher cost of infrastructure development is one of the most influential challenges. Infrastructures development includes the production infrastructure, biorefinery infrastructure, storage infrastructure, transport infrastructure, building infrastructure, and so on. (iv) the availability of feedstock is considered as one of the most influential challenges of biofuel development. Feedstock availability is also connected to the food securities. For example, higher usage of feedstock such as corn or soybeans also raises the concern of higher food insecurity.

From my viewpoint, the biggest obstacles in the development of biofuels are the competition for land and resources. Due to competition for resources and land, the production of biofuels confronts significant challenges. Large amounts of land, water, and resources are needed for the production of biofuels, which can cause conflicts with other land uses, food production, and the protection of wildlife. The sustainability of biofuel production is also a problem since it may not always result in large reductions in greenhouse gas emissions and may have unfavourable environmental effects like habitat loss and deforestation.

2.2. Present landscape of bioeconomy in the EU

In this section, I will discuss the highlights of the current status of overall biofuel production and use in the EU. In particular, the overall trends of biofuels in the EU, the consumption of fuel ethanol feedstock, the proportion of used renewable energy, and a quick overview of biofuel use for transportation in the EU are all topics that will be covered.

2.2.1. Biofuels production trends in the EU

Figure 2 presents the total biofuel production trends in the EU covering the period 2000 to 2021. The European Union is the leading player in biodiesel production and transportation usage. According to the publication BP STATISTICAL REVIEW OF WORLD ENERGY (2021), it was only 12 thousand oil equivalents (TOE/d) in 2001. After 2001, there was a smooth growth trend of biofuel production in the EU till 2010, when there was 165 TOE/d total biofuel production in the EU. After a year of a downward shift from 2010 to 2011, in 2012, it was again grown up to 201 TOE/d total biofuel production in the EU in 2014. Again, there was a drop down of biofuel production in 2016. However, after 2016, again, total biofuel production started rising, and it was 236 thousand oil equivalents (TOE/d) in 2021. Biodiesel production in Europe decreases the demand for fossil fuel imports, greatly contributes to the growth of the circular and bioeconomy, lessens the demand for imported animal feed, and boosts the rural economy. The European biodiesel sector is directly responsible for the creation of 25,000 of the industry's 220,000 employees (POLITICO STUDIO, 2021).

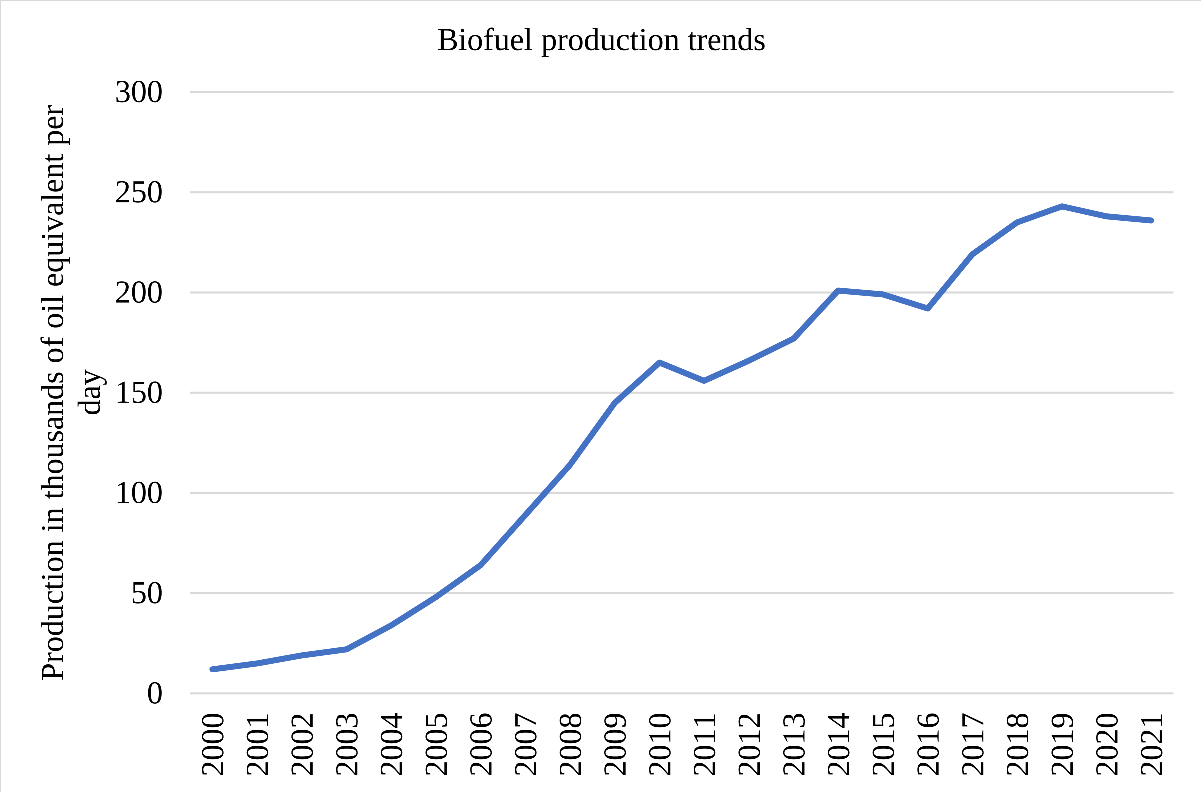


Figure 2: Biofuel production trends in the EU region

Source: Author's illustration (2022)

2.2.2. Fuel ethanol feedstock consumption

Table 1 provides a detailed breakdown of the potential feedstock usage scenario. Other starchy materials, including wheat, barley, and rye, can also be used to make bioethanol. Starchy crops must be turned into sugars. Usually, 1 ton of ethanol is made from 3 tons of grains. Starch crops like wheat and sugar beets are utilized to make bioethanol throughout Europe. Most of the EU countries cultivate sugar beets, which generate more ethanol per hectare than wheat. Sugar beets are the EU's primary ethanol source. Sugar beet consumption reached 7.45 million tons in 2021. Corn was used 6.48 million metric tons in the same year. Sugar beets are the most utilized feedstock, although their value was falling. From 2012-2015, it was above 10k; however, it dropped after 2015.

On the other hand, in 2020, sugar beet consumption was the lowest in the last ten years. This research argues that COVID-19 had an impact both on biofuel production and use. Moreover, COVID-19 affects sugar beets and other feedstocks. In 2021, EU ethanol output reached 5.6 billion litres. In that case, wheat was the most popular feedstock. There are yet additional ethanol feedstocks, for example, rye, barley, triticale, cellulosic biomass, and more. Table 1 explains the feedstock situation.

Table 1: Fuel ethanol feedstock consumption in the EU

Year	Sugar beets	Corn	Wheat	Rye	Barley	Triticale	Cellulosic biomass
2015	10,010	5,218	3,661	712	414	1,031	200
2016	8,830	5,060	3,932	638	379	1,285	200
2017	8,292	5,065	5,197	507	383	720	160
2018	7,949	6,881	3,497	501	503	867	40
2019	8,264	7,066	2,855	373	327	874	40
2020	6,670	6,350	2,510	520	435	835	100
2021	7,450	6,480	2,635	520	450	1,035	200

Source: European Union: Biofuels Annual 2021 (in 1,000 metric tons)

2.2.3. Share most used renewable energy consumption

Biodiesel, bioethanol, renewable electric power, and biogas are popular in the EU. Biodiesel is the EU's most popular renewable energy source, with a 73.8% share. Biodiesel is a biodegradable fuel manufactured from waste cooking oils, animal fats, vegetable oils, or restaurant grease. ALLAMI ET AL. (2022) stated that another name for biodiesel is green diesel different from renewable diesel. According to the RES Transport barometer, bioethanol is the second most prevalent renewable energy source, covering 13.90% of total consumption. On the other hand, renewable electric power accounts for 10.50% of renewable energy utilization. Besides, Biogas made up approximately 2% of the total, and bioethanol 14%. However, Figure 3 shows the most-used renewable energy.

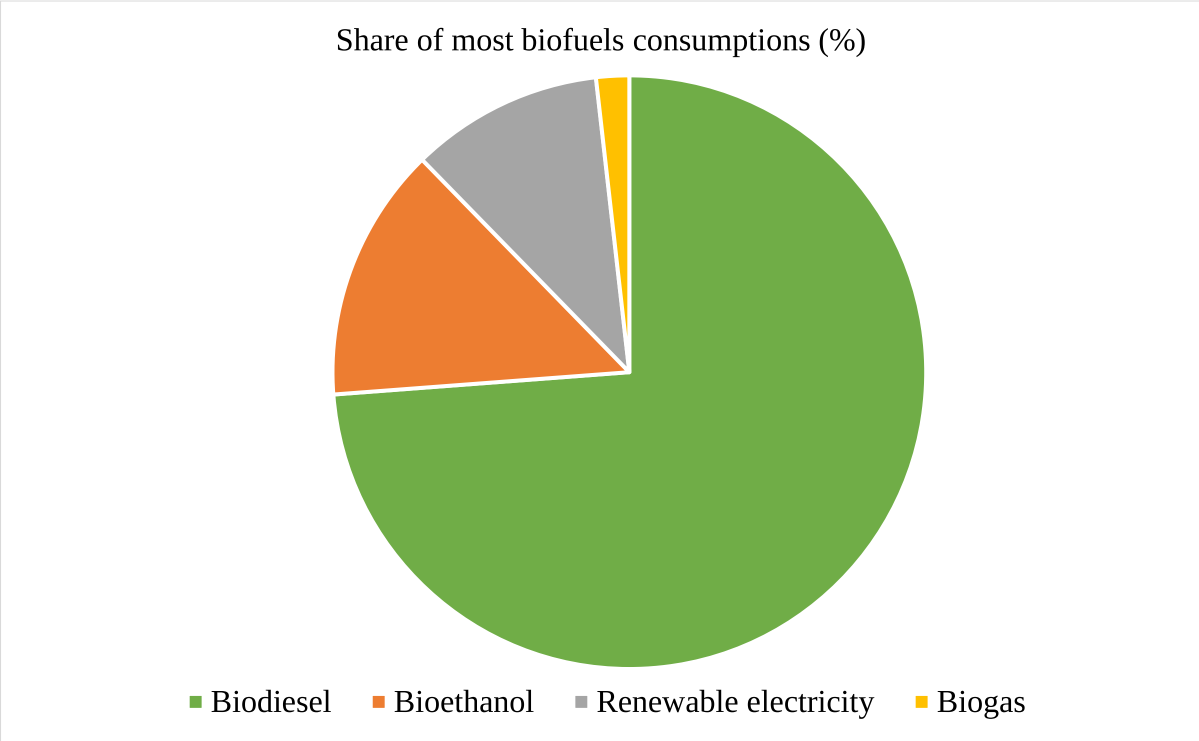


Figure 3: Share the most used renewable energy consumption

Source: Author's illustration (2022)

2.2.4. Biofuels consumption for transport

Biofuels are mostly used in the transportation sector. They're energy dense (unlike electricity and batteries) and easy to transform via existing infrastructure with few adjustments (unlike hydrogen). Because biofuels and petroleum-based fuels are comparable, cars must be modified to utilize biofuels. According to RES Barometer, biodiesel usage continued to increase by 1.6 million metric tons between 2015 and 2020. Biodiesel accounted for 13 million metric tons of oil equivalent in 2020, making Europe the most biofuel user.

Along with the exclusion of the UK from the EU in 2020, the coronavirus epidemic has reduced the utilization of biofuels. According to STATISTA (2022) since 2015, Germany's biodiesel usage for transportation has gradually climbed, reaching a record of 3,300,000 metric tons of oil equivalent in 2020. Additionally, in the same year, bioethanol and biogas consumption reached 701.6 and 76 kilotons of oil equivalent, respectively. On the other hand, in 2018, France used a record 3.4 million metric tons of biofuels for transportation. However, the year 2020 generated a record of 2.6 million metric tons of oil equivalent because 79% of transportation had been converted into biodiesel in the same year. Figure 4 presents the biofuel consumption for transport.

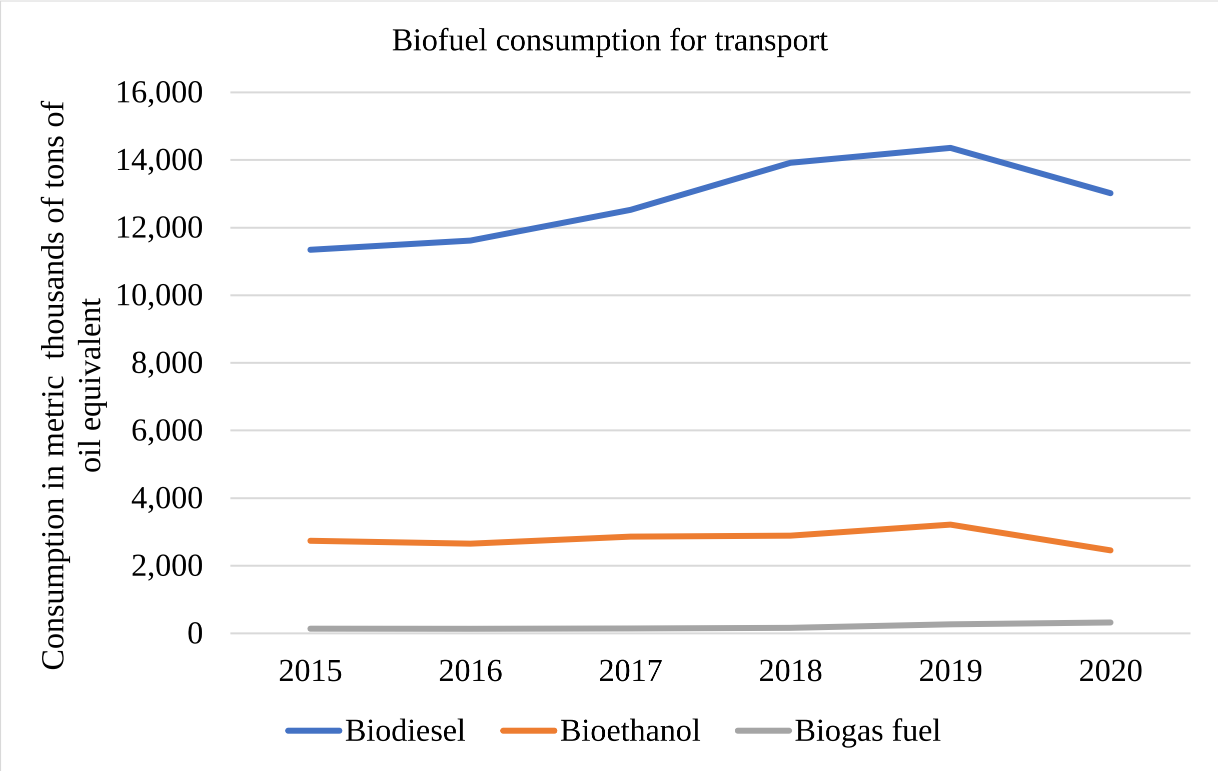


Figure 4: Biofuels consumption for transport

Source: Author's illustration (2022)

2.3. Bibliometric review of sustainable biofuel economy

I have studied the bibliometric review to explore in detail the scientometric status of biofuels research. This bibliometric review was experimented with after conducting specific bibliometric research models. The bibliometric methods are given in the following section before presenting the findings from the bibliometric study.

The abstract and citation database, Scopus (http://www.scopus.com), was initially used to collect data. This database is the most prevalent and most well-known bibliometric data source. This is readily accessible via the online library systems of many colleges (LINNENLUECKE ET AL., 2020). Due to the narrow scope of our investigation, we did not conduct any searches beyond the terms "biofuel," "biofuels," "biodiesel," "bioethanol," "bio-economy," "bioeconomy" in the titles of articles appearing in the designated journals and subject areas. The subject areas are narrowed to Economics, Econometrics, and Finance (EEF) and Business, Management, and Accounting (BMA). A total of 48818 documents were found after the initial search. However, after limiting EEF and BMA, I found 2178 documents, and finally, it came to 2083 after excluding the document that was not published in English. There were 1287 documents in BMA areas and 1085 documents in EEF areas.

After collecting the bibliometric data from Scopus, this research uses R Studio and Biblioshiny for data mapping and modelling, inspired by the ground-breaking work of ARIA & CUCCURULLO (2017). In order to see the results of the study, I make use of two separate software, such as the Bibliometrix package included in R Studio and VOS viewer. R Studio is a command-based programme, and the Bibliometrix package inside it is used to execute most of the visualisations in this work. Another graphical user interface-based piece of software is called VOS viewer is also popular bibliometric research software (please see PERIANES-RODRIGUEZ ET AL. (2016), VAN ECK & WALTMAN (2010), and WALTMAN ET AL. (2010), which was developed by van Eck and Waltman.

2.3.1. Annual scientific production

The rapid increase in publications on the economics of biofuels over the past two decades has good potential. The core potentials are mitigating the adverse effects of climate change, meeting rising energy demand and consumption, ensuring sufficient energy supply, and meeting people's growing aspirations for economic development are all important factors in gaining this advantage of biofuels. Figure 5 presents the annual scientific production starting from 1998 to 2022. According to the figure, it is evident that the significance of biofuels' contribution to the economy started after 2006. Before 2006, it was almost no discussion. A good number of articles discussed the biofuel implication in the economic aspect after 2006. The growth from 2006 (18) to 2008 (112) is highly noticeable. In the next two-year 2009 and 2010 was moderate discussion on biofuels' contribution to the economy. After that, there was, on average moderate discussion regarding biofuel and the economy from 2011 to 2015. However, after 2015, the bioeconomy concept got great attention from the researcher. After 2015, the number of annual publications on bioeconomy reached almost doubled from 2016 to 2022 (156) compared to 2011 to 2015 (93).

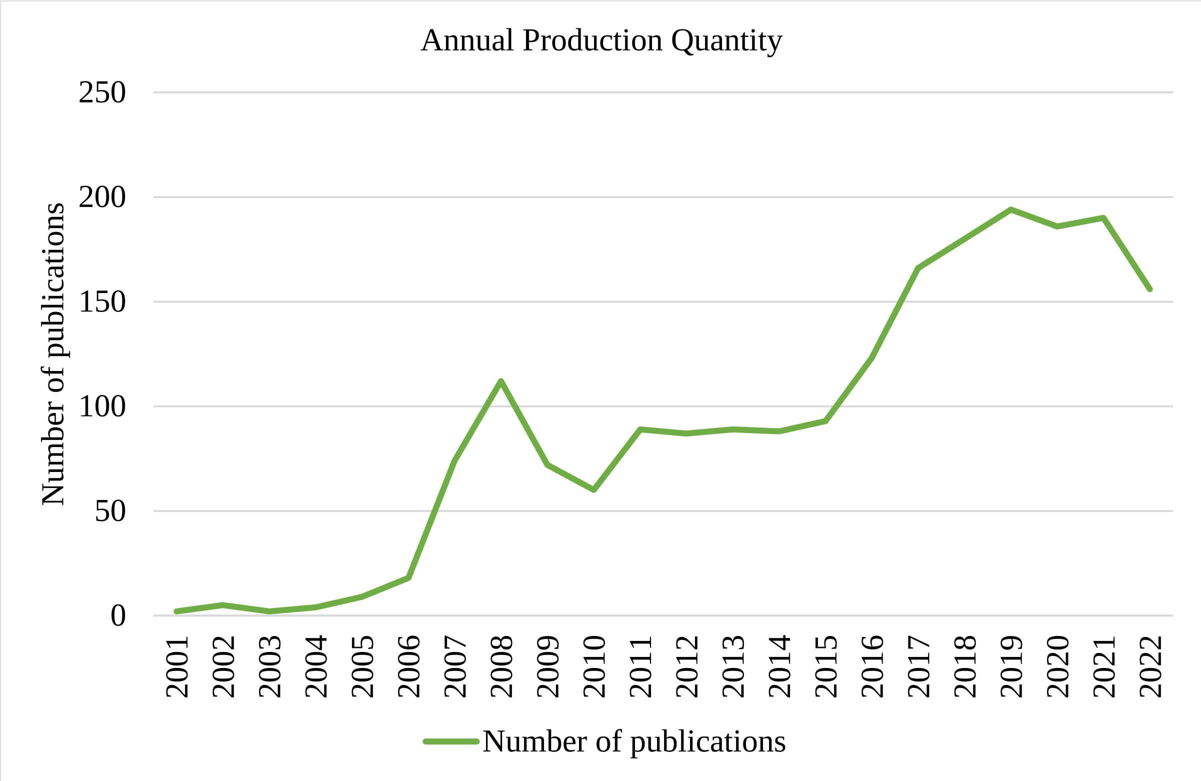


Figure 5: Annual scientific production

Source: Author's illustration (2022)

2.3.2. Country scientific production and collaboration

This section shows the country-specific research contributions from each country to sustainable biofuel economic growth. Figure 6 presents the country's scientific production output (also see Table 49 for details list). The top ten countries that published articles on biofuels linked to the economy are the USA (622), INDIA (345), CHINA (275), BRAZIL (216), GERMANY (189), MALAYSIA (155), ITALY (153), FINLAND (117), UK (113), and SWEDEN (97). Also, some other countries significantly published research on bioeconomy. These are AUSTRALIA (96), INDONESIA (95), NETHERLANDS (95), CANADA (94), IRAN (92), SPAIN (90), FRANCE (89), SOUTH KOREA (89), and THAILAND (75). In this context, another study, LEU ET AL. (2012) also showed that, in terms of the number of patents, the countries with the most biofuel patents are the United States, Canada, Brazil, the European Union and some Asian countries.

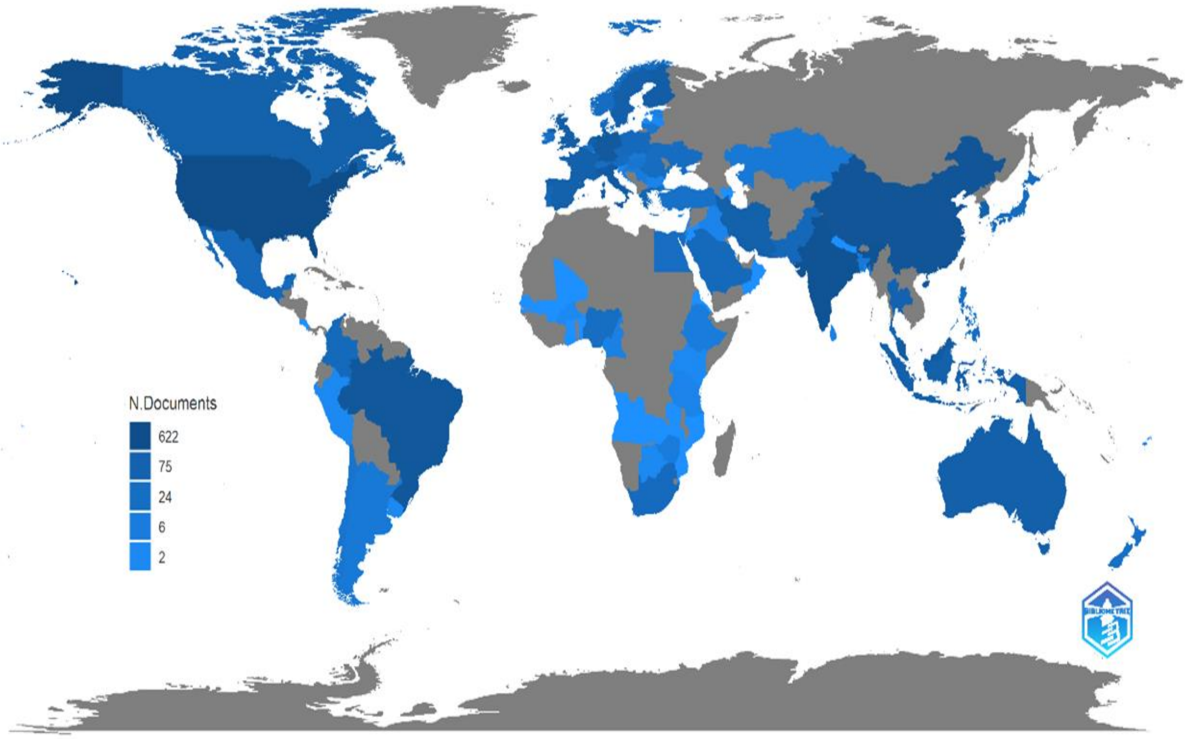


Figure 6: Country scientific production

Source: Author’s analysis

2.3.3. Most cited documents

This study also mentioned the top-cited documents in this area. The most cited documents are mentioned in Figure 7. The list of all the most cited documents is presented in the appendix (Table 47). This study also mentions the top 10 research publications and their main focuses. For example, CHERUBINI ET AL. (2009) studied biofuels and bioenergy and greenhouse gas emission, D’AMATO ET AL. (2017) studied bioeconomy, green economy, and circular economy, BÖRJESSON & TUFVESSON (2011) studied biofuels and resource economy, RAHEEM ET AL. (2018) studied sustainable biofuels and bioenergy, FAROOQ ET AL. (2013) studied biodiesel production development, HUANG ET AL. (2010) studied biofuels supply chain systems, STEGMANN ET AL. (2020) studied circular bioeconomy, CUELLAR-BERMUDEZ ET AL. (2015) studied biofuels and CO_2 emission reduction, BIRCH & TYFIELD (2013) conceptualized the bioeconomy theories and LIEW ET AL. (2014) studied the evaluation, technological development, and sustainable biofuel production assessment.

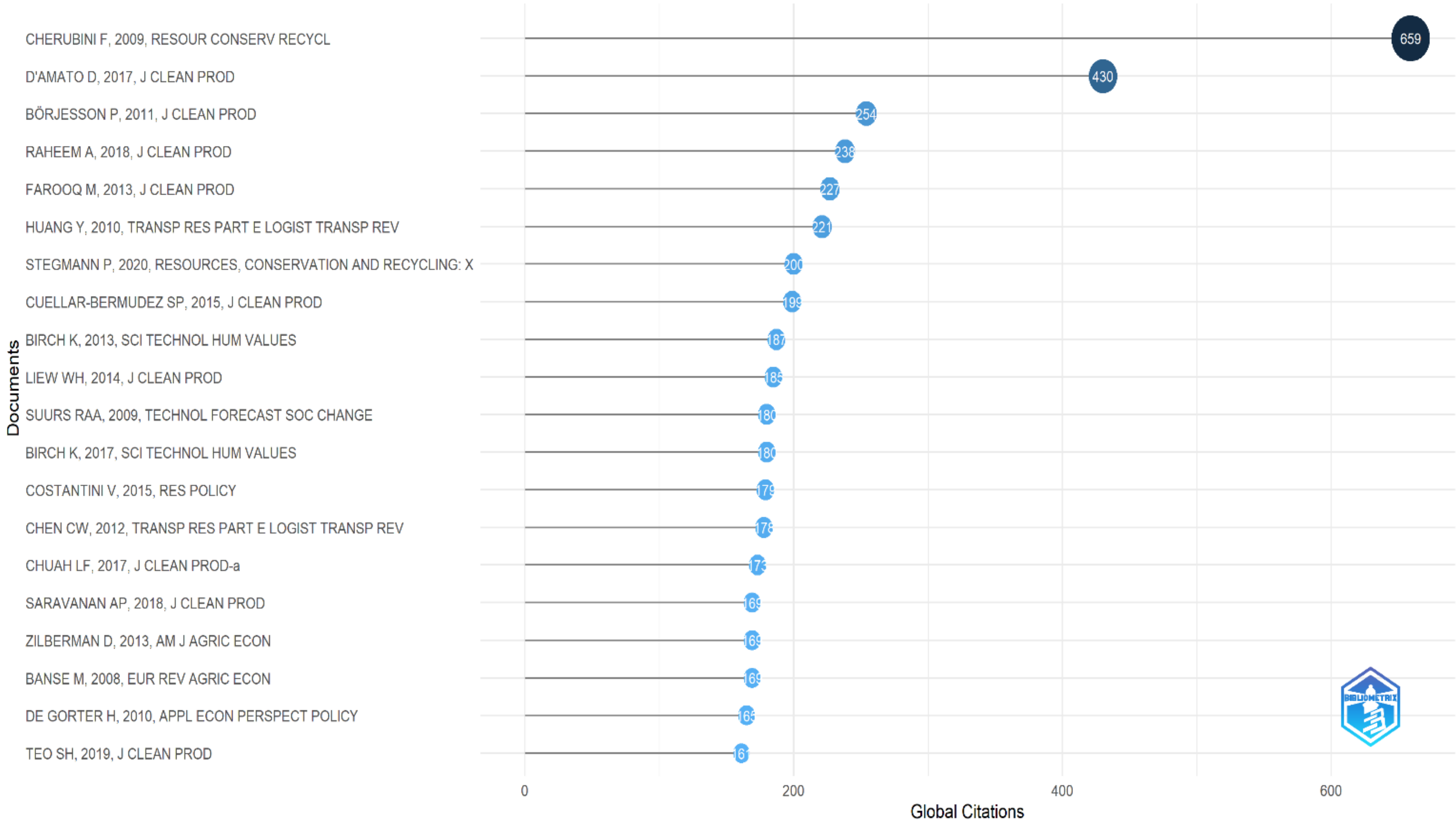


Figure 7: Most cited documents

Source: Author's analysis

2.3.4. Most popular sources

The current study also represents a major source of research in the field of sustainable biofuel economies. Table 2 lists the main sources (top 10) and number of articles published in biofuel research. According to Table 2, the Journal of Cleaner Production is the most frequent publishing journal that publishes research on bioeconomy. Until now, the Journal of Cleaner Production published more than 500 articles on biofuels' importance on the economy in different aspects. The second journal that publishes the second highest number of research that connects biofuels, and the economy is *Fuels and Lubes International*, the number of published research 107. The other eight journals in the top 10 list are mentioned in the following section. These are Frontiers in Energy Research (64), Petroleum Review (55), Forest Policy and Economics (45), Energy Economics (40), Resources, Conservation and Recycling (31), International Journal of Technology (29), AgbioForum (27), Environment, Development and Sustainability (26) (see Table 50 for details list).

Table 2: Primary source journals

Sources	**Articles**
Journal of Cleaner Production	518
Fuels and Lubes International	107
Frontiers in Energy Research	64
Petroleum Review	55
Forest Policy and Economics	45
Energy Economics	40
Resources, Conservation and Recycling	31
International Journal of Technology	29
Agbioforum	27
Environment, Development and Sustainability	26

Source: Author's illustration (2022)

2.3.5. Most relevant words

Figure 8 presents the WorldCloud of biofuels economy research done by the previous study. In this WorldCloud, 75 top-frequently used keywords are used to make an evident figure. The most frequent keywords are biofuels/ biofuel (582), biodiesel (389), ethanol (248), sustainable development (183), biomass (177), biodiesel production (142), fossil fuels (137), life cycle

(136), bioethanol (134), greenhouse gases (117), environmental impact (111), costs (101), forestry (92), biofuel production (86), feedstocks (86), economics (82), fatty acids (80), climate change (75), gas emissions (75), oils and fats (74). Among the top keyword, many studies linked their study output with economic terminologies, such as sustainable development (183), economics (82), economic analysis (69), commerce (64), bioeconomy (60), supply chains (60), investments (55), decision making (53), renewable resource (51), economic and social effects (46), European Union (43), environmental management (39), energy market (33), price dynamics (33), uncertainty analysis (33), renewable energy resources (31), and environmental economics (22). From the keywords mentioned as European Union, it can be confirmed that biofuel economy research is highly important in the EU. The details of WordCloud are presented in Table 48 in the appendix section.

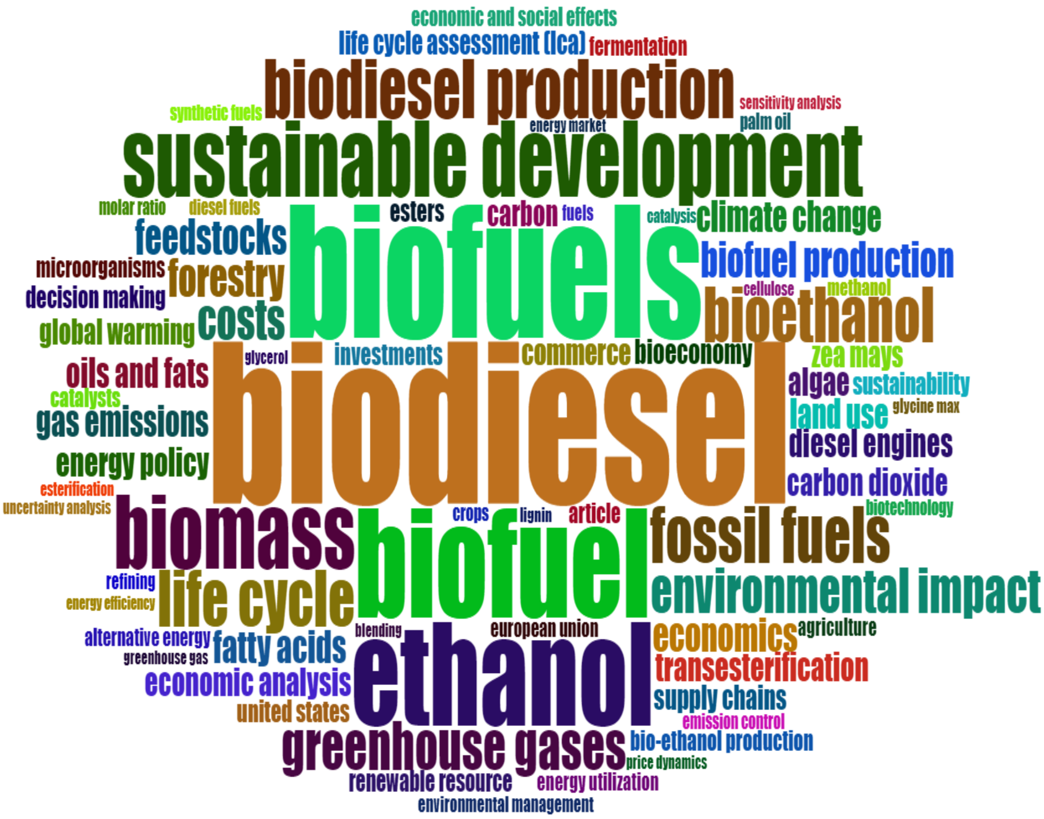


Figure 8: Most relevant words

Source: Author's illustration

2.3.6. Research focus and growth of biofuel economy (word dynamic)

This research also presents the word dynamics of biofuel research linked to the economy. According to Figure 9, word dynamics is presented for the ten most highlighted keywords. These are biodiesel, biodiesel production, bioethanol, biofuels, biomass, ethanol, fossil fuels, life cycle, and sustainable development. These concepts started growing after 2004 and had a high growth rate after 2010. Among these terms, biofuels, biodiesel and ethanol have grown very rapidly since 2010 compared to the others. Sustainable development is the most prominent economic and environmental development keyword, which is also increasing rapidly with the development of biofuels. It can be confirmed that biofuels have important parallels with sustainable development.

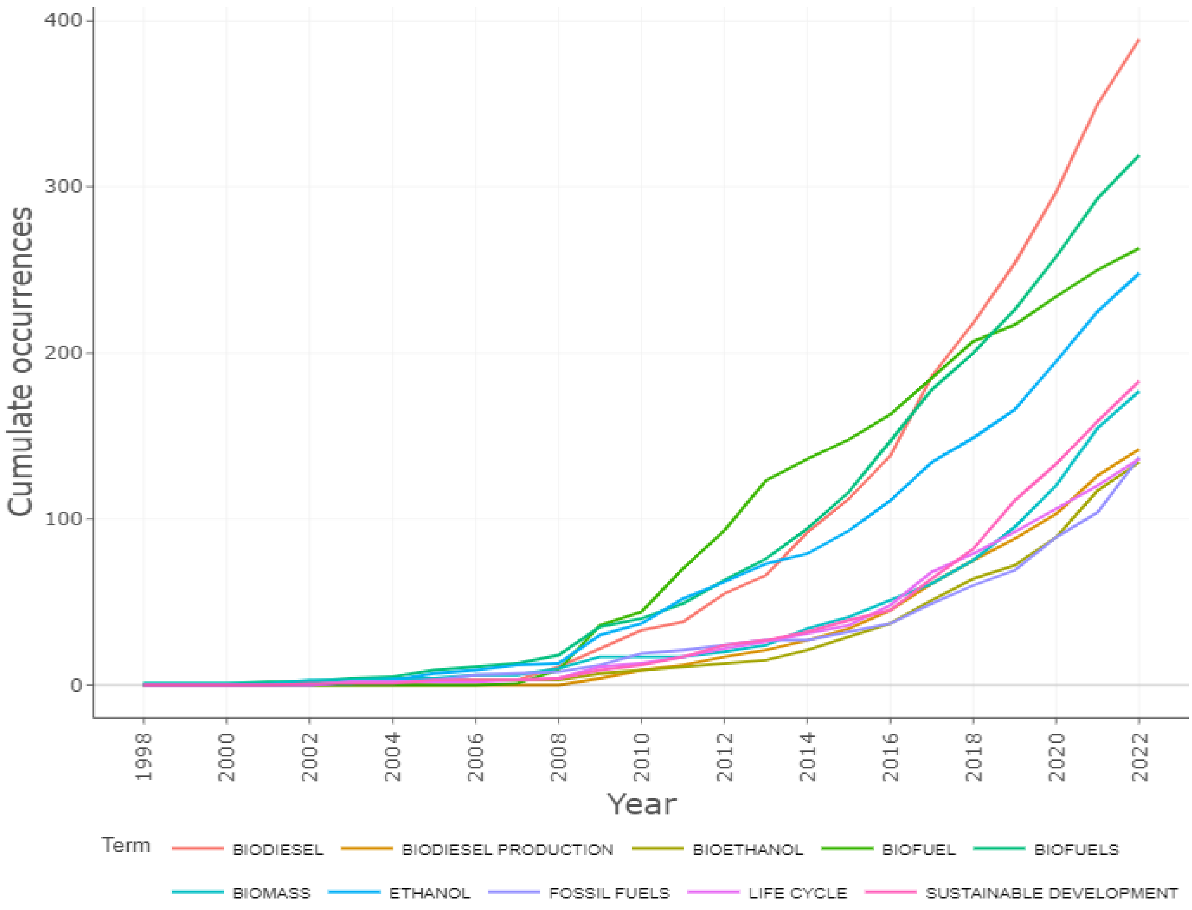


Figure 9: Research focus and growth of biofuel economy

Source: Author's illustration

2.3.7. Co-occurrence assessment

According to Figure 10, the forces of this co-occurrence assessment are carbon emission, environment, economic growth, land-use change, impacts, market, emission, food, greenhouse gas emission, food security, price, agriculture, policies, climate change, costs, economics, management, electricity, supply chain, sustainable development, technology, challenges, sustainability, innovation, performance, uncertainty, China, US, bioethanol, and so on.

From what has been discussed thus far, there is a substantial relationship between biofuel and the factors pertaining to the economy and the SDGs. The SDG factors are economic growth, land-use policy, environment, greenhouse gas emission, carbon emission, food security, climate change, agriculture, electricity, innovation, and technology, and mostly focused on sustainability and sustainable development.

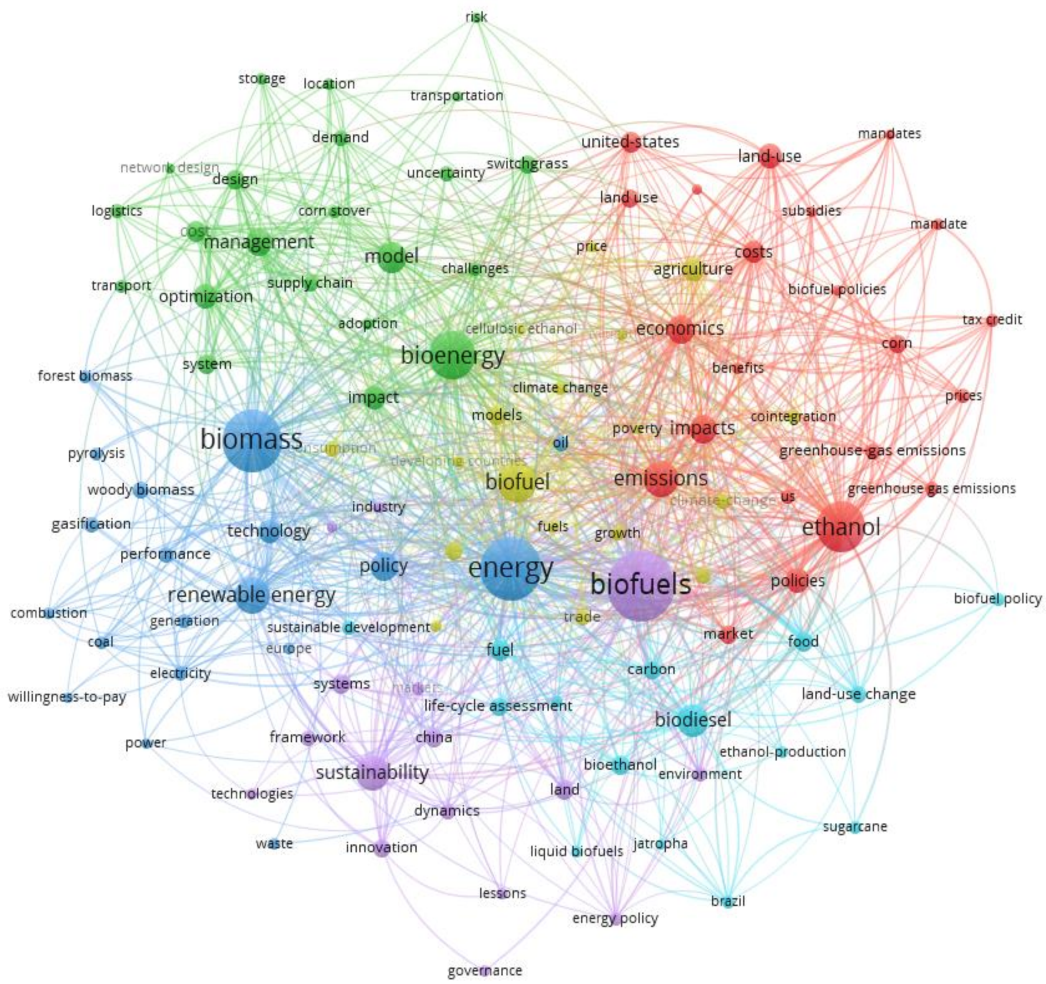


Figure 10: Co-occurrence assessment of biofuels

Source: Author’s illustration using *VOSviewer* (2022)

Note: Co-occurrence, all keywords, the minimum number of occurrence of keywords (10), of the 3387 keywords, 112 meet the threshold, cluster 6, links 2474, total link strength 5982, max length 0, max line 1000.

2.3.8. Conceptual structure map

Figure 11 in this study presents the conceptual structure map that was analyzed in this research using the *"Multiple Correspondence Analysis"* and *"Multidimensional Scaling"* methods. In this instance, we identify two related structures, the larger of which is coloured red and the smaller of which is coloured blue. Twenty-seven keywords are in the red structure, but only three are in the blue one. The first model highlights environmental, food security, transportation, climate, biofuel policy, land-use policy implications, agriculture, and sustainable development as the most important sustainable economic variables related to biofuel. The MDS approach employs a double-linked diagram of relations in its second conceptual map. The small-sized one is exactly like the original map, in short, MCA. The larger map has 18 categories of keywords, as determined by the MDS method. The red map illustrates the interconnectedness of biofuel with key economic factors such as energy, innovation, policy, poverty, environment, GDP growth, agricultural output, and emissions of greenhouse gases.

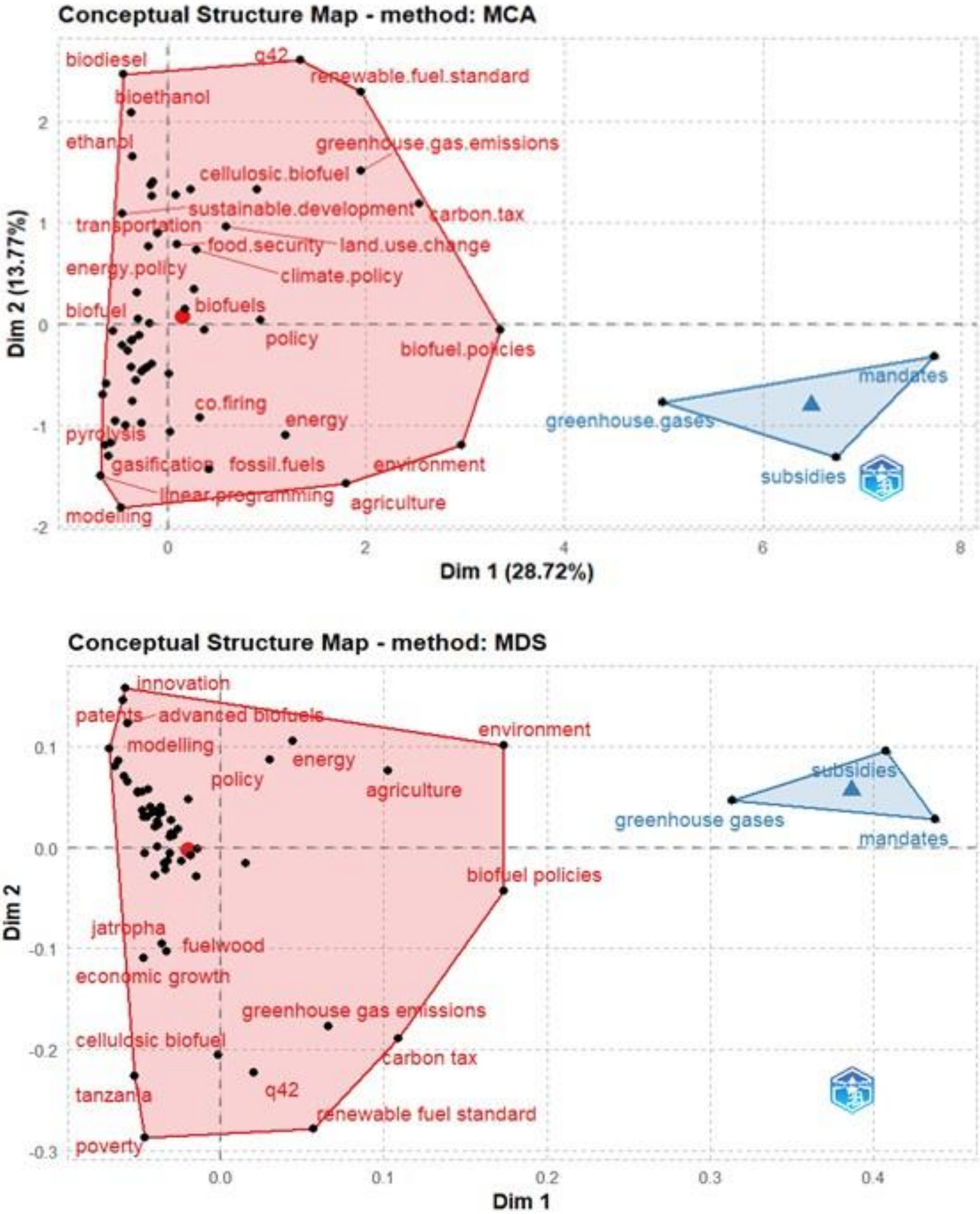


Figure 11: Conceptual structure map

Source: HASAN ET AL. (2023)

2.4. Hypotheses development

2.4.1. Biofuels production and economic growth

Biofuel production impact was connected in the literature with economic growth and other related forces. This literature review section discusses the previous study on biofuel production and economic growth. For example, HASAN (2022) investigate how energy production and consumption impact on economic growth. He conducts non-stationary panel data modelling using 28-year annual panel data covering the period 1992 to 2019. The dependent variable is economic growth, measured by the panel countries' GDP. The independent variables are different energy production variables, including biofuel production. This study finds that along with the other energy production variable, biofuel production significantly impacts economic expansion in the BRICS economy. MEYER ET AL. (2013) explore the influences of biofuel production in Brazil on the economy, agriculture, and the environment. They conduct a qualitative study focusing on biofuel production, economy, agriculture, and the environment using the data from 1991-2010. They discover that the government aid programmes for the lowest socioeconomic classes, along with the expansion of external developing nations hungry for inexpensive meat, as well as the decline in markup per finished animal, will continue to push Brazil's cattle farming towards intensifying cation.

AL-MULALI (2015) examines the influence of biofuel energy on economic development, pollution, agricultural prices, and overall agricultural output. He conducts the Panel Unit Root Test, Panel Co-integration Test, and Panel Granger Causality Test using annual data from 16 major biofuel energy-consuming nations covering the period 2000 to 2010. The dependent variable is GDP growth. The independent variables are biofuel energy consumption, CO_2 emission, agriculture prices, and agriculture production. The results indicate that biofuel energy enhances GDP growth and decreases pollution levels. Moreover, biofuel enhances both agricultural output and crop prices since biofuel energy stimulates economic development and minimizes pollution. QIAO ET AL. (2016) assess the causal relationship among biofuel energy production based on the quantitative contexts of economic growth and environmental and social factors. The research uses panel data and examines its data through unit root test, cointegration test, regression model, likelihood test, and Hausman test. The study uses unbalanced panel data sets based on 15 provinces in China covering from 2003 to 2012. The dependent variable is economic growth (measured by the change of real GDP per capita), and the explanatory variable is biofuel production, the natural logarithm of GHG emissions, income per capita, marginal land, fixed capital formation, and labour force. The result shows that biofuel production significantly influences on the real GDP per capita. Consequently, uplifting the real GDP per capita of any region convince its citizens to use biomass as a new energy source and to make life easy and improve living standards. Similarly, income per capita significantly and positively affects the real GDP per capita because of creating new job opportunities, income sources, and increasing biofuel consumption. On the other hand, as biofuel production uses additional marginal land and may increase GDP per capita, the enlargement of economic development also leads to hampering marginal land development. That is why, marginal land shows a negative relationship with real GDP per capita. However, the labour force shows insignificant and real gross fixed capital formation shows a significant and positive association with GDP per capita in this research.

SIEVERS & SCHAFFER (2016) examine the direct and indirect effects on sectoral output & imports of the German economy of the quota-regulated substitution of fossil fuel with biofuels. An input-output model was run. They discovered that the German biofuel limit had a negligible effect on the country's domestic output and imports. The ultimate demand strategy and the input-output method both shown to be effective. The study also showed that the second-generation biofuels are growing as a result of decreased population and demand for agricultural goods, increasing agricultural productivity, and the development of electricity plants on lignite and coal mines that have been abandoned. MAKUTENAS ET AL. (2018) investigate the impact of the development of biofuel production on economic growth in European Union countries. They conduct a baseline panel regression model using the annual data covering 2003 to 2013. The dependent variable is employment that is measured by the number of jobs created. The independent variable is biofuel production. It is found that there is a positive and highly significant relationship between biofuel production and employment opportunities. This result indicates that the development of biofuel production promotes the economy by creating more employment opportunities. They also find that biofuel development do not impact feed crop prices and food prices in the EU.

HARTLEY ET AL. (2019B) evaluate the effects of growing Mozambique's biofuel manufacturing under both industrial and smallholder agricultural modes, with and without bagasse cogeneration. They conduct a social accounting matrix and recursive CGE model. The dependent variable is economic growth (measured by total GDP). The independent variables are labour supply, capital stock, livestock, land supply, real exchange, and real food price. They demonstrate that the development of a bioethanol value chain positively influences the expansion of the economy and job opportunities in Mozambique. The importance of supporting effective labour markets that allow for labour mobility is highlighted by the fact that the availability of sufficient labour resources also results in greater economic and employment benefits. The inclusion of communal farmers in agricultural production has a negligible effect on GDP, employment, and welfare enhancements. ASHWATH & KABIR (2019) explore the economic, environmental, and social effects of biofuel production in Australia. They conduct a descriptive study and discuss the significance of biofuel production from sugarcane in economic prospects. They find that the economic implications of biofuel production encompass employment creation or labour force flow, revenue generation by farms, worker income, and overall local and national impact. HARTLEY ET AL. (2019A) assess the macro and socio-economic impacts of bioethanol production in Zambia from three potential crops: sugarcane, cassava and sweet sorghum. They conduct the DCGE model, computable general equilibrium (CGE) models, and Social Accounting Matrix. The dependent variable is economic growth (measured by GDP growth). The independent variables are labour supply, capital stock, livestock, land supply, real exchange, real food price. They discover that cassava, which has the most value added per unit of product generated, experiences the biggest growth benefits. Sugarcane comes next, with sweet sorghum showing the smallest increases in real GDP growth.

The most current developments in the field of synchronous waste mitigation with energy development strategies are examined by MALODE ET AL. (2021). They find that biofuels are economically friendly and non-toxic in nature, but they are still at the beginning of the development phase. It has been criticised for inciting rivalry among crops grown for food and used as a raw material for biofuels since it includes human foods including peanuts, maize, soy, and sugarcane in its production. It's eco-friendly and less polluting. SUBRAMANIAM & MASRON (2021) examine the impact of globalization on biofuel. They conduct panel data modelling using the data from 2012 to 2016. Biofuel production is the dependent variable, and the key explanatory variable is economic globalization. The results of this study demonstrate a favourable connection between the production of biofuels and economic globalisation. Renewable energy's inclusion into the world market is aided to a greater extent by economic globalisation. OLÁH & POPP (2022) assess the impact of food production, land use change, biodiversity, energy efficiency and climate change on biofuel production's environmental and social sustainability. They conduct a descriptive research method. They find that the complexity of economic, environmental, and social problems necessitates a holistic approach to take advantage of the future synergy effect. In reality, biofuel’s sustainability is about optimising the economic, social, and environmental components.

Some other studies show how other renewable energy production impact on economic growth. For example, KAZAR & KAZAR (2014) examine the impact of renewable energy production on economic growth. They conduct a granger causality test using 157 countries' annual panel data including from 1980 to 2010. The dependent variable is economic development. The key independent variable is renewable energy, measured by the electricity production from renewable sources. They find that for middle-income developed countries, there is evidence of a bidirectional causative relationship between renewable energy generation and economic progress over the long term. However, there is evidence of a one-way causation relationship over the short term. Additionally, this outcome makes sense because these nations are typically emerging ones with lower capital intensity. Since investing in renewable energy is difficult and expensive, any rise in capital in these nations will likely encourage growth, which will advance development. SINGH ET AL. (2019) examine how renewable energy's progress significantly influences the economy's progress. The conduct FMOLS regression model using twenty developing and developed countries annual panel data covering the period 1995 to 2016. The dependent variable is economic growth that was measured by real GDP. The key independent variable was the production of renewable energy, which is measured by the production of electricity from different renewable sources. The other independent variables are gross capital formation and labour forces. It is found that the production of renewable energy significantly promotes economic growth. This significant impact of renewable energy production is relatively less in developing countries than in developed economies. It is also found that both the gross capital formation as well as labour forces also promote the economic growth of both developing and developed nations. DINÇ & AKDOĞAN (2019) investigate how renewable energy production influence Turkey’s long-term economic growth. They conduct a VECM method using annual panel data from 1980 to 2016. The dependent variable is economic growth, and the explanatory variables are the production of renewable energy and total energy consumption. They demonstrated that there is a long-term bidirectional relationship exists between the production of renewable energy and economic growth in Turkey. This result indicates that both productions of renewable energy and economic growth cause each other in the longer term. This output indicated that the longer-term production of renewable energy impact on sustainable economic growth.

The above circumstances and empirical justification help this study assume Hypothesis 1 as follows.

Hypothesis 1: Biofuel production has a significant positive impact on EU economic growth.

2.4.2. Biofuels consumption and economic growth

AL-MULALI ET AL. (2016) examine how the use of biofuels for energy affected Brazil's economic growth. They conduct ARDL, VECM, and PGMM methods using data from 1980 to 2012. The key dependent variable is the growth of the economy. The explanatory variables are the consumption of biofuel energy, urbanization, capital, and globalization. Their findings show an important relationship between the uses of biofuel energy, capital stock, urbanization, globalization, and economic development. The economic growth of Brazil is additionally boosted by the use of biofuels, higher capital stock, urbanization, population growth, and globalization. However, it is shown that the two factors had a considerable negative effect on the growth of Brazil's economy. When the capital is excluded, the VECM Granger causality results show a causal link between all the variables. Still, capital is shown to have a one-way causal relationship with measures of economic development, biofuel energy use, urbanization, and globalization. BILDIRICI (2017) examine a relationship between militarization, the use of biofuels, CO_2 emissions, and economic expansion in the US from 1984 to 2015. The supplementary estimators, Autoregressive Distributed lag, Canonical Cointegration, Dynamic OLS, Regression, and Fully Modified OLS regression are used to examine the aim of the study. The major variables are biofuel consumption, economic growth, CO_2 emissions, and the armed force and the defence industry. According to the findings, there is a long-term cointegration relationship between militarism, biofuel consumption, economic expansion, and CO_2 emissions. According to the findings, this energy source contributes to militarism, economic expansion and carbon dioxide emissions. As biodiesel use is causally linked to militarism, economic growth, and levels of CO_2 emissions, understanding this is critical for effective policy decisions. The United States should immediately implement real policies on energy transition from fossil fuels to biofuels to minimize CO_2 emissions. In this case, however, CO_2 emissions could be reduced if government policymakers and the military are more aware of the problem. BOUTABBA & AHMAD (2017) investigate the previous work on the elements of renewable energy consumption for twelve OECD countries. They conduct FMOLS, DOLS, and OLS tests using annual data from World Bank and US Energy Information Administration databases covering the period from 2002 to 2012. The dependent variable is biofuel energy consumption. The independent variables are real income, CO_2 emissions, oil prices, and biofuel prices. This study reveals that real income, biodiesel prices, oil prices, and carbon emissions all have a role in determining long-run biofuel usage behaviour. However, it appears that real income and carbon emissions have a greater influence on biofuel usage than biodiesel and oil prices. This study mentions that biofuel has become the best source of renewable energy because of the growing problems with greenhouse gas emissions and reducing poverty. As economic, social, and environmental problems get worse, it seems likely that biofuel will become a very important source of renewable energy in the future. KOENGKAN (2017) investigate the relationship between the utilization of biofuels and the growth of the Brazilian economy. To experiment with the investigation, they conduct Vector Auto Regressive (VAR), Multicollinearity, and Unit Root models using annual panel data covering the period 1990 to 2015. The extract study data from the World Bank Database (WBD) and BP Statistical Review. The major variables of this nexus relationship are the consumption of biofuels, economic growth, and consumption of oil. The findings indicate the presence of a bidirectional link between the consumption of biofuels and the growth of the economy, the consumption of oil and expansion of the economy, and the consumption of biofuels and oil. OZTURK & BILGILI (2015) examine a dynamic relationship between economic growth and biomass consumption. They conduct both FMOLS and DOLS regression using the data of 51 Sub-Saharan African nations between the period of 1980 and 2009. The key dependent variable is economic growth, and the independent variables are biomass consumption, openness, and population. The results of this study indicate that biomass consumption, openness, and population have a substantial and positive effect on economic growth in African nations. GDP elasticity in relation to biomass consumption is near one, while GDP elasticity in relation to openness is statistically significant.

SIMIONESCU ET AL. (2019) assess how biodiesel use in transportation affects EU economic expansion. They conduct the DEA approach and total factor energy efficiency (TFEE) model using the variables biodiesel consumption, transport, and economic growth. They find that the use of energy from biodiesel in transportation has a positive but very small effect on the growth of the EU's economy. During the years 2010–2016, the real GDP rate in the EU went up by an average of 0.0019 percentage points for every thousand tons of oil equivalent of extra energy that come from biodiesel. The Granger causality relationship between these two things only goes in one direction: From 2010 to 2016, the EU economy grew because Granger used biodiesel. They also reveal that biodiesel is better than gasoline and petroleum diesel because it is better for the environment. When there is less pollution, it costs less to protect the environment, which means there are more chances for the economy to grow. SIMIONESCU ET AL. (2017) empirically evaluate the influence of biodiesel and bioethanol-based transport energy consumption on sustainable development in terms of economic growth and greenhouse gas emissions. They conduct dynamic panel, vector panel, auto-regression models, and granger causality tests using the European Union nations' annual panel data from 2010 to 2015. The dependent variable is economic growth. The independent variables are biofuel consumption, transport, and greenhouse emissions. The findings indicate that only biodiesel-based transport energy use has a favourable effect on economic development. The greenhouse gas emissions do not affect economic development; however, bioethanol-based energy usage in transportation has a negative effect. The research contributes to the intense use of energy derived from biofuels for the transportation sector, which may ameliorate environmental concerns. AZAM (2020) investigate the effects of energy use on economic development over time for a panel of ten rising Asian nations within the constraints of the production process. They conduct panel unit root tests, panel cointegration tests, Panel FMOLS estimator, Panel DOLS estimator, and PMG estimator. Here, the dependent variable is economic growth (measured by GDP per capita). The exploratory variable is energy, human, physical and capital, and inflation rate. They use quarterly cross-section time-series data covering the period from 1990Q1 to 2014Q4. They find that all the exploratory variables individually have a significant impact on economic growth. This output indicates that increasing those stated variables boost economic growth in Asian economics.

Some other studies show how other renewable energy production impact on economic growth. For example, APERGIS & PAYNE (2010B) examine how the consumption of renewable energy effects on economic growth. They conduct a heterogeneous panel cointegration test using the Eurasian countries annual panel data covering from 1992 to 2007. Economic growth, measured by GDP growth, is the dependent variable. The main independent variable is the production of renewable energy, which is measured by the production of electricity from different renewable sources. The other independent variables are gross capital formation and labour forces. It is found that the consumption of renewable electricity significantly promotes economic growth. It is also found that both the gross capital formation as well as labour forces also promote the economic growth of Eurasian economics. LIN & MOUBARAK (2014) examine a dynamic relationship between the consumption of renewable energy and the progress of China's economy. The ARDL and granger causality tests are conducted using

China’s annual panel data from 1977 to 2011. The variables are consumption of renewable energy, GDP per capita, and labour forces. It reveals a bidirectional correlation between the consumption of electricity from renewable sources and the progress of the economy measured by per capita GDP. This output refers to the fact that both of these two variables influence each other in the longer term. Another study YILDIRIM ET AL. (2012) investigate a relationship between the consumption of renewable energy and economic growth considering the United States' economic aspect. The major variables are GDP (real), capital formation, total consumption of renewable energy, employment, and total consumption of biomass energy. It is found that the causality test indicates that there is only one causal link between the amount of energy obtained from biomass waste and real GDP. There is no discernible link between any other renewable energy type and actual GDP.

The above circumstances and empirical justification help this study assume Hypothesis 2 as follows.

Hypothesis 2: Biofuel consumption has a significant positive impact on EU economic growth.

This study has already assumed two individual hypotheses for biofuel production’s impact and biofuel consumption’s impact on EU economic growth. As the existing literature supports the concepts of energy production and consumption impact on economic growth, this study assumes another hypothesis adding both production and consumption of biofuels in a single hypothesis to show the relative significance, Hypothesis 3.

Hypothesis 3: Biofuel production has a higher significant positive impact compared to biofuel consumption on EU economic growth.

2.4.3. Biofuels production and consumption cause economic growth

AJMI & INGLESI-LOTZ (2020) investigate the cointegrated association between the consumption of biomass energy as well as economic expansion of 26 OECD economies' using 1980 to 2013 period panel data. The findings support the feedback hypothesis by demonstrating the existence of long-run equilibrium connections between the variables. OZCAN & OZTURK (2019) examine the nexus association between the consumption of renewable energy and selected 17 countries' economic expansion during the period 1990 to 2016. With Poland being the exception, the findings show that the growth hypothesis is true for all of the markets under study. As a result, energy conservation (mitigation) measures have no negative effects on the growth rates of these 16 rising nations since there is no causal relationship between the demand for renewable energy and economic growth. However, for Poland, energy conservation measures can have a negative impact on the level of the nation's economic performance. TRAN ET AL. (2022) observe a threshold impact of GDP on the causality between 26 OECD countries' GDP as well as energy consumption using a set of panel data from 1971 to 2014. It is empirically found the existence of 26 OECD countries, over which GDP affects the consumption of energy; nonetheless, the causality direction depends on the GDP beginning values. In the case of a GDP less than $47170, exists unidirectional causation. No unidirectional causation exists in the case of GDP value more than the stated figure.

KAZAR & KAZAR (2014) examine the relationship between renewable energy (electricity) production and economic development using worldwide panel data covering two different periods (1980-2010 and 2005-2010). It is found that in the shorter period, there is a bidirectional causal relationship between the production of renewable energy as well as economic development. This study also reports that the causal relationship between economic development and the production of renewable energy differs during different periods due to countries' human development levels. DINÇ & AKDOĞAN (2019) probe the causality among the production of renewable energy, the total energy consumption, and economic expansion for Turkey using data from 1980 to 2016. It is obtained that there is a bidirectional relationship for both short- and longer-term between renewable energy and Turkey's economic expansion. In addition, it is found that there is a bidirectional relationship for both short- and longer terms between the consumption of renewable energy and Turkey's economic expansion. However, the bidirectional relationship between the consumption of renewable energy and Turkey's economic expansion is not consistent. LISE & MONTFORT (2007) investigate the cointegrated relationship between energy consumption and the growth of Turkey's GDP undertaking data over the period 1970 to 2003. It is found that there is a cointegrated connection between the two variables, energy consumption and Turkey's GDP. This output indicates that there is a bidirectional causal association between GDP and energy consumption. AL-MULALI ET AL. (2016) observe biofuel energy consumption's influence on Brazil's economic expansion using data from the period 1980 to 2012. They reveal a cointegrated association among economic expansion, consumption of biofuel energy consumption, urbanization, capital, and globalization. The use of biofuel energy, capital investments, globalisation, as well as urbanisation all have a long- and definite short-term effect on Brazil's economic expansion. The occurrence of structural breaks, however, has a detrimental effect. Except for capital formation, which has a one-way causal association with economic expansion, consumption of biofuel energy, globalisation, and urbanisation, all variables are related causally. SALAMALIKI & VENETIS (2013) research the causal association between the consumption of energy, GDP (real), as well as capital stock for the G-7 economies experimenting with multiple causality testing models using 51 years of annual data (from 1960 to 2010). The findings demonstrate that structural breaks do exist as well as seem to be crucial for causality inference, while multi-horizon causality testing does uncover important information on the dynamic interaction consumption of energy, GDP (real), as well as capital stock. Besides, it is discovered that real GDP dominated in predicting the consumption of energy in the G-7 economies in terms of causality direction. LIN & MOUBARAK (2014) aim to examine the association between the consumption of renewable energy and China's economic expansion during the period 1977 to 2011. It demonstrates a long-term bidirectional causal connection between the use of renewable energy and China's economic expansion. China's expanding economy is considered as favourable for the growth of the renewable energy sector, which in turn supports economic booming. However, labour also has a causal connection for a shorter term with the use of renewable energy.

Some other studies also experiment with the causality among renewable energy consumption as well as economic prosperity in several other countries and geopolitical zone, for example, Turkey (OCAL & ASLAN, 2013), OECD (AYDIN, 2019), low and lower-middle-income economies (NARAYAN & DOYTCH, 2017), Nepal (KHATRI & PAIJA, 2022), South Asia (RAHMAN & VELAYUTHAM, 2020), and so on. Correspondingly in renewable energy production aspects, CHEN, WANG, & ZHONG (2019) investigate the causal connection between the production of renewable energy and China's economic expansion; VURAL (2021) examine the causal connection between the production of renewable energy and Latin

American countries' economic expansion; CERDEIRA BENTO & MOUTINHO (2016) investigate the causal connection between the production of renewable electricity and Italy's economic expansion; TEMIZ DINÇ & AKDOĞAN (2019) research the causal connection between the production of renewable energy and Turkey's sustainable economic expansion; and so on.

Based on the above previous literature, I assume another hypothesis, Hypothesis 4 (two-subsection).

- *Hypothesis 4A: Biofuel production causes financial development and EU economic growth.*
- *Hypothesis 4B: Biofuel consumption causes financial development and EU economic growth.*

2.4.4. Biofuels and financial development

SAIDI (2023) investigate a nexus relationship between renewable energy, financial development, and economic growth based on emerging economics. This study tests panel cointegration modelling particularly FMOLS and DOLS model using emerging countries data over the period 1990 to 2019. This study shows that renewable energy consumption and financial development positively impact economic growth. This study also find a single direction relationship between countries financial development and the consumption of renewable energy. WANG et al. (2021) examine the impact of consumption of renewable energy to economic expansion and financial development. They experiment ARDL-PMG regressions using regional and national level data from China during the period 1997 to 2017. The extended connections suggest that in the case of China, economic expansion encourages the use of renewable energy, whereas financial advancement has an adverse effect on it. EREN (2019) test the effects of financial development & economic growth on the consumption of renewable energy consumption in the case of India. This study tests panel cointegration modelling particularly DOLS model using data over the period 1971 to 2015. This study shows that financial development as well as economic expansion positively impact the consumption of renewable energy. Based on the above previous literature, this study assumes another hypothesis, Hypothesis 5.

- *Hypothesis 5: Biofuel production and consumption have positive impact on financial development, and vice versa.*

3. DATA AND METHODOLOGY

3.1. Research area, data, and variable measurement

This study uses annual panel data for the experiments. Biofuel production and consumption data are not available before 2000 for most countries. Even in some other countries, there is no data available before 2009. However, considering the data availability in the European Union zone, I have found Austria, Belgium, Germany, Spain, Finland, Italy, France, Netherlands, Portugal, and Sweden. Basically, the study focuses on those EU countries that has significant biofuel production capabilities. The specific study area is mentioned in the following Figure 12.

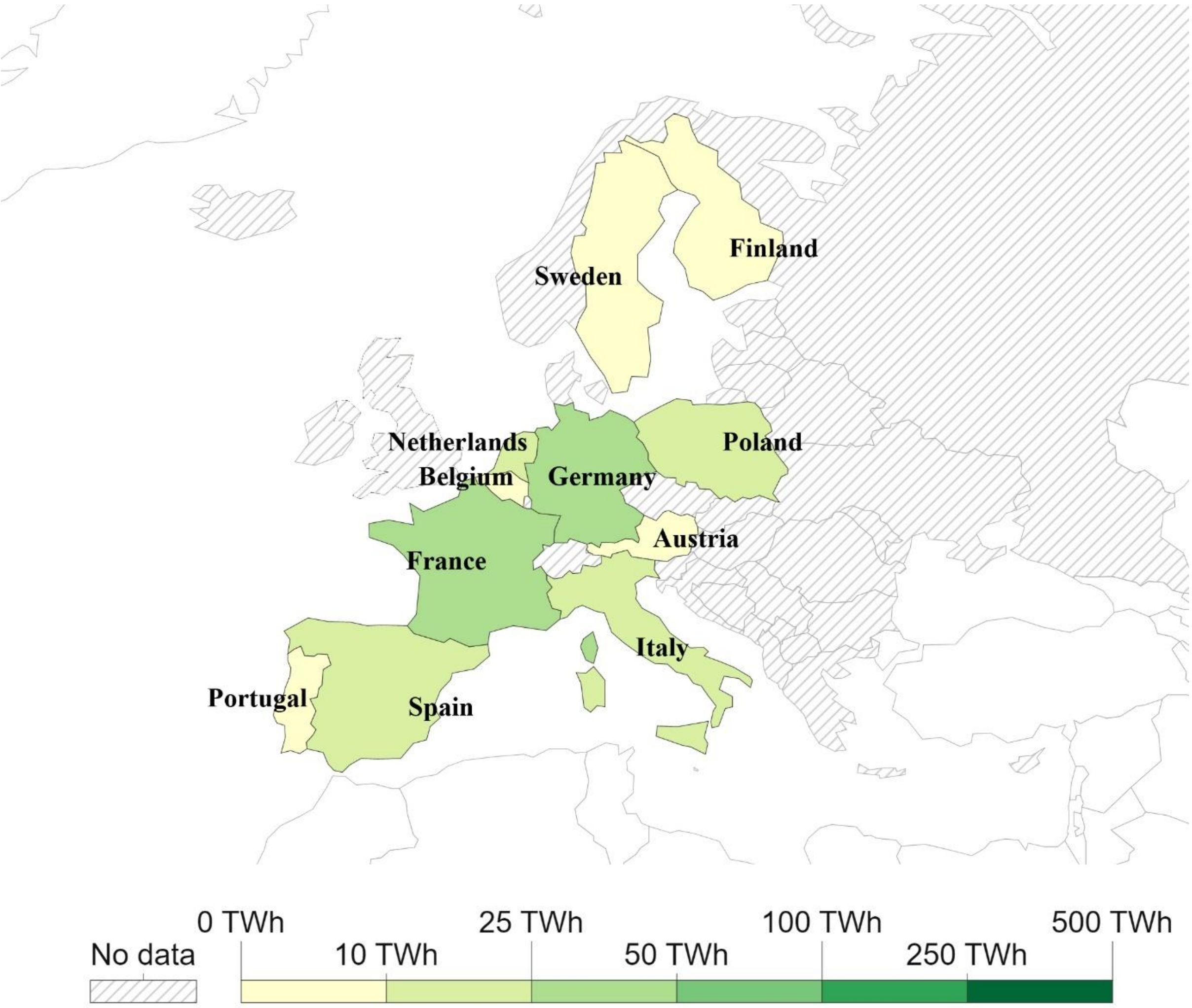


Figure 12. Study area (biofuel producing countries in EU)

Source: Our World in Data (2022)

All countries' have available data on biofuel production and consumption from 2001 to 2019 except for Belgium (data available from 2008-2019), Netherlands (data available from 2004-2019), and Portugal (data available from 2006-2019). The details of the variable measurement are mentioned in the following Table 3.

Table 3: Variable measurement

Variables	Definition	Measure	Sources
GDP	GDP at purchaser's prices is the total of the gross value contributed by all of the economy's resident manufacturers plus any product taxes and minus any subsidies that aren't included in the product value.	(Constant 2015 US$)	The World Bank Database, 2022
Gross capital formation	Gross capital formation (previously gross domestic investment) is the sum of outlays on additions to the economy's fixed assets plus net changes in the stock of inventories.	(Constant 2015 US$)	The World Bank Database, 2022
Labour force	The labour force consists of persons aged 15 and above who provide work for the production of products and services throughout a specific time period.	Total labour force (Constant 2015 US$)	The World Bank Database, 2022
Financial development	Financial development is measured by the % of domestic credit to private section to GDP.	Domestic credit to private sector (% of GDP)	The World Bank Database, 2022
Biofuel Production	Total biofuel production includes the fuel ethanol production and diesel production data	Biofuels Production – Mb/d - Total	Energy Information Administration, 2022

Biofuel Consumption	Total biofuel consumption includes the fuel ethanol consumption and biodiesel consumption data	Biofuels Consumption – Mb/d - Total	Energy Information Administration, 2022

Source: Author’s explanation (2022)

This study also presents all countries' data description individually in the following Table 4. Here, though I use the logarithm of all variables in the empirical modelling, the real data is used here to present the real scenario of the data. Initially, I present the mean, median, maximum (Max), minimum (Min), standard deviation (Std.Dv), and the number of observations of each country. Here, GDP value and capital formation are presented in billion USD, labour is presented in a million, and financial development is presented in a billion USD.

Table 4: Data descriptive statistics (by country)

Variables	Mean	Median	Max	Min	Std.Dv	Obs
AUSTRIA						
GDP (Billion USD)	365.00	370.00	414.00	315.00	28.90	19
Capital (Billion USD)	88.60	88.10	105.00	77.20	8.05	19
Labour (Million USD)	4.30	4.31	4.67	3.91	0.25	19
Financial Development (Billion USD)	330.08	335.68	358.32	282.72	26.33	19
Biofuel Production	5.85	6.39	10.55	0.42	3.83	19
Biofuel Consumption	8.22	11.46	14.46	0.42	5.51	19
BELGIUM						
GDP (Billion USD)	432.00	433.00	495.00	370.00	36.70	12
Capital (Billion USD)	99.20	101.00	124.00	75.00	14.60	12
Labour (Million USD)	4.80	4.88	5.18	4.32	0.26	12
Financial Development (Billion USD)	277.07	266.08	343.73	243.04	35.28	12
Biofuel Production	10.97	11.10	13.49	7.89	1.55	12
Biofuel Consumption	7.99	8.55	11.55	0.00	3.18	12
FINLAND						
GDP (Billion USD)	232.00	234.00	255.00	201.00	15.40	19

Capital (Billion USD)	52.90	53.20	61.80	45.60	4.86	19
Labour (Million USD)	2.68	2.69	2.76	2.61	0.04	19
Financial Development (Billion USD)	190.49	205.92	242.98	105.94	43.24	19
Biofuel Production	6.53	6.90	9.99	2.07	2.14	19
Biofuel Consumption	6.09	5.33	10.93	0.00	3.30	19
FRANCE						
GDP (Billion USD)	2340.00	2340.00	2620.00	2090.00	150.00	19
Capital (Billion USD)	532.00	530.00	630.00	464.00	46.50	19
Labour (Million USD)	29.64	29.96	30.62	27.64	0.91	19
Financial Development (Billion USD)	2143.31	2222.20	2791.48	1605.70	359.96	19
Biofuel Production	43.19	56.70	73.64	7.94	24.13	19
Biofuel Consumption	46.39	58.97	81.49	7.94	26.86	19
GERMANY						
GDP (Billion USD)	3170.00	3140.00	3600.00	2860.00	245.00	19
Capital (Billion USD)	659.00	663.00	767.00	566.00	55.90	19
Labour (Million USD)	41.97	41.91	44.35	40.00	1.31	19
Financial Development (Billion USD)	2890.92	2858.77	3241.17	2622.99	211.93	19
Biofuel Production	54.93	65.73	78.00	6.96	24.63	19
Biofuel Consumption	56.02	66.36	76.34	6.96	23.68	19
ITALY						
GDP (Billion USD)	1900.00	1890.00	1990.00	1820.00	47.30	19
Capital (Billion USD)	375.00	384.00	445.00	307.00	45.00	19
Labour (Million USD)	24.95	24.60	26.14	23.60	0.76	19
Financial Development (Billion USD)	1514.19	1580.29	1800.10	1133.42	199.23	19
Biofuel Production	11.02	12.45	23.22	2.80	5.73	19
Biofuel Consumption	16.06	21.71	33.63	0.00	12.63	19
NEDERLANDS						
GDP (Billion USD)	738.00	740.00	840.00	659.00	53.20	16

Capital (Billion USD)	150.00	144.00	187.00	131.00	17.30	16
Labour (Million USD)	8.87	8.90	9.45	8.40	0.30	16
Financial Development (Billion USD)	846.37	849.52	896.35	761.36	34.32	16
Biofuel Production	21.05	27.07	37.95	0.65	14.92	16
Biofuel Consumption	8.78	8.19	17.34	1.09	3.67	16
POLAND						
GDP (Billion USD)	411.00	413.00	570.00	285.00	86.50	19
Capital (Billion USD)	80.40	83.30	115.00	45.20	22.00	19
Labour (Million USD)	17.77	17.84	18.24	17.19	0.39	19
Financial Development (Billion USD)	270.99	275.92	326.80	207.70	45.01	19
Biofuel Production	13.33	14.63	21.94	2.97	6.86	19
Biofuel Consumption	13.44	15.53	23.21	1.35	7.30	19
PORTUGAL						
GDP (Billion USD)	204.00	203.00	222.00	194.00	7.57	14
Capital (Billion USD)	39.80	41.10	50.40	28.70	6.71	14
Labour (Million USD)	5.39	5.44	5.55	5.20	0.12	14
Financial Development (Billion USD)	270.99	275.92	326.80	207.70	45.01	14
Biofuel Production	5.61	6.17	7.26	1.79	1.67	14
Biofuel Consumption	5.36	5.76	7.34	1.58	1.70	14
SPAIN						
GDP (Billion USD)	1180.00	1190.00	1320.00	1010.00	83.60	19
Capital (Billion USD)	255.00	248.00	327.00	195.00	37.90	19
Labour (Million USD)	22.34	23.19	23.76	18.19	1.71	19
Financial Development (Billion USD)	1569.60	1498.64	2126.05	958.19	381.56	19
Biofuel Production	19.54	20.40	45.07	1.61	13.33	19
Biofuel Consumption	20.85	22.04	45.75	1.61	14.29	19
SWEDEN						
GDP (Billion USD)	458.00	454.00	550.00	370.00	53.80	19

Capital (Billion USD)	107.00	106.00	138.00	80.60	18.80	19
Labour (Million USD)	4.96	4.94	5.46	4.56	0.29	19
Financial Development (Billion USD)	536.95	555.77	720.74	331.54	130.22	19
Biofuel Production	5.46	6.43	10.60	0.45	3.63	19
Biofuel Consumption	13.80	10.89	34.57	0.45	10.79	19

Source: Author experiment (2022)

3.2. Model construction

This study employs the augmented neo-classical framework provided in (AL-MULALI ET AL., 2016; APERGIS & PAYNE, 2010A; SMOLOVIĆ ET AL., 2020) to evaluate the link between energy production and consumption with GDP growth. The aggregated production function is given in the following section.

$$GDP_{it} = f(CAPITAL_{it}, LABOUR_{it}, FINDEV_{it}, BIOFPRO/BIOFCON_{it})$$

In the above equation, Gross Domestic Product (GDP), Gross Capital formation (CAPITAL), Labour force (LABOUR), Financial development (FINDEV), biofuel production (BIOFPRO) and biofuel consumption (BIOFCON). Later, based on the above concept, this study transforms the model into a logarithmic structure that is mentioned in the following section.

$$(1)\ LnGDP_{it} = \beta_0 + \beta_1 LnCAPITAL_{it} + \beta_2 LnLABOUR_{it} + \beta_3 LnFINDEV_{it} + \beta_4 LnBIOFPRO_{it} + e_{it}$$

$$(2)\ LnGDP_{it} = \beta_0 + \beta_1 LnCAPITAL_{it} + \beta_2 LnLABOUR_{it} + \beta_3 LnFINDEV_{it} + \beta_4 LnBIOFCON_{it} + e_{it}$$

$$(3)\ LnGDP_{it} = \beta_0 + \beta_1 LnCAPITAL_{it} + \beta_2 LnLABOUR_{it} + \beta_3 LnFINDEV_{it} + \beta_4 LnBIOFPRO_{it} + \beta_5 LnBIOFCON_{it} + e_{it}$$

Here, *i* refers to 1,…,11 for each country, *t* refers to the time starting from 2001 to 2019, LnGDP refers to log of gross domestic products, LnCAPITAL refers to the log of gross capital formation, LnLABOUR refers to the log of total labour forces, LnFINDEV refers to the domestic credit to private sector, LnBIOFPRO refers to the log of biofuel production including bioethanol production and biodiesel production, LnBIOFCON refers to the log of biofuel consumption including bioethanol consumption and biodiesel consumption.

3.3. Panel unit root test modelling

This study conducts panel unit root for all the variables. The concept of unit root test for this study has been taken from the study APERGIS & PAYNE (2010A, 2010B) that show both IM, Pearson, and Shin test done by IM ET AL. (2003) and ADF unit root test done by DICKEY & FULLER (1979). In the unit root test, this study assumes the null hypothesis is there is a unit root, and the alternative hypothesis - data is stationary. The basic formula of the IM, Pearson, and Shin unit root test is given in the following section. IM ET AL. (2003) defined the basic formula as follows.

Considering the number of cross-section id such as countries in this study and the number of observed years of this study. y_{it} is supposed to be the stochastic process that is generated by the first-order autoregressive process.

$$y_{it} = (1-\phi)\ \mu_i + \phi_i\, y_{i,t-1} + \varepsilon_{it}$$

here the null hypothesis $\phi_i = 1$ for all cross sections. The above equation also can be written as

$$\Delta y_{it} = \alpha_i + \beta_i\, y_{i,t-1} + \varepsilon_{it}$$

Here, Δy_{it} refers to $y_{it} - y_{i,t-1}$, β_i refers to $-(1-\phi)$, and α_i refers to $(1-\phi)\mu_i$.

The basic formula of ADF unit root test is mentioned in the following section. Here I mention the equation for first difference unit root test with no trend.

$$\Delta y_{it} = \beta_i\, y_{i-t} + \varepsilon_{it}$$

Δy_{it} refers to $y_i - y_{i-1}$, and β_i refers to ϕ-1. So now the null hypothesis for all observations for IM, Pearson, and Shin test and ADF unit root test becomes H0: βi = 0, equivalent to $\phi_i = 1$.

3.4. Panel cointegration tests

After testing with the static data test, this study proceeded with the panel cointegration test to show whether the variables are cointegrated. I use the two types of panel cointegration tests to check with the panel cointegration test. The first one is the Pedroni Residual Cointegration Test (PEDRONI, 1999; PEDRONI, 2000). There are seven test statistics to examine the null hypothesis that no cointegration occurs in nonstationary panels. The seven statistical tests account for panel heterogeneity, both in terms of short-run dynamics and long-run slope and intercept coefficients (NEAL, 2014). The Pedroni's panel cointegration test model is mentioned following the research conducted by HAMIT-HAGGAR (2012). Based on the, this study also investigates cointegration relationship for each three estimated models.

(1) $LnGDP_{it} = \alpha_{it} + \delta_i t + \beta_{1i}\, LnCAPITAL_{it} + \beta_{2i}\, LnLABOUR_{it} + \beta_{3i}\, LnFINDEV_{it} + \beta_{4i}\, LnBIOFPRO_{it} + e_{it}$

(2) $LnGDP_{it} = \alpha_{it} + \delta_i t + \beta_{1i}\, LnCAPITAL_{it} + \beta_{2i}\, LnLABOUR_{it} + \beta_{3i}\, LnFINDEV_{it} + \beta_{4i}\, LnBIOFCON_{it} + e_{it}$

(3) $LnGDP_{it} = \alpha_{it} + \delta_i t + \beta_{1i}\, LnCAPITAL_{it} + \beta_{2i}\, LnLABOUR_{it} + \beta_{3i}\, LnFINDEV_{it} + \beta_{4i}\, LnBIOFPRO_{it} + \beta_{5i}\, LnBIOFCON_{it} + e_{it}$

Here, the α_{it} as well as δ_i allow for the probability of industry-specific fixed effects and deterministic trend, respectively. The second cointegration test conducted here is Kao Residual Cointegration Test (KAO, 1999). Here, for both tests, I assume the '*Null Hypothesis: No cointegration*' and *"Alternative Hypothesis: There is a cointegrated relationship."*

3.5. Experimental model selection

This study mainly considers both unit root test and panel cointegrated test output. Considering the output of the panel co-integrated test, this study considers the experiment the cointegrated panel regression, more particularly Panel Fully Modified Least Squares (FMOLS) and later compares the result with another panel cointegrated model, Panel Dynamic Least Squares (DOLS) models (PEDRONI, 2001; PEDRONI, 2004). These models are also appropriate when the number of observations is less than the times. Many previous studies, such as AL-MULALI (2015), APERGIS & PAYNE (2010B), KAYHAN & ÖZDEMIR (2021), KHAN ET AL. (2019), N. SINGH ET AL. (2019), also conducted these two models in the above circumstances.

3.6. Description of biofuel production and consumption trend by country

Figure 13 shows the scenario of biofuel production in Austria. Biofuel production in Austria started growing after 2006. From 2006 to 2011, biodiesel production was higher compared to bioethanol production. Between 2012 to 2013, there was a noticeable fluctuation in both productions of bioethanol and biodiesel. After 2013, both biodiesel and biofuel production continue to grow simultaneously. Finally, in 2019, bioethanol production was 4.09 Mb/d, biodiesel 5.16Mb/d, and total biofuel production was 9.25 Mb/d. Figure 14 shows the scenario of biofuel consumption in Austria. Biofuel consumption in Austria started growing after 2006. From 2006 to 2009, biodiesel consumption was way higher compared to bioethanol consumption. Between 2009 to 2018, there was a noticeable fluctuation in the consumption of biodiesel. After 2013, bioethanol consumption continued to stay in the same range, with slight fluctuation from growth in 2007 to 2018. Finally, in 2018, bioethanol consumption was 1.93 Mb/d, biodiesel 9.75 Mb/d, and total biofuel consumption was 11.68 Mb/d.

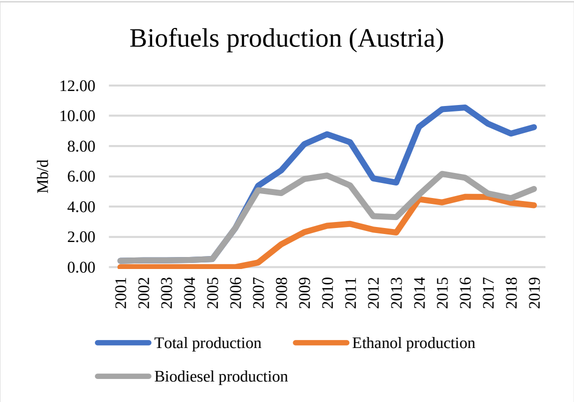


Figure 13: Biofuels production in Austria

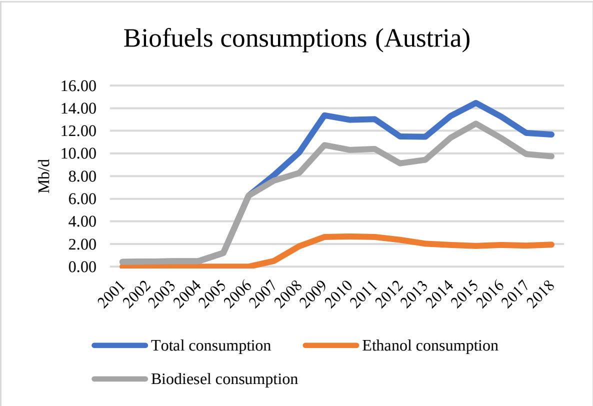


Figure 14: Biofuels consumption in Austria

Figure 15 shows the scenario of biofuel production in Belgium. Biofuel production in Belgium started growing in 2008. From 2008 to 2015, biodiesel production was higher compared to bioethanol production. But after that, from 2015 to 2019, biodiesel production was lower than bioethanol production. From 2008, biodiesel and biofuel production continued to grow simultaneously until 2011. Between 2011 to 2017, there was a visible fluctuation in the production of biodiesel and a slight fluctuation in bioethanol production. Finally, in 2019, bioethanol production was 6.71 Mb/d, biodiesel 4.66 Mb/d, and total biofuel production was 11.37 Mb/d. Figure 16 shows the scenario of biofuel consumption in Belgium. Overall, the consumption of biodiesel is much higher than the consumption of ethanol fuel. Biofuel consumption in Belgium started growing in 2008. From 2008, both biodiesel and biofuel consumption continued to grow simultaneously till 2009, when biodiesel got a peak. From 2008 to 2010, biodiesel consumption increased, and after that, till 2014, there was a slight fluctuation (dropped down from 7.79 Mb/d to 4.56 Mb/d). From 2009 to 2016, the consumption of bioethanol was quite in the same range with a very slight change. From 2014 to 2015, biodiesel consumption faced a drastic drop. After 2015 both biodiesel and bioethanol consumption started to increase simultaneously again till 2018. Finally, in 2018, bioethanol consumption was 3.51 Mb/d, biodiesel 8.03 Mb/d, and total biofuel consumption was 11.55 Mb/d.

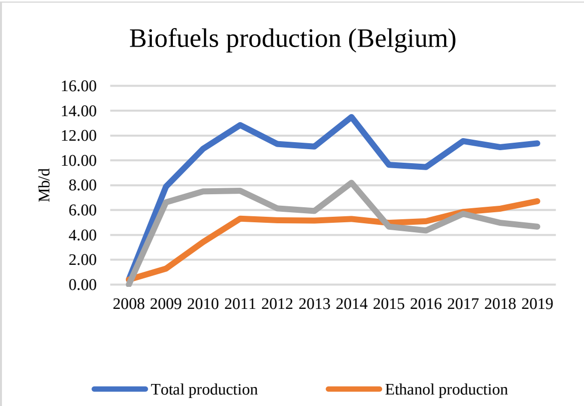


Figure 15: Biofuels production in Belgium

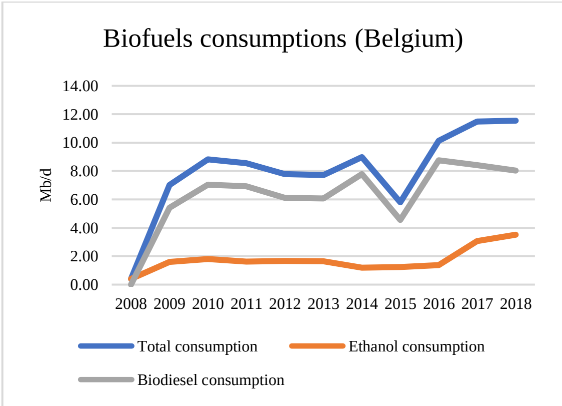


Figure 16: Biofuels consumption in Belgium

Figure 17 shows the scenario of biofuel production in Finland. Biofuel production in Finland started growing in 2007. There was a simultaneous growth in biodiesel production from 2007 to 2010. But after that, from 2010 to 2011, there was a slight drop in production. After that, again, biodiesel production increased simultaneously till 2015. Then biodiesel production dropped drastically from 9.58 Md/d in 2015 to 2.07 mb/d in 2016, and then it started again to increase in 2019. Biodiesel had a very high demand compared to bioethanol in Finland. That is why biodiesel production was always way higher compared to bioethanol production. From 2007 to 2016, bioethanol production was quite the same, with very few changes. After 2016, it seems there is no bioethanol production. Finally, in 2019, bioethanol production was 0.00 Mb/d, biodiesel 8.30 Mb/d, and total biofuel production was 8.30. Mb/d. Figure 18 shows the scenario of the consumption of biofuel in Finland. From 2007 to 2011, the consumption of biofuel increased simultaneously. The consumption of bioethanol was higher than biodiesel from 2007 to 2012. But from 2013 till 2018, the consumption of biodiesel was higher than the consumption of bioethanol. From 2011 to 2013, the consumption of biodiesel slightly decreased then it started having drastic fluctuations from 2013 to 2018. The consumption of bioethanol had slight ups and downs from 2008 to 2018. Finally, in 2018, bioethanol consumption was 2.96 Mb/d, biodiesel 5.43 Mb/d, and total biofuel consumption was 8.39 Mb/d.

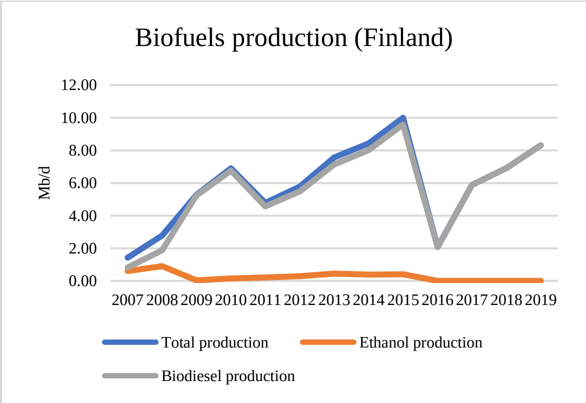


Figure 17: Biofuels production in Finland

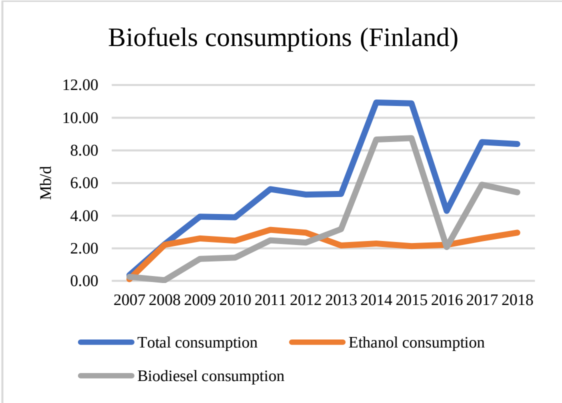


Figure 18: Biofuels consumption in Finland

Figure 19 shows the scenario of biofuel production in France. Biofuel production in France started growing in 2001. From 2007 to 2010, biodiesel production increased simultaneously. But after that, from 2010 to 2011, there was a slight drop in production. After that, biodiesel production increased simultaneously till 2015. Then biodiesel production dropped drastically till 2016; then, it increased until 2019. Biodiesel production was always way higher compared to bioethanol production. From 2007 to 2016, bioethanol production was quite the same, with very little change. After 2016 bioethanol production stopped. Finally, in 2019, bioethanol production was 0.00 Mb/d, biodiesel 8.30 Mb/d, and total biofuel production was 8.30 Mb/d.

Figure 20 shows the scenario of biofuel consumption in France. There was almost no noticeable change in biofuel consumption in France from 2001 to 2004. From 2004 to 2006, there was a slowly increasing trend in biofuel consumption. But after 2006 to 2009, there was a drastic increase in the consumption of biodiesel; however, a slight increase in the consumption of bioethanol. After 2009, biofuel consumption increased simultaneously till 2018 for both biodiesel and bioethanol. There was no significant fluctuation between 2009 to 2017. The consumption of biodiesel was always way higher than the consumption of bioethanol. Finally, in 2018, bioethanol consumption was 17.91 Mb/d, biodiesel 57.11 Mb/d, and total biofuel consumption was 75.01 Mb/d.

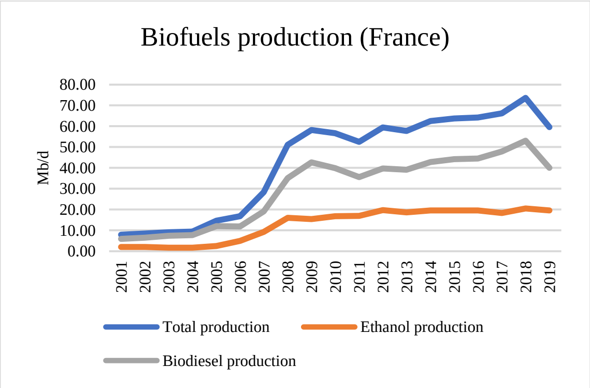


Figure 19: Biofuels production in France

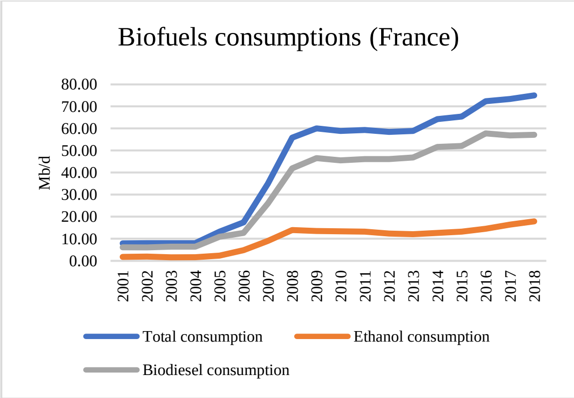


Figure 20: Biofuels consumption in France

Figure 21 shows the scenario of biofuel production in Germany. Biofuel production in Germany started growing in 2001. From 2001 to 2007, biofuel production was increasing simultaneously for both the production of bioethanol and biodiesel production. But from 2007 to 2019, both the production of bioethanol and biodiesel fluctuated frequently. Compared to bioethanol production, biodiesel production has been much higher in Germany. Finally, in 2019, bioethanol production was 10.52 Mb/d, biodiesel 62.29 Mb/d, and total biofuel production was 72.81 Mb/d.

Figure 22 shows the scenario of biofuel consumption in Germany. Biofuel consumption in Germany started growing in 2001. From 2001 to 2007, biofuel consumption increased simultaneously for both the consumption of bioethanol and the consumption of biodiesel. But after that, from 2007 to 2019, both the consumption of bioethanol and biodiesel fluctuated frequently. The consumption of biodiesel was always way higher than the consumption of bioethanol. Finally, in 2019, bioethanol consumption was 22.99 Mb/d, biodiesel 42.79 Mb/d, and total biofuel consumption was 65.78 Mb/d.

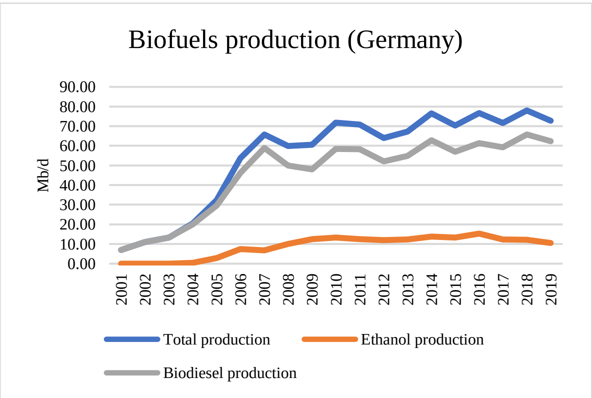


Figure 21: Biofuels production in Germany

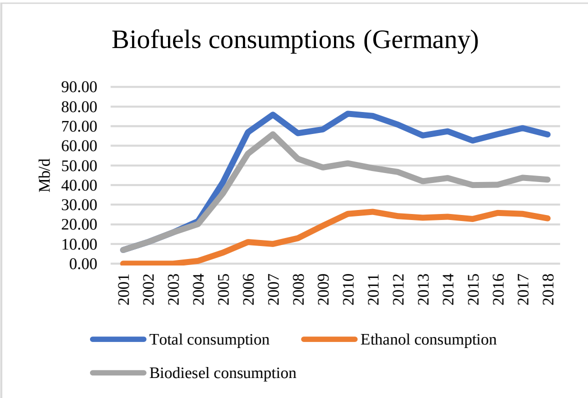


Figure 22: Biofuels consumption in Germany

Figure 23 shows the scenario of biofuel production in Italy. In 2001, Italy produced biofuels, particularly biodiesel 2.80 Mb/d. Till 2004, there was almost no ethanol production in Italy. From 2001 to 2005, biodiesel production increased simultaneously. After that, from 2005 to 2007, the production of bioethanol fluctuated, and the production of biodiesel remained constant. There was a noticeable increase between 2007 and 2010, and a noticeable decrease between 2011 and 2012 in biodiesel production. Between 2012 and 2019, biodiesel production increased greatly at the same time, while bioethanol production decreased slightly. The production of biodiesel was always higher than the production of bioethanol. Finally, in 2019, bioethanol production was 0.30 Mb/d, biodiesel 22.92 Mb/d, and total biofuel production was 22.93 Mb/d.

Figure 24 shows the scenario of biofuel consumption in Italy. Biofuel consumption in Italy started growing from 2001. Starting from 2001 to 2003, there were no biofuel consumptions. From 2003 the biofuel consumption was increasing simultaneously for biodiesel till 2004 but there was no consumption of bioethanol. After that from 2005 to 2010, the consumption of biodiesel and the consumption of bioethanol increased simultaneously where consumption of biodiesel got a high peak and bioethanol slightly increased. After 2010 the consumption of bioethanol decreased simultaneously till 2018 while, the consumption fluctuated for numbers of biodiesel consumption. The consumption of biodiesel was always higher than the consumption of bioethanol. Finally, in 2018, bioethanol consumption was 0.84 Mb/d, biodiesel 27.09 Mb/d, and total biofuel consumption was 27.92 Mb/d.

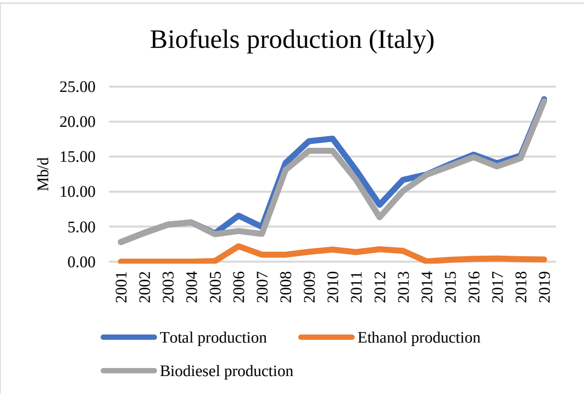


Figure 23: Biofuels production in Italy

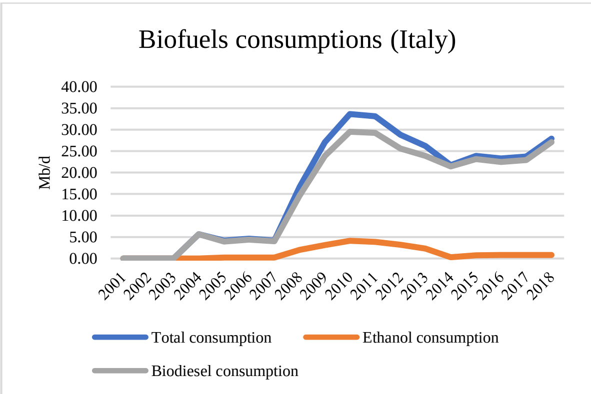


Figure 24: Biofuels consumption in Italy

Figure 25 shows the scenario for biofuel production in the Netherlands. Biofuel production in Netherlands started growing from 2006. Compared with bioethanol, the Netherlands focuses on the production of biodiesel. Starting in 2006, the production of biodiesel and bioethanol was almost similar, but by 2011, the production of biodiesel was almost double that of ethanol.

Biodiesel production increased simultaneously from 2011 (6.95 Mb/d) to 2016 (28.76 Mb/d). Although biodiesel production declined slightly between 2014 and 2016, it recovered again to 37.95 Mb/d in 2017 when bioethanol production was 0.00. Finally, in 2019, bioethanol production was 0.00 Mb/d, biodiesel 35.08 Mb/d, and total biofuel production was 35.08 Mb/d.

Figure 26 shows the biofuel consumption scenario in the Netherlands. Biofuel consumption in Netherlands started growing from 2006 and before 2006, biofuels consumption was not popular in Netherlands. There was a high increase in both biodiesel and bioethanol consumption from 2006 to 2007. After that, from 2007 to 2018 there were lot of fluctuations in the consumption of the biofuel in both cases of the consumption of bioethanol and the consumption of biodiesel. Both of biofuels were consumed simultaneously and the consumptions varied in a range of 2.0 Mb/d to 6.0 Mb/d mostly, with slight exception in 2018. The most significant changes are seen in rate of consumption of biodiesel where it went up and down several times. Finally, in 2018, bioethanol consumption was 5.80 Mb/d, biodiesel 8.42 Mb/d, and total biofuel consumption was 14.23 Mb/d.

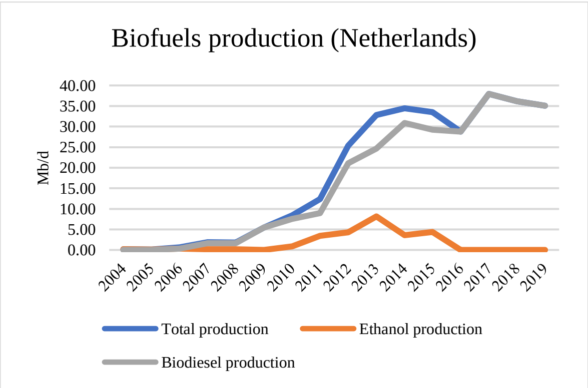


Figure 25: Biofuels production in Netherlands

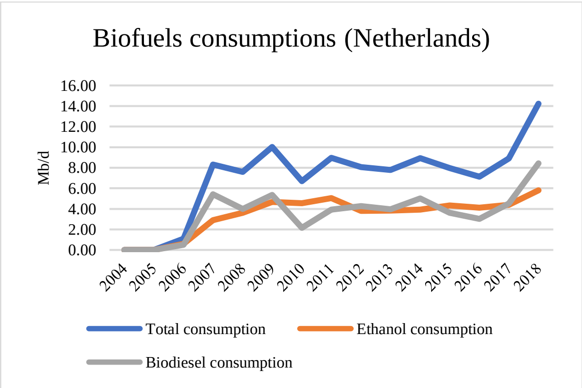


Figure 26: Biofuels consumption in Netherlands

Figure 27 presents the picture of biofuel production in Poland. Biofuel production in Poland started growing from 2002. There was no output of biofuel production till 2002, and almost no biodiesel production till 2004. From 2014 to 2019, bioethanol and biodiesel production increased in tandem. Biodiesel production peaked in 2007, while bioethanol production increased slightly. The production of biodiesel is much higher than that of bioethanol after 2007. With slight fluctuation the production of biodiesel reached its peak in 2019. Finally, in 2019, bioethanol production was 3.84 Mb/d, biodiesel 17.26 Mb/d, and total biofuel production was 21.10 Mb/d.

Figure 28 shows the trends of biofuel consumption in Poland. Biofuel consumption in Poland started growing from 2006. From 2006 to 2018, the consumption trend of biofuels fluctuated several times in terms of both bioethanol consumption and biodiesel consumption. Both of biofuels were consumed simultaneously and the consumptions varied in a range of 2.0 Mb/d to 6.0 Mb/d mostly, with slight exception in 2018. The most notable changes were seen in the consumption rate of biodiesel, which rose and fell several times. Finally, in 2018, bioethanol consumption was 5.80 Mb/d, biodiesel 8.42 Mb/d, and total biofuel consumption was 14.23 Mb/d.

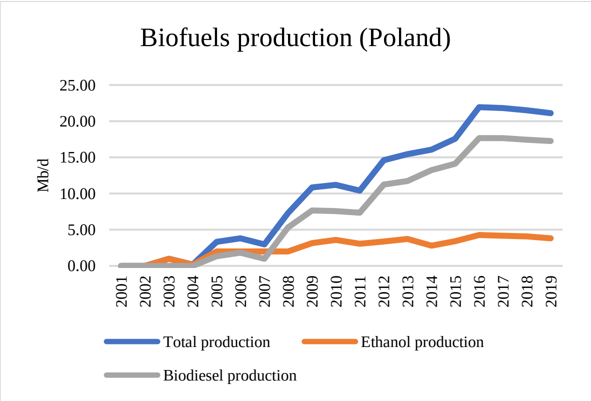


Figure 27: Biofuels production in Poland

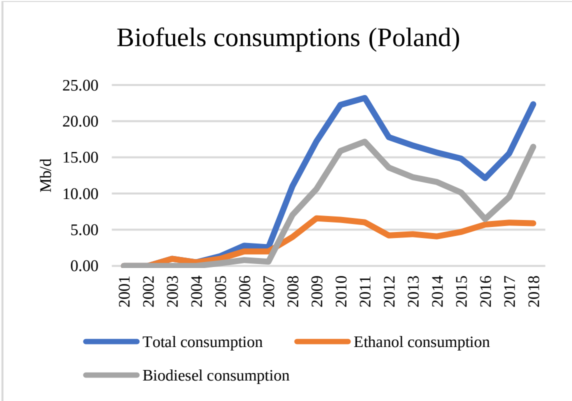


Figure 28: Biofuels consumption in Poland

Figure 29 shows the scenario of biofuel production in Portugal. Biofuel production in Portugal started growing from 2006. Portugal only has the production of the biofuel biodiesel, there was no production of bioethanol. Starting from 2006 to 2011, the biodiesel production increased sequentially and reached to its peak with a single fluctuation in the middle. In 2011 to 2012 it dropped. Again, in from 2012 to 2019 it increased sequentially. Finally, in 2019, bioethanol production was 0.00 Mb/d, biodiesel 7.04 Mb/d, and total biofuel production was 7.04 Mb/d.

Figure 30 shows the scenario of biofuel consumption in Portugal. Biofuel consumption in Portugal started growing from 2006. Portugal has the consumption of the biofuel biodiesel in large with a very less consumption of bioethanol, there was no consumption of bioethanol. Starting from 2006 to 2012, the biodiesel consumption increased sequentially and reached to its peak with a single fluctuation in the middle. In 2011 to 2012 it drops. Again, in from 2012 to 2018 it increased sequentially with fluctuations letter. The consumptions of bioethanol from 2014 to 2015 reached at peak following fluctuations till 2018. Finally, in 2018, bioethanol consumption was 0.19 Mb/d, biodiesel 3.90 Mb/d, and total biofuel consumption was 6.15 Mb/d.

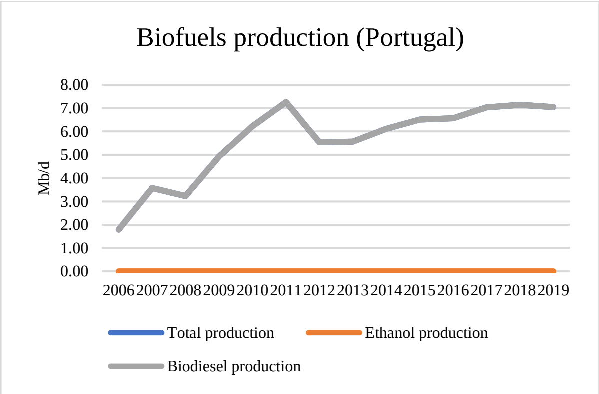


Figure 29: Biofuels production in Portugal

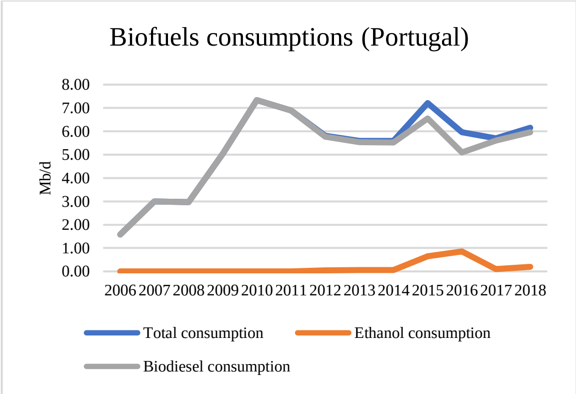
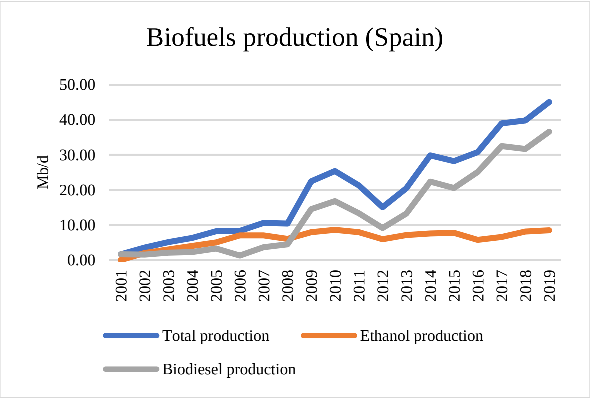


Figure 30: Biofuels consumption in Portugal

Figure 31 shows the development trends of biofuel production in Spain. There was almost similar trends of bioethanol and biodiesel production from 2001 to 2008. After 2008, the biofuel production increased where the rise of the production of bioethanol was sequential, but the production of biodiesel went very high eventually with some fluctuations. From 2010 to 2019 there was a sequential increase in the production of bioethanol. From 2010 to 2012 there a significant drop is seen in the production of biodiesel. After that from 2012 to 2019 the productions of biodiesel significantly raised eventually after slight fluctuations. Finally, in 2019, bioethanol production was 8.46 Mb/d, biodiesel 36.61 Mb/d, and total biofuel production was 45.07 Mb/d.

Figure 32 shows the picture of biofuel consumption in Spain. Biofuel consumption in Spain started growing from 2001. During the period 2001 to 2005, there weas almost same quantity of biodiesel and bioethanol consumption in Spain. After 2006 to 2012, the biodiesel consumption increased significantly and reached to its peak without any fluctuation. In 2012 to 2013 it dropped significantly from 36.60 Mb/d to 15.20 Mb/d. Again, from 2012 to 2018 it increased sequentially from 15.20 Mb/d to 31.79 in 2018. The consumption of bioethanol showed little growth and fluctuated slightly between 2001 and 2018. It almost stayed in the same range through the time. Finally, in 2018, bioethanol consumption was 4.74 Mb/d, biodiesel 31.79 Mb/d, and total biofuel consumption was 36.53 Mb/d.



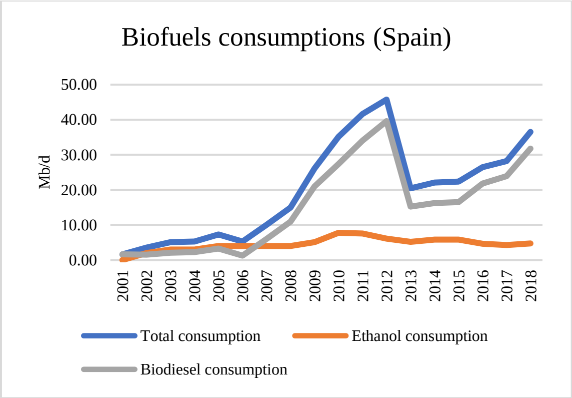
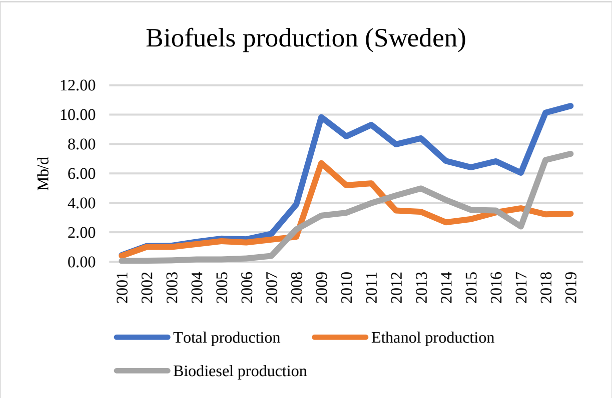


Figure 31: Biofuels production in Spain

Figure 32: Biofuels consumption in Spain

Figure 33 shows the scenario of biofuel production in Sweden. Biofuel production in Sweden started growing from 2001. Starting from 2001 to 2007, there was steady growth of biofuel production in Sweden. During this period, fuel ethanol production in Sweden was more than three times higher than biodiesel production. Sweden emphasized in biodiesel production after 2007. From 2009 to 2019 the production of biodiesel increased eventually with fluctuation and a remarkable increase from 2017. For bioethanol from 2009 to 2019 the production decreased with little fluctuations. Finally, in 2019, bioethanol production was 3.26 Mb/d, biodiesel 7.34 Mb/d, and total biofuel production was 10.60 Mb/d.

Figure 34 shows the scenario of biofuel consumption in Sweden. Biofuel consumption in Sweden started growing from 2001. Starting from 2001 to 2018, the biodiesel consumption increased to a significant higher value sequentially. From 2001 to 2008 the consumption of bioethanol increased eventually. After 2008 and till 2018 the consumption of bioethanol decreased from 7.30 in 2008 to 3.94 Mb/d in 2018. Finally, in 2018, bioethanol consumption was 3.94 Mb/d, biodiesel 30.63 Mb/d, and total biofuel consumption was 34.57 Mb/d.



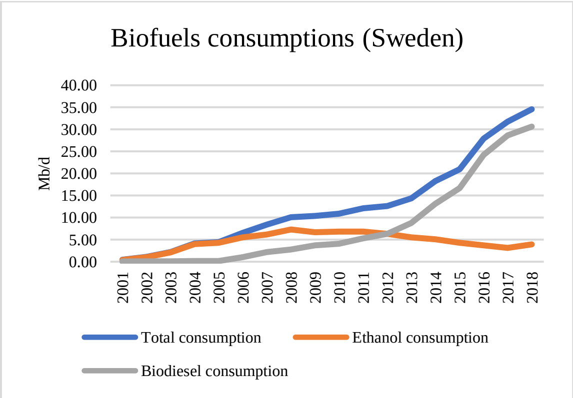


Figure 33: Biofuels production in Sweden

Figure 34: Biofuels consumption in Sweden

4. FINDINGS AND ANALYSIS

4.1. Descriptive statistics and findings

4.1.1. Descriptive statistics

The descriptive statistic of this study is mentioned in the following Table 5. Here, all countries' descriptive statistics are presented. I present the mean, median, maximum (Max), minimum (Min), standard deviation (Std.Dv), Skewness, Kurtosis, Jarque-Bera, Probability and the number of observations of each country.

Table 5: Descriptive statistics

Stat	LnGDP	LnCAPITAL	LnLABOUR	LnFINDEV	LnBIOPRO	LnBIOCONL
Mean	6.5865	5.0440	2.3955	6.4553	2.1242	2.1401
Median	6.2590	4.8183	2.2227	6.4496	2.2258	2.3086
Maximum	8.1888	6.6430	3.7921	8.0837	4.3568	4.4005
Minimum	5.2696	3.3563	0.9587	3.6223	-2.9957	-3.9120
Std. Dev.	0.9109	0.9162	0.9158	1.0408	1.4312	1.5346
Skewness	0.2664	0.1792	-0.0399	-0.1301	-0.7871	-1.0541
Kurtosis	1.6874	1.8222	1.4919	-0.9549	3.7980	4.7623
Obs	194	194	194	194	194	194

Source: Author experiment (2022)

4.1.2. Unit root test statistics

Table 6 presents the unit root test result. I experiment with the unit root at level I (0) and the first difference I (1). In most cases, the variables are non-stationary, indicating there is a unit root. More particularly, GDP, capital formation, labour are non-stationary variables in I (0); however, biofuel production shows significance at both I (0) and I (1). This significant output indicates that biofuel production is stationary in both the level and first difference. In the case of biofuel consumption, it shows insignificant at I (0) and significant at I (1) in ADF - Fisher Chi-square output. Considering the above circumstances, I move forward with the cointegration test to decide on further experiment modelling. More particularly, except for biofuel production, all variables are non-stationary at I(0). Thereby, I consider proceeding with the panel cointegration test.

Table 6: Unit root tests

Variables	lm	ADF - Fisher Chi-square
LnGDP	2.1482	9.2189
ΔLnGDP	-4.7964***	65.5402***
LnCAPITAL	0.2639	16.5662
ΔLnCAPITAL	-7.1084***	93.8294***
LnLABOUR	0.8011	22.2541
ΔLnLABOUR	-4.2816***	59.5353***
LnFINDEV	-2.8163***	47.3372***
ΔLnFINDEV	-1.9311**	34.0323**
LnBIOFPRO	-2.5258***	41.2788***
ΔLnBIOFPRO	-3.6859***	52.1074***
LnBIOFCON	-1.7345***	29.9191
ΔLnBIOFCON	-1.5210**	31.5921*

Source: Author experiment (2022) (Note: *Δ* refers to first difference unit root test)

4.2. Impact of biofuel production on EU economy

4.2.1. Panel cointegration test (production model)

Table 7 presents the *Pedroni Residual Cointegration Test* for the biofuel production model. I test within-dimension, weighted statistic (PEDRONI 1999; PEDRONI 2000; PEDRONI 2004), and alternative hypothesis: individual AR coefficient (between-dimension). Table 7 presents seven test statistics, such as v-Statistic, rho-Statistic, PP-Statistic, ADF-Statistic, Group rho-Statistic, Group PP-Statistic, and Group ADF-Statistic. According to Table 7, (i) v-Statistic, PP-Statistic, ADF-Statistic of within dimension show significant value, (ii) PP and ADF-Statistic of weighted statistics, and (iii) Group PP-Statistic and ADF-Statistic of between dimension show significant values, which indicate null hypothesis is rejected and there is cointegrated relationship exist in the estimated equation.

Table 7: Pedroni Residual Cointegration Test (production model)

Alternative hypothesis: common AR coefs. (within-dimension)		
Tests	**Statistic**	**Weighted Statistic**
Panel v-Statistic	1.6487**	0.1425
rho-Statistic	0.5753	1.1618
PP-Statistic	-2.6979***	-1.8024**
ADF-Statistic	-2.8350***	-2.1457**
Alternative hypothesis: individual AR coefficient (between-dimension)		
Group rho-Statistic	2.4519	
Group PP-Statistic	-4.1303***	
Group ADF-Statistic	-3.9025***	

Source: Author experiment (2022)

To show the robustness of the output of the panel cointegration test in Table 7, I also conduct the *Kao Residual Cointegration Test*. Table 8 presents the output of *the Kao Residual Cointegration Test*. Here, the null hypothesis is there is no cointegration. According to the ADF statistics, the t-statistics is significant (the coefficient is -2.4120), and that support rejects the null hypothesis. Therefore, the Kao Residual Cointegration Test shows that the variables are cointegrated.

Table 8: Kao Residual Cointegration Test (production model)

Statistics	**t-Statistic**
ADF	-2.4120***

Source: Author experiment (2022)

4.2.2. Cointegrated regressions (production model)

After the unit root and panel cointegration tests, I find a cointegration relationship in the estimated model. That is why I follow the cointegrated panel regression methods. Table 9 shows the regression output of the biofuel production model. Here, the study experiments are performed on FMOLS and DOLS regression. These two models are used widely to experiment with regression when cointegrated relationships exist.

According to Table 9, capital formation is positively significant on GDP. The coefficient in the FMOLS model is 0.3827 at the 99% confidence level. This positive output means that a 1% increase in the capital formation increases GDP by 0.3827%. The result of this section supports existing literature output. Capital formation is also grossly discussed in the literature with a significant impact on economic growth. For example, SINGH ET AL. (2019) conduct multivariate studies based on developed and developing countries' samples in renewable energy production and economic growth nexus relationship. They reveal gross capital formation significantly promotes economic growth. More particularly, a 1% surge in capital formation surges 0.44% in GDP. Labour also has a positive effect on the economy. A 1% increase in labour increases GDP by 0.4013%. This study result also supports the findings from the previous study. For example, SINGH ET AL. (2019) reveal a significant positive relationship between labour forces and economic growth. Particularly, 1% increase in labour force raises GDP by 0.27% for all countries, 0.31% for developed countries, and 0.23% for developing countries. Financial development also significantly impacts on economic growth (coefficient 0.0606) at the 99% confidence level. Higher level of financial development promotes EU economies. More specific output is discussed in the following section.

The most important variable in this biofuel production model is the effect of biofuel production on economic expansion. Biofuel production is also very significant in the FMOLS models. A 1% growth in biofuel production surge in 0.0185% GDP growth (FMOLS). Some other studies also support the result of the study. For example, HASAN (2022) investigates how energy production and consumption impact on economic growth in BRICS countries. This study found that along with the other energy production variable, the production of biofuel significantly impacts on economic expansion in the BRICS economy. This study found that a 1% increase in biofuel production increases 0.492% GDP (at a 95% confidence interval). This study's output is also similar to the output of AL-MULALI (2015), who also find that biofuel production has a significant positive impact on the Czech Republic's economic growth (0.2722), indicating a 1% rise in biofuel energy production raises Czech Republic GDP by 0.2722%. QIAO ET AL. (2016) also experiment with the relationship between biofuel production and economic development, particularly focusing on sustainable development. They show that biofuel production significantly and positively impacts on economic development, particularly they show per capita real GDP. A 1% increase in economic growth promotes 0.2949% growth in per capita real GDP. There is also some other literature that shows how renewable energy production influences economic growth. Considering the aspect of biofuels as one of the highlighted parts of renewable energy, some other studies, such as KAZAR & KAZAR (2014), find there is a significant impact of renewable energy production on long-term economic growth. DINÇ & AKDOĞAN (2019) also conduct the impact of renewable energy production and demonstrated the existence of the long-term impact of renewable energy production on countries' economic growth. In addition, SINGH ET AL. (2019) also find that a 1% increasing renewable energy production boosts the economy by 0.06%. Considering the above circumstances, this study strongly demonstrates that biofuel production has a significant positive proven influence on economic growth in the panel region of this study.

Table 9: Panel Fully Modified Least Squares - FMOLS (production model)

Variable	**FMOLS**
LnCAPITAL	0.3827***
	(0.0297)
LnLABOUR	0.4013***
	(0.1138)
LnFINDEV	0.0606***
	(0.0187)
LnBIOFPRO	0.0185***
	(0.0044)
R-squared	0.9988
Adjusted R-squared	0.9987
S.E. of regression	0.0324
Durbin-Watson stat	0.3376
Mean dependent var	6.5967
S.D. dependent var	0.9095
Sum squared residual	0.1762
Long-run variance	0.0016

Source: Author experiment (2022)

This study tests another experiment for the production model that investigates the impact of biofuel production on EU economic growth. The output of another well-known cointegrated regression, DOLS model, is mentioned here Table 10.

Table 10: Panel Dynamic Least Squares - DOLS (production model)

Variable	**DOLS**
LnCAPITAL	0.4386***
	(0.0380)
LnLABOUR	0.1182
	(0.1277)
LnFINDEV	0.0406*
	(0.0234)
LnBIOFPRO	0.0272***
	(0.0070)
R-squared	0.9999
Adjusted R-squared	0.9999
S.E. of regression	0.0066
Mean dependent var	6.5865
S.D. dependent var	0.9109
Sum squared residual	0.0028
Long-run variance	0.0002

Source: Author experiment (2022)

According to Table 10, the output of FMOLS model for capital formation has also high significance in DOLS model. The coefficient is 0.4386, which means that a 1% increase in the capital formation increases GDP by 0.4386% in selected European countries' economic growth. Financial development is also significant in DOLS model. Biofuel production is also very significant in DOLS model. A 1% growth in biofuel consumption increase GDP by 0.0272%. Therefore, this study confirms the robustness of FMOLS model for the impact of biofuel production on the economic growth in the panel region.

4.3. Impact of biofuel consumption on EU economy

4.3.1. Panel cointegration test (consumption model)

Table 11 presents the Pedroni Residual Cointegration Test for the biofuel consumption model. I test within-dimension, weighted statistic (PEDRONI 1999; PEDRONI 2000; PEDRONI 2004), and alternative hypothesis: individual AR coefficient (between-dimension). Here I also assume the '*Null Hypothesis: No cointegration*'. According to Table 11, (i) v-statistics, PP-Statistic and ADF-Statistic of within dimension show significant value, and (ii) PP-Statistic and ADF-Statistic of weighted statistics show significant value, and (iii) Group PP-Statistic and Group ADF-Statistic of between dimension show significant values, which indicate null hypothesis rejected and there is cointegrated relationship exist in the estimated equation.

Table 11: Pedroni Residual Cointegration Test (consumption model)

Alternative hypothesis: common AR coefs. (within-dimension)		
Tests	**Statistic**	**Weighted Statistic**
v-Statistic	1.6453**	-0.3492
rho-Statistic	0.8438	1.2424
PP-Statistic	-5.3723***	-2.5325***
ADF-Statistic	-5.8389***	-3.7481***
Alternative hypothesis: individual AR coefficient (between-dimension)		
Group rho-Statistic	2.6402	
Group PP-Statistic	-4.8963***	
Group ADF-Statistic	-5.2594***	

Source: Author experiment (2022)

Following the same strategy of the biofuel production model, I also conduct the Kao Residual Cointegration Test to show the robustness of the panel cointegration test of the consumption model. Table 12 present the output of the *Kao Residual Cointegration Test*. Here, the null hypothesis is there is no cointegration. According to the ADF statistics, the t-statistics is significant (-2.5093***), which supports rejecting the null hypothesis. Therefore, the *Kao Residual Cointegration Test* shows the variables are cointegrated.

Table 12: Kao Residual Cointegration Test (consumption model)

Statistics	t-Statistic
ADF	-2.5093***

Source: Author experiment (2022)

4.3.2. Cointegrated regressions (consumption model)

Table 13 shows the regression output of the biofuel consumption model. Here, I also experiment the FMOLS regression. According to Table 13, capital formation is also very significant, and the coefficient is positive (0.4010). This output means that a 1% increase in the capital formation increases GDP by 0.4010%. The output of this study supports the output of previous literature that experiments with the energy consumption economic nexus. For example, AL-MULALI ET AL. (2016) investigate both the long-run and short-run effects of bioethanol consumption and capital formation on economic performance in Brazil. According to the findings, both capital formation and ethanol consumption are favorably related to economic growth. They reveal that if capital formation rises by 100%, then it will improve the country's economic progress by 13.9%.

Labour also has a positive impact on the economy in the consumption model. A 1% increase in labour increases GDP by 0.4879%. In terms of both labour forces and gross capital formation, APERGIS & PAYNE (2010B) reveal that both two variables have a significant positive impact on both short- and long-term economic growth. Financial development is also significantly impact on economic growth (coefficient 0.0579) at the 99% confidence level in the biofuel consumption model.

The most important variable in the biofuel consumption model is the effect of biofuel consumption on economic expansion. Similar to biofuel production, biofuel consumption is also very significant in FMOLS. A 1% growth in biofuel consumption, 0.0115% GDP growth. However, compared to the significance of production of biofuel, the significance of the consumption of biofuel is slightly lower. This output supports the output of AL-MULALI (2015), who conduct the impact of biofuel production and consumption on economic growth by conducting the FMOLS model using data from 2000 to 2010. They find that biofuel consumption has a significant positive impact on economic growth. They also find that in the overall panel, a 1% rise in biofuel energy consumption raises GDP by 0.667%. In the case of individual countries, a 1% rise in biofuel energy consumption raises GDP in Italy by 0.027%, in the Netherlands by 0.0202%, in Poland by 0.0894%, in Portugal y 5.8172%, and in Sweden by 0.0719%. AL-MULALI ET AL. (2016) also demonstrate that if bioethanol consumption rises by 100%, then this consumption will improve the country's economic progress by 2.2%. This result is very similar significance to this study's findings. The result of this study supports the output of some other important literature on renewable energy consumption. For example, one of the most highlighted literatures on renewable energy consumption and economic growth is APERGIS & PAYNE (2010B), which show that renewable energy consumption significantly and positively influences economic growth. LIN & MOUBARAK (2014) conduct the renewable energy consumption and economic growth relationship from China's perspective and find there is a significant impact of renewable energy consumption on economic growth. Therefore, biofuel consumption also has a significant impact on the economic growth of the panel region.

Table 13: FMOLS (consumption model)

Variables	**FMOLS**
LnCAPITAL	0.4010***
	(0.0313)
LnLABOUR	0.4879***
	(0.1084)
LnFINDEV	0.0579***
	(0.0206)
LnBIOFCON	0.0115***
	(0.0039)
R-squared	99%
Adjusted R-squared	0.9986
S.E. of regression	0.0345
Durbin-Watson stat	0.3930
Mean dependent var	6.5967
S.D. dependent var	0.9095
Sum squared residual	0.2005

Source: Author experiment (2022)

This study tests another experiment for the consumption model that investigates the impact of biofuel consumption on EU economic growth. The output of another well-known cointegrated regression, DOLS model, is mentioned here in Table 14.

Table 14: DOLS (consumption model)

Variables	**DOLS**
LnCAPITAL	0.4561***
	(0.0474)
LnLABOUR	0.1220
	(0.2107)
LnFINDEV	0.0697
	(0.0488)
LnBIOFCON	0.0178***
	(0.0076)
R-squared	99%
Adjusted R-squared	0.9999
S.E. of regression	0.0070
Mean dependent var	6.5865
S.D. dependent var	0.9109
Sum squared residual	0.0032

Source: Author experiment (2022)

According to Table 14, it can be seen that the output of FMOLS model for capital formation has also high significance with DOLS model. However, coefficient is higher in DOLS model (0.4561). This output means that a 1% increase in the capital formation increases GDP by 0.4561% in selected European countries' biofuel energy consumption-economic growth model. Somehow, labor and financial development is insignificant here in DOLS. However, biofuel consumption is also very significant in DOLS models. A 1% growth in biofuel consumption increase GDP by 0.0178%. Therefore, this study confirms the impact of biofuel consumption on the economic growth of the panel region.

4.4. Impact of biofuel production and consumption on EU economy

4.4.1. Pedroni residual cointegration test (combined model)

Table 15 presents the Pedroni Residual Cointegration Test for the model that includes both the production and consumption of biofuel I test within-dimension, weighted statistic (PEDRONI 1999; PEDRONI 2000; PEDRONI 2004), and alternative hypothesis: individual AR coefficient (between-dimension). Here I also assume the '*Null Hypothesis: No cointegration*'. According to Table 15, (i) PP-Statistic and ADF-Statistic of within dimension show significant value, and (ii) Group PP-statistics and ADF-Statistic of between dimension show significant values, which indicate null hypothesis rejected, and there is a cointegrated relationship exist in the estimated equation.

Table 15: Pedroni Residual Cointegration Test (combined model)

Alternative hypothesis: common AR coefs. (within-dimension)		
Tests	**Statistic**	**Weighted Statistic**
v-Statistic	0.5757	-1.0028
rho-Statistic	1.7054	2.4776
PP-Statistic	-3.3448***	-0.9843
ADF-Statistic	-3.1080***	-1.0402
Alternative hypothesis: individual AR coefficient (between-dimension)		
Group rho-Statistic	3.7760	
Group PP-Statistic	-3.4890***	
Group ADF-Statistic	-2.1790***	

Source: Author's experiment (2022)

Following the same strategy of the biofuel production and consumption model, I also conduct the Kao Residual Cointegration Test to show the robustness of the panel cointegration test of the consumption model. Table 16 presents the output of the *Kao Residual Cointegration Test*. Here, the null hypothesis is there is no cointegration. According to the ADF statistics, the t-statistics is significant (-2.4415***), which supports rejecting the null hypothesis. Therefore, the *Kao Residual Cointegration Test* shows the variables are cointegrated.

Table 16: Kao Residual Cointegration Test (combined model)

Statistics	**t-Statistic**
ADF	-2.4415***

Source: Author’s experiment (2022)

4.4.2. Cointegrated regressions (combined model)

After the unit root and panel cointegration tests, I find a cointegration relationship in the estimated model. That is why I follow the cointegrated panel regression methods. Table 17 shows the regression output of both FMOLS. This model is used widely to experiment with regression when cointegrated relationships exist. According to Table 17, capital formation is positively significant on GDP at a 99% confidence interval level. This positive output of capital formation means that a 1% increase in the capital formation increases GDP by 0.3834%. Labour shows moderate positive significant output on economic growth at a 99% confidence interval level (coefficient is 0.3939). The output of variable, labour, indicates that a 1% increase in labour increases GDP by 0.3939%. Financial development is also significant in combined model. The coefficient is 0.0604, which is significant at 99% confidence intervals.

The most important variables in this model are the effect of biofuel production and consumption on economic expansion. Biofuel production is also very significant in FMOLS model. A 1% growth in biofuel production surge in 0.0181% GDP growth in EU. This study output indicates that a 1% rise in biofuel energy production raises GDP by 0.0181%. Considering the impact of the consumption of biofuels on economic growth, biofuel consumption is insignificant on GDP in combined model.

Table 17: FMOLS (combined model)

Variables	**FMOLS**
LnCAPITAL	0.3834***
	(0.0304)
LnLABOUR	0.3939***
	(0.1146)
LnFINDEV	0.0604***
	(0.0199)
LnBIOFPRO	0.0181***
	(0.0052)

LnBIOFCON	0.0004
	(0.0045)
R-squared	99%
Adjusted R-squared	0.9987
S.E. of regression	0.0325
Durbin-Watson stat	0.3375
Mean dependent var	6.5967
S.D. dependent var	0.9095
Sum squared residual	0.1764
Long-run variance	0.0016

Source: Author's experiment (2022)

This study tests another experiment for the combined model that investigates the impact of both biofuel production and consumption on EU economic growth. The output of another well-known cointegrated regression, DOLS model, is mentioned here in Table 18.

Table 18: DOLS (combined model)

Variables	**DOLS**
LnCAPITAL	0.3612***
	(0.0346)
LnLABOUR	0.4640***
	(0.1207)
LnFINDEV	0.0580***
	(0.0223)
LnBIOFPRO	0.0184***
	(0.0058)
LnBIOFCON	0.0007
	(0.0052)
R-squared	99%
Adjusted R-squared	0.9987
S.E. of regression	0.0326
Mean dependent var	6.5865
S.D. dependent var	0.9109

Sum squared residual	0.1892

Source: Author’s experiment (2022)

According to Table 18, it can be seen that a 1% growth in biofuel production surge in 0.0184% GDP growth. Reflecting the impact of the consumption of biofuels on economic growth, biofuel consumption is also insignificant in DOLS model. I am not surprised to see this output because biofuel consumption was also insignificant in FMOLS model. The conclusion is regarding combined production and consumption in a single model, the production of biofuels has a greater impact compared to the consumption of biofuels.

4.5. Robustness check with higher and lower economy

This study also tests the robustness of the study results. Among the 11 countries, this study divided into two groups according to the size of the economy. Group 1 includes five countries with higher GDP compared to the rest. In these five country GDP more than 1 trillion. The list of the countries is Germany (GDP 4.260 trillion), France (GDP 2.958 trillion), Italy (GDP 2.108 trillion), Spain (GDP 1.427 trillion), Netherlands (GDP 1.013 trillion). In the second group, the rest of the six countries included. These countries are Poland (GDP 679.4 billion), Sweden (GDP 635.7 billion), Belgium (GDP 594.1 billion), Austria (GDP 480.4 billion), Finland (GDP 297.3 billion), and Portugal (GDP 253.7 billion).

This study presents the output of robustness check in three steps. First, the impact of biofuel production on EU economic growth for both group 1 and group 2. Second, the impact of biofuel consumption on EU economic growth for both group 1 and group 2. Third, the impact of both biofuel production and consumption on EU economic growth for both group 1 and group 2.

First, the output of the impact of biofuel production on EU economic growth for both group 1 and group 2 are presented in Table 19 that shows biofuel production is positively significant in both groups. In group 1, biofuel production is significant at 99% confidence interval indicating biofuel production moderately promotes economic growth in Group 1 countries (Germany, France, Italy, Spain and Netherlands). In group 2, biofuel production is significant at 99% confidence interval indicating biofuel production highly promotes economic growth in Group 2 countries (Poland, Sweden, Belgium, Austria, Finland, and Portugal). The production of biofuels has higher impact in group 2 compared to group 1 countries. However, overall, the robustness confirms that biofuel production is positively significant in EU economies.

Table 19: Production model: Group 1 and Group 2

Variable	Group 1	Group 2
LnCAPITAL	0.3399***	0.4361***
	(0.0268)	(0.0583)
LnLABOUR	1.0492***	0.0824
	(0.1203)	(0.1900)
LnFINDEV	0.0054***	0.0612**
	(0.0246)	(0.0305)
LnBIOPRO	0.0088**	0.0220***
	(0.0043)	(0.0067)
R-squared	0.9985	0.9902
Adjusted R-squared	0.9983	0.9892
S.E. of regression	0.0204	0.0342
Durbin-Watson stat	0.6795	0.4190
Mean dependent var	7.4426	5.8301
S.D. dependent var	0.5012	0.3285
Sum squared resid	0.0324	0.1007
Long-run variance	0.0007	0.0017

Source: Author's experiment (2022)

Second, the output of the impact of biofuel consumption on EU economic growth for both group 1 and group 2 are presented in Table 20 that shows biofuel consumption is positively significant in group 1, higher income countries. In group 1, biofuel consumption is significant at 99% confidence interval indicating biofuel consumption highly promotes economic growth in higher economic groups. However, biofuel consumption is insignificant in group 2, comparatively lower income economies. This result is also acceptable, because in main model biofuel consumption is insignificant (see FMOLS – Consumption model). Thereby, the robustness confirms that biofuel consumption is positively significant in EU economies.

Table 20: Consumption model: Group 1 and Group 2

Variable	Group 1	Group 2
LnCAPITAL	0.3616***	0.3911***
	(0.0235)	0.0607
LnLABOUR	0.9961***	0.2722
	(0.0917)	0.1839
LnFINDEV	0.0067***	0.1020***
	(0.0222)	0.0312
LnBIOCON	0.0171***	0.0065
	(0.0039)	0.0051
R-squared	0.9985	0.9886
Adjusted R-squared	0.9984	0.9875
S.E. of regression	0.0202	0.0368
Durbin-Watson stat	1.1441	0.3623
Mean dependent var	7.4426	5.8301
S.D. dependent var	0.5012	0.3285
Sum squared resid	0.0318	0.1165
Long-run variance	0.0005	0.0019

Source: Author's experiment (2022)

Third, the output of the impact of both biofuel production and consumption on EU economic growth for both group 1 and group 2 are presented in Table 21, which shows biofuel production is insignificant in group 1 (moderately significant in group 1 in production model - Table 19). However, in group 2, biofuel production is significant at 99% confidence interval indicating biofuel production highly promotes economic growth in Group 2 countries. This study initially assumes biofuel production impacts on economy relatively lower economies. This output also supports the output of Table 19). Regarding the biofuel consumption that is significant in group 1 but insignificant in group 2 (similar to individual consumption model Table 21.

Table 21: Combined model: Group 1 and Group 2

Variable	Group 1	Group 2
LnCAPITAL	0.3572***	0.4191***
	(0.0243)	(0.0584)
LnLABOUR	0.9946***	0.0990
	(0.1087)	(0.1891)
LnFINDEV	0.0050***	0.0730**
	(0.0234)	(0.0310)
LnBIOPRO	0.0016	0.0291***
	(0.0044)	(0.0083)
LnBIOCON	0.0156***	-0.0087
	(0.0044)	(0.0060)
R-squared	0.9986	0.9901
Adjusted R-squared	0.9984	0.9890
S.E. of regression	0.0201	0.0345
Durbin-Watson stat	1.0987	0.4201
Mean dependent var	7.4426	5.8301
S.D. dependent var	0.5012	0.3285
Sum squared resid	0.0311	0.1013
Long-run variance	0.0005	0.0017

Source: Author's experiment (2022)

4.6. Panel granger causality tests

This study also experiments the panel granger causality of all the variables, GDP, capital formation, labour, financial development, biofuel production, and biofuel consumption. Table 22 presents the output of panel granger causality test, particularly the Stacked test (common coefficient), using samples from 2001 to 2019, and the number of lags is 2. According to Table 22, both capital formation and GDP have a direct and reverse causality relationship; however, capital formation causes GDP at a 90% confidence interval level. Labour and GDP also have both direct and reverse causality relationship; however, labour cause GDP at a 90% confidence interval level. The production of biofuels does not cause GDP; however, GDP significantly causes the production of biofuels. Financial development and GDP have both direct and reverse causality relationship. The consumption of biofuels does not cause GDP; however, GDP significantly causes the consumption of biofuels. Labour does not cause capital formation, but capital formation significantly causes labour. Biofuel production does not cause capital formation, but capital formation causes biofuel production. Financial development and capital formation have both direct and reverse causality relationship. However, financial development cause capital formation at a 90% confidence interval level. Biofuel consumption does not cause capital formation, but capital formation causes biofuel consumption. Biofuel production does not cause labour, but labour cause biofuel production. Financial development and labour have both direct and reverse causality relationship. Biofuel consumption does not cause labour, but labour causes biofuel consumption. The production of biofuels does not cause financial development; however, financial development significantly causes the production of biofuels. Biofuel production causes consumption, but biofuel production does not cause biofuel consumption. Biofuel consumption does not cause financial development; however, financial development significantly causes biofuel consumption. In conclusion, regarding the main relation of this study, GDP, financial development, biofuel production and consumption, none of the biofuels variable cause economic growth. However, economic growth and financial development significantly causes the production and consumption of biofuels.

Table 22: Panel Granger Causality Tests

Null Hypothesis:	**F-Statistic**	**Prob.**
Capital formation > GDP	2.7972*	0.0638
GDP > Capital formation	7.2953***	0.0009
Labour > GDP	2.7642*	0.0659
GDP > Labour	9.4430***	0.0001
Biofuel production > GDP	0.7575	0.4704
GDP > Biofuel production	6.7366***	0.0015
Financial development > GDP	6.1811***	0.0026
GDP > Financial development	26.8736***	0.0000
Biofuel consumption > GDP	1.1809	0.3096
GDP > Biofuel consumption	5.2148**	0.0064
Labour > Capital formation	1.2022	0.3031
Capital formation > Labour	5.5529***	0.0046
Biofuel production > Capital formation	0.0637	0.9383
Capital formation > Biofuel production	6.7163***	0.0016

Financial development > Capital formation	2.5612*	0.0802
Capital formation > Financial development	28.7656***	0.0000
Biofuel consumption > Capital formation	1.8394	0.1621
Capital formation > Biofuel consumption	5.2643**	0.0061
Biofuel production > Labour	2.3929*	0.0945
Labour > Biofuel production	6.5600***	0.0018
Financial development > Labour	8.5492***	0.0003
Labour > Financial development	15.2531***	0.0000
Biofuel consumption > Labour	0.7295	0.4837
Labour > Biofuel consumption	4.3554**	0.0143
Financial development > Biofuel production	13.2301***	0.0000
Biofuel production > Financial development	1.0328	0.3583
Biofuel consumption > Biofuel production	8.5865***	0.0003
Biofuel production > Biofuel consumption	1.5156	0.2227
Biofuel consumption > Financial development	1.7790	0.1720
Financial development > Biofuel consumption	7.2622***	0.0009

Source: Author’s explanation (2022)

Some other previous studies also support the key findings of this study. In the biofuel production context, this study finds economic expansion causes biofuel production. There are very few studies on biofuel production and economic growth relation. This study supports the previous literature on renewable energy production and economic growth relationship findings. Such as KAZAR & KAZAR (2014) show that economic expansion significantly causes renewable energy production in both high & middle-human development countries and the whole sample. DINÇ & AKDOĞAN (2019) also confirm that economic growth significantly causes renewable energy production in Turkey. In the context of biofuel consumption, this study finds that GDP causes biofuel consumption. Regarding this finding, some other study found that GDP cause energy consumption. Such as, LISE & MONTFORT (2007) find that GDP causes energy consumption in Turkey, MOZUMDER & MARATHE (2007) reveal that GDP causes energy consumption in Bangladesh. SALAMALIKI & VENETIS (2013) studies the G7 economy and found that GDP causes energy consumption. APERGIS & PAYNE (2010B) also confirm that GDP and gross capital formation significantly cause renewable energy consumption in Eurasian countries. There is one study AL-MULALI ET AL. (2016), which find bioethanol consumption also causes economic growth measured by GDP. However, our study doesn’t find a significant causal relationship between biofuel consumption to economic growth.

4.7. Nexus between biofuels, financial development, and economic growth

In previous experiments, this study only analysis the impact of economic proxies (capital and labour), financial development, biofuel production, and consumption on economic expansion. In this section, this study also experiments the nexus relationship between biofuels, financial development, and economic growth. The purpose of this nexus relationship is to explore the regression relationship in other perspectives. In regression 1 (Dependent variable is GDP): financial development and biofuel production significantly promote economic growth. This output supports the findings of SAIDI (2023) and WANG et al. (2021). However, biofuel consumption is insignificant here. This insignificance is consistent with the previous analysis.

In regression 2 (Dependent variable is financial development): the key finding is GDP and biofuel consumption positively promote financial development. This study implies that biofuel consumption promotes financial development through number of channels and mechanisms. For example, higher energy consumption is also indicating the industrial development, which is also usually assumed positively connected to financial development. This recommendation is also applicable for regression 3 (dependent variable is biofuel consumption). The findings from WANG et al. (2021) are similar in case of economic growth. This study suggests the implication of the findings in following way. Biofuel consumption can increase domestic credit to the private sector by stimulating investment in biofuel infrastructure, agricultural financing, technology research, and job creation, among other factors. Government incentives and policies, as well as export opportunities, can also indirectly impact credit availability.

In regression 4 where this shows financial development impact on biofuel consumption. The finding says financial development is positively significant. In this case, the output from WANG et al. (2021) supports this study output in the case of positive relation between financial development and renewable energy consumption. Output from regression 4 indicates financial development promotes the usage of biofuel consumption. This output has also support from EREN et al. (2019) that shows financial development significantly promotes the consumption of renewable energy.

In regression 3 (dependent variable is biofuel production): biofuel consumption and economic growth significantly boost the production of biofuel and overall biofuel industry. On the other hand, biofuel production is also boosting biofuel consumption (Regression 4). This output refers vice-versa relationship.

Table 23: Nexus between biofuels, financial development, and economic growth in EU

	Dependent variables			
Independent variables	**(1) LnGDP**	**(2) LnFINDEV**	**(3) LnBIOPRO**	**(4) LnBIOCON**
LnGDP		2.0861***	4.3028***	-2.4001**
		(0.2552)	(1.0287)	(1.2231)
LnFINDEV	0.2103***		-0.6417	1.5415***
	(0.0289)		(0.3695)	(0.3866)
LnBIOPRO	0.0417***	-0.0537		0.7914***
	(0.0088)	(0.0280)		(0.0821)
LnBIOCON	-0.0126	0.0829***	0.6424***	
	(0.0082)	(0.0230)	(0.0644)	

Source: Author’s explanation (2022)

Note: Regression 1 to 4: FMOLS, Here I show 99% and 95% significance, *** and ** refers 99% and 95% significant level.

4.8. Hypotheses evaluation

This study initially proposes five hypotheses to investigate the study research questions and objectives. The first hypothesis concerns the significant impact of biofuel production on EU economic growth. It was found that biofuel production is very important in terms of economic growth. A 1% growth in biofuel production surge in 0.0252% GDP growth (FMOLS) and 0.0234% GDP growth (DOLS) models. This result is fully consistent with *Hypothesis 1: Biofuel production has a significant positive impact on EU economic growth*. Therefore, I accept hypothesis 1. The second hypothesis concerns the significant impact of biofuel consumption on EU economic growth. It was found that the consumption of biofuels is very significant in the FMOLS and DOLS models. A 1% increase in biofuel consumption increases GDP by 0.0192% (FMOLS) and 0.0148% (DOLS) models. This result is fully consistent with *Hypothesis 2: Biofuel consumption has a significant positive impact on EU economic growth*. Therefore, I accept hypothesis 2. The third hypothesis involves the comparative impact of biofuel production over biofuel consumption on economic growth. It is found that biofuel production is highly significant in both FMOLS and DOLS model, whereas the consumption of biofuel is insignificant in FMOLS and DOLS model. Therefore, this study also accept hypothesis 3 that confirm biofuel production has a higher significant impact on EU economic growth compared to biofuel consumptions.

Considering the Hypothesis 4A & Hypothesis 4B, the production of biofuels does not cause GDP and financial development, thus, this outcome inconsistent with the *Hypothesis 4A: Biofuel production causes EU economic growth and financial development.* Thereby, I reject the hypothesis 4A. Furthermore, the study found that the consumption of biofuels does not cause GDP and financial development. This outcome is also not consistent with the *Hypothesis 4B: Biofuel consumption causes EU economic growth and financial development*. Thereby, I also reject *Hypothesis 4B*. Overall, Hypothesis 4 is rejected here based on the study findings.

Regarding the hypothesis 5, which states *biofuel production and consumption has positive impact on financial development, and vice versa.* This study finds biofuel consumption have positively significant impact on financial development. On the other hand, financial development is also positively impacts on biofuel consumption. However, financial development is not highly significant on biofuel production. Thereby, hypothesis 5 is also partially accepted

5. CONCLUSION AND POLICY IMPLICATIONS

5.1. Conclusion

This study investigated the impact of the production and consumption of biofuel energy (including both bioethanol and biodiesel production and consumption) on economic growth. Initially, European Union was selected as the research area. And later, 11 countries were considered for this study and the other countries were excluded due to the unavailability of biofuels data. The countries included in this study are Austria, Belgium, Germany, Spain, Finland, Italy, France, Netherlands, Portugal, Poland, and Sweden. Mainly, non-stationary panel data modelling such as panel unit root, panel cointegration test, FMOLS, DOLS, and panel causality test models are used to experiment with the aims using data covering from 2001 to 2019. Considering the economic growth of EU countries as dependent variable, this study finds that in separate model, the production of biofuels and the consumption of biofuels significantly impact on economic growth. However, the production of biofuel has greater impact than the consumption of biofuels.

In the combined model, both the production and consumption of biofuels used in a single model to shows impact on economic expansion. The consumption of biofuels was found to be insignificant, however, the production of biofuels has highly significant positive impact on EU economic growth. In addition, in the nexus relationship, biofuel consumption positively promotes financial development, and financial development is also significantly promoting the consumption of biofuel. In conclusion, bio-economy has noticeable significance in EU economic aspects. In all cases, financial development has significant impact on economic expansion. This study makes a significant contribution to the existing literature. The first contribution is findings showing the importance of biofuels (in terms of production and consumption) for economic growth in the EU. The research also shows that the production of biofuels should first emphasize the consumption of biofuels. The consumption of biofuels will only be effective if the development of biofuels is more evident. The study's contribution extends to showing the importance of biofuel production and consumption for other still-growing EU countries. Finally, this study contributes not only to the EU economics literature but also to global biofuel research.

5.2. Limitations of the study

The first limitation is the unavailability of biofuel consumption and production data of all EU countries; hence, only 11 countries' data is used in this experiment. Even if the 11 countries' data is available, there is no data available before 2001 for most of the countries. Also, among the selected countries that have available data, in some financial years, there was no value in the production and consumption of biofuel data, indicating no production and consumption of biofuel. For example, data available for Belgium from 2008 – 2019 and the Netherlands from 2004-2019).

5.3. Future research directions

This study assumes that biofuel will substantially impact the economy and other factors, including policies, management, technical progress, sustainability, and innovations. Therefore, this study recommends future research on a sustainable biofuel economy, with an emphasis on pressing global challenges such as SDG:1, SDG:2, SDG: 7, SDG:8, SDG:13, SDG:15, and SDG:17. In addition, research on producing cost-effective and technologically advanced biofuels needs more focus, therefore greatly lowering the negative influence on environmental quality. This study also suggests future research on more comprehensive study areas such as other regions (OECD, Africa, Asia, and other economic zones). Also, as this study only considers the economic aspect, the environmental aspect is missing here. This study suggests integrating biofuel production and consumption models into a single investigation to explore the environmental impact. Future research is important to emphasize policies that may promote the production and consumption of biofuels. Future research is also important in how to produce cost-effective biofuels compared to fossil fuels.

5.4. Policy implications

The implication of this study is that the findings of this research provide policymakers with a chance to emphasize the development of biofuels considering the economic growth perspective. This study contributes to rural and urban people with their systems for agricultural land displacement and food security, preventing micro-level impacts on specific households. This more comprehensive impartial research at the microeconomic level assists in understanding the individual level about the consequences on specific households. Due to the relatively convenient pricing of biofuels, investors should invest more in biofuel plants. The development of biofuel plants will ultimately increase the production of biofuels and reduce the dependence on fossil fuels. Besides, biodiesel is the best diesel fuel alternative for diesel engines, and biodiesel is better than gasoline and petroleum diesel because it is better for the environment. When there is less pollution, it costs less to protect the environment, which means there are more chances for the economy to grow. The policy suggestions should focus on getting people to use biofuels by making them cheaper. The implications are to support the provision of ethanol policies that are required to promote global commerce and boost capital development. These measures may not only directly impact economic growth but may also stimulate it by expanding the energy industry. For instance, increased capital formation leads to new investments, which are necessary to develop the nation's present ethanol distribution network. Also, this study implies that the government should encourage the development and use of advanced biofuels made from non-food crops, lignocellulosic feedstocks, residue streams or industrial waste that have little or no effect on land use. Tax policies should stay the same because they help pay for the high-tech biofuels industry. National governments should encourage the use of biofuel energy by giving tax breaks to companies that make and use biofuel energy. Finally, this research certainly says the implication for the related authorities' efforts to achieve sustainable economic development. It suggested to the policymakers to set policies that are supportive of sustainable energy to promote economic growth.

6. NOVEL FINDINGS AND CONTRIBUTIONS

The main key purpose of this study is to show the contribution of both production and consumption of biofuels to EU economic growth. Considering the key purpose of this study, I specified five questions that ultimately connect the contribution of this study. Considering the key questions, aims, and hypotheses of this study, the novel findings and contributions are mentioned in the following section.

1. *The first novel output:* I proved it with my research that the production of biofuels has a significant positive impact on economic growth in the EU. The output implies that the increasing and higher production and development of biofuels boost economic progress in the EU. This first contribution is aligned with the first research question, objective one, as well as hypothesis 1 of the study.
2. *The second novel output:* I verified that the consumption of biofuels significantly positively impacts economic growth in the EU. The output implies that the increasing and higher consumption and usage of biofuels boost economic progress in the EU. This second contribution is aligned with the second research question, objective two, as well as hypothesis 2 of the study.
3. *The third novel output:* Based on my research work I established that there is a comparative investigation of both production and consumption of biofuels' effects on the economic aspect of the EU. Thereby, this study contributes by showing that when comparing production and consumption in individual models, the impact of biofuel production on economic growth is relatively greater than that of biofuel consumption. This third contribution is aligned with the third research question, objective three, as well as hypothesis 3 of the study.
4. *The fourth novel output:* I investigated both production and consumption variable in a single regression and based on it in this model, including both production and consumption variables, the production of biofuels significantly and positively impacts on economic growth. On the other hand, the consumption of biofuels is slightly significant on the economic expansion. Therefore, regarding the relative significance of biofuel production and consumption in an integrated model, biofuel production has a relatively more significant and higher impact on economic growth compared to the consumption of biofuels. This fourth contribution is also aligned with the third research question, objective three, as well as hypothesis 3 of the study.

5. *The fifth novel output:* Based on my research work I verified that there is a causal relationship among the variables. Notably, GDP causes both the production of biofuels and the consumption of biofuels. This contribution indicates the higher the GDP, on in other words, the more GDP expansion support higher production of biofuels as well as higher consumption of biofuels. On the other hand, none of the two variables causes GDP. Indicating production of biofuels and the consumption of biofuels do not cause EU GDP.
6. *The sixth novel output:* I verified that biofuel consumption has positively significant impact on financial development. On the other hand, financial development also positively impacts on biofuel consumption.

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List of publications related to the dissertation

Articles, studies (3)

1. **Hasan, M. M.**, Abedin, M. Z., Amin, M. B., Nekmahmud, M., Oláh, J.: Sustainable biofuel economy: A mapping through bibliometric research.
   Journal of Environmental Management. 336, 1-17, 2023. ISSN: 0301-4797.
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2. **Hasan, M. M.**: Energy economic expansion with production and consumption in BRICS countries.
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   DOI: http://dx.doi.org/10.1016/j.esr.2022.101005
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3. **Hasan, M. M.**, Oláh, J.: Present landscape of biofuel production and consumption in European Union.
   Journal of Central European Green Innovation. 10 (2), 37-50, 2022. EISSN: 2064-3004.
   DOI: http://dx.doi.org/10.33038/jcegi.3472

Conference presentations (1)

4. **Hasan, M. M.**, Amin, M. B., Nekmahmud, M.: Mapping the potential of a sustainable biofuel economy through bibliometric research.
   In: European Union Policies International Thematic Conference : Book of Abstracts. Ed.: Kiss Rebeka, Doktoranduszok Országos Szövetsége, Budapest, 20, 2022. ISBN: 9786156457080

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List of other publications

Articles, studies (7)

5. Khaing Soe, A., Gavurova, B., Oláh, J., **Hasan, M. M.**: Does auditor's attributes impact on professional judgement in financial audit?: empirical evidence from Myanmar Sai.
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7. Wang, C., Zhang, B., Oláh, J., **Hasan, M. M.**: Factors Influencing the Quality of Life of Empty Nesters: empirical Evidence from Southwest China.
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11. **Hasan, M. M.**, Popp, J., Oláh, J.: Current landscape and influence of big data on finance.
    Journal of Big Data. 7 (21), 1-17, 2020. EISSN: 2196-1115.
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19 June, 2023

DECLARATION

I undersigned (name: **Mohammad Morshadul Hasan**, date of birth: 1992. 03 .25) declare under penalty of perjury and certify with my signature that the dissertation I submitted in order to obtain doctoral (PhD) degree is entirely my own work.

Furthermore, I declare the following:

- I examined the Code of the Károly Ihrig Doctoral School of Management and Business Administration and I acknowledge the points laid down in the code as mandatory;
- I handled the technical literature sources used in my dissertation fairly and I conformed to the provisions and stipulations related to the dissertation;
- I indicated the original source of other authors' unpublished thoughts and data in the references section in a complete and correct way in consideration of the prevailing copyright protection rules;
- No dissertation which is fully or partly identical to the present dissertation was submitted to any other university or doctoral school for the purpose of obtaining a PhD degree.

Debrecen, 2022 December 12

Morshadul Hasan

Mohammad Morshadul Hasan

signature

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APPENDIX

In this section, I also attach the questions that were asked by reviewers in the review stage.

- **Question 1: *Which sectors would be the winners of biofuels utilisation in the economy?***

Answer: The economic beneficiaries of biofuel use will rely on several variables, including governmental regulations, technical developments, and market forces. However, it is widely anticipated that several industries would gain from the greater use of biofuels. From my understanding, the three sectors are energy***, transportation, and environmental sustainability***.

Regarding the energy sector, the greater use of biofuels in the energy mix may positively affect the energy industry, particularly businesses engaged in renewable energy. Biofuels provide more choices for producing clean energy since they may be utilised to produce electricity, heat, and steam.

Regarding the transport sector, liquid fuel use in the transportation sector is high, and using biofuels in automobiles can help cut greenhouse gas emissions. The development of biofuel-compatible engines and related industries, as well as the production and distribution of biofuels, might prosper. Regarding the environmental sustainability sector, as businesses work to use biofuels to satisfy renewable energy and emissions reduction targets, demand for environmental consultancy, carbon offset services, and sustainability evaluations may rise.

However, the utilisation of biofuel is not limited to these three sectors. Bioeconomy also promotes the agriculture sector by promoting the production technology and waste management sectors by utilising converted waste to biofuels. Biofuel also promotes rural development, such as rural communities' benefit from job creation and increased economic activity associated with the biofuel industry.

To conclude, it's crucial to remember that several variables, such as governmental regulations, technical developments, and affordable feedstocks, might affect whether biofuels are successful in a particular industry. The environmental sustainability of biofuels may also be a contentious issue because the development of these fuels must be balanced with considerations for biodiversity, water resources, and land usage.

- ***Question 2: What would be the optimal ratio of biofuels in the economy comparing fossil minerals?***

Answer: Determining the ideal ratio of fossil fuels to biofuels in the economy is a difficult undertaking that depends on a number of variables, including social, economic, technological, and environmental issues. There is no universally applicable solution to this problem since the appropriate ratio might differ from one country or area to another and can alter over time as conditions and technological advancements change. When determining the ideal ratio of fossil fuels to biofuels, the following factors should be taken into account:

- The ideal ratio must align with regional or national goals for cutting carbon emissions.
- The amount and sustainability of feedstock sources, as well as the accessibility of feedstock, will all affect the ideal proportion.
- The optimum ratio should follow developments in technology. The ideal ratio may change as biofuel production technology advances.
- Energy security should be in line with the ideal ratio. Enhancing energy security may be possible through lowering reliance on imported fossil fuels.
- The ideal ratio should be compatible with the viability of the business. One important consideration is the price of biofuel production compared to fossil fuels. The ideal ratio needs to find a balance between economic viability and environmental objectives.

To conclude, the best mix of biofuels and fossil fuels for the economy depends on the situation and is dynamic and affected by a range of social, economic, technological, and environmental issues. Rigorous planning, constant assessment, and adaptive policies are necessary to fulfil energy and environmental goals.

- ***Question 3: Is there any influence of financial development in EU bioeconomy?***

<u>Answer:</u> This question helped me explore financial development's impact on EU bioeconomy. To address this question, I explore the literature and pick a new variable, 'financial development', that refers to the domestic credit to the private sector.

- In the production model, integrating with biofuel production and other economic proxies, financial development promotes EU economic expansion (coefficient is 0.0606, significant at 99% CI level).
- In the consumption model, integrating with biofuel consumption and other economic proxies, financial development promotes EU economic expansion (coefficient is 0.0579, significant at 99% CI level).
- In the combined model, integrating with biofuel production, consumption, and other economic proxies, financial development promotes EU economic expansion (coefficient is 0.0604, significant at 99% CI level).
- The robustness test supports financial development and is significant in promoting economic growth.
- Finally, this study examines the nexus relationship and finds that biofuel consumption promotes financial development and vice versa through several channels and mechanisms. For example, higher energy consumption also indicate industrial development, which is also usually assumed to be positively connected to financial development.

This study finds that financial development is also significant and positively related to economic development, biofuel production, and consumption.

Table 24: Details output of Unit Root Test

Variables	lm	p-value	ADF - Fisher Chi-square	p-value
LnGDP	2.1482	0.9842	9.2189	0.9921
ΔLnGDP	-4.7964	0.0000	65.5402	0.0000
LnCAPITAL	0.2639	0.6041	16.5662	0.7868
ΔLnCAPITAL	-7.1084	0.0000	93.8294	0.0000
LnLABOUR	0.8011	0.7885	22.2541	0.4448
ΔLnLABOUR	-4.2816	0.0000	59.5353	0.0000
LnFINDEV	-2.8163	0.0024	47.3372	0.0013
ΔLnFINDEV	-1.9311	0.0267	34.0323	0.0488
LnBIOFPRO	-2.5258	0.0058	41.2788	0.0076
ΔLnBIOFPRO	-3.6859	0.0001	52.1074	0.0003
LnBIOFCON	-1.7345	0.0414	29.9191	0.1204
ΔLnBIOFCON	-1.5210	0.0641	31.5921	0.0846

Source: Author's experiment (2022)

Table 25: Details output of Pedroni Residual Cointegration Test (production model)

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	**Prob.**	**Weighted Statistic**	**Prob.**
v-Statistic	1.6487	0.0496	0.1425	0.4434
rho-Statistic	0.5753	0.7174	1.1618	0.8773
PP-Statistic	-2.6979	0.0035	-1.8024	0.0357
ADF-Statistic	-2.8350	0.0023	-2.1457	0.0159
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group rho-Statistic	2.4519	0.9929		
Group PP-Statistic	-4.1303	0.0000		
Group ADF-Statistic	-3.9025	0.0000		

Source: Author's experiment (2022)

Table 26: Details output of Kao Residual Cointegration Test (production model)

Tests	t-Statistic	Prob.
ADF	-2.4120	0.0079
Residual variance	0.0002	

HAC variance	0.0003	

Source: Author's experiment (2022)

Table 27: Details output of FMOLS (production model)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.3827	0.0297	12.8888	0.0000
LnLABOUR	0.4013	0.1138	3.5252	0.0005
LnFINDEV	0.0606	0.0187	3.2435	0.0014
LnBIOFPRO	0.0185	0.0044	4.2238	0.0000
R-squared	0.9988	Mean dependent var		6.5967
Adjusted R-squared	0.9987	S.D. dependent var		0.9095
S.E. of regression	0.0324	Sum squared residual		0.1762
Durbin-Watson stat	0.3376	Long-run variance		0.0016

Source: Author's experiment (2022)

Table 28: Details output of DOLS (production model)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.4386	0.0380	11.5548	0.0000
LnLABOUR	0.1182	0.1277	0.9256	0.3581
LnFINDEV	0.0406	0.0240	1.6942	0.0951
LnBIOFPRO	0.0272	0.0070	3.8794	0.0002
R-squared	0.9999	**Mean dependent var**		6.5865
Adjusted R-squared	0.9999	**S.D. dependent var**		0.9109
S.E. of regression	0.0066	**Sum squared residual**		0.0028
Long-run variance	0.0000			

Source: Author's experiment (2022)

Table 29: Details output of Pedroni Residual Cointegration Test (consumption model)

Alternative hypothesis: common AR coefficient (within-dimension)				
Statistics	**Statistic**	**Prob.**	**Weighted Statistic**	**Prob.**
v-Statistic	1.6453	0.0500	-0.3492	0.6365
rho-Statistic	0.8438	0.8006	1.2424	0.8930
PP-Statistic	-5.3723	0.0000	-2.5325	0.0057

ADF-Statistic	-5.8389	0.0000	-3.7481	0.0001
Alternative hypothesis: individual AR coefficient (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	2.6402	0.9959		
Group PP-Statistic	-4.8963	0.0000		
Group ADF-Statistic	-5.2594	0.0000		

Source: Author's experiment (2022)

Table 30:Details output of Kao Residual Cointegration Test (consumption model)

Statistics	**t-Statistic**	**Prob.**
ADF	-2.5093	0.0060
Residual variance	0.0002	
HAC variance	0.0003	

Source: Author's experiment (2022)

Table 31: Details output of FMOLS (consumption model)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.4010	0.0313	12.8256	0.0000
LnLABOUR	0.4879	0.1084	4.4988	0.0000
LnFINDEV	0.0579	0.0206	2.8137	0.0055
LnBIOFCON	0.0115	0.0039	2.9358	0.0038
R-squared	0.9986	**Mean dependent var**		6.5967
Adjusted R-squared	0.9984	**S.D. dependent var**		0.9095
S.E. of regression	0.0345	**Sum squared residual**		0.2005
Durbin-Watson stat	0.3930	**Long-run variance**		0.0017

Source: Author's experiment (2022)

Table 32: Details output of DOLS (consumption model)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.4561	0.0474	9.6276	0.0000
LnLABOUR	0.1220	0.2107	0.5792	0.5645
LnFINDEV	0.0697	0.0488	1.4295	0.1577
LnBIOFCON	0.0178	0.0076	2.3435	0.0222
R-squared	0.9999	**Mean dependent var**		6.5865

Adjusted R-squared	0.9997	**S.D. dependent var**	0.9109
S.E. of regression	0.0070	**Sum squared residual**	0.0032
Long-run variance	0.0000		

Source: Author's experiment (2022)

Table 33:Details output of Pedroni Residual Cointegration Test (combined model)

Alternative hypothesis: common AR coefs. (within-dimension)				
Tests	**Statistic**	**Prob.**	**Weighted Statistic**	**Prob.**
v-Statistic	0.5757	0.2824	-1.0028	0.8420
rho-Statistic	1.7054	0.9559	2.4776	0.9934
PP-Statistic	-3.3448	0.0004	-0.9843	0.1625
ADF-Statistic	-3.1080	0.0009	-1.0402	0.1491
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group rho-Statistic	3.7760	0.9999		
Group PP-Statistic	-3.4890	0.0002		
Group ADF-Statistic	-2.1790	0.0147		

Source: Author's experiment (2022)

Table 34: Details output of Kao Residual Cointegration Test (both model)

ADF	**t-Statistic**	**Prob.**
	-2.4415	0.0073
Residual variance	0.0002	
HAC variance	0.0003	

Source: Author's experiment (2022)

Table 35: Details output of FMOLS (combined model)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.3834	0.0304	12.6242	0.0000
LnLABOUR	0.3939	0.1146	3.4367	0.0007
LnFINDEV	0.0604	0.0199	3.0274	0.0029
LnBIOFPRO	0.0181	0.0052	3.4606	0.0007
LnBIOFCON	0.0004	0.0045	0.0778	0.9381
R-squared	0.9987	**Mean dependent var**		6.5967
Adjusted R-squared	0.9986	**S.D. dependent var**		0.9095

S.E. of regression	0.0325	**Sum squared residual**	0.1764
Durbin-Watson stat	0.3375	**Long-run variance**	0.0016

Source: Author's experiment (2022)

Table 36: Details output of DOLS (combined model)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.3612	0.0346	10.4418	0.0000
LnLABOUR	0.4640	0.1207	3.8455	0.0002
LnFINDEV	0.0580	0.0223	2.6016	0.0101
LnBIOFPRO	0.0184	0.0058	3.1989	0.0016
LnBIOFCON	0.0007	0.0052	0.1424	0.8869
R-squared	0.9999	**Mean dependent var**		6.5865
Adjusted R-squared	0.9998	**S.D. dependent var**		0.9109
S.E. of regression	0.0326	**Sum squared residual**		0.1892
Long-run variance	0.0023			

Source: Author's experiment (2022)

Table 37: Details output of Group 1 - production model

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.3399	0.0268	12.6912	0.0000
LnLABOUR	1.0492	0.1203	8.7194	0.0000
LnFINDEV	0.0054	0.0246	-3.8794	0.0002
LnBIOFPRO	0.0088	0.0043	2.0291	0.0459
R-squared	0.9985	**Mean dependent var**		7.4426
Adjusted R-squared	0.9983	**S.D. dependent var**		0.5012
S.E. of regression	0.0204	**Sum squared resid**		0.0324
Durbin-Watson stat	0.6795	**Long-run variance**		0.0007

Source: Author's experiment (2022)

Table 38: Details output of Group 1 - consumption model

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.3616	0.0235	15.4176	0.0000
LnLABOUR	0.9961	0.0917	10.8656	0.0000
LnFINDEV	0.0067	0.0222	-5.7155	0.0000

LnBIOFCON	0.0171	0.0039	4.4501	0.0000
R-squared	0.9985	**Mean dependent var**		7.4426
Adjusted R-squared	0.9984	**S.D. dependent var**		0.5012
S.E. of regression	0.0202	**Sum squared resid**		0.0318
Durbin-Watson stat	1.1441	**Long-run variance**		0.0005

Source: Author's experiment (2022)

Table 39: Details output of Group 1 - combined model

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.3572	0.0243	14.6866	0.0000
LnLABOUR	0.9946	0.1087	9.1533	0.0000
LnFINDEV	0.0050	0.0234	-5.3541	0.0000
LnBIOPRO	0.0016	0.0044	0.3641	0.7167
LnBIOCON	0.0156	0.0044	3.5298	0.0007
R-squared	0.9986	**Mean dependent var**		7.4426
Adjusted R-squared	0.9984	**S.D. dependent var**		0.5012
S.E. of regression	0.0201	**Sum squared resid**		0.0311
Durbin-Watson stat	1.0987	**Long-run variance**		0.0005

Source: Author's experiment (2022)

Table 40: Details output of Group 2 - production model

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnCAPITAL	0.4361	0.0583	7.4780	0.0000
LnLABOUR	0.0824	0.1900	0.4338	0.6655
LnFINDEV	0.0612	0.0305	2.0053	0.0481
LnBIOPRO	0.0220	0.0067	3.2769	0.0015
R-squared	0.9902	**Mean dependent var**		5.8301
Adjusted R-squared	0.9892	**S.D. dependent var**		0.3285
S.E. of regression	0.0342	**Sum squared resid**		0.1007
Durbin-Watson stat	0.4190	**Long-run variance**		0.0017

Source: Author's experiment (2022)

Table 41: Details output of Group 2 - consumption model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnCAPITAL	0.3911	0.0607	6.4454	0.0000
LnLABOUR	0.2722	0.1839	1.4803	0.1424
LnFINDEV	0.1020	0.0312	3.2729	0.0015
LnBIOCON	0.0065	0.0051	1.2630	0.2100
R-squared	0.9886	**Mean dependent var**		5.8301
Adjusted R-squared	0.9875	**S.D. dependent var**		0.3285
S.E. of regression	0.0368	**Sum squared resid**		0.1165
Durbin-Watson stat	0.3623	**Long-run variance**		0.0019

Source: Author’s experiment (2022)

Table 42: Details output of Group 2 - combined model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnCAPITAL	0.4191	0.0584	7.1725	0.0000
LnLABOUR	0.0990	0.1891	0.5237	0.6018
LNFINDEV	0.0730	0.0310	2.3534	0.0209
LnBIOPRO	0.0291	0.0083	3.5194	0.0007
LnBIOCON	-0.0087	0.0060	-1.4445	0.1523
R-squared	0.9901	**Mean dependent var**		5.8301
Adjusted R-squared	0.9890	**S.D. dependent var**		0.3285
S.E. of regression	0.0345	**Sum squared resid**		0.1013
Durbin-Watson stat	0.4201	**Long-run variance**		0.0017

Source: Author’s experiment (2022)

Table 43: Nexus regression 1 (GDP dependent)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnFINDEV	0.2103	0.0289	7.2717	0.0000
LnBIOPRO	0.0417	0.0088	4.7269	0.0000
LnBIOCON	-0.0126	0.0082	-1.5357	0.1265
R-squared	0.9968	**Mean dependent var**		6.5967
Adjusted R-squared	0.9966	**S.D. dependent var**		0.9095
S.E. of regression	0.0532	**Sum squared resid**		0.4787

Durbin-Watson stat	0.3335	**Long-run variance**	0.0056

Source: Author's experiment (2022)

Table 44: Nexus regression 2 (Financial development dependent)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnGDP	2.0861	0.2552	8.1746	0.0000
LnBIOPRO	-0.0537	0.0280	-1.9240	0.0560
LnBIOCON	0.0829	0.0230	3.6111	0.0004
R-squared	0.9770	**Mean dependent var**		6.4744
Adjusted R-squared	0.9752	**S.D. dependent var**		1.0328
S.E. of regression	0.1627	**Sum squared resid**		4.4716
Durbin-Watson stat	0.3167	**Long-run variance**		0.0476

Source: Author's experiment (2022)

Table 45: Nexus regression 3 (Biofuel production dependent)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnGDP	4.3028	1.0287	4.1827	0.0000
LnFINDEV	-0.6417	0.3695	-1.7369	0.0842
LnBIOCON	0.6424	0.0644	9.9808	0.0000
R-squared	0.8003	**Mean dependent var**		2.2415
Adjusted R-squared	0.7850	**S.D. dependent var**		1.3603
S.E. of regression	0.6308	**Sum squared resid**		67.2430
Durbin-Watson stat	0.9375	**Long-run variance**		0.5545

Source: Author's experiment (2022)

Table 46: Nexus regression 4 (Biofuel consumption dependent)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnGDP	-2.4001	1.2231	-1.9631	0.0513
LnFINDEV	1.5415	0.3866	3.9871	0.0001
LnBIOPRO	0.7914	0.0821	9.6444	0.0000
R-squared	0.7769	**Mean dependent var**		2.2558
Adjusted R-squared	0.7598	**S.D. dependent var**		1.4845
S.E. of regression	0.7276	**Sum squared resid**		89.4602
Durbin-Watson stat	1.0510	**Long-run variance**		0.6608

Source: Author’s experiment (2022)

Table 47: Extended list of most cited documents

Paper	TC	TCP	NTC	DOI	Journal
CHERUBINI F, 2009	659	47.07	20.65	10.1016/j.resconrec.2009.03.013	RESOUR CONSERV RECYCL
D'AMATO D, 2017	430	71.67	16.19	10.1016/j.jclepro.2017.09.053	J CLEAN PROD
BÖRJESSON P, 2011	254	21.17	15.14	10.1016/j.jclepro.2010.01.001	J CLEAN PROD
RAHEEM A, 2018	238	47.60	10.68	10.1016/j.jclepro.2018.01.125	J CLEAN PROD
FAROOQ M, 2013	227	22.70	8.98	10.1016/j.jclepro.2013.06.015	J CLEAN PROD
HUANG Y, 2010	221	17.00	8.10	10.1016/j.tre.2010.03.002	TRANSP RES PART E LOGIST TRANSP REV
STEGMANN P, 2020	200	66.67	11.59	10.1016/j.rcrx.2019.100029	RESOURCES, CONSERVATION AND RECYCLING: X
CUELLAR-BERMUDEZ SP, 2015	199	24.88	10.64	10.1016/j.jclepro.2014.03.034	J CLEAN PROD
BIRCH K, 2013	187	18.70	7.40	10.1177/0162243912442398	SCI TECHNOL HUM VALUES
LIEW WH, 2014	185	20.56	6.63	10.1016/j.jclepro.2014.01.006	J CLEAN PROD
SUURS RAA, 2009	180	12.86	5.64	10.1016/j.techfore.2009.03.002	TECHNOL FORECAST SOC CHANGE
BIRCH K, 2017	180	30.00	6.78	10.1177/0162243916661633	SCI TECHNOL HUM VALUES

COSTANTINI V, 2015	179	22.38	9.57	10.1016/j.respol.2014.12.011	RES POLICY
CHEN CW, 2012	178	16.18	6.08	10.1016/j.tre.2011.08.004	TRANSP RES PART E LOGIST TRANSP REV
CHUAH LF, 2017,	173	28.83	6.51	10.1016/j.jclepro.2016.05.017	J CLEAN PROD-a
SARAVANAN AP, 2018	169	33.80	7.58	10.1016/j.jclepro.2018.05.033	J CLEAN PROD
ZILBERMAN D, 2013	169	16.90	6.69	10.1093/ajae/aas037	AM J AGRIC ECON
BANSE M, 2008	169	11.27	17.81	10.1093/erae/jbn023	EUR REV AGRIC ECON
DE GORTER H, 2010	165	12.69	6.05	10.1093/aepp/ppp010	APPL ECON PERSPECT POLICY
TEO SH, 2019	161	40.25	8.57	10.1016/j.jclepro.2018.10.107	J CLEAN PROD
BANERJEE A, 2009	154	11.00	4.83	10.1016/j.resconrec.2009.04.003	RESOUR CONSERV RECYCL
SERRA T, 2013	152	15.20	6.02	10.1016/j.eneco.2013.02.014	ENERGY ECON
ZHONG L, 2020	150	50.00	8.69	10.1016/j.ijbiomac.2020.02.258	INT J BIOL MACROMOL
ONG HC, 2019	146	36.50	7.77	10.1016/j.jclepro.2019.02.048	J CLEAN PROD
DE GORTER H, 2009	143	10.21	4.48	10.1111/j.1467-8276.2009.01275.x	AM J AGRIC ECON
MORAIS S, 2010	140	10.77	5.13	10.1016/j.jclepro.2010.04.014	J CLEAN PROD
ROSEGRANT MW, 2008	138	9.20	14.54	10.1111/j.1467-9353.2008.00424.x	REV AGRIC ECON
SANJID A, 2014	137	15.22	4.91	10.1016/j.jclepro.2013.09.026	J CLEAN PROD

ARIZA-MONTOBBIO P, 2010	136	10.46	4.98	10.1016/j.ecolecon.2010.05.011	ECOL ECON
HERTEL TW, 2010	134	10.31	4.91	10.5547/ISSN0195-6574-EJ-Vol31-No1-4	ENERGY J
CAVALETT O, 2010	132	10.15	4.84	10.1016/j.jclepro.2009.09.008	J CLEAN PROD
GURGEL A, 2007	131	8.19	25.71	10.2202/1542-0485.1202	J AGRIC FOOD IND ORGAN
MACOMBE C, 2013	130	13.00	5.14	10.1016/j.jclepro.2013.03.026	J CLEAN PROD
RIZWANUL FATTAH IM, 2020	129	43.00	7.47	10.3389/fenrg.2020.00101	FRONT ENERGY RES
KEENEY R, 2009	128	9.14	4.01	10.1111/j.1467-8276.2009.01308.x	AM J AGRIC ECON
BÓRAWSKI P, 2019	127	31.75	6.76	10.1016/j.jclepro.2019.04.242	J CLEAN PROD
RAMCILOVIC-SUOMINEN S, 2018	127	25.40	5.70	10.1016/j.jclepro.2016.12.157	J CLEAN PROD
HARDING KG, 2008	125	8.33	13.17	10.1016/j.jclepro.2007.07.003	J CLEAN PROD
MOAZENI F, 2019	122	30.50	6.49	10.1016/j.jclepro.2019.01.181	J CLEAN PROD
AITKEN D, 2014	120	13.33	4.30	10.1016/j.jclepro.2014.03.080	J CLEAN PROD
HALL J, 2009	115	8.21	3.60	10.1016/j.jclepro.2009.01.003	J CLEAN PROD
AHMED W, 2018	115	23.00	5.16	10.1016/j.jclepro.2018.02.289	J CLEAN PROD
D'AMATO D, 2020	114	38.00	6.61	10.1016/j.forpol.2018.12.004	FOR POLICY ECON

BABAZADEH R, 2017	112	18.67	4.22	10.1016/j.omega.2015.12.010	OMEGA
NANAKI EA, 2012	111	10.09	3.79	10.1016/j.jclepro.2011.07.026	J CLEAN PROD
LEVIDOW L, 2013	110	11.00	4.35	10.1177/0162243912438143	SCI TECHNOL HUM VALUES
DHINESH B, 2018	109	21.80	4.89	10.1016/j.jclepro.2018.06.002	J CLEAN PROD
SILALERTRUKSA T, 2012	108	9.82	3.69	10.1016/j.jclepro.2011.07.022	J CLEAN PROD
GIAMPIETRO M, 2019	107	26.75	5.69	10.1016/j.ecolecon.2019.05.001	ECOL ECON
HAYYAN A, 2014	104	11.56	3.73	10.1016/j.jclepro.2013.08.031	J CLEAN PROD
KIWJAROUN C, 2009	103	7.36	3.23	10.1016/j.jclepro.2008.03.011	J CLEAN PROD
KRISTOUFEK L, 2012	100	9.09	3.41	10.1016/j.eneco.2012.06.016	ENERGY ECON

Source: Author's experiment (TC – Total Citation, TCP – Total Citation per year, NTC – Normalized TC)

Table 48: Extended list of most relevant words

Terms	**Frequency**	**Terms**	**Frequency**
Biofuel/Biofuel	582	Life Cycle Assessment (LCA)	58
Biodiesel	389	Investments	55
Biofuels	319	Esters	54
Biofuel	263	United States	54
Ethanol	248	Decision Making	53
Sustainable Development	183	Sustainability	53
Biomass	177	Renewable Resource	51
Biodiesel Production	142	Bio-Ethanol Production	50
Fossil Fuels	137	Article	49
Life Cycle	136	Microorganisms	49

Bioethanol	134	Catalysts	48
Greenhouse Gases	117	Fermentation	47
Environmental Impact	111	Economic And Social Effects	46
Costs	101	Agriculture	44
Forestry	92	Energy Utilization	44
Biofuel Production	86	Alternative Energy	43
Feedstocks	86	European Union	43
Economics	82	Methanol	42
Fatty Acids	80	Crops	40
Climate Change	75	Palm Oil	40
Gas Emissions	75	Environmental Management	39
Oils And Fats	74	Fuels	39
Land Use	73	Refining	39
Energy Policy	71	Synthetic Fuels	39
Transesterification	71	Biotechnology	38
Diesel Engines	70	Diesel Fuels	38
Algae	69	Emission Control	38
Economic Analysis	69	Molar Ratio	38
Carbon Dioxide	68	Glycine Max	35
Commerce	64	Lignin	35
Carbon	63	Catalysis	34
Global Warming	63	Cellulose	34
Zea Mays	63	Esterification	34
Bioeconomy	60	Blending	33
Supply Chains	60	Energy Market	33

Source: Author's experiment

Table 49: Extended list of country scientific production

Region	**Frequency**	**Region**	**Frequency**
USA	622	POLAND	36
INDIA	345	DENMARK	34
CHINA	275	CZECH REPUBLIC	33

BRAZIL	216	SOUTH AFRICA	33
GERMANY	189	JAPAN	30
MALAYSIA	155	ROMANIA	29
ITALY	153	UKRAINE	29
FINLAND	117	NORWAY	28
UK	113	AUSTRIA	27
SWEDEN	97	EGYPT	25
AUSTRALIA	96	NIGERIA	25
INDONESIA	95	BELGIUM	24
NETHERLANDS	95	PHILIPPINES	23
CANADA	94	SWITZERLAND	21
IRAN	92	NEW ZEALAND	20
SPAIN	90	IRELAND	19
FRANCE	89	TURKEY	17
SOUTH KOREA	89	CHILE	13
THAILAND	75	HUNGARY	13
GREECE	57	LITHUANIA	12
PORTUGAL	46	ARGENTINA	9
PAKISTAN	43	BANGLADESH	9
MEXICO	40	KAZAKHSTAN	9
COLOMBIA	39	SLOVAKIA	8
SAUDI ARABIA	37	SERBIA	7

Source: Author's experiment

Table 50: Extended list of primary source journals

Sources	**Articles**
Journal of Cleaner Production	518
Fuels and Lubes International	107
Frontiers in Energy Research	64
Petroleum Review	55
Forest Policy and Economics	45
Energy Economics	40

Resources, Conservation and Recycling	31
International Journal of Technology	29
Agbioforum	27
Environment, Development and Sustainability	26
Ecological Economics	25
American Journal of Agricultural Economics	24
International Journal of Scientific and Technology Research	24
Petroleum Economist	24
International Journal of Biological Macromolecules	23
Agricultural Economics (United Kingdom)	16
The Law and Policy of Biofuels	15
International Journal of Energy Economics and Policy	14
Technological Forecasting and Social Change	14
Bio-Based and Applied Economics	13
Clean Technologies and Environmental Policy	13
Applied Economic Perspectives and Policy	12
Advanced Biofuels: Applications, Technologies and Environmental Sustainability	11
Economic Complexity and Evolution	11

Source: Author’s experiment