Image: Coffee grounds [1]

The Impact of bioenergy on EU energy security

A comprehensive analysis

Anuj Sharma
4375505

Delft University of Technology

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By

Anuj Sharma

4375505

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Thesis supervisor: Dr. D.J. (Daniel) Scholten, TU Delft

Thesis Committee: Prof.dr. R.W. (Rolf) Künneke, TU Delft

Thesis Committee: Dr. L.M. (Linda) Kamp, TU Delft

TU Delft — Delft University of Technology

Preface and acknowledgments

Bioenergy came across as a very intriguing subject to me when I had done a course on it as part of my SET (Sustainable Energy Technology) masters syllabus. It touched upon many technical aspects of bioenergy in Europe. Given, the Netherlands has also a big and active bioenergy sector, I wanted to contribute something in this field and wanted to do research on bioenergy under the faculty of TBM at TU Delft. When I got an opportunity to choose from all other forms of renewable energies for my master thesis, I chose bioenergy without hesitation. It is a challenging topic mainly on account of its vast and wide definition, scope and characteristics. And to combine it with energy security made it even more challenging for me. Unlike solar energy or wind energy, this was not a straight forward topic, this is what I liked about it. There was, and is, so much scope to formulate your own study and research.

For the most part, I had to deal with the 'abstractness' of this theme. It took me a long time before I got my head around it and a big credit goes to my thesis supervisor, Dr. Daniel Scholten, who guided me throughout the process. I have made colossal mistakes, but it has given me a different and new way of thinking. Plus, I have now a huge log of errors, which I would never like to repeat. It still remains a tricky topic for me but I feel confident that I can proceed with further research into this field. In fact, I would very much like to do it if an opportunity presents itself to me.

At the outset, I would like to convey my deepest gratitude to Dr. Scholten, for keeping infinite patience with me and guiding me throughout the thesis. His feedback has been invaluable and been a big driving force in trying to finish my thesis. I have received constant encouragement and feedback which got me through difficult times. I should and could have done better, I am sorry.

I am blessed to receive constant support from my family and friends, who continue to believe in me. I earnestly hope that this experience propels me forward in my life, as there are many lessons to be learnt from this journey. I like to thank Delft University of technology for giving me an opportunity to experience how education can be and should be. As a result, I have gained a new analytical approach to thinking and reasoning.

It took me a long time to finish my thesis, but if continue to work hard, this would be remembered as one of the better phases in my professional life as I have had so much to learn and most importantly, I got a chance to improve my attitude towards challenges and setbacks. I understand this is only the beginning, and much tougher challenges lie ahead. For all of this, I am immensely thankful and express my gratitude for the opportunity that I have received.

Last but not least, I would like to thank Dr. Linda Kamp, Prof.dr. R.W. (Rolf) Künneke, the thesis committee, and my academic counsellor, Mrs. Leonie Boortman, for their kind help.

Anuj Sharma

Executive Summary

At the start of this millennium, bioenergy entered the domains of public and private sectors, and biofuels were hailed as the panacea for all energy problems. However, in 2019, things look different. Public opinion for bioenergy has mostly turned negative and pessimistic. Despite the potential, algae and other 2nd generation biofuels have been underwhelming in their productivity and costs. At present, bioenergy forms a supportive role in the energy mix and is far from being a major component of any sustainable future and economic plans. The potential of bioenergy is limited and will not scale up to the demands and sustainability concerns. Furthermore, the phenomenal growth and potential of solar and wind energy in the past two decades have led to an inhibition of international bodies, governments and investors to limit or stop investing in bioenergy.

While bioenergy has received less attention in recent times, its share in the global energy mix has increased the last two decades. It is hence of interest to take stock of its contribution. For the EU, bioenergy was considered mostly for its contribution to greening and diversifying its energy mix. While its impact on CO2 emissions is hotly debated, there is a dearth of studies regarding the energy security implications of bioenergy in the EU. This opens up a window of opportunities and challenges to perform such a study.

The main research question of this thesis is:

What has been the impact of bioenergy on the energy security for the EU from 2000 to 2018?

The main research question and the sub-research questions will be addressed in the context of the EU economy and its vision for climate mitigation. the thesis starts with the literature review of energy security leading up to framing a new theoretical framework. Past implications of bioenergy that includes biofuels in the last decade and a half since 2000 are analyzed. the thesis will assess what bioenergy has delivered in that time. Positive and negative developments are taken into account and analyzed with respect to the selected energy security indicators and metrics.

Energy security and bioenergy are both very broad terms encompassing numerous definitions and wide interpretations with an even wider scope of its constituents. On this very account, they also suffer from a certain vagueness, which is not very acute to fossil fuel or even other renewable energy like solar energy and wind energy. This also gives an opportunity to develop and contribute to a specific line of research. The framework developed in this thesis is the first of its kind for the evaluation of bioenergy in the EU. Under the energy security section (section 2.2), a complete chronological order of definition of energy security has been provided as to reflect upon the growth of the concept and the way it is headed to.

PEST has been employed to narrow down the data gathering and relevance of energy security indicators for bioenergy. The use of the PEST analysis tool also offers a unique combination of elements in the framework and a boarder categorization, which in traditional energy security is often not employed. It helped to give a direction to the research by providing the most relevant areas associated with the impacts of bioenergy int he EU. With the PEST, the effects and results can be viewed under the broader elements of P-E-S-T (Political, economic, Social and technological) elements. Sections on energy security and bioenergy (section 2 and 3 respectively) provide a base and tool for further research into the link

between energy security and bioenergy, which is absent from the current work of research. The thesis makes use of the best of both the ES and PEST literature to select and gather relevant data respectively for the energy security indicators and metrics in order to fully capture the effects of bioenergy in the EU.

The definition of energy security in this research follows that of Sovacool and Mukherjee (2011), as the energy security dimensions and their indicators and metrics are derived from that paper. So, to keep continuity with the literature that definition has been adopted. This had an impact on the result of the effects on all the indicators and metrics, as they conform to the applied definition and approach. The various definitions and meaning of energy security in the EU context have been explored. ES has also been represented in a historical context signifying the changing themes, historical development, and definitions of energy security over the last two and half decades. The main energy security indicators and metrics have been taken from energy security dimensions of availability, regulation and governance, environment and social sustainability, and technology development and efficiency. In order to better gauge the implications of these ES dimensions and have a wider context, PEST analysis tool has been employed. With the PEST, all the selected ES dimensions and their indicators have been broadly classified under the political, economic, social, and technological elements. Overall, 22 simple energy security indicators and metrics have been identified for this study and these have been tested and rated on the proposed rating scale in this thesis. The choice of simple indicators over complex indicators has been made as simple indicators are more suitable for a thorough overview of energy security in the EU. It gives an opportunity to cover more indicators for a comprehensive analysis. The full list of simple and complex indicators along with all the dimensions and components have been provided in Appendix I.

After having formed a framework, an introduction is given to the trends, economy, and characteristic of bioenergy in the EU. This provides knowledge for the growth and status of bioenergy and also the data to test the selected energy security indicators and their effects. To get a better overview of bioenergy, a review of the current policy of the EU for bioenergy has been done. It presents all relevant data related to bioenergy like various bioenergy potential, total energy consumption, and demand, etc. Then, different characteristics and featured of bioenergy are described along with the various conversion routes to obtain different forms of energy (namely biofuels, bio-electricity, and bio-heat) are explained. This helps provide the essential bioenergy characteristics and also insights in bioenergy policies of the EU. Some of the projections for 2020 for bioenergy in the EU have also been provided to better gauge the state of availability of resources and likely policy direction taken in the future.

The effects on the energy security indicators of bioenergy in the EU have been derived from the data on EU bioenergy and is assessed with respect to the 22 selected energy security indicators and metrics from the analytical framework.

The distinct features and the characterization of bioenergy in its varied forms show the unique characteristics of both fossil-fuels and other renewable resources. A lot of characteristics can be seen as a hybrid between the two. This entails that it has the advantages and disadvantages of both the resources. It indeed shares some similarities with the present fossil fuels scenario with regards to the fixed locations of resources and with transient renewable resources with regards to its potential/ability to be obtained infinitely or non-exhaustively with dedicated energy crops and microalgae biofuels. Land use and the associated changes that a wider bioenergy implication has brought with it is a key issue in sustainable bioenergy production as land availability is a limiting factor.

Section 2.3 provides more information regarding the rating scale. A rating of 3.0 here implies no or a little effect to a particular energy security indicator or metric on account of bioenergy. Any rating above 3.0 has a positive impact on that particular indicator or metric and any rating below 3.0 has a negative impact. The results show the effects of bioenergy on the energy security in the EU from 2000 up to 2018.

The ratings were awarded for every selected energy security indicator, an average of all the energy security dimension present a clearer picture of the analysis. It is found the overall effects have slightly positive implications with an average rating of 3.09 for all the 22 selected energy security indicators and metrics.

The results of the assessment show that the effect of bioenergy on the energy security for the EU has been just slightly on the positive side. For two of the dimension, it has had no major or a little effect. For the dimension of 'technology development and efficiency', it has the most positive effect implying an increase in employment in the bio-sector and high research budget for bioenergy. The positive implications include employment generation related to bioenergy sector. The availability of raw biomass ensures a secure supply of energy.

However, for the dimension of 'Environmental & social sustainability', the effects have been overall negative. This also confirms the sustainability concerns raised over the widespread use of bioenergy in the EU in the last couple of decades.

The main finding of the energy security assessment and its effects is shown in the table below for all the 22 studied ES indicators and metrics:

TABLE I: Summary of the finding of the study

Dimension	**Average Ratings and Effects**
Availability	3.0. Some indicators have a slightly positive effect while some have slightly negative. Overall or a little effect on this dimension.
Regulation and Governance	4.0. All the indicators have a little or no effect.
Environmental & social sustainability	2.9. Most indicators have a slightly negative effect while only a few have a slightly positive. Overall a negative effect on this dimension.
Technology development and efficiency	3.5. All the indicators have positive ratings or no effects, overall a positive effect.
Overall (Average)	**3.09. The average of all the rate indicators shows a net positive effect on the selected energy security dimensions.**

The main conclusions from this research thesis are:

• The widespread and continuous availability of bioenergy has made for secure energy supply with a slightly positive effect on supply of raw materials for energy, storage, stability of prices, and diversification of transportation fuels.

• There are tougher climate goals in place enforced by the EU in an effort to reduce GHG emissions in the last 10 years. This has given impetus to more sustainable bioenergy in the final energy mix.

• Food vs fuel debate has had a negative impact both on the perception of bioenergy as well as its large-scale application. Damage to habitats, ecology, and land use changes had implied more negative ratings. It thus has severe repercussions attached.

• The sustainability of bioenergy has been questionable, and the ratings suggest it is not a very clean alternative fuel. Although most of the bioenergy production has been carbon neutral and new stringent laws adopted by the EU employs more sustainable bioenergy.

• Diversification indicators related to bioenergy have largely positive ratings, making it a more reliable and safe source of energy resource.

• Bioenergy has given a boost to the local economy in the last 18 years. The effects on local industries, direct and indirect employment, capital generation have been positive. The ratings for related indicators and metrics are mostly positive.

• Non-energy raw material and critical materials have not been the bottlenecks deployment of bioenergy in the past. Components of artificial fertilizers are nitrogen, phosphorus, and potassium have been available in large quantities to meet the existing demand.

The selection of a different set of energy security indicators and metrics for the same ES components and dimensions could produce a different result. This aspect can be further researched on as to how the results differ with the selection of ES indicators and metrics.

One of the drawbacks of this analysis would be that all the indicators have been given the same weight, the same importance. This may actually not be the case as some indicators tend to affect more than others for a given adopted policy. So, the average rating of every dimension should be seen just as an indicative result but it is still important as no single indicator with a greater weight can form a comprehensive energy security assessment.

This study provides an opportunity for subsequent research and pathways. Bioenergy is a broad term comprising of biomass, biofuels, biomaterials, etc. Recommendations are made for further academic research and future policy actions in the EU.

Some of the recommendations based on this research for policy actions and studies are as follows:

- More budget allocation for research and development for bioenergy, as it directly affects several key dimension of energy security as concluded from this study.

- Conduct research on the sustainability aspect of bioenergy with the relevant energy security indicators and metrics for all types of bioenergy. With changing policies and differing criteria, more indicators relating to sustainability could be studied.
- Research into the effects on the ES indicators for more imports from outside the EU and for more percentage of bioenergy in the EU energy mix. Imports of both the raw biomass as well as electricity.
- Conduct more expert interviews with the bio-industry and carry out such research in co-operation with governments co-operations or bio-industry.
- The study of comprehensive energy security effects of bioenergy on every member state of the EU;
- The study of comprehensive energy security effects of a specific type of bioenergy like biofuels, soid biomass, forestry residues, municipal waste, etc.;
- Find out what energy security components, dimensions, and indicators carry the most significance and weight for bioenergy in the EU and conduct a study on them.

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Chapter 1

Introduction to the research

1.1 Introduction

According to Scott Victor Valentine, (2011), the relationship between energy security and the current energy system based on fossil fuels is no more symbiotic but is now parasitic (Scott Victor Valentine, 2011). The huge fossil subsidies granted need reformation. There is a need for carbon taxation and fossil fuel subsidy reform in order to attain the sustainable development goals (SDGs). The dominance of fossil fuels is not a very natural one: With a carbon tax and without fossil subsidies, the current landscape would have taken a very different look (Jim Philp, 2018). The heavy reliance of the EU on imported energy to run its economy is also an issue to deal with (REE, 2010). This chapter will try to highlight the importance of bioenergy and why it has been selected for this study.

It is indeed not hard to envisage a fossil fuels free energy scenario in the future. There is a need for innovative thinking in order to reach a sustainable solution for the future energy needs. Out of the plethora of renewable energy options, bioenergy has the potential for being the source of baseload power in the EU without any significant capital costs to the grid. Solar and Wind energy with the solar roof-top and wind farms could provide only a limited share and cannot fully serve this purpose, so bioenergy provides a chance for the European utilities to scale-up and take advantage of the second wave of renewable energy source growth (Albani et al., 2014). Bioenergy thus gives an opportunity for the EU utilities to realize and further their renewable targets and simultaneously exploit their existing assets.

Furthermore, bioenergy is a diverse source of fuel with a multitude of extraction options. Their geographic concentration is more widespread within the EU than fossil fuels. Given, bioenergy comprises a myriad of energy supply options, it brings a significant degree of diversification to the energy security of the EU.

Just like fossil fuels, raw biomass has the potential to be stored long-term in dedicated storage houses, tanks, etc. Moreover, they could be relocated or transported from any location directly to the desired European or national plant without any decrease in their calorific value. The availability of several conversion routes to the final form of energy and storage options gives the EU a handy strategic asset for the energy security.

Bioenergy is the final energy in the form of heat, electricity, and biofuels derived from all kinds of biomass. Bioenergy based systems refer to political, social and technological systems which are based on the use of bioenergy. At present, a large number of production of chemicals, transportation fuels, materials, pharmaceuticals, heat, and electricity is carried out by bioenergy. The opportunities for positive impacts flowing from the advanced bioenergy systems are there to be explored. The technical potential for the bioenergy systems is high, for example, about 90% of oil-based products have the potential to be replaced by bio-based alternatives (McCormick and Kautt, 2013).

The first generation of biofuels had critical issues with food security on account of its demand for incessant availability of water and land to produce biomass feedstock, increasing food prices; resulting in vulnerability to people getting cheap food, also emitting higher GHG emissions. The second and third generation of biofuels, like the micro-algae biofuels, so far haven't shown the same problems (Lee, 2017). The new generation of biofuels and bio-based materials has the potential to be the alternatives to fossil fuels as they generate neutral-carbon energy. This entails lower greenhouse gas (GHG) emissions, hence more benign to the environment with greater energy security. These constitute the factors which can power transition to more bio-based energy systems.

The challenges of contemplating to analyze a bioenergy implication in the EU are many-fold. To start with, all the resultant implications of bioenergy are interrelated. If the demand for biofuels surges, then pressure on production or importing feedstocks mounts. This may result in changes in land-use, bio-industry production and preferences, and deforestation, which would affect the bio-market. Another difficulty arises from the fact that these effects, in turn, have their own indirect and other implications. The debate on food prices and indirect land-use changes with respect to an increase in biofuel production is a prime example. Another challenge is to get accurate and current data in order to assess the implications.

1.2 EU energy security

Energy security is an important concept. It is vital for a nation's growth as well as national security, this is even more relevant for developing nations as their demand for energy is more and directly related to growth (L. Proskuryakova, 2018). Furthermore, energy security forms an important factor for international trade relations and geopolitics. Security of supply is a key theme to eb taken into account by policymakers and stakeholders (L. Proskuryakova, 2018). The significance of energy security in energy policy and international relations make it a key factor in determining in future energy transitions (L. Proskuryakova, 2018).

L. Proskuryakova (2018) further describes the concept of energy security in light of new energy scenario as, "Energy security, as perceived by international development organizations and national policies, often focus on fossil fuels, while neglecting energy equity and environmental sustainability. This is particularly a problem for most of the developing countries. Therefore integration of energy governance and energy security perspectives is required to understand and address the difficulties of a just energy transition in the context of the standard energy trilemma. At the same time, energy policy should avoid excessive securitization of all energy issues." (Proskuryakova, 2018).

According to Gökgöz and Güvercin (2018), the European Union (EU) is prone to undergoing a higher effect of fluctuations in the international market. The EU imported 54% of the total energy needed for its needs showing the vulnerability of EU's energy security (Gökgöz and Güvercin, 2018).

Mengal et al., (2018) observes that the EU is looking ahead to future beyond fossil fuels and wants the growth to be independent of imported resources and adverse environmental effects.

The vision of European Commission is for a competitive, innovative and sustainable Europe transitioning towards a post-fossil-fuel based society while at the same time decoupling economic growth from resource depletion and environmental impact (Mengal et al., 2018). Further, L. Proskuryakova (2018) finds that energy security ranks among the most important parameters for ensuring a strong and steady development of the EU region (L. Proskuryakova, 2018).

In June 2018, the EU governments reached a political agreement to raise renewable energy targets to 32% by 2030 (European Commission, 2018). This is seen as an ambitious target which would further spur the growth of renewables. The RES policy framework of the EU had started to take shape in March 2007 when the 27 EU members agreed on a binding target of at least 20 percent renewable energy from final energy consumption by 2020.

From 2020 onwards, the EU has adopted even more ambitious targets for the renewable energy share in the energy mix (European Commission, 2018). Of all the research undertaken on bioenergy, energy security has been a slightly less touched theme as compared to the traditional themes of economic growth or environmental sustainability. With all the major focus on wind and solar energy, one of the widely available resources is often overlooked on account of its both ubiquitous and controversial nature: Biomass. In this thesis, investigations have been made into the impact of bioenergy for the energy security of the bioenergy driven sectors in the EU since 2000 and leading up to 2020.

Bioenergy is defined by Carmen Lago et al., (2019) as "renewable energy produced from natural sources capable of replacing fossil energy". A gamut of biological resources could be employed as to be used for bioenergy production such as wet organic wastes, wastes, and by-products from agro-industries and pulp and paper industries, energy crops, from forest and crops, biomass residues, and municipal solid wastes (mainly the organic part). Other potential options include seaweeds, microalgae, seaweeds, macroalgae and aquatic plants (OECD/IEA, 2017). In recent times, biomass has found new applications as in for the production of biomaterials and bioproduct (Carmen Lago et al., 2019).

International Energy Agency (IEA) offers a clear vision and projection for the significance of growth of bioenergy. It states that by 2060, bioenergy would be able to provide for almost 17% of the world's total demand for energy. As a result, bioenergy use could result in 20% reductions in GHG emissions (Carmen Lago et al., 2019). To achieve these projections, bioenergy has to be sustainably obtained as to contribute to decarbonizing of the energy systems. Modern bioenergy can be procured by using the mature technologies such as the ones being employed for biomethane from wastes and other residues (Carmen Lago et al., 2019).

1.3 Problem statement

The knowledge about the availability and affordability, domestic production and import, environmental impacts, etc. of bioenergy on the EU in the last 20 years need to be known to carry this analysis. The debate about the inclusion of more bioenergy in the EU and, thus, a larger bio-based economy has so far shown little progress on the account of the fact that it is very difficult to assess the implications on energy security (Langeveld et al., 2010). The research on the energy security related to bioenergy has so far only been limited to biofuels, while other forms of bioenergy, and other related services have received little to no attention. By describing bioenergy with respect to the dimension of energy security, the effects of all these sectors could be understood together under one framework. This, thus, provides both an opportunity to assess the implications that bioenergy has had on the energy security for the EU.

There is a dearth of research on exploring energy security implications of bioenergy in the EU as most of the focus has been on either the non-dispatchable renewables (solar, wind) or has been only confined to biofuels. Therefore, there exists a need to understand what have been the consequences of implementing bioenergy usage in the EU not only for the present discussion but also for the current and immediate future scenarios and policy-making.

1.4. Research objective

The objective of this thesis is to understand the possible implications that bioenergy had on EU energy security. Using a new framework to assess the energy security consequences, with the help of the PEST analysis tool, selection of energy security dimensions and their indicators have been made and using a rating scale, these indicators are scored upon their effects on energy security. This new comprehensive energy security assessment framework is deployed to assess the political, environmental, social, technical, and economic effects of bioenergy on energy security for the EU. After sketching the current picture of bioenergy in the EU, the consequences of technical and geographical characteristics of bioenergy are also explored.

The main focus of the thesis is on the energy security indicators and their implications of indicators on bioenergy for the member states of the EU. In the process, a new working and comprehensive energy security assessment framework has been developed keeping bioenergy in the EU in mind. So, this thesis also aims to provide food for thought for policymakers and also a pathway for further research using the framework.

1.5. RQ and SQs, Research design (theory and method) and outline.

In order to fully to understand the possible implication of the bioenergy systems and economy on the energy security for the EU, more insights into the effects of this scenario are necessary. From the research perspective, the following questions (Research and sub-questions) arise for the bioenergy in the EU.

1.5.1 Research Question

The main research question of this thesis is:

What has been the impact of bioenergy on EU energy security from 2000 to 2018?

The research question will be answered by the conclusions drawn from the results of applying the framework for the assessment of energy security in chapter 4.

1.5.2 Sub research questions

As the question touches upon a wide-ranging concept, to help define and obtain an overall picture, sub-questions have been framed for this research.

The sub-questions (SQs) are:

SQ1. How to assess energy security?

SQ2. What are the bioenergy developments in the EU?

SQ3. How did bioenergy impact EU energy security?

SQ4. What can we learn from the EU experience?

Each of these sub-research questions is to be answered using the research methods described later in this chapter.

1.6. Research scope

The geographical scope in this project is the EU including all the 28 member states. They form the main focus of this research, but other EEA countries like Iceland, Liechtenstein, and Norway are also taken into consideration in this research.

The nature of the study necessarily entails that no definite and rigid timescale could be applied. The used time scale in this research is the period from the year 2000 up to the year 2018 with the conclusion drawn from past policies. Projections have been also provided till next year to show the state of current trajectory in terms of resource availability and policies, so that is the time scale and the end period for this thesis. The starting point for reference data also varies, with energy security definition dating back as far as 1992 to biofuels analysis starting from 2000 onwards.

The bioenergy in this thesis refers to all kinds of biomass including, but not limited to, solid biomass and liquid biofuels. In this research, not only the bioenergy of the EU has been considered but other major bioenergy producing nations like Brazil, the USA, and Canada have been taken into account as potential trading partners/options for various energy security measurement and their role in the bioenergy development so far.

1.7. Research approach

The research employs a thorough energy security analysis and use of the PEST tool. What the PEST adds and what energy security literature does not offer is the comprehensiveness, a better structuring, and relevance to its study. As bioenergy in the EU is a function of many variables, the PEST as a tool captures most closely the effects under the Political, Economic, Social and Technological indicators.

The organization of the study is done in six chapters, starting with chapter 1 which is the introduction and the overview of the thesis. Chapter 2 provides a critical review of most of the indicators of energy security developed up to now. Chapter 3 introduces the biomass case as the backdrop for this study. Chapter 4 is the analysis section where the framework is applied on the rating scale. Chapter 5 includes discussion and finally, chapter 6 offers conclusions.

The new framework formed will be then applied to answer the research question and the other sub-questions. Figure 1 (below) shows a schematic view of the research overview of this thesis.

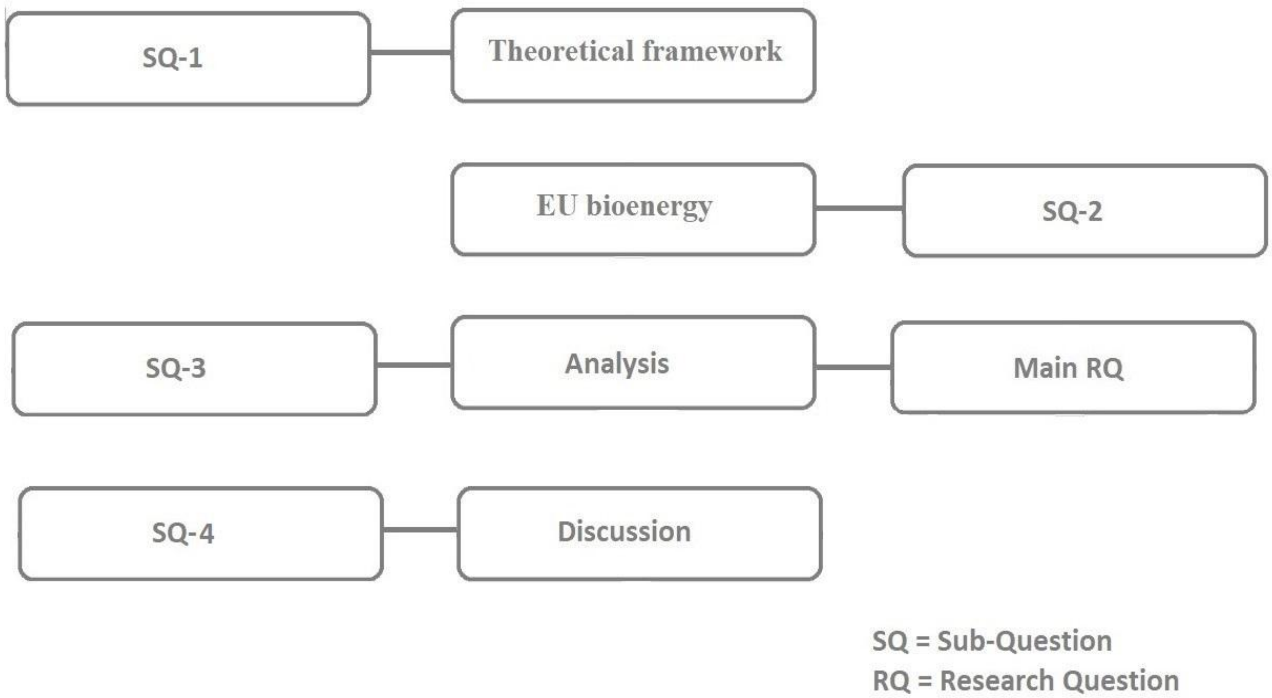

Fig. 1. Research outline for the thesis.

The research questions are part of the empirical and analytical phases.

Input in the form of data collected from the literature study is used for the new comprehensive energy security framework. The facts and statistics are collected together for analysis for the new energy security framework to investigate the effects of bioenergy in the EU.

The literature in this thesis touches the subject of energy security frameworks, biofuels, the EU energy sector and infrastructure, biomass, the EU energy markets, the EU electricity markets, stakeholders, economic activities in the EU region, the climate policies of the EU, electricity policies of the EU, trade and cooperation between the EU and other countries.

The data has been gathered from the literature review for various bioenergy sources and policy frameworks in the EU to help answer the research questions. The data is processed in relation to the energy security dimensions and policy scenarios in question, from which conclusions are drawn. The processing of data is aided by using PEST tool, as it helps in defining the specific area of research.

1.8. Framing of a new energy security assessment framework

The energy security components and dimensions have been selected from the Sovacool and Mukhrejee (2011) framework, as it provides a comprehensive and exhaustive list of energy security indicators and metrics for each ES dimension. Appendix I shows the list of all energy security dimensions included in that study, and from which the energy security indicators and metrics have been selected for this thesis. The 5 major ES dimensions are divided into several components, each being further sub-classified into multiple ES indicators and metrics.

For this framework, PEST tool has been employed and has been merged with it the ES literature in order to get a relevant direction to the thesis and narrowing down the scope and data for the energy security indicators and metrics.

The following steps are taken to construct the framework:

- For the selection of energy security indicators, the availability of data for the time period for the research is tested.

- The energy security indicators selected are tested on the quantification in order to come up with a score on the rating scale.

- The relevance of the ES indicators with respect to various bioenergy sources.

The following figure captures the research question and method structure. SQ-1 and SQ-2 would be answered from theoretical and literature review in chapter 2 and chapter 3 respectively. SQ-3 and the main research question are then answered from chapter 4, the analysis of the ES indicators and finally SQ-4 is then answered from chapter 5, discussions and conclusions.

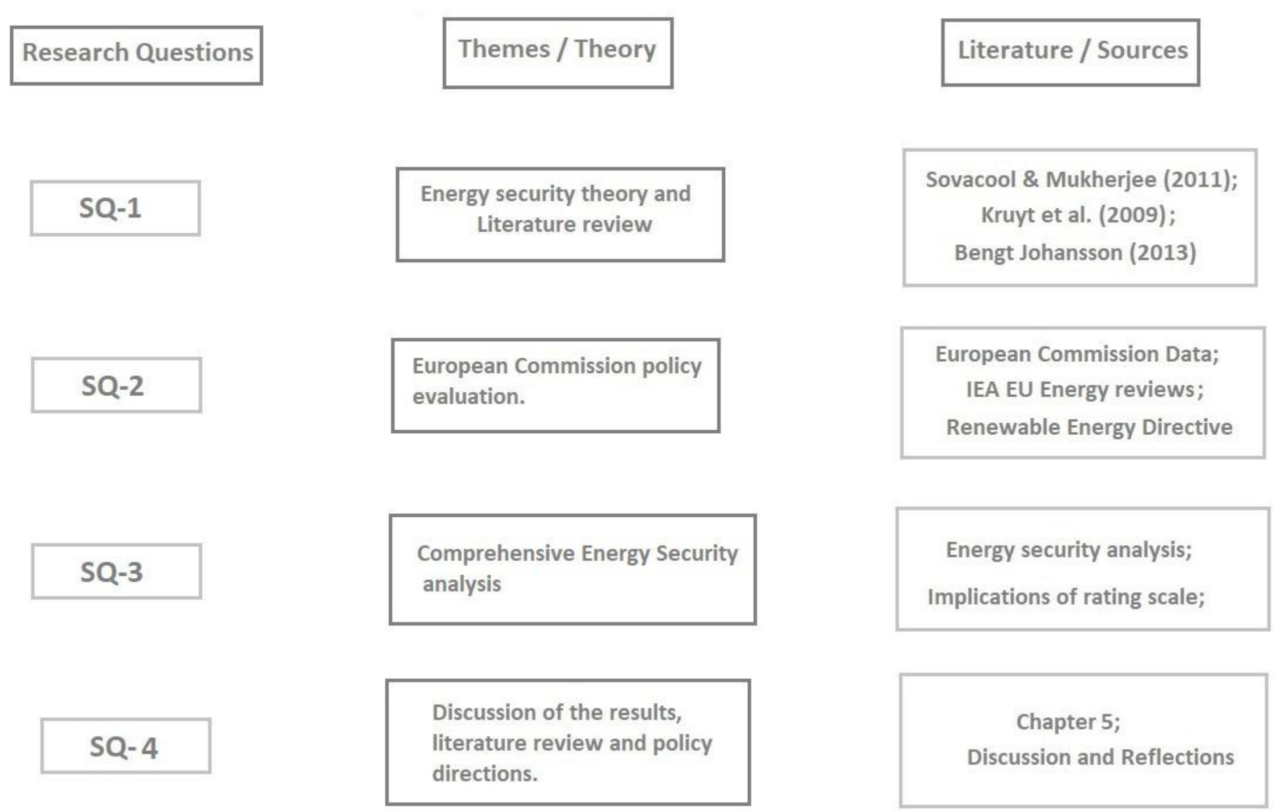

Fig. 2. Research questions and their method structure

1.9. Research methods

The main research question and the sub-research questions will be addressed in the context of the EU economy and its vision for climate mitigation. the thesis starts with the literature review of energy security leading up to framing a new theoretical framework. Past implications of bioenergy in the EU in the last decade and a half since 2000 are analyzed. The thesis will assess what biofuels have delivered in that time. Positive and negative developments are taken into account for the last 20 years. As the EU has varying economic growths, it is worthwhile to investigate the case of the different ES indicators and the effect that have had in order to have a longer base for reference. Several other factors such as the EU trade markets, diversification from natural gas to biomass, co-generation using biofuels instead of oil are analyzed.

No interviews have been conducted for the validation of this research. Given the nature of the study i.e. being theoretical and data available to carry it out, interviews were not deemed to be necessary initially, as the literature sources themselves were deemed to be sufficient for the study of the selected of relevant energy security indicators and metrics. This has been further elaborated under the discussion section.

1.9.1 Sub-questions and Main research questions

As the above figure 2 suggests the research outline of the thesis, the main research question and the sub-questions will be answered in each of the chapter as follows:

SQ-1 will be answered from the features of the energy security theory and literature from chapter 2, ‘Energy security and theory’. The thesis starts with a literature review, which acts as preliminary research. A theoretical study of energy security concepts and definition is carried out. To access the energy security indicators and metrics, qualitative research has been employed for this study on account of the vague definitions and interpretations of every energy security indicator and metric involved. The indicators and metrics provide quantifiable results to understand comprehensively the energy security effects.

SQ-2 will be answered from the characteristics and data of bioenergy drawn from chapter 3, ‘Bioenergy in the EU’. The mapping of bioenergy potential in the EU has been undertaken in various shapes and forms, including forestry biomass potential, industrial waste potential, biofuel potential.

SQ-3 will be answered from the conclusions drawn from chapter 4, energy security assessment. The thesis formulates a new framework for the assessment of bioenergy implication on energy security for the EU.

SQ-4 will be answered from the conclusions drawn from chapter 4, energy security assessment. The thesis formulates a new framework for the assessment of bioenergy implication on energy security for the EU.

The main research question will then be evaluated and a critical analysis of the whole research will help provide the answer. The implications of the results of the main research question and all other sub-questions will be discussed in chapter 5. The conclusion of the thesis starts with a short summary of the research question and a detailed list of the conclusion drawn are given in chapter 6. The effects of all the energy security indicators and metrics are presented and the conclusions are drawn from their results. The thesis ends with recommendations and directions that may be employed for the future policy actions in the EU as well as further academic research related to bioenergy in the EU.

CHAPTER 2

Energy Security Theory

In this section, a new framework will be developed through a critical review of existing energy security literature and relating it to the characteristics of bioenergy in the EU. The use of PEST tool on account of limitations of energy security has also been employed and delineated. A look into the historic growth of energy security related definition has been made with the aim of understanding the general pattern of energy security and its evolution over the years.

2.1 Themes of energy security

2.1.1 Introduction to energy security

There does not exist a single accepted or followed definition of energy security in the international corridors, yet energy security stands on a list of priorities of almost all countries (Ren and Sovacool, 2014). A large number of existing definitions can be divided into the ones that either divides the energys ecurity in terms of short-term i.e. the security of supply or long-term i.e. a more wider ES concept.

In a paper published by Wizner (2012), 36 different definitions of energy security were reviewed and the paper itself defined energy security as "the continuity of energy supplies relative to demand" (Winzer, 2012).

Filipović et al., (2018) refers to the definite adopted by International Energy Agency (IEA) in its 2014 report in the perspective of short-term and long-term. The concept of energy security in the short-term , according to Filipović et al., (2018), is defined as follows: “the ability of the energy system of a certain country to react promptly and in the best possible way to changes in the supply-demand balance”. While for the long-term energy security, the focus is on environmental standards while keeping up pace with the economic growth (Filipović et al., 2018).

As energy security is indeed a multidisciplinary concept*,* each discipline tends to analyzes energy security from its own perspective, which can result in a conflict of assumptions. Furthermore, as the procedure of defining energy security is linked with a number of challenges on account of the fact that the relevance of same factors is different to every country, their significance changes over time (Vivoda, 2010).

This puts energy security into a dynamic category as the approach can vary determined by the analyzed time-frame. Consequently, depending on the analyzed time-frame, differences can arise in the perception of the perspective and in primary considerations of the energy security (Johansson, 2013).

2.2 Energy security: Historical perspective

The concept of energy security has undergone change in the past few decades (L. Proskuryakova, 2018). Later in the 20th century, in the decades of 70s and 80s, scope of research was confined to the study of steady availability of fuels, after the embargo and price instability in the gulf nations, which were major exporters of oil (L. Proskuryakova, 2018).

At the dawn of the 21st century, the focus was directed to the availability of energy to all i.e. energy equity, fighting energy poverty and environmental concerns (L. Proskuryakova, 2018).

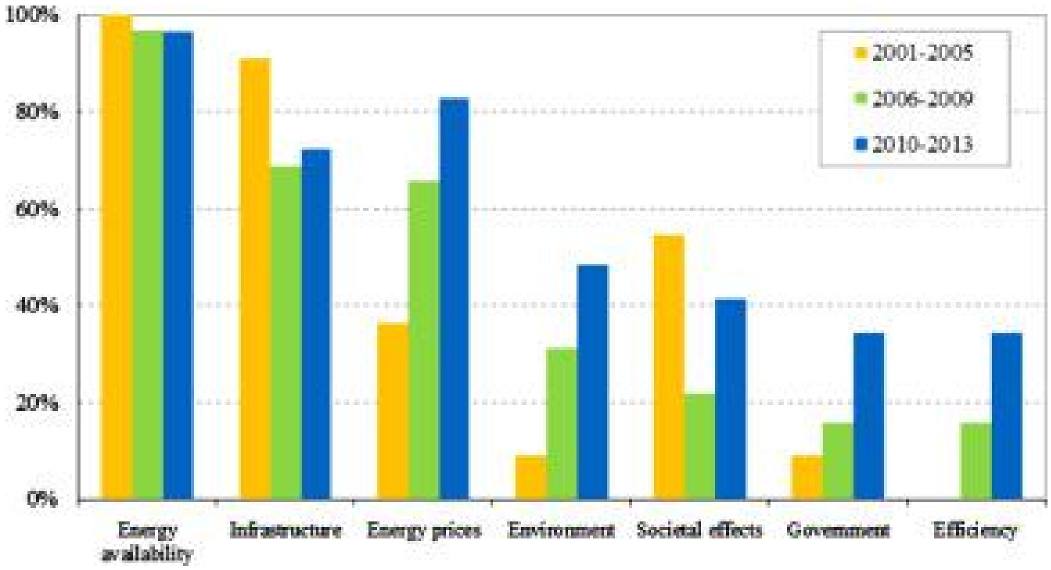

Fig. 3. Focus on energy security literature from 2001 to 2013 (Ang et al., 2015).

Figure 3 (above) shows the focus of energy security literature over the years. Most of the research has been focused on the energy availability dimension in the last 20 years.

In the period of 2001-2005, there was no literature on the efficiency of energy security which has since risen to more than 35% in the period 2010-2013.

Also, the frequency and interest in the last decade have grown almost exponentially as shown in figure 4 (below) illustrating the importance that energy security has acquired in recent times. This exponential growth in the energy security definitions can also be seen from the period 2001-2016 when the number of publication has risen from a mere 7% in 200-2005 to almost 30% in 2011-2016.

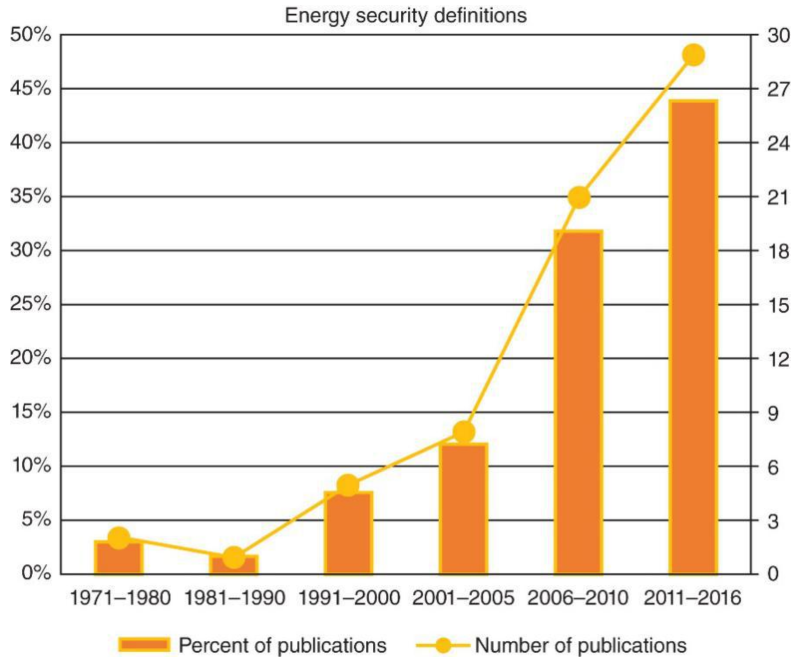

Fig. 4. The rise in the publications of energy security in recent years (Azzuni et al., 2018).

Owing to such a surge and interest in the theme, it can thus be followed that energy security has been defined in a myriad way. Some of the prominent definitions are compiled in the following table 1. By the multitude of definitions, the table also tries to capture the changing themes, perspectives, focus, and patterns over the time period of 25 years starting from 1993 to 2018. It shows the gamut of range and topics that security of supply touches. The table has been largely adopted from the work of Winzer (2011).

Table 1: Change in description of security of supply and energy security over the last 25 years (adopted from Winder (2011)).

Author (Ascending Year)	Paper title	Description of security of supply and energy security
Bohi and Toman (1993)	Energy security: externalities and policies.	‘‘Energy insecurity can be defined as the loss of welfare that may occur as the result of a change in price or availability of energy.’
Newbery (1996)	Development of natural gas trade between east and west	‘‘Security in turn requires an analysis of the possible shocks that might disturb the original equilibrium’
European Commission (EC) (2000)	Green Paper—towards a European strategy for the security of energy supply	‘‘Strategy for energy supply security must be geared to ensuring, for the well-being of its citizens and the proper functioning of the economy, the uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial), while respecting environmental concerns and looking towards sustainable development.’’
Stern (2002)	Security of European natural gas supplies	There are two major dimensions of risks associated with the sources of gas supplies, the transit of gas supplies and the facilities through which gas is delivered: • short-term supply availability versus long-term adequacy of supply and the infrastructure for delivering this supply to markets; • operational security of gas markets, i.e. daily and seasonal stresses and strains of extreme weather and other

		operational problems versus strategic security, i.e. catastrophic failure of major supply sources and facilities
Lieb-Do´czy et al. (2003)	Who Secures the Security of Supply? European perspectives on security, competition and liability.	‘‘Security of supply is fundamentally about risk. More secure systems are those with lower risks of system interruption.’
Lesbirel (2004)	Diversification and energy security risks: the Japanese case.	‘‘Energy security, like the concept of security itself is a contestable concept. Rather than seeking to define energy security comprehensively and while acknowledging different conceptions of it, I stress the notion of insurance against risks. An important aspect of energy security is the relative ability to insure against the risks of harmful energy import disruptions in order to ensure adequate access to energy sources to sustain acceptable levels of social and economic welfare and state power both nationally and internationally.’
Wright (2005)	Liberalization and the security of gas supply in the UK.	‘‘Security of gas supply’’: ‘‘an insurance against the risk of an interruption of external supplies.’’
Turton and Barreto (2006)	Long-term security of energy supply and climate change.	‘Security is measured as resources to consumption ratio (R:C).’
Spanjer (2007)	Russian gas price reform and the EU–Russia gas relationship: Incentives, consequences and European security of supply.	‘‘Security of supply can broadly be divided into two parts: system security—the extent to which consumers can be guaranteed, within foreseeable circumstances, of gas supply—and quantity security—guaranteeing an adequate supply of gas now as well as in the future. This comprises not only gas volumes, but also price and diversification of gas supplies.’’
Scheepers et al. (2007)	EU standards for security of supply.	‘‘A security of supply risk refers to a shortage in energy supply, either a relative shortage, i.e. a mismatch in supply and demand inducing price increases, or a partial or complete disruption of energy supplies. A secure energy supply implies the continuous uninterrupted availability of energy at the consumer’s site.’
Rutherford et al. (2007)	Linking consumer energy efficiency with security of supply.	‘‘In the context of this thesis, we will use the term energy security to refer to a generally low business risk related to energy with ready access to a stable supply of electricity/energy at a predicable price without threat of disruption from major price spikes, brown-outs or externally imposed limits.’’
O¨lz et al. (2007)	Contribution of renewables to energy security	‘‘This study defines energy security risk as being the degree of probability of disruption to energy supply occurring. A forthcoming IEA report on the interactions between energy security and climate change policy uses an analogous definition of energy insecurity as ‘‘the loss of economic welfare that may occur as a result of a change in the price and availability of energy.’’
McCarthy et al. (2007)	Assessing reliability in energy supply systems	‘‘Security includes the dynamic response of the system to unexpected interruptions, and its ability to endure them. Adequacy refers to the ability of the system to supply customer requirements under normal operating conditions.’
Mulder et al. (2007)	The economics of promoting security of energy supply	‘‘From a political viewpoint, ensuring security of supply often means that a stable supply of energy needs to be guaranteed at ‘affordable’ prices, regardless of the circumstances. …From an economic viewpoint, however, the concept of security of supply is related to the efficiency of providing energy to consumers… In this thesis, we approach the issue of security of supply from the economic perspective.’
Mabro (2008)	On the security of oil supplies, oil	‘‘Security is impaired when supplies are reduced or interrupted in

	weapons, oil nationalism and all that.	some places to an extent that causes a sudden, significant and sustained increase in prevailing prices.''
Nuttall and Manz (2008)	A new energy security paradigm for the twenty-first century.	''Interruption of the energy supply has been identified by many as the primary threat that faces global energy security.''
Patterson (2008)	Managing energy wrong.	''The energy security that worries politicians concerns supplies of imported oil and natural gas, not the secure delivery of energy services, such as keeping the lights on.''
Kruyt et al. (2009)	Indicators for energy security.	security is an issue dependent on the risk-adverseness of consumers. Its focus is thus not the absolute level of energy prices but the size and impact of changes in energy prices.'' ''...elements relating to SOS: availability – or elements relating to geological existence. Accessibility – or geopolitical elements. Affordability – or economical elements. Acceptability – or environmental and societal elements.''
Noel and Findlater (2010)	Gas supply security in the baltic states: a qualitative assessment	''For the purpose of this article ''security of supply'' (or gas supply security) refers to the ability of a country's energy supply system to meet final contracted energy demand in the event of a gas supply disruption.''
European Commision (2011)	The EU energy policy: engaging with partners beyond our borders	"the ability to ensure that future essential energy needs can be met, both by means of adequate domestic resources worked under economically acceptable conditions or maintained as strategic reserves, and by calling upon accessible and stable external sources supplemented where appropriate by strategic stocks"
Wizner (2012)	Conceptualizing energy security.	"the continuity of energy supplies relative to demand"
International Energy Agency (2014)	Energy supply security: the emergency response of IEA countries.	"the ability of the energy system of a certain country to react promptly and in the best possible way to changes in the supply-demand balance, while long-term energy security is focused on finding and supplying energy in accordance with economic development, along with the need to preserve environmental quality"
Jonsson et al., (2015)	Energy security matters in the EU Energy Roadmap	"There is no established, all-encompassing definition of energy security partly because the notion of energy security is highly context dependent. Moreover, since security generally is a question of subjective perceptions such definitions would not be universally applicable. In order to facilitate an understanding on the meta-level however, we promote the view that energy security can be regarded from two separate perspectives; when the energy system is exposed to insecurity, and when the energy system generates insecurity."
Kisel et al., (2016)	Concept for Energy Security Matrix	"From the variety of definitions one could come to the conclusion that we should distinguish between short- and long-term energy securities. Short-term energy security can be largely assessed by the potential of an energy system to deal with disturbances. For long-term energy security, one could distinguish three layers, which should be part of every energy security policy: Technical Resilience and Vulnerability, Economic Dependency and Political Affectability."
Gylnn et al., (2017)	Energy security assessment methods: Quantifying the security co-benefits of decarbonising the Irish Energy System	"Energy security is an interdisciplinary concept. Its definitions leaves it vulnerable to exploitation as a justification for energy policy instruments. The concepts of security of supply (SOS), continuity of supply, diversity of supply, supply/demand balances, reserve/production ratios, and fuel diversity, all focus on physical availability of energy resource supply under the understanding that an uninterrupted energy supply is critical for a functioning modern economy"

Hongtu Zhao, 2019	Energy Security: From Energy Independence to Energy Interdependence	"In general, the energy problem has a trend of "de-securitization" so energy cooperation and global energy governance will gradually become the mainstream of energy security issues." "Energy security is a global problem. The energy security of all countries depends on the stability of the global market. No country can guarantee its own security without the energy security of other countries and regions." Energy security has gradually shifted from country security and group cooperation to global dialog and cooperation on energy security."

2.3 Challenges and opportunities: Measuring energy security

Quantifying and measuring energy security has been sought after for a long time in terms of different concepts and indicators (European Commission, 2010). Most of the research literature divides itself on the reference of energy security to fossil fuels, oil (M. Mišik, 2016) and gas (European Commission, 2014).

Factors like the changes in the political, environmental, social and economic elements are reflected in energy security along with the characteristics of the energy sector (Onat and Bayer, 2010). Many studies have tried to measure all these elements in terms of indicators and dimensions of energy security questioning (Filipović et al., 2018). With this regard, Sovacool and Mukherjee (2011) were very thorough and reviewed more than 300 complex energy security indicators with multiple dimensions (Sovacool and Mukherjee, 2011).

Energy security measurement presents a multitude of approaches that help define the complexity and comprehensiveness of the energy security indicators. However, the selection of relevant indicators and their ranking based on importance and independence poses a major challenge and disagreements in the academic discussions. To help with this conundrum, Sovacool (2011) came up with a solution that can be seen as a clear distinction between the study of quantitative and qualitative assessment factors (Filipović et al., 2018).

In this, a critical approach is given importance, as it is argued that energy security cannot only be derived from the important quantitative factors of importance, but to provide the social elements and political elements and their analyses, qualitative studies must also be factored in. These qualitative indicators, owing to their subjective nature, are open to questioning (Filipović et al., 2018).

Filipović et al., (2018) describes the relation between environmental concerns and energy security in the EU as follows: "Environmental concerns and related policy decision could have a potentially significant impact on energy security in EU-28 countries where carbon reduction is one of the development priorities. In the beginning, definitions (interpretations) of energy security were mostly oriented to the security of supply, while contemporary definitions are much more comprehensive. They include more aspects of energy security, as well as environmental concerns." (Filipović et al., 2018).

One of the major policies of the EU is to secure energy supply as well as decrease the emissions of gasses i.e. meeting climate change goals. The EU stresses on securing both long term and short-term energy strategy. Filipović et al., (2018) states that, “As energy is a vital part of Europe's economy and future, related policies have been developed, whose main objective is to create a more sustainable energy system in the EU. Thus, due to the 2020 energy and climate policies of the EU (energy efficiency, the renewable energy policies, and the planned 2030 policies), a range of measures exist to address the security of supply concerns.” (Filipović et al., 2018).

Social and/or political aspects are seldom included on account of their being accurately measured. Political risk (including geopolitical risk) includes the risks that may occur due to a nation’s change in its political scenario or stability. Investors would have to take these political risk (Simoes and Barros, 2007). Investment returns could also be influenced by the political instability that could led from a shift in a country’s policies, governmental, laws or constitution (Jewell, 2011).

The political risk is of great significance, as investment returns could drag down and it can also jeopardize the withdrawal of financial support destruction. Instability and regional turbulence (like the Ukrainian crisis) in energy import countries are directly linked to energy supply and prices, hence the energy-dependent countries can see a dramatic increase in energy costs. This shows why taking into account this type of risk is significant with respect to the analysis of energy security (Filipović et al., 2018).

L.Proskuryakova (2018) observes that, “neorealism, neoliberalism, constructivism, and political economy” are at present the 4 ES themes that encompass the theory on international relations. They all in their own capacity offers a specific interpretation of all the key ES indicators and their structure and importance (L.Proskuryakova, 2018).

While the security of supply and security of demand captures the security threats, several risk factors like economic, political, technological and environmental factors relate to enhancing or generating energy security (Bengt Johansson, 2013).

Figure 5 (below) illustrates the methodology used in this thesis for understanding the relationship between the terms of ‘energy security’ and ‘energy’ (Bengt Johansson, 2013).

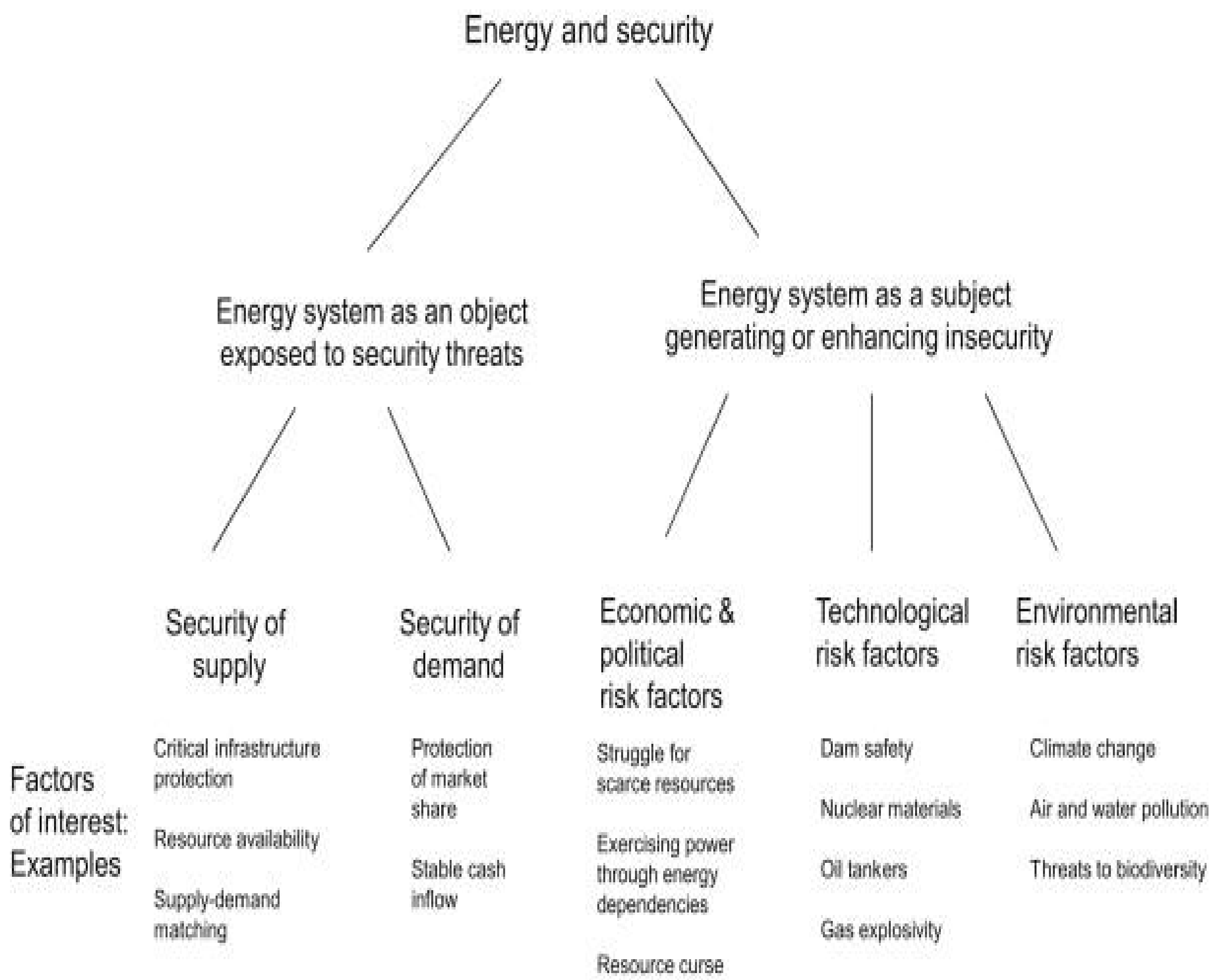

Fig. 5. The methodology used in this thesis for understanding the relationship between the terms of energy security and energy (Bengt Johansson, 2013).

2.4 Shortcomings of energy security literature with respect to bioenergy

There is a dearth of literature on the energy security of bioenergy. This implies that the energy security dimensions and indicators that would capture the properties of bioenergy sources have yet not been analyzed. The current frameworks, like that of Sovacool & Mukherjee (2011), focuses more on the sectors based on fossil fuel-based and also excludes the general strategic implications. The IEA (2011) study on energy security along with other such studies by international organizations do not mention the economic indicators.

Notwithstanding the plethora of literature on energy security, a substantial part of it is limited to the geographic boundaries or a specific inter-regional relationships (L.Proskuryakova, 2018). Hardly any study focuses on the conceptualization of energy security, or analyze it with keeping energy security concepts in mind, and almost none updates or reviews the concepts in a comprehensive manner with constant new developments in the sector (L.Proskuryakova, 2018). As noted by (Tarasova, 2018) both scholarly and policy literature offers a huge range of often conflicting and fragmenting definitions and deductions of energy security.

One of the ways to overcome the shortcoming is by analyzing the methodologies and theories developed for international relations (L.Proskuryakova, 2018). It is based on the theory that ES theories are formulated on obsolete security patterns and are asynchronous with the modern times, therefore unable to inform any meaningful and constructive energy trends of recent time (Brown et al., 2014). The importance of taking into consideration latest development becomes more apparent from the fact that these energy concepts have direct effect on international relationships and policy decision making (Kessler and Kessler, 2017). As a result, the changes in energy security may bring about substantial changes in the international system itself (Nyman, 2017).

There are many factors that can lead to direct or indirect effects on energy security. One example was of the surges in oil prices in 2008 that was followed by global recession. In contrast, another example is from the start of 2016, which saw the sudden decline in oil prices. These both events resulted in market instability and negative growth (Filipović et al., 2018).

A lot of significant energy security factors are not quantitatively measurable, which can further worsen a situation.To quantify such factors, however, is extremely difficult. There is no standard benchmark to quantitatively measure, say, a nation's political instability (Radovanovic et al., 2016).

Moreover, it should be acknowledged that energy security is not confined to local situation but is a global phenomenon and any changes on the global market directly affects it. It is, thus, by continuously keeping track of energy security over an extended period of time can a certain conclusion be drawn and changes made correspondingly.

To understand what old challenges does bioenergy solve or what new challenges does it bring with respect to the energy security of the EU, it becomes imperative to access the political and economic forces present in the EU that influence the effects of large-scale bioenergy distribution.

2.5 PEST Analysis: Definition and rationale

Owing to the theme of the thesis, a thorough analysis of energy security indicators is required for the selection of the relevant Energy security components, dimensions, indicators, and metrics. Therefore, the PEST tool is used to provide a holistic overview and coherence to the energy security framework as the elements of PEST interact directly with the dimension (and, therefore, indicators) of the energy security literature that has been used here.

With regards to bioenergy, Nunes et al. (2016) used a PEST analysis to test and subsequently prove that biomass could be employed as a replacement for fossil fuels in the Portuguese textile dyeing industry (Iglinski et al., 2016). So, in the context of bioenergy, the PEST analysis has been successfully employed before.

2.5.1 PEST Analysis: Definition

PEST is an abbreviation for the Political, Economic, Social and Technological issues that may have implications on the strategic development of a business (Nunes et al., 2016). According to Nunes et al., (2016), it helps to study external operating conditions of a business by capturing the variables involved for that particular scenario.

Figure 6 captures the over compassing theme of PEST toll with the renewable energy resources (Igliński et al., 2016).

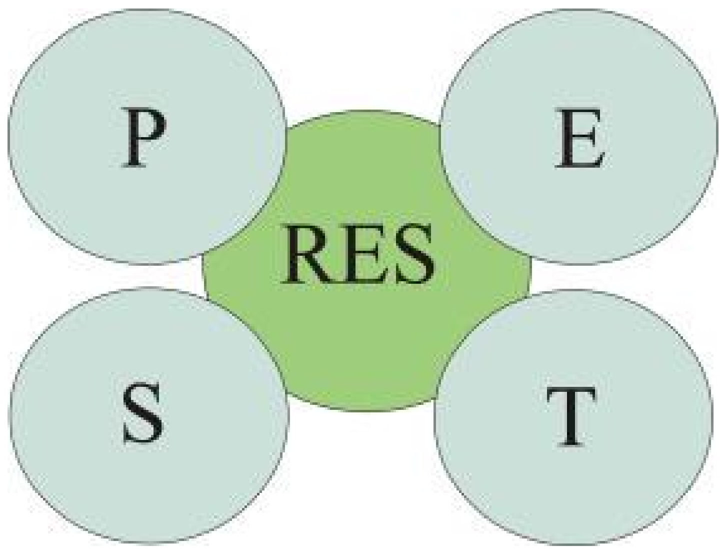

Fig. 6. Macro-environmental factors RES; P – political, E – economic, S – social, T – technological (PEST analysis) (Igliński et al., 2016)

PEST is a market analysis tool that is also helpful in tracking the growth of external elements as well helping in as making strategic decisions for a business (L. Shilei, W. Yong, 2009), (D.N. Koumparoulis, 2013). The business environment to be tracked for this thesis is the bioenergy sector of the EU.

A. Gupta (2013) states that the environmental factors for the PEST can be specified as:

“- Political macro-environmental factors: among others, political stability, renewable energy policy, legislative framework.

- Economic macro-environmental factors: among others, the current business environment in Poland and the rest of the world, job market, interest rates.

- Social macro-environmental factors: among others, demographics, knowledge of renewable energy sources, human resources structure and availability of workforce.

- Technological macro-environmental factors: among others, economic innovation in the renewable energy sector, transfer of techniques and technologies.” (A. Gupta, 2013).

Hence, it is possible to use the PEST analysis tool to identify multiple ES indicators from energy security literature and categorize them into political, economic, social, and technological (P-E-S-T) indicators respectively.

2.5.2 PEST analysis: Rationale

According to D.N. Koumparoulis, (2013) "P.E.S.T analysis is a useful strategic tool for understanding market growth or decline, business position, potential and direction for operations. The use of P.E.S.T. analysis can be seen as an effective tool for business and strategic planning, marketing planning, business, and product development and research reports" (D.N. Koumparoulis, 2013).

The prevailing economic conditions tend to affect capital availability and cost, and demand, which in turn is the measure of the ease or difficulty (in terms of success and profit) of implementation of strategies at any given point of time (Thompson, 2002). Economic conditions dedicate the timing and relative success of any strategy.

The economic condition, in turn, tends to be largely influenced by the prevailing political and government policies. The social-cultural environment captures changing demands and needs (D.N. Koumparoulis, 2013). Technology is also included in various literature on strategic (Johnson and Scholes, 2008), as an integral tool in any energy sector which helps provide a competitive edge. Furthermore, with the help of government policies and instrument, the technology which is external to the energy sector can also be incorporated and taken advantage of.

Table 2. List of elements in the PEST components (Yasemin Oraman, 2014).

PEST components	Elements in the component
POLITICAL	Global, national, regional, local and community trends, changes, events etc.
ECONOMIC	World, national and local trends, changes, events etc.
SOCIAL	Development in society-culture, behavior, expectations, composition etc.
TECHNOLOGICAL	Developments: computer hardware, software, applications, equipment, materials, products etc.

From Table 2, an indication is given into one of the sets of components and elements which is derived from the PEST analysis tool. Many elements can be taken into account when considering the bioenergy implication and possible changes it could bring (Yasemin Oraman, 2014).

Therefore, the PEST components can be further delineated in the form of elements and factors. Some of the main factors indicating each component has been described below (D.N. Koumparoulis, 2013):

Political Factors (D.N. Koumparoulis, 2013)

- There are structural changes in public administration.
- Government cutbacks.
- The Political environment of the EU can change (BREXIT, talks of Netherlands and Italy leaving the EU in the elections).
- Due to a relaxed policy in trade restrictions and tariffs, the market of the EU is very much accessible to the rest of the world.

Economic Factors (D.N. Koumparoulis, 2013)

- This directly results in the volume of trade as it affects the capacity of the customer to spend and a business firm's ability to supply.

Social Factors (D.N. Koumparoulis, 2013)

- Demographic changes: Market patterns depends upon the changing landscape of average population age and ethnic distribution.

Technological Factors (D.N. Koumparoulis, 2013)

- International communications
- Technological changes: Advancement in technology has led to shake-up of business around the world. New technologies require new set of services that the business companies must offer and adhere to.

With the P-E-S-T elements, the dimensions of energy security and their respective indicators and matrices now can be analyzed in the light of their socio-economic and political context of the EU and bioenergy.

2.6. Added Value of PEST for this thesis

A literature study has been done in order to group indicators into the categories of political, economic, social, and technological components which relate the dimensions of energy security studied in this thesis.

The shortcoming of energy security literature have shortcomings for a more comprehensive context of bioenergy based systems and its effects, PEST tool can give a more overarching umbrella in the context of bioenergy. The interaction between environmental and political aspects of bioenergy is paramount to carry this research. It helps provide the study of indicators by imposition and characterization of bioenergy sources in the larger context of current energy scenarios.

After a detailed Energy security literature review, from the ES literature, the ES dimensions were selected into clear areas of technological, availability, regulation and governance. The PEST analysis, apart from the wider categorization, provides new link and insights among the ES indicators and metrics relevant to bioenergy in the EU. The interaction of PEST and ES for bioenergy system derived from this thesis has been further outlined in chapter 5.

As seen from fig.5, the current energy security frameworks provide too many metrics without any solid line of approach for selection and relevance of ES indicators and metrics. Here, the PEST tool fulfills the void and the relevant selection of ES indicators and metrics can be done for the analysis.

The PEST and ES are combined for the understating of the impacts on ES indicators and metrics in new and complete scenarios/domains of fields, which is included in the ES literature. The ES indicators do not exclusively focus on renewable energy systems, and bioenergy systems become even more important to be specifically defined. The current ES literature cannot suffice the needs to evaluate a bioenergy-based system. PEST adds relevance for data gathering for each ES indicator and metric and identify the type of bioenergy source to be investigated.

PEST capture the overall interactions between different dimensions of energy security literature and how they develop and link in bioenergy systems. It gives an overview of ES interaction and narrows down the scope of research for this thesis.

Additionally, PEST gives a framework to the ES indicators and metrics by giving a more clearer structure in form of poetical, economic, social, and technological categories. It is a very helpful tool in order to figure out the most suitable and relevant energy security indicators and metrics for this study.

All the indicators related to political, environmental, social and technological factors of bioenergy have been selected as to try to reflect the goal of the thesis i.e. to provide a working framework for gauging the impact of bioenergy for the energy security of the EU. The selection has been made for the dimensions of political, economic, social and technical. All the key variables from the literature for these dimensions have been specified and studies.

The dimensions have been selected keeping in mind the central theme of this thesis: the role of biomass for the energy security for the European Union. The selected dimensions would help in understanding the new challenges that bioenergy bring with regard to energy security and its effect on the old challenges that already exist. These dimensions would also help to strengthen the technical profile of energy security.

The following section compares the difference between the PEST and ES literature with regards to bioenergy security and why PEST is needed to better carry out this study.

2.7 Formation of a new framework

2.7.1 Selection of the ES Indicators: PEST vs ES

In order to identify the indicators for the analysis of the impact of bioenergy on the energy security for the EU, a thorough energy security analysis along with the PEST analysis tool was employed.

Apart from the shortcomings of energy security literature mentioned in section 2.4, there are some more factors as to why the current ES literature is deemed not sufficient for this thesis. Figure 5 also captures the approach for the ES literature with regards to energy security. Although it has outlined many potential ES indicators, it does not suffice the need of this research as it fails to provide the clear broader classification on how to proceed with the selection of the indicators and metrics. The ES literature, by itself, could not have sufficed for this thesis because of too many undefined and vague metrics, especially for the study of the effects of bioenergy. With factors like dam safety, oil tankers, nuclear material, gas explosivity, etc., the current ES literature is more suited for the study of the traditional fossil fuel based energy systems rather than bioenergy based systems.

Therefore, for the formulation of a bespoke framework for the study of bioenergy in the EU, it is necessary to have the PEST tool.

2.7.1.1 New comprehensive energy security assessment framework

After the full analysis of energy security literature that is relevant to bioenergy in the EU and the definition of PEST, the relevant energy security factors and dimension can now be selected as to form a new framework. This new framework would analyze the theme.

Figure 7 (below) shows the schematic diagram of the new working framework to access the impact of biomass on the energy security for the EU on selected dimensions and variables**.**

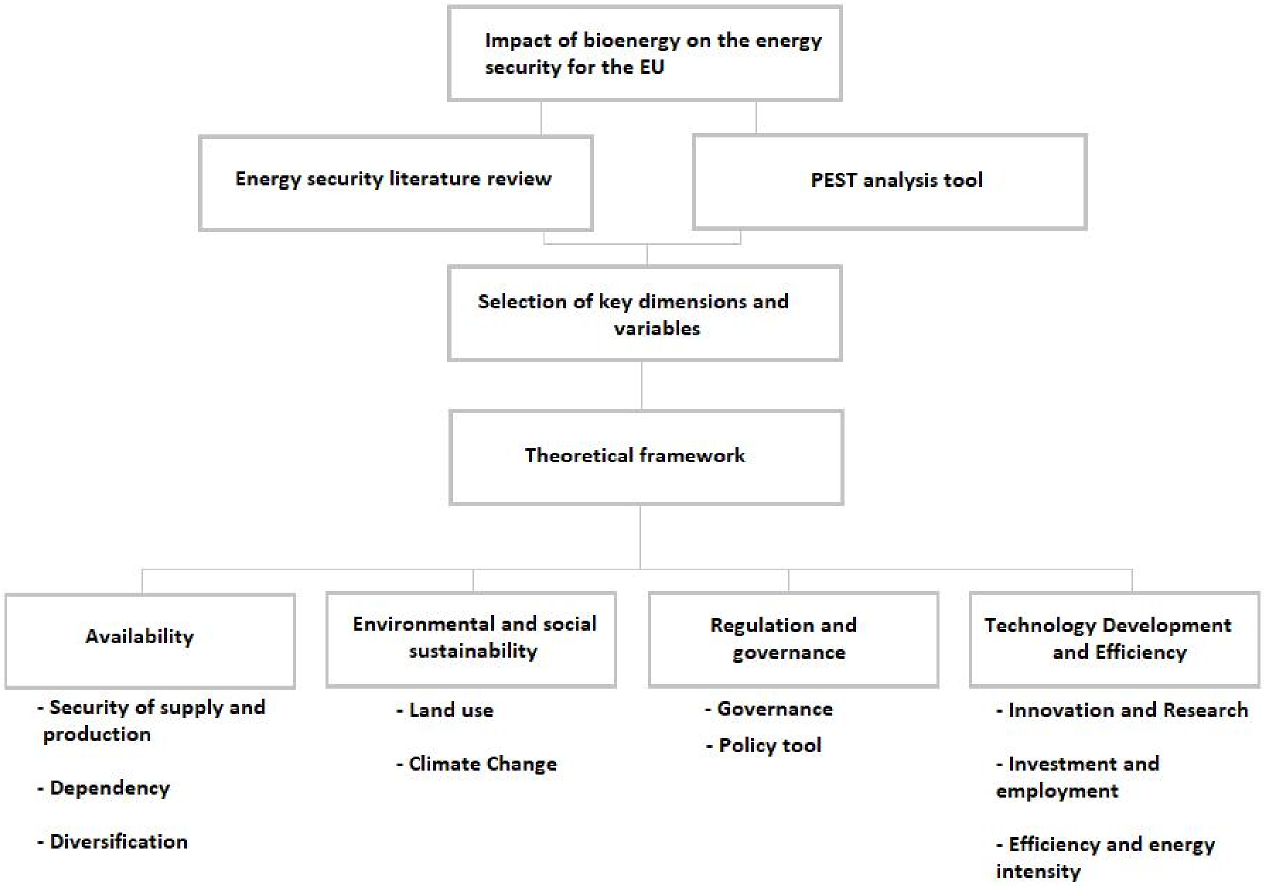

Fig. 7. The schematic diagram of the new working framework to access the impact of biomass on the energy security for the EU on selected dimensions and variables**.**

All the indicators along with the corresponding dimension are represented in table 3. This would be tested throughout the subsequent sections of this thesis. The indicators and dimension have mainly been derived from the energy security literature of Sovcool and Mukherjee (2011) and The GBEP sustainability indicators for bioenergy (GBEP, 2011). These papers on energy security are comprehensive in their research regarding the energy security dimensions and indicators and most importantly, their relevance meets the requirements of this study.

Following is the derived table (table 3) from Sovacool and Mukherjee (2011) of the energy security indicators and metrics for the bioenergy in the EU:

Table 3: New framework assessment for energy security

Dimension	Indicator

Availability	• Share of renewable energy in total primary energy supply • Total energy supply • Availability of renewable energy resource • Proven recoverable energy reserves • % of imports coming from outside the region • Diversification of fuels for transport • Diversification of fuels for heating and cooling
Environmental & social sustainability	• Deforestation related to energy use and fuel collection • Generation of energy-related industrial and municipal solid waste • Energy pollution's impact on habitats • Expenditures on financial support mechanisms for renewable energy • Planned new energy projects including construction status of approved project • Total greenhouse gas emissions from energy production and use • Generation of energy-related hazardous waste • CO_2 reduction targets • Share of zero-carbon fuels in energy mix • Carbon content of primary fuels
Regulation and Governance	• Presence of climate change goals or targets
Technology development and efficiency	• Research budget for biofuels • Induced employment in the energy sector • Indirect employment in the energy sector • Research budgets for renewable sources of energy

2.7.2 Summary of criteria and conclusion

In order to access the impact that bioenergy in the EU would have on the energy security, this section discusses many routes that could be employed to reach a working framework that could test the impact of the stated goal. The section started by revisiting the existing definition of energy security and literature related to it. It is found that energy security in itself would not be sufficient as there are many shortcomings regarding the greater political-economic implications in the context of the EU. Hence, the PEST analysis tool was employed to make up for this shortcoming and provide additional structure.

The indicators and dimension have been derived mainly from the exhaustive work of Sovacool and Mukherjee (2011) on energy security dimensions which describe over 20 components and indicators. It forms the basis for the new comprehensive assessment framework. For the purpose of this research study, the 20 components and indicators from Sovacool and Mukherjee (2011) have been distributed over five chief dimensions. They are as follows: availability, regulation and governance, technology development and efficiency, and environmental sustainability. From these four dimensions, key simple indicators and metrics are selected. Table 3. shows the relevant indicators and metrics selected from Sovacool and Mukherjee (2011) for this study.

The framework, therefore, is a bespoke framework catered to test the case for this thesis. The selection of dimensions for this framework along with the employment of only the relevant indicators and metrics has been made.

Figure 8 represents the selected energy security dimensions and their indicators and metrics for this study. All the indicators have been tested on the rating scale which will be described in the next section. There are a total of 22 selected energy security indicators and metrics.

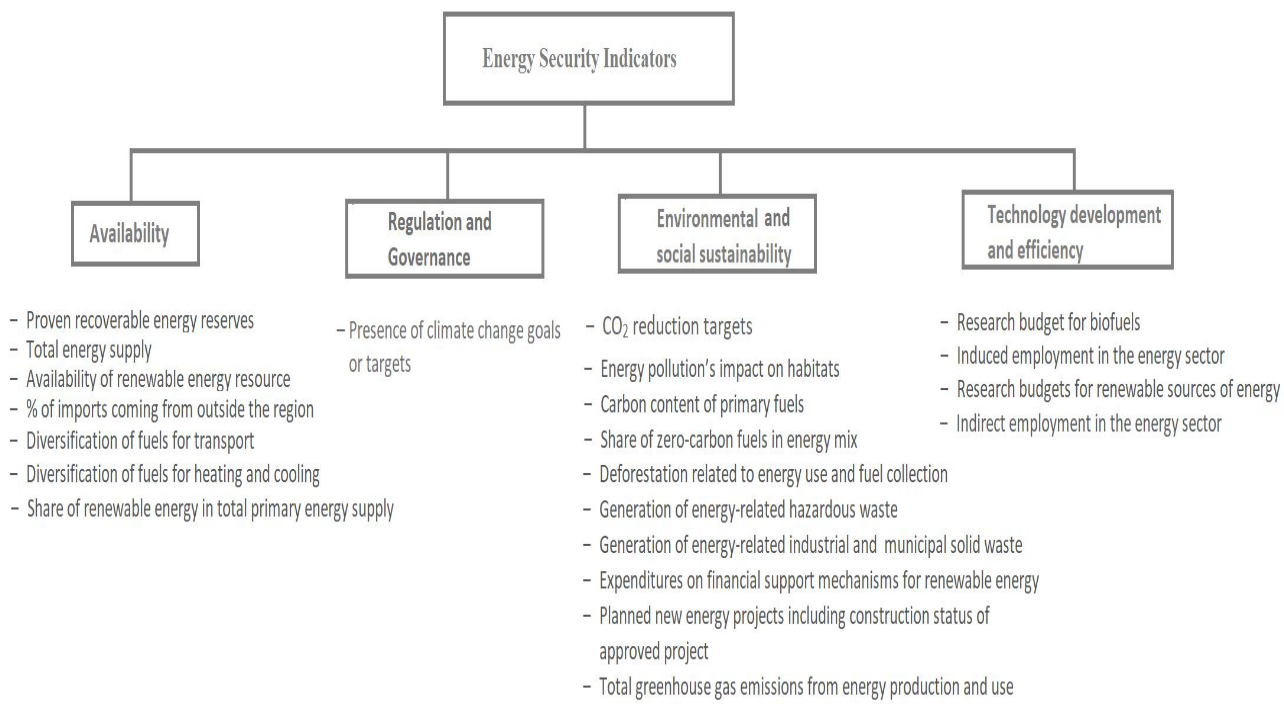

Fig 8. The selected energy security dimensions and their indicators for this study.

2.8. Operationalization of framework: Ratings and Effects

The literature analysis in this section has led to the selection of security indicators relevant to the themes of the thesis. Every dimension of energy security has been divided into several indicators. This resulted in the new framework, as depicted in table 3. The framework is selected to test the implications with respect to bioenergy. The implications of bioenergy in the past 20 years, post-2000 for the energy security for the EU, will be tested on the new energy security framework. It will be done by investigating the political, economic and technical effects of implementing bioenergy in the EU. The effects will be measured and rated in a qualitative way on a rating scale of 1 to 5. The indicative scale measures the effects on the energy security of a particular indicator or metric. The indicators and metrics who have a very negative effect get a score of 1, negative with a score 2, no effect with a score of 3, positive effect rated at 4 and very positive effect with a score 5.

Therefore, the rating scale (1 - 5) is as follows:

1 = It has a very negative effect

2 = It has a negative effect compared

3 = No effect or a very little effect

4 = It has a positive effect

5 = It has a very positive effect

Rating Scale: Schematic for the rating scale used for the energy security assessment criteria.

The rating scale works as follows:

- When an indicator gets '1' on the rating scale, it implies that the effect of this indicator on the energy security for bioenergy in the EU has been very negative.
- When an indicator gets '2' on the rating scale, it implies that the effect of this indicator on the energy security for bioenergy in the EU has been negative.
- When an indicator gets '3' on the rating scale, it implies that the effect of this indicator on the energy security for bioenergy in the EU has had no major effect.

- When an indicator gets ‘4’ on the rating scale, it implies that the effect of this indicator on the energy security for bioenergy in the EU has been positive.
- When an indicator gets ‘5’ on the rating scale, it implies that the effect of this indicator on the energy security for bioenergy in the EU has been very positive.

With regards to the weight of each indicator, for the present study, all have been kept equal as it serves the purpose of the study to get a comprehensive and holistic overview of effects of energy security indicators and metrics in general. These points are discussed in the section of ‘discussions and reflection’ in chapter 5.

2.9. Salient features of the framework

The selection of energy security dimensions is made in order to capture the role of bioenergy sources in the EU since 2000. It includes the past and current bioenergy status in the EU.

The selection of variables is done to include all the major dimensions of energy security in the analysis. The dimensions of ‘Environment’ has the most number of ES indicators and metrics. As the sustainability of bioenergy has been fiercely debated in the EU since 2010, as it examined more carefully in the thesis. The ES indicators of other dimensions are also analyzed to help reflect and gauge the changes not only in the energy security of the EU but also in the policy-making of the EU with indicators related to regulation and governance, and employment effects.

Other variables like different forms of bioenergy are also included. Biofuels and solid biomass form the bulk of the bioenergy sources but the study is not limited to them. Municipal Solid waste, forest and industrial bio-waste, biogas, biomaterials are also included in the energy security indicators where they are relevant. PEST tool helps in framing the content and data for the ES indicators. This interaction of PEST and ES elements gives a definite direction to the research as well as more insights into the effects of ES indicators and metrics on bioenergy.

The framework is first of its kind for the assessment of effects of bioenergy on the energy security for the EU. The selection of energy security dimensions included in the framework is based in order to provide a holistic view of bioenergy implications. It is not limited to just biofuels or biomass but includes all forms of bioenergy in the EU. A link between the PEST and ES for these selected energy security indicators is made to reflect the impacts on the broader context of political, social, economic and technological scale.

While, there are frameworks for other renewable sources of energy like wind energy and solar energy, the source, generation and operation of the energy systems of bioenergy and other renewable energies widely differ, and therefore, a new framework is needed specifically to deal with bioenergy.

The framework tries to fulfill the space for an analysis of energy security dimensions related to bioenergy. It is employed for the study of the consequences that bioenergy has had on the ES in the EU in the last two decades. The ES components have been so selected as to provide a thorough picture of the bioenergy implications.

The components of bioenergy assessed, including biofuels and raw biomass, cover the range of social, environmental, political and technological elements. Unlike, conventional fossil fuel frameworks on energy security, the sustainability theme receives the most attention.

The earlier frameworks have not touched upon on the consequences of bioenergy on the major energy security components in the EU. Some of the frameworks who include bioenergy does not focus on it exclusively but with other renewable sources like solar and wind. This thesis tries to include all major and different forms of bioenergy employed in the EU under one framework.

The use of the PEST analysis tool also offers a unique combination of elements in the framework and a boarder categorization, which in traditional energy security is often not employed. With the PEST, the results can be viewed under the broader elements of P-E-S-T. Chapters on energy security and bioenergy (Chapter 2 and 3 respectively) provide a base and tool for further research into the link between energy security and bioenergy, which is absent from the current work of research.

Another important aspect is to answer as to how far the concept of energy security is able to capture security challenges or solutions that bioenergy is offering.

Energy security indicators form a new detailed energy security assessment framework. This framework is employed for analyzing the effects of large-scale biomass energy deployment and development for the broader operating system of the EU region. This broader system for developing bioenergy in the EU is described in the subsequent sections. It provides current status, projections, characteristics and a general profile of bioenergy in the EU. With the help of above the literature, the main indicators have been derived and the new framework has been formulated.

The new framework developed in this thesis has also moved beyond the traditional oil and gas frameworks. This framework combines the elements of bioenergy-related indicators and metrics of sustainability, climate change goals, economic, political, and technological elements, which allow for exploring the comprehensive implications of bioenergy based systems. Given the intricacies of bioenergy and its wide sources, production, and applications, bioenergy systems are different from the current oil and gas based systems. Therefore, there is a need to develop a new framework for the energy security of bioenergy systems.

2.10. Conclusion

This section tried to analyze the concept of energy security in different settings and also highlighted the different themes and roles it adopted over the years. With the multitude of definitions and approach, energy security comes across as a concept with various themes and definitions (Jonsson et al., 2015).

From the analysis of energy security literature, it can be concluded that energy security is indeed more of a concept than a theory. Therefore, the concept relevant to this study has been selected and tested to form a new working framework for bioenergy in the EU. PEST tool is also employed as the selected indicators and metrics fall under the scope of its analytical assessment.

From the energy security indicators of Sovacool and Mukherjee (2011), the relevant energy security components and dimensions were identified and a suitable list of indicators was selected. The relationship between the PEST elements and energy security dimension was established in figure 6. With the help of the PEST tool, a broader classification of the energy security dimensions was made for this study. These dimensions fall under the important and broad categories of political, economic, social and technological elements.

Overall, 22 simple energy security indicators and metrics have been identified for this study and these will be tested and rated on the proposed rating scale in this thesis. The choice of simple indicators over complex indicators has been made as the simple indicators are more suitable for a rapid, snapshot appraisal of energy security (Sovacool and Mukherjee, 2011) and it also gives an opportunity to cover more indicators for a comprehensive analysis. The full list of simple and complex indicators along with all the energy security dimensions and components have been provided in Appendix I.

CHAPTER 3

Bioenergy in the EU: Trends, projections, and characteristics

After having formed a framework in the last section, this section will serve as an introduction to the trends, economy, and characteristic of bioenergy in the EU. The goal of this section is not only to inform the growth and status of bioenergy but also provide data that will serve the case in the next section to test the indicators and their net effect.

The chapter starts with a review of the current policy of the EU for bioenergy. It then presents all relevant data related to bioenergy like various bioenergy potential, total energy consumption, and demand, etc. Then, different characteristics and featured of bioenergy are described along with the various conversion routes to obtain different forms of energy (namely biofuels, bio-electricity, and bio-heat) are explained.

3.1 Bioenergy: Definitions, Characteristics, and sustainability

3.1.1 Bioenergy definitions

Bioenergy is defined by Carmen Lago et al., (2019) as "renewable energy produced from natural sources capable of replacing fossil energy". A gamut of biological resources could be employed as to be used for bioenergy production like wet organic wastes, agro by-products, energy crops, from forest and crops, biomass residues, and municipal solid wastes (mainly the organic part). Other potential options include seaweeds, microalgae, seaweeds, macroalgae and aquatic plants (OECD/IEA, 2017).

Carmen Lago et al. (2019) describes bioenergy as a sustainable source that can be used to generate power and provide for heat, gas, and fuel to produce heat, electricity, and co-generation and transportation fuels irrespective of its derived source. In recent times, biomass has found new applications as in for the production of biomaterials and bioproduct (Carmen Lago et al., 2019).

For the research of this thesis, the biomass refereed here excludes the traditional use of solid biomass (cooking fuel, lighting), prevalent in most underdeveloped and developing countries, on account of its polluting nature. Use of processed biomass such as pellets refers to modern biomass.

For the supply of biomass, dry biomass has the ability to get transported easily for longer distances. Biofuels are mainly deployed for road transport, with significant potential for shipping and aviation sectors still there to be utilized. Waste biomass for electricity. Bioenergy can be used for heating directly or indirectly for CHPs plants.

Biomass technologies have significant advantages of scale and the use of CCS, a technology attributed to fossil fuels in the past, will become a significant option for GHG mitigation (Johansson, 2013). In terms of bioenergy sustainability, bioenergy feedstock comprises various different products and by-products from areas like forestry, waste sectors (animal waste, sugarcane, wood, wheat straw) and agriculture.

The following representation provided by EUBIA illustrates the various conversion routes of raw biomass to different forms of bioenergy.

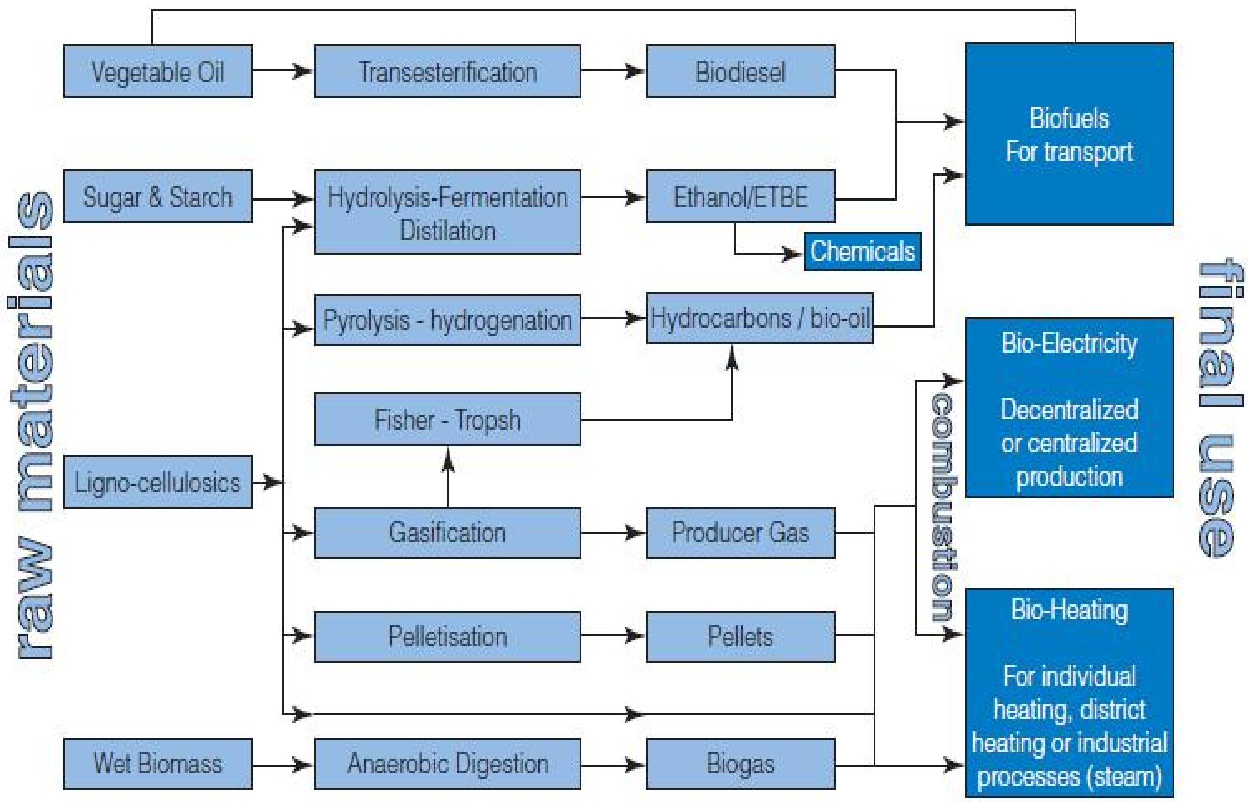

Fig. 9. Biomass raw materials conversion routes to various forms of bioenergy (EUBIA, 2009).

Figure 9 above demonstrates the multiple conversion routes available for biomass to be converted and modified to the final products. The three main final forms of energy have been shown here: Biofuels, bio-electricity, and bio-heat. Chemical treatment or non-combustion routes are employed to obtain biofuels as the final energy source, while combustion results in bio-electricity and bio-heat as the final form of energy. This versatility makes bioenergy unique than other sources of energy, and with it comes the complexity to map-out an efficient energy plan.

There has been an increase in active research for biobased chemicals like bioplastics. Many chemical-based industries have adopted the route of bioenergy and the production of biochemicals, bioplastics, and bioproducts, in general, have increased in recent times. This field holds much promise, as it has been endorsed largely by the chemical industry. A simple process may look like as shown in figure 11. Figure 10 (below) shows the many conversion routes that are available to biomass feedstock to be converted into polymer. Biomass can be processed by many methods like mechanical, chemical, thermochemical and biochemical, making it very versatile as raw material and ensuring a wide range of end-use applications/products.

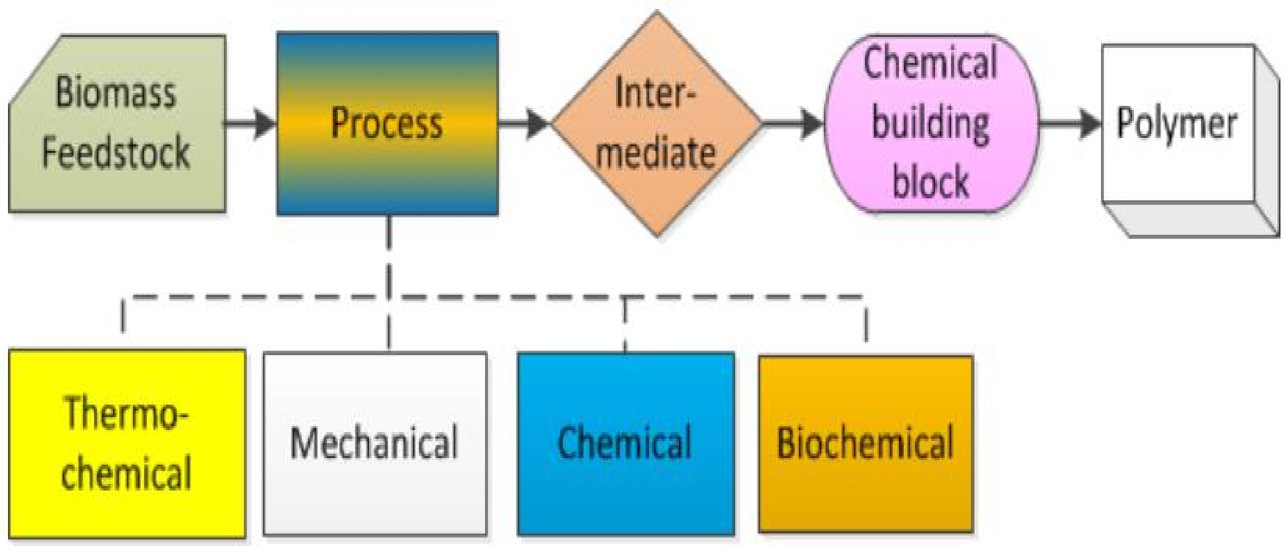

Fig. 10. Biobased process for conversion to various polymers (Harmsen and Hackmann, 2014).

3.1.2 Biomass Characteristics (Prabir Basu, 2018)

The characteristics and features of bioenergy can be classified into several elements. From the distinct characteristics to its ability to be used as a fuel, and from its technological benefits to its environmental effects. The following are the various characteristics/features of bioenergy.

3.1.3. The Distinct characteristics of bioenergy (Şebnem Yılmaz Balaman, 2019)

Biomass can be manually produced (2nd generation biofuels and energy crops). Some biomass is a dispatchable form of energy. It can be stored for a long duration. Some biomass is seasonal, it comes under the variable renewables like seasonal energy crops. Transportation is possible for long distances without loss in the energy content (Michael S.A.Bradley, 2016). There are varied conversion paths that can transform biomass into all forms of energy: heat, electricity, biogas or biofuels.

3.1.4 Technological benefits (Röder and Welfle, 2019)

Technology transfer and exports on account of modern competitive biomass technologies and experience. Wastelands and marginal agricultural areas can be productively utilized.

It offers an enhanced efficiency of energy conversion and usage with various other forms of energy carrier that can be derived (Johansson, 2013). This results in increased energy security and less dependence on politically volatile regions (fossil fuel exporters).

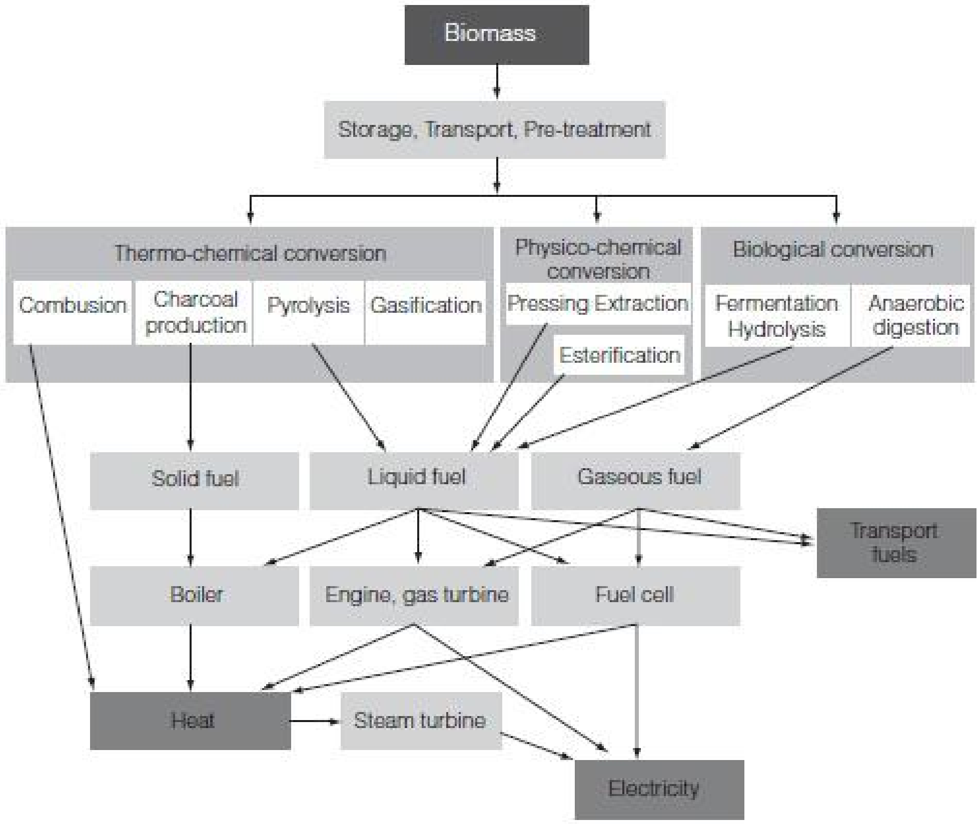

Fig. 11: Various paths of bioenergy conversion to final products (European Commission, 2012).

*3.1.5. Biomass as a fuel (*Sánchez et al., 2019.)

Biomass as fuel is widely available through the European Union. It can be employed in all energy sectors: transport, heating, and power. Furthermore, It has better price mechanisms than fossil fuels. It also got huge potential in the long term use and, finally, it is easy to store and transport.

3.1.6 Environmental characteristics

Replacing fossil fuels by bioenergy results in the reduction in toxic emissions and greenhouse gases like SO_x and CO_2 mitigation. It can be derived from residues and waste (forestry, agro-industrial), reducing pollution and the cost of disposal (S.Sacchelli, 2016). Biomass-based fuels tend to be bio-degradable and non-toxic in nature. Finally, the potential is huge, algae biofuel and jet fuel based applications are highly sustainable (Araújo et al., 2017).

3.1.7 Other characteristics

Biofuels can be artificially produced through algae and other bioprocesses. Some forms of bioenergy are finite yet replenishable (Plants, waste, etc.) (Jeguirim et al., 2019). All the EU countries have some kind of bioenergy but the quantity differs. It offers active trading of raw materials. The transportation routes are well established like for fossil fuels.

Figure 12 (below) suggests that the biodiesel has a high volumetric density (38MJ/l), its gravimetric density (26 MJ/KG) is on the lower side (Fisher et al., 2009). When compared to diesel, it falls short on both densities which means it has less power to deliver for the same volume. Hence, there would be a small compromise in the overall performance. However, the difference between biodiesel and fossil fuel derived diesel is significantly large, and with technological advancement, it is likely that the overall performance of biodiesel and well as bioethanol would show a lot of improvement. Furthermore, biofuels, though controversial, are seen environmentally much more benign than fossil fuels, especially advanced biofuels. As a result, many EU member states promote and mandates the active bending of fuels in the transportation sector.

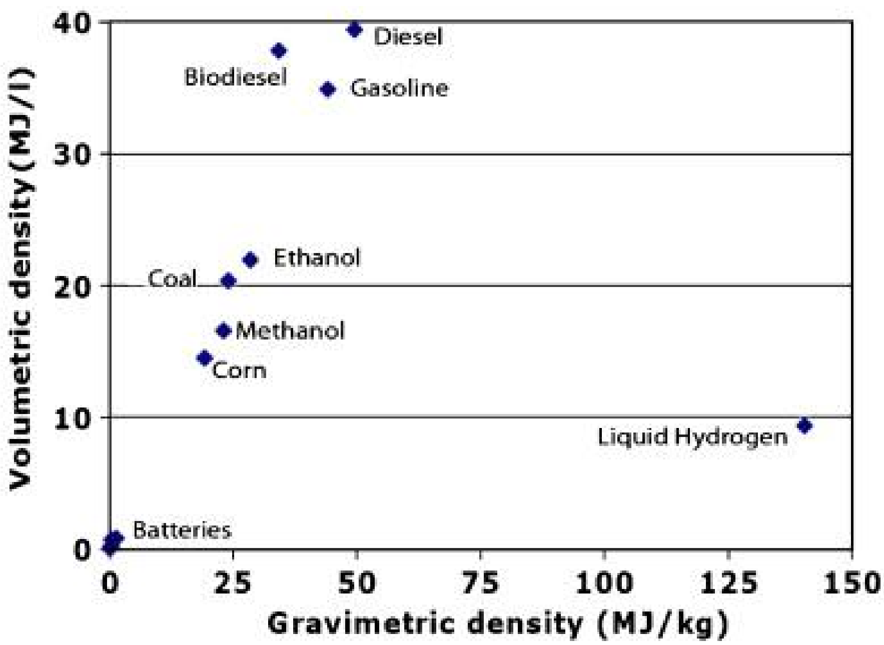

Fig. 12. The caloric energy density of biodiesel compared with liquid fuels and energy sources (Fisher et al., 2009).

Biomass is a renewable resource that can be produced infinitely given fertile soil and land quality and water management. Biomass rather than being a depleting stock can be modeled as a continuous stock given the resource quantity is proportional to the selected time-frame (Islas et al., 2019.)**.** Tensions for land usage between biomass production and other applications raises a possibility for conflicts between biomass production and production for paper, food, and wood along with concerns for urbanization and biodiversity (Popp et. al, 2014).

Unlike gas and oil fields or coal mines, biomass is geographically spread over a wide area but lower in concentration. Despite an increase in the productivity of land, the quantity of biomass obtained is still strongly proportional to the area that is used for harvesting. As a result, the biomass production land effects (both indirect and direct) are difficult to gauge and record.

Conversion of biomass to useful energy services requires a panoply of conversion technologies as biomass can vary from wet or dry materials, agricultural or forestry residues, energy crops or municipality waste, etc. However, some of these conversion technologies are in a nascent state and are not yet commercially viable. Therefore, as with biofuels, the development and biomass resources largely depend on the shape of technological markets (J. Speirs et al., 2015).

As bioenergy is able to substitute for fossil-fuel based application on a large scale (like energy application) and also provide a base for other chemical and materials applications, it becomes an essential part of the green economy. It can fully integrate the myriad range of natural and renewable biological resources like the plants or sea resources and biological processes (Merklein et al., 2016).

3.2 Bioenergy in the EU: 2000 and 2020

Although the main theme of the thesis is to study the past implications, a sub-section has been dedicated to showing the potential and some projections for bioenergy sources in the EU in the immediate future i.e. 2020 and beyond. This would serve as a direction and better help understand the way policy-making has changed and will likely to change in the immediate future. This is an added feature of the thesis, which though, not directly affecting or contributing the end analytical research goal of the thesis, does give an overall picture and direction of bioenergy in the EU, which makes the research more comprehensive and helps in forming better-informed recommendations.

3.2.1. Statement of the current policy of the EU

European Commission (EC) has put in a continuous effort and reinforce policies that promote renewable energy (RE) and energy efficiency among the member states which has seen positive aggregated outcomes (Gökgöz and Güvercin, 2018).

Bioenergy has always attracted attention within the EU. While much focus has been on bioethanol in the US, biodiesel has dominated the bioenergy landscape in the EU. There are policies in place which mandates and promotes bioenergy in the EU. The energy policy of EU is structured around 3 goals of 'the security of supply, sustainability and competitiveness' (Bengt Johansson, 2013).

In June 2018, the EU governments reached a political agreement to raise renewable energy targets to 32% by 2030 (European Commission, 2018). This is seen as an ambitious target which would further spur the growth of renewables. The RES policy framework of the EU had started to take shape in March 2007 when the 27 EU members agreed on a binding target of at least 20 percent renewable energy from final energy consumption by 2020 (European Commission, 2018).

In 2016 for the total gross inland energy consumption of the EU, the renewable energy sources (RES) amounted up to 13.2 %. Wood and other solid biomass accounted for the highest share of the renewable energy sources. Tin the same year, the share from RES was the highest in Latvia (37.2%), closely followed by Sweden (37.1%) (European Commission, 2018).

In this period, 30% of the electricity generated came from renewable sources, nearly one-fifth of energy used in the heating sector i.e. for heating and cooling application came from renewable sources. For the transportation sector, of which biofuels are an integral part, 7% of renewable energy was used in 2016 (Eurostat, 2018). According to the Dutch national railway company NS, all electric trains are now powered by wind energy. The energy demand in Sweden is met with more than 50% bioenergy (Scarlat et. al, 2015).

Figure 13 depicts that the EU member states saw their consumption of renewable energy doubling between the time period between 2004 and 2016. The share of renewable energy sources in the gross final energy consumption jumped to 17.0 % in the EU-28 in 2016, from 8.5 % in 2004. Figure 18 (below) shows the total share of energy from renewable energy sources (RES), in 2004 and in 2016 in % of gross final energy consumption (Eurostat, 2018).

11 member states had already reached the renewable targets set for 2020 in the year 2016 itself. All other member states have increased the percentage of renewable energy share in 2016 as compared to 2004 in the final energy consumption (Eurostat, 2018).

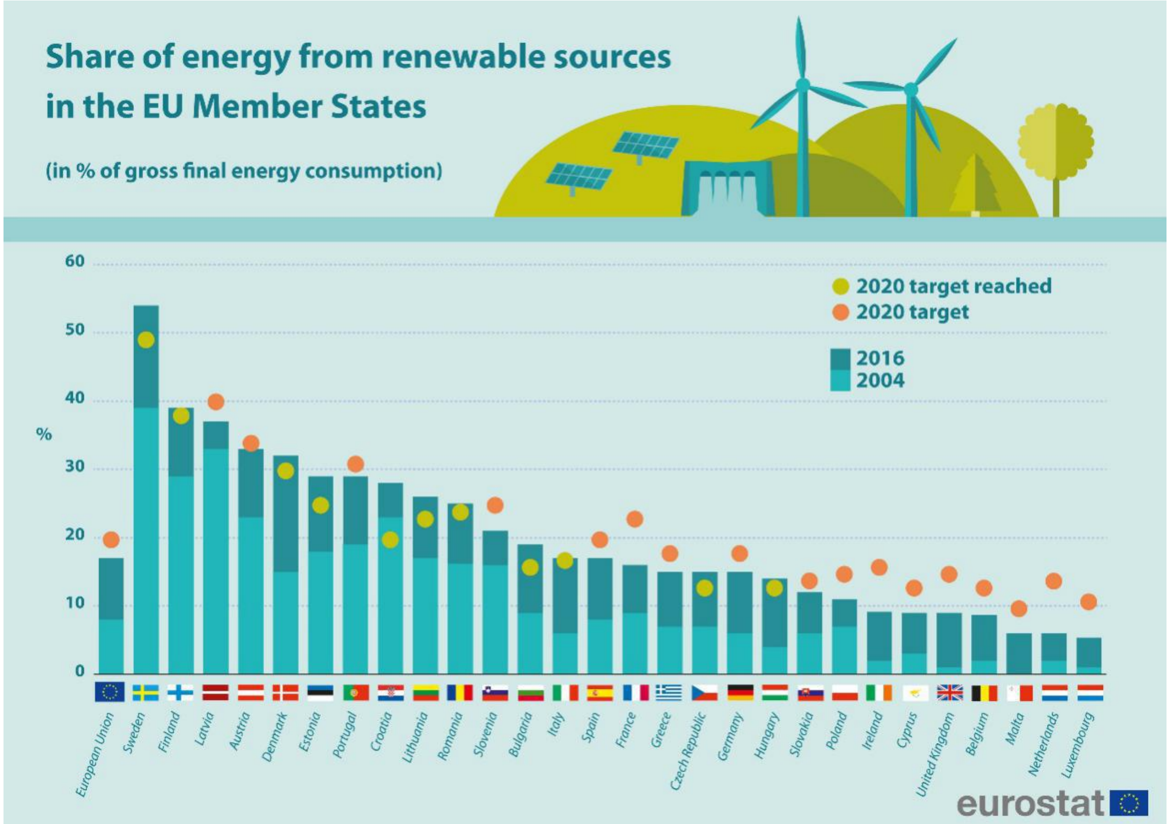

Fig. 13. The gross final energy consumption of renewable energy in EU member states in 2004 and 2016 (%) (Eurostat, 2018).

3.2.2. Current status of bioenergy in the EU

The European commission's EU commitment towards the three goals of the EU energy policy: competitiveness, the security of supply and sustainability will be duly analyzed in light of this scenario.

IEA Bioenergy in its 2016 reports describes the 'The Renewable Energy Directive' issued by the European commission. In this directive, new sustainability criteria are lined out for biofuels to be used in transportation sector that must met the target of a reduction in GHG emissions by 35% by 2017 and 50% after that (IEA Bioenergy, 2016).

Furthermore, under this directive, the EU member states need to make and comply with the official action plan for renewable energy, (called NREAPs) in order to meet their target of 2020.

Table 4 gives the total renewable energy targets for the EU states in 2020.

Table 4: Total renewable energy targets of the EU in 2020.

Sector	Share in gross final consumption per sector
Overall target	20%
Heating and cooling	21%*
Electricity	34%*
Transport	10%

(Source: NREAP, 2016)

Although bioenergy is one sustainable source of energy with high potential and availability to replace current oil-based fuels, clouds of uncertainty hang over its future availability. One of the major points of conflicts has been the inter-linkages and effects of biomass use on food production. Speirs et al., (2011) mention that large-scale use of biomass have resulted in a fierce debated over the sustainability of bioenergy and its continuity in the policy domain of the EU (Speirs et al., 2011).

The EU offers a fertile ground for bioenergy to flourish. To start with, bioenergy offers major financial benefits and savings. It accounts for a very cost efficient transition from fossil-fuel and coal economy to sustainable and renewable one as the need for capital investment is minimal. Biomass co-firing and conversions to the biomass of coal-derived fuels utilizes the existing infrastructure and coal reserves to produce renewable energy. For other renewable energy sources, this doesn't exactly hold true (Albani et al., 2014). Secondly, bioenergy has the potential for being the source of base-load power in the EU without any significant capital costs to the grid. Solar and Wind energy with the solar roof-top and wind farms could provide only a limited share and cannot fully serve this purpose, so bioenergy provides a chance for the European utilities to scale-up and takes advantage of the second wave of renewable energy source growth. Bioenergy thus gives an opportunity for the EU utilities to realize and further their renewable targets and simultaneously exploit their existing assets (Albani et al., 2014).

Technical and geographic characteristics of bioenergy have to be understood in order to follow a thorough analysis The set of new risks along with tensions in these new relations could be more localized and national. Additionally, the massive diffusion of bioenergy in all the EU (hence, global energy mix) energy sectors would result in a shift to completely new energy dependencies (Emmanuel Hache, 2017).

The mapping of bioenergy potential in the EU has been undertaken in various shapes and forms, including forestry biomass potential, industrial waste potential, biofuel potential. A lot of estimates made by different organizations, governments, authors, etc. tend to contradict each other, and the scope and definition of as to what bioenergy accounts for also differ. In this thesis, official data published and used by government agencies in the EU has been used as the reference point.

Figure 19 (below) shows one such difficulty in estimating bioenergy potential in terms of knowledge of potential and knowledge of outcomes. One of the striking features of this figure 14 is the differences in the size of shapes of the theoretical eclipse and the realistic/implantable outcomes, showing the chasm between them. This implies there is more certainty as we move from a theoretical to a realistic outcome that the resources indeed exist and could be technically extracted. As we move toward the left, the figure indicates an increased probability that the prevailing social and political climate and policies will allow for the technical extraction and recovery of the resources.

This figure has been further discussed in the light of the results of energy security assessment framework in the section of discussion and reflection in chapter 6.

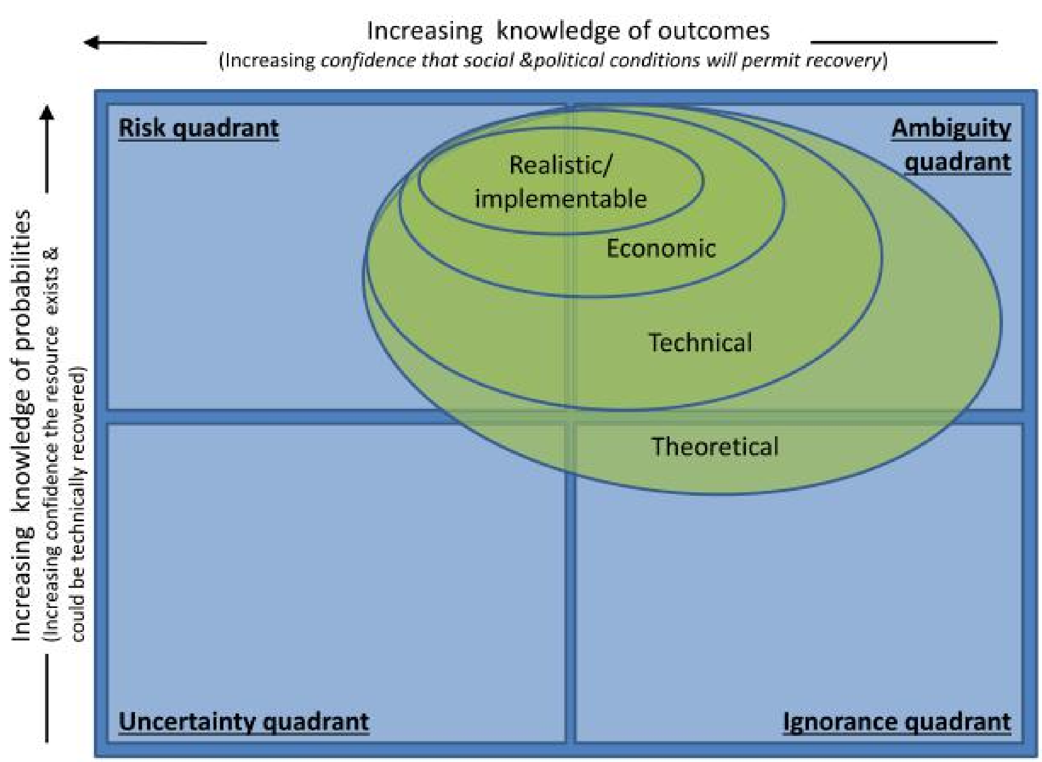

Fig. 14. Mapping biomass resource classifications to contrasting states of incomplete knowledge (J. Speirs et al, 2015).

3.2.3 Bioenergy trends in the EU: 2000-2018

Projections from many studies have been considered and taken into account. Most projections are drawn from the recent studies between the period 2016 to 2019, in order to obtain the latest estimations. Projection of development of energy sectors, based on the current review of plans and policy directions, that governments and other international bodies perceive have been delineated and discussed in this section.

There have been several scenarios envisaged where renewable energy is assumed to be the main policy instrument for the governments to combat climate change and safeguard energy security. The most relevant report has been published by the International Energy Agency (IEA) in its 2016 report, world energy outlook (WEO, 2016).

The consumption of bioenergy has been gradually increasing over the last few years in the EU. Bioenergy for heating has been the major sector of this consumption followed by biofuels and bioelectricity. A graph of this gradual consumption per sector from 2000 to 2020 has been shown in the figure below.

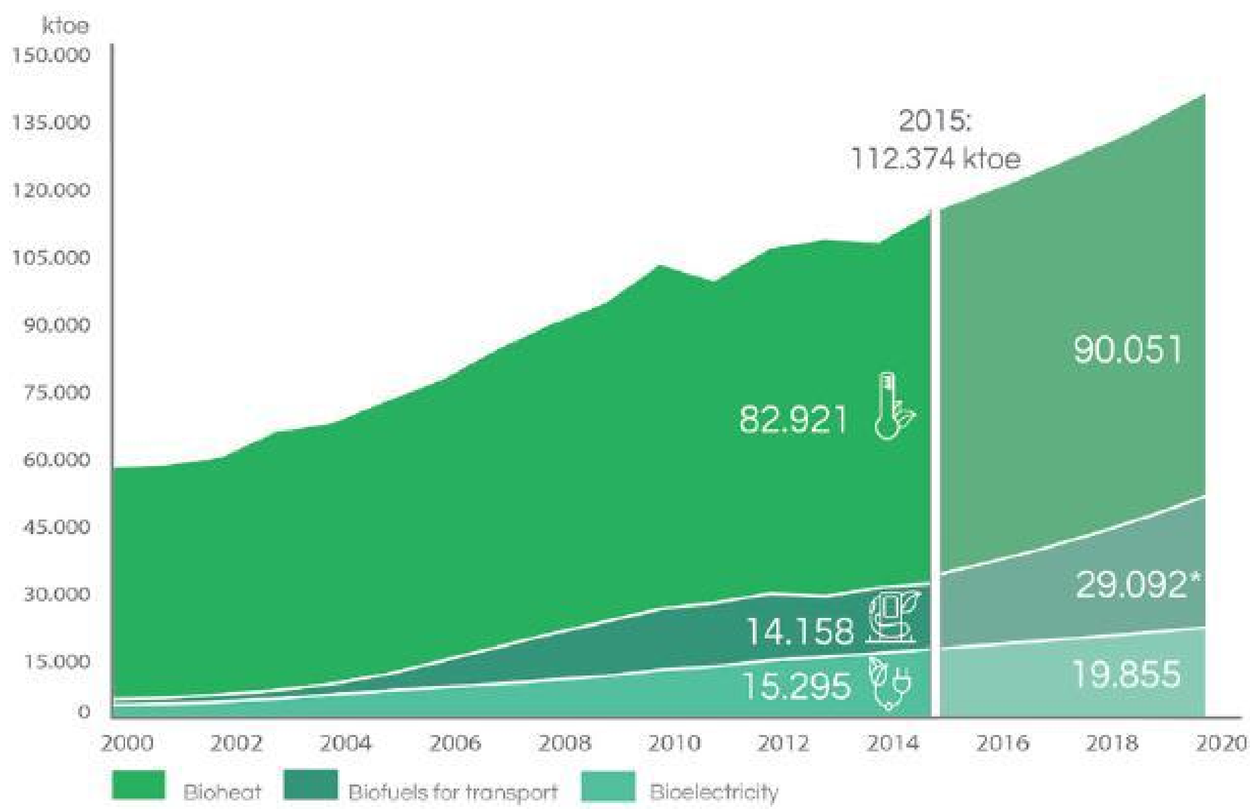

Fig. 15. The contribution of bioheat, biofuels, and bioelectricity of the total consumption of bioenergy from 200o to 2020 in Ktoe (AEBIOM, 2017).

Figure 24 shows how the consumption of bioenergy has evolved since 2000. In 2015, bioheat accounted for 73.79% of all bioenergy consumption, followed by bioelectricity at 13.61 % and lastly by biofuels for transport at 12.59%. The predictions for 2020 for bioenergy consumption stands as - bioheat accounts for 64.78 %, bioelectricity has a share of 14.28% and biofuels for transport at 20.93%. So, biofuels for transport see the highest growth from 2015 to 2020, an increase of 8% and the share of bioheat consumption drops by 9% in this time period.

Analyzing further, each sector can be divided per percentage share of the market segment. For example, for bioheat consumption, the residential heating market segment accounts for 51% of the total bioheat sector. A detailed pie chart has been provided below in figure (16) below.

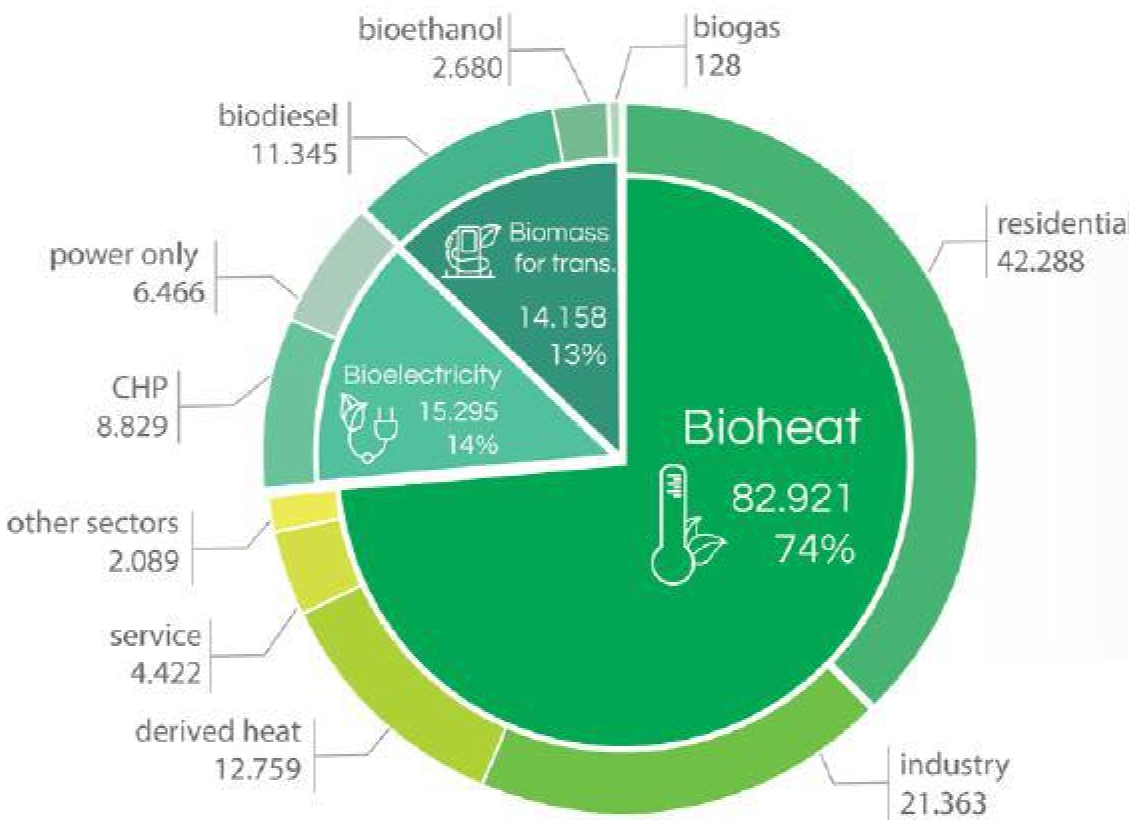

Fig. 16. Gross final energy consumption of bioenergy in the EU per market segment in 2015 in Ktoe, % (AEBIOM, 2017).

It is clear from the figure that biodiesel dominated the consumption of biomass for transportation with 80.13% of the total demand. While CHP (Combined heat and power) accounts for 57.72% of the total bioelectricity consumption. Heating sector by far remains the largest consumer of bioenergy in the EU with 74% of total consumption.

Currently, heat accounts for about 80% of energy demand in the buildings sector. In the EU, this demand is mostly directed to space heating. Bioenergy contributes to more than 50% of the total renewables that accounts for 9% of heat demand in buildings.

In the EU, when the costs of fossil fuels are high, then the levelized cost of heating favors bioenergy (due to energy taxation). Currently, bioenergy meets 15% of space heating demand in the EU and is set to be one of the lowest cost options for space heating in building by 2020 2020 (WEO, 2016) as is shown in Figure 17.

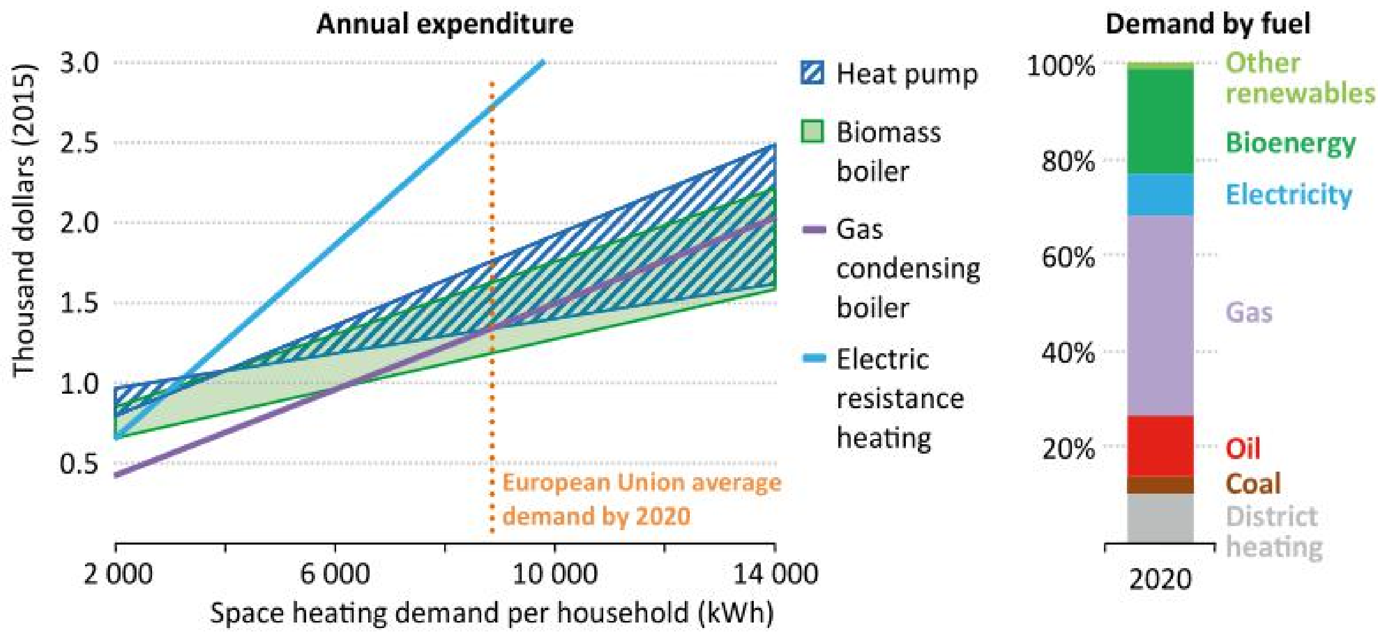

Fig. 17. Annual Expenditure in the European Union and Demand by fuel for space heating in 2020 (WEO, 2016).

From figure 17 it is clear that even by 2020, bioenergy (in this case, biomass heat) will get competitive with fossil fuels for a mainstream and high demand energy segments such as space and district heating.

3.2.4 Broader economic aspects

Rapid strides in technological advancements have resulted in various new ways of generating bioenergy. Noticeable of which includes fuels like bio-hydrogen, bio-butanol, bio-methane, and bio-methanol. These technological progress has been achieved as a result of extensive research and developed aided by private investors and governments. Such funding decisions are taken only after solid evidence that bioenergy will offer a bright future, make financial sense and produce profits. Based on empirical evidence and assumptions of economic behaviors of governments, industrial partners, producers, consumers, international organization, trade unions, and firms, economists develop econometric models to help to evaluate the prospects of bioenergy in the future. Economists generally take the help of statistics, econometric theory and probability theory to predict such behaviors (Lee, 2017).

These models are effective in evaluating the development of bioenergy on the account of their exhaustive inclusion of multiple interlinked factors related to supply chain management, macroeconomics, transportation routes and biomass feedstock, alternative fuels, land use, trading, sustainability (net emissions), forestry, agricultural and industrial waste, societal effects and topography. As bioenergy involves multiple production techniques and local economic dependencies, they should thoroughly be outlined through econometric assessments. This would help in mapping out accurate and detailed simulations which is vital in the accelerating the growth of new generation biofuels while also feeding important input for investors, government agencies and other policy makers (Lee, 2017).

GDP growth for the EU is projected at 1.5% compared to 2015 figures. Demand for heat is the largest of all energy services. Electricity demand is projected to grow 2% per year and two-thirds by 2040. Efficiency measures slow the electricity demand by 30% (IEO, 2016). There is an overall improvement in energy efficiency, resulting in less energy consumption per capita.

3.2.4.1 Efficiency gains

A recent study undertaken by Alsaeh et al., (2018) found that, "capital and labour costs, GDP growth, inflation and interest rate affected the cost efficiency of the bioenergy industry in the EU, both for developing and developed members, during the period between 1990 and 2013" (Alsaeh et al., 2018)**.** Earlier studies also tend to indicate this form of reasoning. In one such case, for standalone heat plant in Sweden (small-scale district heat system), a positive co-relation between capital and cost efficiency was found: The higher the investment costs in plant and technologies, the higher the cost efficiency (Alsaeh et al., 2018).

However, these positive relations are not always consistent. Research by Alsaeh et al., (2018) concluded with, "a negative correlation between capital cost and cost efficiency" (Alsaeh at al., 2018). The efficiency and cost of production are often dictated by the degree of integration and investment (capital cost) of biofuel plants with district heat system (DHS), development of these systems play an important role in decreasing the production cost and ensuring high efficiency.

This comprehensive report by Alsaeh et al., (2018) demonstrated that in the period between 1990 and 2013, for the bio-sector in Europe was affected by external economic factors as well as by internal economic factors (Alsaeh at al., 2018).

3.2.4.2 Energy risks

The political and social factors related to bioenergy energy security may result in new and changed infrastructure, leading directly to technical risk. This can further percolate to secondary risks such as the risk of interruption of energy supply which would subsequently expose the vulnerabilities like connectivity. Hence, a risk always lingers over the economy and society from primary energy risks. Figure 18 encapsulates these risks starting from the primary energy risks and leading to general risks.

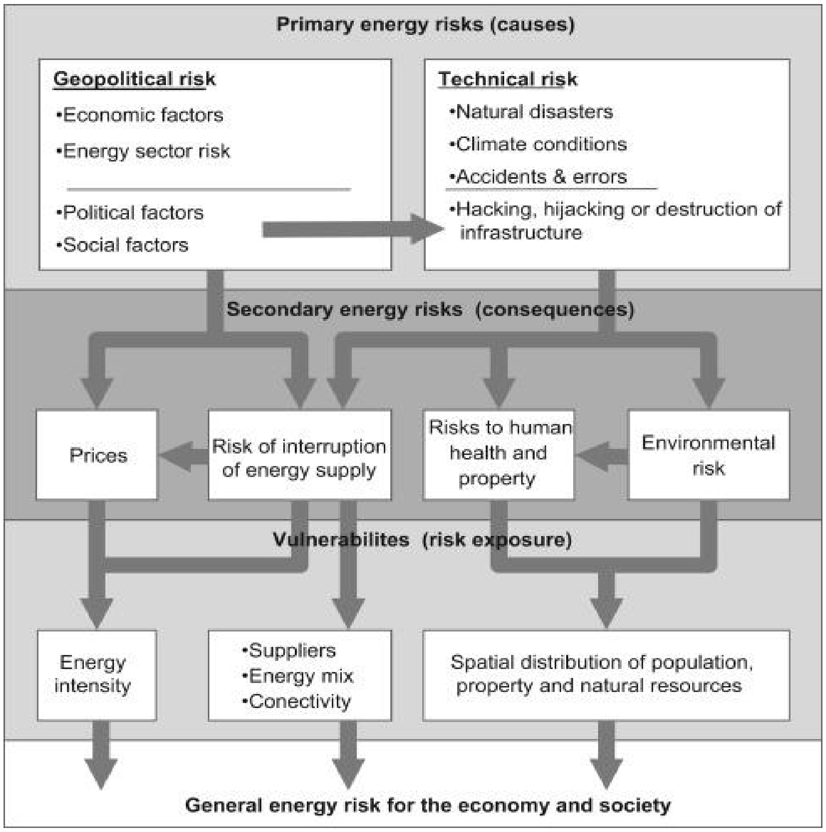

Fig. 18. A rough taxonomy of energy risk (Noel Valdés Lucas et al., 2016).

3.2.5 Ethical Concerns

Bioenergy has been the topic of an immense public, political, and academic debate across the EU, especially the issue of its sustainable credentials, since its inclusion in the renewable future schemes in the EU (Mohr and Raman, 2013).

The challenge facing the EU in governing of bioenergy, especially solid biomass, and liquid biofuels, are many. The challenges related to a disagreement over values and regulatory complexity are especially hard (Ekardt and von Bredow, 2012). The present sustainability criteria of the EU for the bioenergy is also questioned with regards to the current climate of sustainable policies and Ekardt and von Bredow (2012) also deem the EU criteria as being ill-suited to tackle and represent the various intricacies involved with regards to sustainability.

Furthermore, besides biofuels, the legal aspect of the debate on the use of solid biomass bioenergy is also not being taken into account (Gamborg et al., 2014). In the same paper, Gamborg et al., (2014) argues that for the bioenergy, “the ethical and legal challenge is to make the governance of bioenergy more transparent by revealing salient value-related and regulation-related conflicts over governance, and by clearly showing the goals as well as the constraints of bioenergy governance, and not least by keeping the inherent trade-offs in the open” (Gamborg et al., 2014).

The bioenergy sustainability debate gets more intricate when it can be firmly established that energy crop production increases the risk of intensive deforestation (Röder and Welfle, 2019) (Rathmann et al., 2010). Land competition has merged as another major concern (Helmut Haberl, 2015) due to increase in prices of several agricultural products (Haberl et al., 2014) (Smith et al., 2010), (Smith et al., 2014). Intensive pressure on biodiversity, forests, biologically diverse and fragile ecosystems are seen as some of the effects of environmental damages/degradation due to land competition (Coelho et al., 2012).

The food versus fuel debate further raises objections on the ethical aspects of allowing to divert land meant for food production to energy production. This aspect has two main points. The first being that the demand for biofuels directly impacts the food prices, which as result, severely affects the poor communities (e.g. Monbiot, 2004, Monbiot, 2007, Monbiot, 2012, Brown, 2009, Gamborg et al., 2012); and second being that it has led to increased competition with existing food production that is already well established agricultural sectors and that it also results in expansion into new and fragile environments (Spangenberg, 2008, Searchinger et al., 2008). (Tomei et al., 2016).

Furthermore, surges in food prices, leading to increased rental prices of land, would only get worse on account of increasing food demand, coupled with demand for bioenergy and protection of ecosystem and forests (Popp et al., 2011). This would further restrict the use of land for food crops/production (Wise et al., 2009. This price rise would have a detrimental effect on food security and environmental (Lambin and Meyfroidt, 2011). Deforestation, ecological damages, and increased GHG emissions may even negate, in the first place, the very aim of mitigating climate change of the EU (Searchinger et al., 2008, Haberl, 2013).

The possible direct and indirect effect of land use on account of bioenergy production is unclear. The trickle-down impacts indirect effects can be difficult to quantify in the long run. How the change in consumption will shape or to what extent the conversion of non-farmed land would take place is difficult to predict accurately (EEA, 2013). Land use and the associated changes that a massive development and deployment of bioenergy would bring with it would be an important point in sustainably obtaining bioenergy as the availability of land could end as putting a restraint or a boundary condition (Bentsen et al., 2012).

The EU is among the few global biofuel markets that have, in its policy, addressed the issue of the sustainability of biofuels and the environmental costs of it. There exists a 7% cap for biofuels that are derived from food crops, and each EU member states has the option of choosing a lower percentage of the cap according to their policies (EurActiv, 2015b).

3.3 Future Bioenergy Potential in the EU

This section shows the potential development in the present, immediate future, and future of bioenergy in the EU*.*

3.3.1. Broader Technological potential

The end use of energy by all the sectors (heat, electricity & transport) is well documented. On the other hand, hardly there is any data about the quality or type of biomass used by the EU member states, particularly solid biomass (wood, forestry biomass, etc.), which makes it even more difficult to exactly map out the overall bioenergy potential (Indufor, 2017). The present use of biomass for energy in Europe is much smaller than its overall potential. Out of which, the agricultural sector has the greatest potential. This is on account of the fact that dedicated energy crops, like reed canary grass, willows, poplars, etc., which are used for the production of electricity and heat have enormous potential and could substantially improve the yield per hectare (REE, 2010). Out of the total 114 million ha of arable land in Europe, with an estimate of 10-15 tons of dry biomass matter per hectare, even a small percentage of this land used from energy crops would yield a very high energy potential. Figure 19 (below) shows one such estimated biomass potential, including all the categories in the EU.

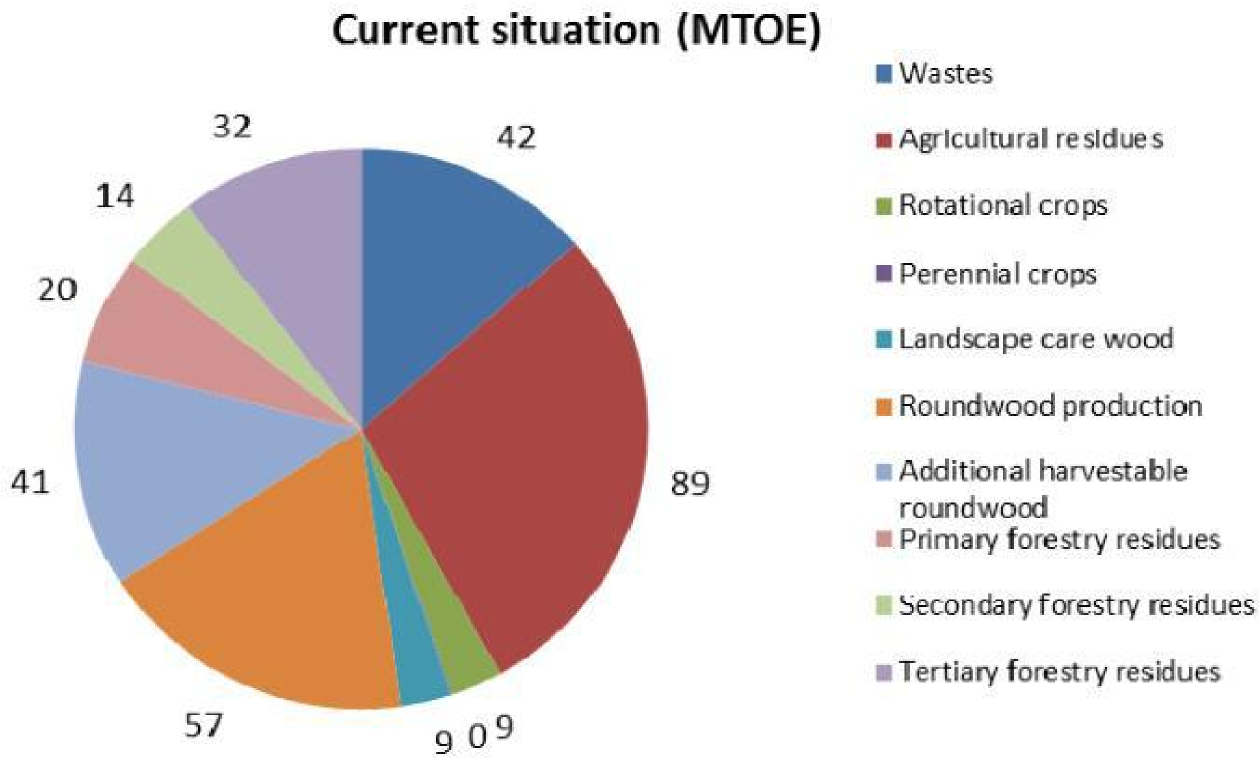

Fig. 19. Biomass potential of all categories in the EU (Biomass futures, 2012).

Around 64% of the total primary energy production of renewable energy in the EU-28 in 2015 was generated from biomass (Eurostat, 2018). One estimate suggests, given the current policies, in 2030, bioenergy would account for meeting 16 percent of the gross energy demand of the EU-28 (REE, 2010). There has been a surge in the use of biomass for power and CHP generation in Europe in recent years. The rise of CHP's market can be illustrated by the revalorization of feed-in tariffs for biomass electricity and also by quotas issued in EU member states in the initiation of green certificate systems. According to a 2006 EEA (European) report, in 2030 about 12.5 % of EU's demand would be met bioenergy (REE, 2010).

The demand for bioenergy by sector in current and up to 2030 in figure 20 shows that heating would remain the primary consumption sector (18.1%) for bioenergy, followed by electricity (12.5%) and finally transport (5.4%).

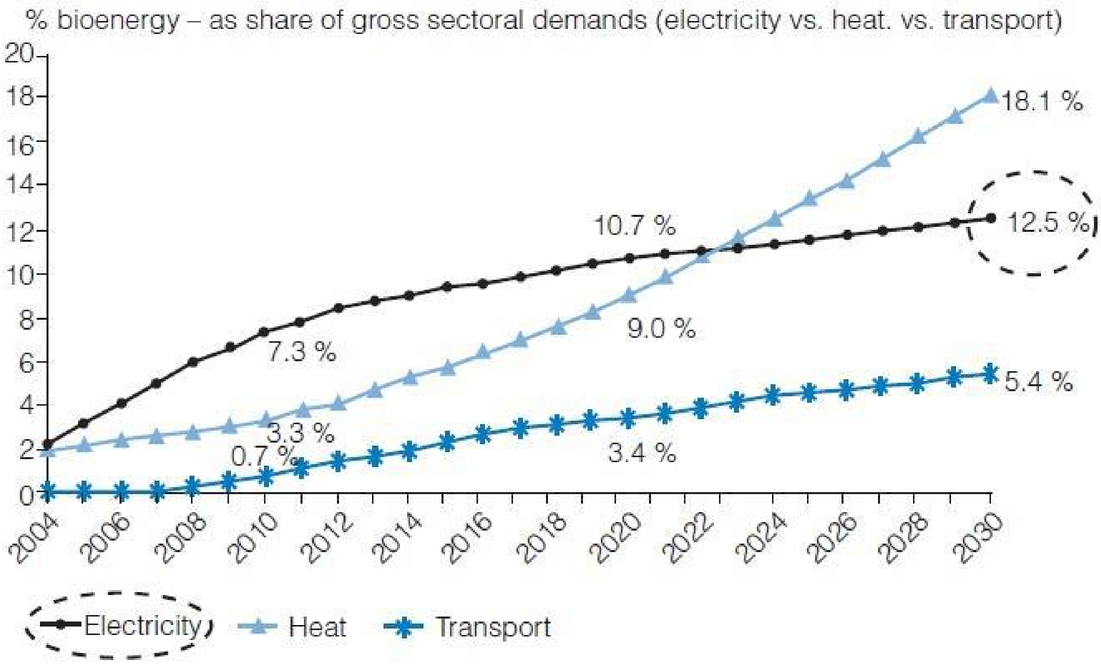

Fig. 20. Bioenergy demand by sector in the current and coming years (WEO, 2016).

Different studies take into account different themes like the investigation of different types of bioenergy (e.g., agriculture residues, energy crops. The definitions of potentials taken into account, the time frame considered, and the geographical scope of the study also differs (e.g., EU-15, EU-27, Europe, etc.) (Scarlat and Dallemand, 2019). Therefore, biomass resource assessments tend to have different potential measurements.

The marked differences in the potential can be attributed to the multiple methodology and approaches adopted for calculating the availability of land these different approaches would result in different results, which also includes the applied criteria for biomass sustainability (Scarlat and Dallemand, 2019).

The Biomass Energy Europe (BEE) project in its 2010 report particularly stressed on the importance and requirement for a uniform and homogeneous methodology to calculate the potential of various types of bioenergy (Scarlat and Dallemand, 2019).

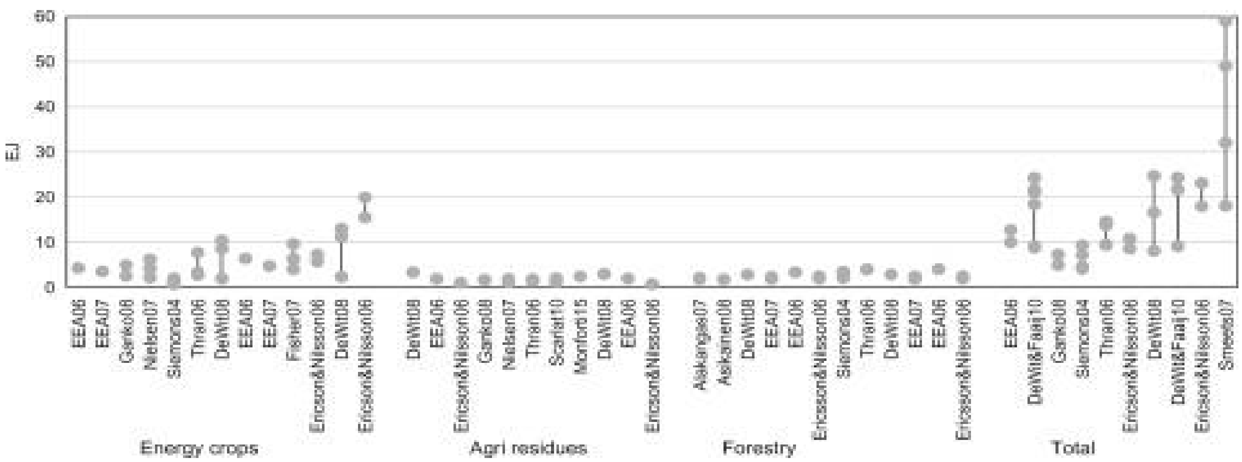

Fig. 21. Assessments of biomass potential in the EU (Scarlat and Dallemand, 2019).

Along with the bioenergy potential, Scarlat and Dallemand, (2019) finds that the agricultural residues have the potential in the range of 1.8 and 3.8 EJ. In the long run, for forest waste products, the potential lies in the range of 1.4 and 4.0 EJ in the long run. The demand for bioenergy by sector at present and up to 2030 (figure 21) shows that heating would remain the primary consumption sector (18.1%) for bioenergy, followed by electricity (12.5%) and finally transport (5.4%) (Scarlat and Dallemand, 2019).

The ability to mobilize the unexploited potential of biomass will determine the final potential of available biomass (BEE, 2010). Figure 22 shows the share of EU's bioenergy potential for various sources of bioenergy (Scarlat and Dallemand, 2019). It is seen that energy crops have substantial potential while agricultural residues and forestry have slightly lower potential.

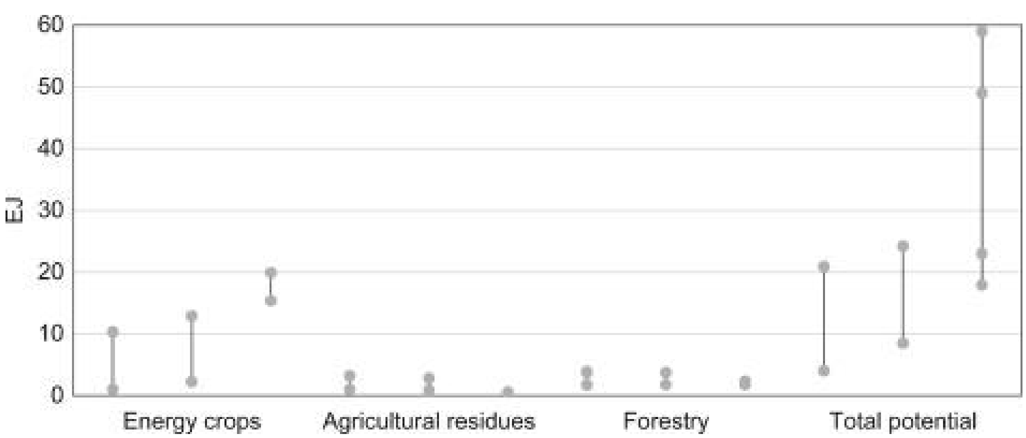

Fig. 22. Share of EU's bioenergy potential for various sources of bioenergy (Scarlat and Dallemand, 2019).

The potential of different types of bioenergy can be concluded from this of research works as follows (Scarlat and Dallemand, 2019):

Total biomass potential: 14.8 and 21.1 EJ.
The agricultural sector: 6.0 and 9.6 EJ.
Forestry sector: 7.0 and 9.9 EJ

Waste sector: 1 and 1.8 EJ (Scarlat and Dallemand, 2019).

3.3.2 Bioenergy potentials and consumption in the EU

According to World energy outlook 2016, if favorable policies persist, then renewables would account for 31% of the primary energy mix in 2040, which would be led by bioenergy (World Energy Outlook, 2016). The European Union has always been on the front in promoting and embracing renewable energy with a clear aim of climate change mitigation. In 2016, 14% of the primary energy mix in the EU was renewable, which was 6% in 2000. Over half of all the electricity generation in the EU is expected to be from renewables in 2040 (World Energy Outlook, 2016).

The following table 5 is a projection of how bioenergy might grow in terms of total primary energy demand (TPED) and total electricity generation, given that the current policies are pursued for the complete time period.

Table 5 European Union: Total energy demand and total electricity generation from bioenergy for current policies (Adopted from World Energy Outlook, 2016).

Bioenergy	2014	2040
Total Primary Energy Demand (Mtoe)	163	203
Total Electricity Generation (TWh)	221	271

There is a projected 24.5 % increase in total primary energy demand from bioenergy in 2040 as compared to 2014. Also, the total electricity generation increases by 22.6% from 2014 to 2040.

Accurately gauging the bioenergy projection in the EU remains a difficult task. According to Matzenberger et al., (2014), one of the ways to calculate the biomass potential could be to multiple the total land availability with the production capacity for that piece of land (Matzenberger et al., 2014). Findings from the paper of Searle and Malins, 2015) found that the upper theoretical limit in primary energy to total availability of biomass in the EU is 60–120 EJ/yr (Searle and Malins, 2015).

Figure 23 (below) illustrates one of the estimated biomass potentials for the EU member states in 2012. The country with the highest biomass potential is Germany (DE=16%) followed by France at 13% and Italy at 10%.

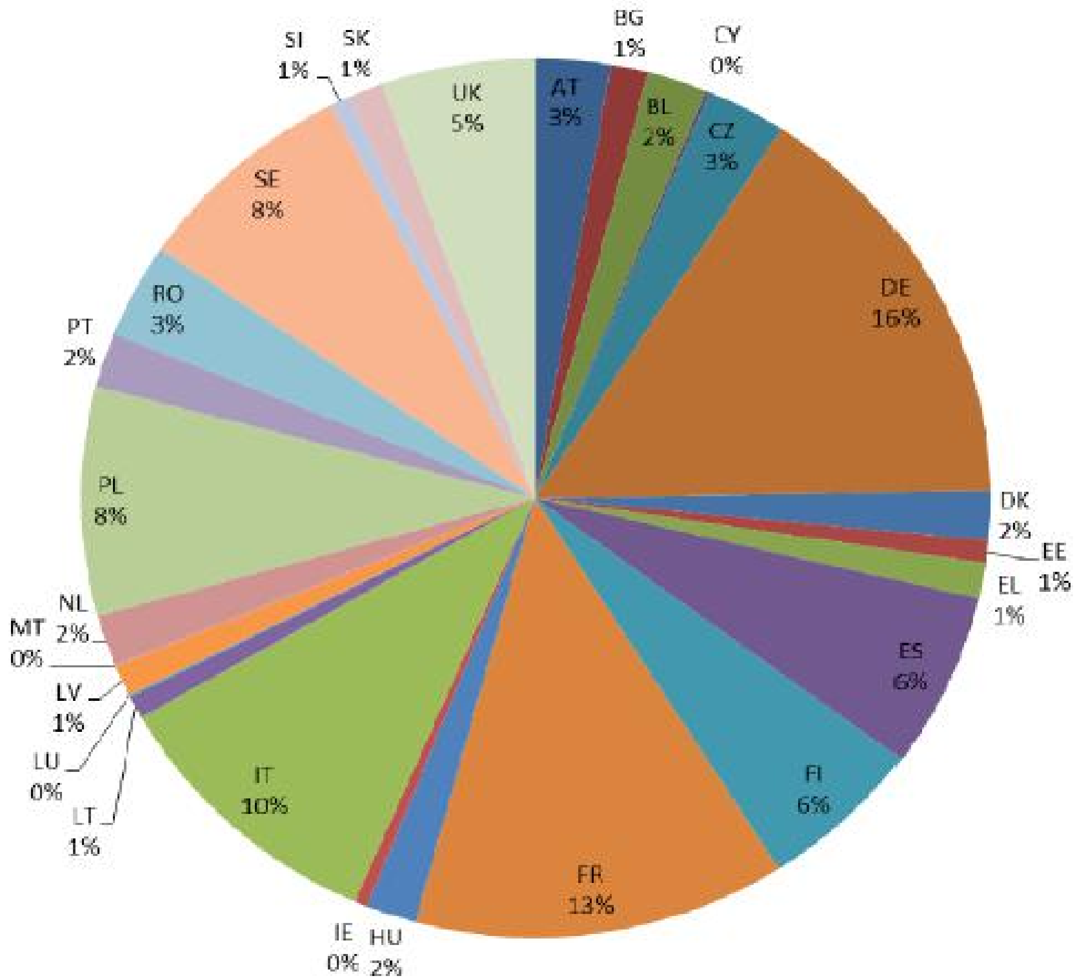

Fig. 23. Biomass potential in the EU by nations (Biomass Futures, 2012).

While figure 24 (below) illustrates the bioenergy consumption of the top five EU member states of Germany, France, Italy, Sweden and Finland and the rest of the EU in 2015 (Ktoe, %). Germany tops the bioenergy consumption in the EU with 17% of the total consumption. France is second with a 12% consumption, followed by Italy at 9%, Sweden at 9% and finally Finland at 7%. The rest of the EU member states account for 47% of the remaining bioenergy consumption.

Another interesting aspect from these two figures is that the top 3 member states in figure i.e. with nations the highest biomass potential and top 3 member nations (figure 24) with total bioenergy consumption are the same. This may indicate that the current focus is on the domestic production from biomass rather than export or trade of bioenergy and that a domestic demand exists for the available resources for every country.

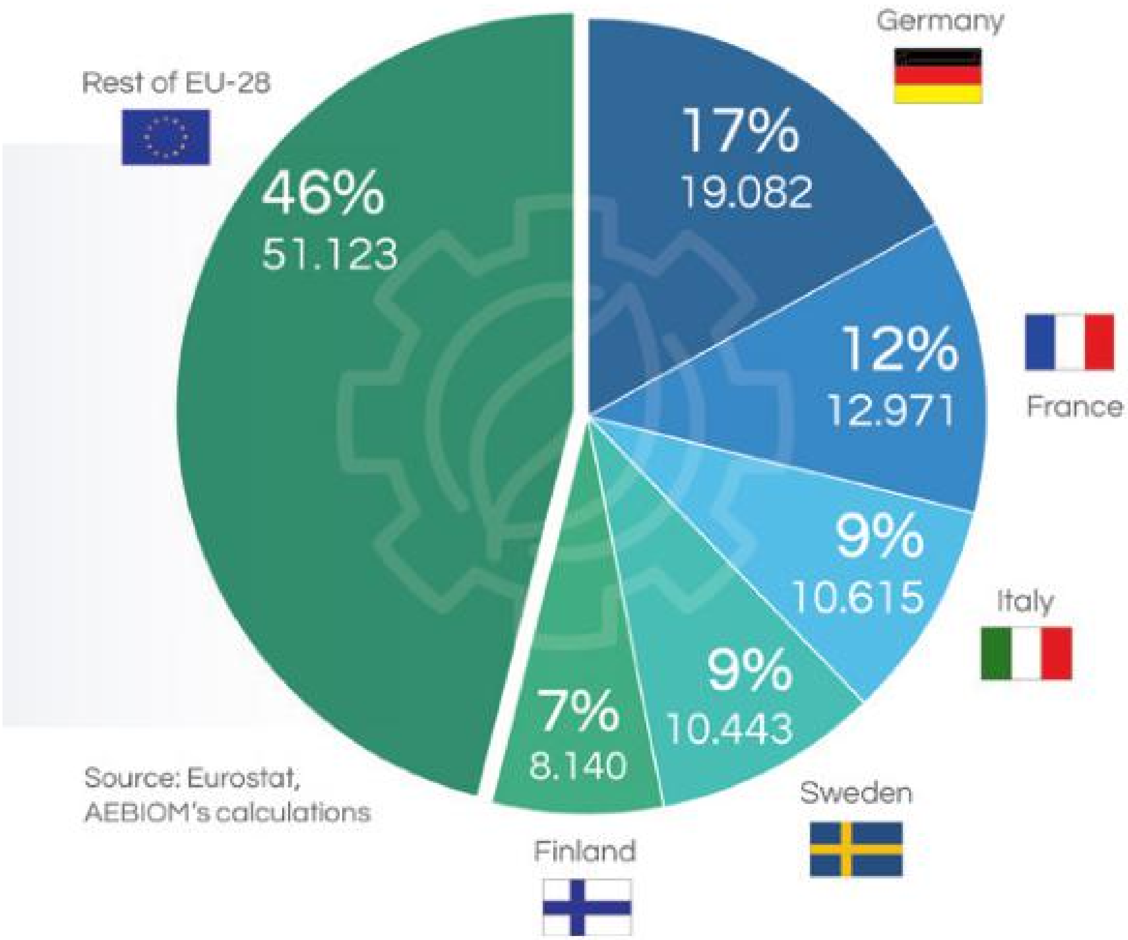

Fig. 24. Top five EU countries in bioenergy consumption in 2015 (Ktoe, %), (AEBIOM, 2017)**.**

3.4 Conclusion

This chapter gave an overview of the current state of bioenergy in the EU and also the path it may take in the region. The section started off with providing the distinct features and the characterization of bioenergy in its varied forms. Bioenergy systems show the unique characteristics of both fossil fuel based systems and renewable energy based systems. A lot of characteristics can be seen as a hybrid between the two. This entails that it has the advantages and disadvantages of both the systems. It indeed shares some similarities with the present fossil fuels scenario with regards to the fixed locations of resources and with transient renewable resources with regards to its potential/ability to be obtained infinitely or non-exhaustively.

Although, questions over the sustainability and ethical concerns over bioenergy have been reflected in the policy undertakings of the EU.

With supportive policies and frameworks, some EU members, like Sweden, have demonstrated a transition to a more active bioenergy based systems. Sweden invested in district heating using bioenergy. The policies adopted, backed by the government, and the resources available and deployed made it possible for Sweden to have a large share of bioenergy in their domestic energy production and other applications. The many years of the bio-based focus of these countries have shown at least the short term sustainability of bioenergy.

The effects on the energy security indicators of bioenergy in the EU thus have been derived from the above data and the effects have been compiled on the rating scale that was derived in section 2. In the next section, the comprehensive energy security effects of bioenergy on the selected indicators will be analyzed on the 37 energy security indicators have been identified for this study and these will be tested and rated on the proposed rating scale in this thesis.

This section helped establish the properties of bioenergy that are similar to the current fossil fuel scenario and hence would provide for a clear and thorough comparison and on the effects on the rating scale. This section also paved the way for the comprehensive energy security analysis in section 4 by providing the data and a general overview of the bioenergy characteristics that are relevant to the selected energy security dimensions and indicators.

CHAPTER 4

Comprehensive energy security analysis

In this section, the newly developed assessment framework would be applied to the relevant energy security indicators. The assessment in this chapter is based on the data gathered in the previous section as well as more data in this section wherever applicable.

The assessment is made for the selected 22 indicators and metrics of the energy security components in the order of 'availability', 'regulation and governance, 'environmental & social sustainability', 'regulation and governance', and 'technology development and efficiency'.

4.1 Assignment of ratings, scores, time-scales and different types of bioenergy sources

Appendix IV shows the rating scale, ranges, and data of the energy security indicators and metrics from every energy security dimension. The ratings are mainly data driven, some of them have been laid out in Chapter 3 and some more data have been provided in this chapter before the relevant indicators from which the ratings are derived. **Appendix IV** shows all the ranges of the energy security indicators and metrics. Different types of bioenergy are analyzed on the respective data of the given ES indicator on which it is being rated upon. Therefore, all the forms of bioenergy are analyzed in this way, the biofuels are rated on the relevant data and the selected ES indicator, in a similar way, the solid biomass or the municipal solid waste are rated upon.

As for every ES indicator and metric, the bioenergy source varies, the major type of bioenergy sources that are being investigated have been mentioned alongside the indicator. The types of bioenergy included for each indicator has sufficient data and relevance to it from which rating could be derived. The time-scale for data collection and evaluation of every ES indicator and metric is specified along with the type of bioenergy studied.

4.2 Energy security dimension of 'Availability'

For the dimension of 'availability', the availability of bioenergy has been shown in chapter 3 and continuous availability in the form of future potential prediction, where accurate data up to 2018 was not available, have been taken into account for the overall ratings.

The share of renewable energy in total primary energy supply (biomass, biofuels)
According to the estimates made by GBS (2017), AEBIOM (2017), and Indufor, (2017), the share of renewable energy in total primary energy supply fell between 50 EJ to 100EJ in 2018. The EU had a share of almost 30% renewable electricity in 2016, out of which 20% of electricity came from biomass. During the same period, the share of biofuels for transport amounted to 4.4%. The share of biomass for heating in all sectors amounted to 15%. Furthermore, 24% of the total heat was generated by CHP and other heat plants were produced from biomass. Finally, in the residential sector use of biomass accounted for 20% of the total consumption of heat/fuel (IEA Bioenergy, 2018).

The consumption of all forms of bioenergy for the EU increased from 3.8 EJ in 2005 to 10.0 EJ by 2018 as indicated in the figure below. In 2009, for the EU member states, the primary production of bioenergy in the form of biomass and waste stood at 4.2 EJ (Bensten and Felby, 2012).

The consumption of biomass in 2018 had a share of around 0.1 EJ use from the traditional food crops, which includes cereals and sugar beet for the production of first-generation biofuels (bioethanol in this case) and oil crops for biodiesel. Furthermore, around 0.5 EJ was used as the feedstock for biofuels which were imported from outside the EU. In 2018, heat and electricity production had the highest share of all bioenergy production, however, the demand for bioenergy for transportation increased from 5% in 2005 to around 18% in 2018 (IEA Bioenergy, 2018).

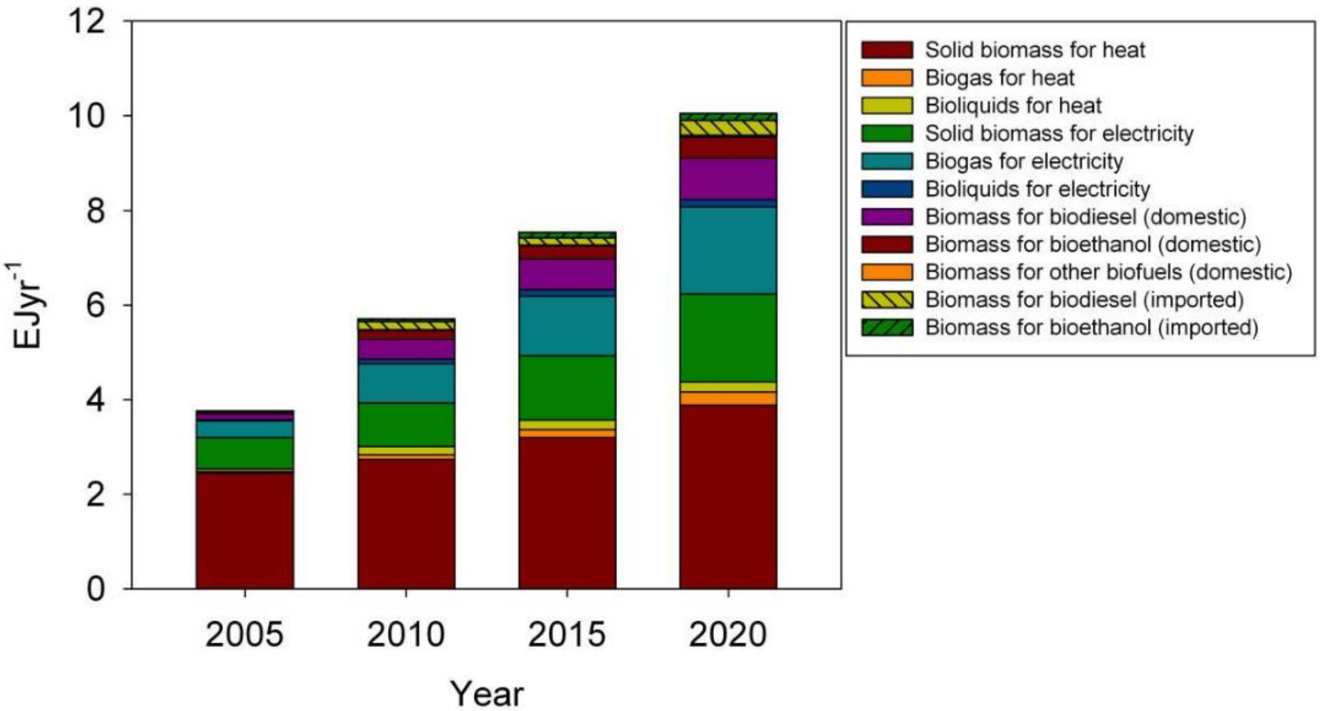

Fig. 25. The demand for biomass from various sources for energy in the EU from 2005 up to 2020 (Bensten and Felby, 2012)

As a result, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

Table 6: Share of bioenergy in 2016 in electricity production, transport energy consumption and overall heat/fuel consumption (IEA Bioenergy, 2018).

Sector	Share of bioenergy
Electricity production	**5.6%**
Transport energy (final consumption)	**4.4%**
Overall fuel and heat consumption	**Direct biomass: 15.0%** **Bio-based heat: 2.4%**

Total energy supply (All bioenergy)

The total bioenergy consumption in the EU increased two-fold between 2000 and 2010; An average growth of further 3% was recorded for the period 2011-2016. During this period, the share of bioenergy in total primary energy supply increased from 7.0% to 8.8%.

According to JRC science policy report for EU (2018), 1466 Mt of dry matter of biomass is produced annually by the land-based sectors of the EU, of which agriculture accounts for 956 Mt and forestry amounts to 510 Mt (JRC Science, 2018). The marine-based sectors that included algae-culture, aqua-culture and fisheries supply around 2 Mt of dry biomass annually.

In 2015, around 64% of the total primary energy production of renewable energy in the EU-28 was generated from biomass (Eurostat, 2018). Table 7 shows the total primary energy supply figures per capita for the EU for 2016, to which bioenergy contributed to 11.5 GJ/capita (IEA Bioenergy, 2018).

Table 7: The total primary bioenergy supply (TPES) for the EU in 2018 (figures per capita) (IEA Bioenergy, 2018).

	GJ/capita
Total energy	130.9
Bioenergy	11.5
Solid biofuels	8.0
Renewable MSW	0.8
Biogas	1.4
Liquid biofuels	1.2

From figure (26) below, it is observed that from 2000 to 2010, there was an increase of 100% for the consumption levels of bioenergy in the EU. In 2010- 2011 the growth was stable, from 2011 to 2016, it then again had an increase in the growth rate at 3% per year. Also, for this time period, the total share of bioenergy in TPES (Total Primary Energy Supply) saw an increment from 7.0% to 8.8%. For different forms of bioenergy, Solid biomass saw an aggregate growth of around 2% per year from 2010 and 2016; for renewable municipal solid waste, the growth rate amounted to 4%, for biogas it was 11%. After 2010, liquid biofuels were stabilized between the values of 600 and 650 PJ (IEA Bioenergy, 2018).

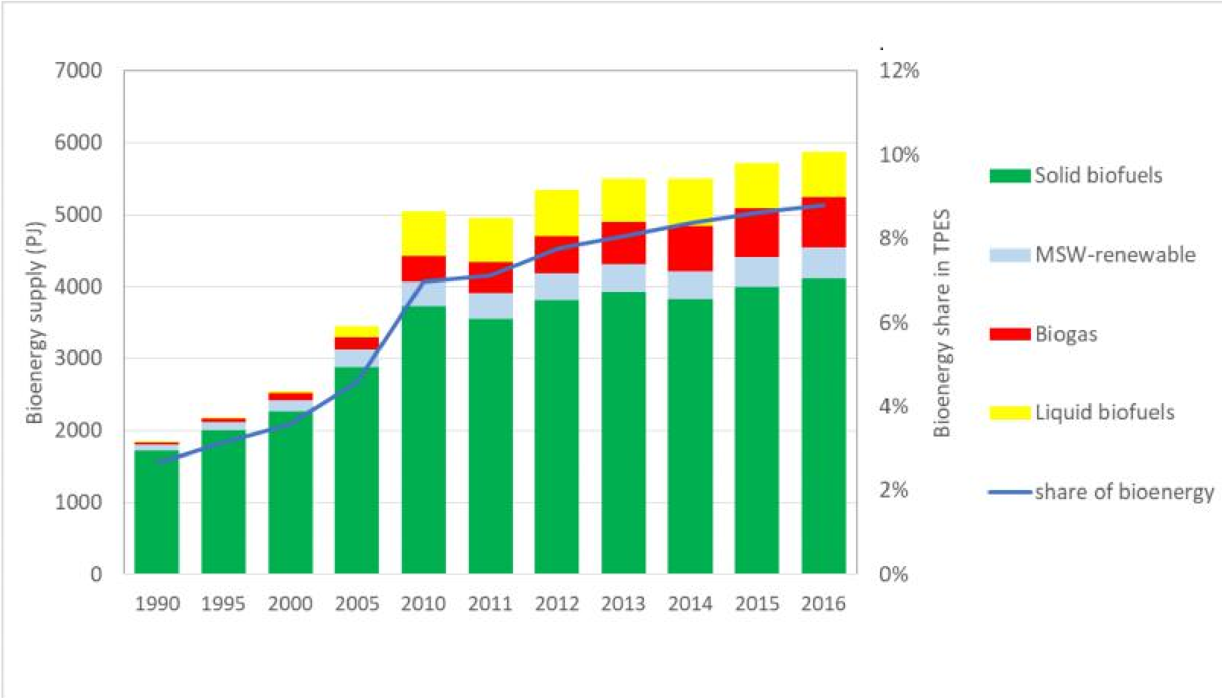

Fig. 26. Development of total primary energy supply from bioenergy in the EU 1990 – 2016 (IEA Bioenergy, 2018).

From the above analysis, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

Availability of renewable energy resource (biomass, forest and agricultural residues)

The raw fuel for bioenergy had always been in abundant supply because of its large potential. Along with the bioenergy potential, the potentials of agricultural residues varied between 1.8 and 3.8 EJ in 2010 (BEE, 2010). For forestry and forest residues, the potential was between 1.4 and 4.0 EJ in 2015 (JRC, 2015). Although the availability estimates differ from study to study, the most approximate estimates made by BEE (2010), JRC (2015) and Scarlat and Dallemand (2019) for the availability of bioenergy resource had been between 15-20 EJ. This shows a continues availability and potential throughout, so it gets a rating of 3, which implies a little or no change on the indicator.

Proven recoverable energy reserves (biomass)

It is calculated that the maximum limit in primary energy to the total biomass availability in the EU has been between the range of 60–120 EJ/yr (Elbersen et al., 2012). Biomass is available widely across the EU, from the findings, it is observed that the maximum limit in primary energy to long-term total biomass availability in the EU is 60–120 EJ/yr. The estimates of total biomass potentials range between 8.5–24 EJ for the period 2030 and between 18–59 EJ around 2050 (Eurostat, 2017).

The proven recoverable energy reserves of biomass vary a lot from study to study. As the biomass resources in the EU are abundant but finite in nature, the situation has not been very different from the current fossil fuel scenario (BEE, 2010). As shown in chapter 3, the technical potential of bioenergy in the EU has been calculated by many studies and was found to be on par with the past and current demands (JRC, 2015). Therefore, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

The indicators and the effects have been summarized in table 8 below:

Table 8: Energy security indicators and their ratings for availability dimension.

Indicator	Effect (Rating)
SHARE OF RENEWABLE ENERGY IN TOTAL PRIMARY ENERGY SUPPLY	**3**
TOTAL ENERGY SUPPLY	**3**
AVAILABILITY OF RENEWABLE ENERGY RESOURCE	**3**
PROVEN RECOVERABLE ENERGY RESERVES	**3**

4.3 Trade Impacts

The patterns of wide-spread bioenergy use have changed in the last two decades. Power generation and production of biofuels for transportation with modern biomass and production methods would replace the current use of traditional biomass. Any such changes would most likely alter the trade balance in the region (Matzenberger et al., 2014). So, the trade patterns would necessarily include new dimensions to current trade patterns across the EU.

4.3.1. Imports and risks

Importing biomass comes with its own sets of risk. Like any other energy resource, importing constituents a dependence on an external instrument which may not always work smoothly. Specific study with respect to biomass has not been conducted but there is research (Lilliestam and Ellenbeck, 2011) on the impacts of large-scale renewable energy, especially solar energy imports from North Africa to the EU.

A bigger share of renewable energy nullifies the import of fossil fuels and direct electricity, giving leverage to energy security at the EU level. However, as every EU member state has its own set of policies, infrastructure, energy demand, and energy regime, so as a result, the outcome is different for every member state in terms renewable energy production (Gökgöz and Güvercin, 2018).

A high share of energy imports to full its demand and a considerable difference between the capacity for energy production and energy consumption makes Europe more susceptible to fluctuations in the international markets (Gökgöz and Güvercin, 2018). Although the EU may or may not depend on large-scale imports of biomass, such a vulnerability cannot be denied and should be fully considered.

Energy security is a concern of all EU countries, however, each of them is affected to a very different degree. The Dutch government was among the first to impose restrictions on biomass imports having historically realized the potential impact of large-scale imports.

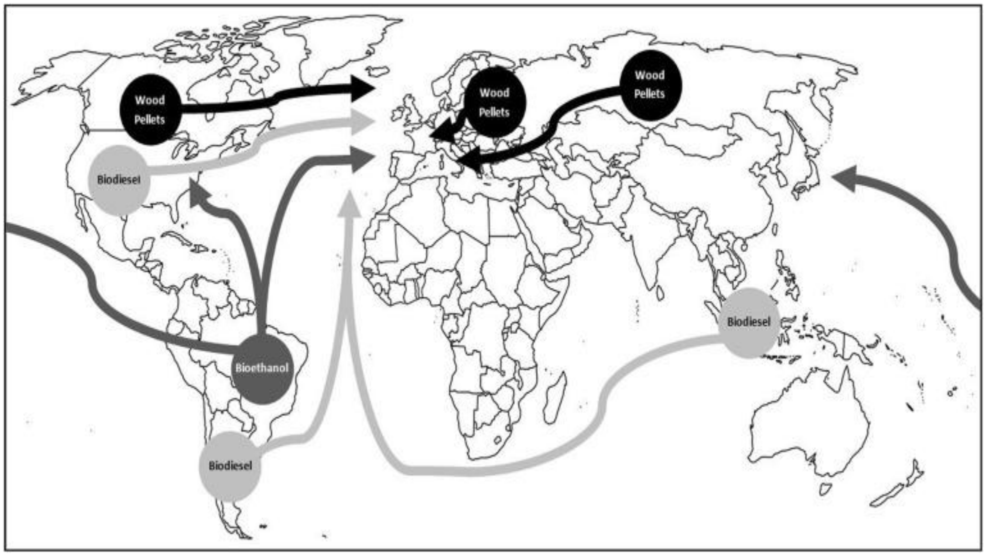

Fig. 27. Current bioenergy trade route flows to the EU (Andrew Welfle, 2017)

The main bioenergy components for the EU over the years has been biofuels: biodiesel and ethanol in particular. The bioenergy trade route can be broken down into biodiesel and ethanol trade routes as follows:

Figure 28 (below) encapsulates the present trading routes for bioenergy across the world, in particular, EU. All the incoming arrows into the EU shows a well-established trade route for imports from Indonesia to Brazil.

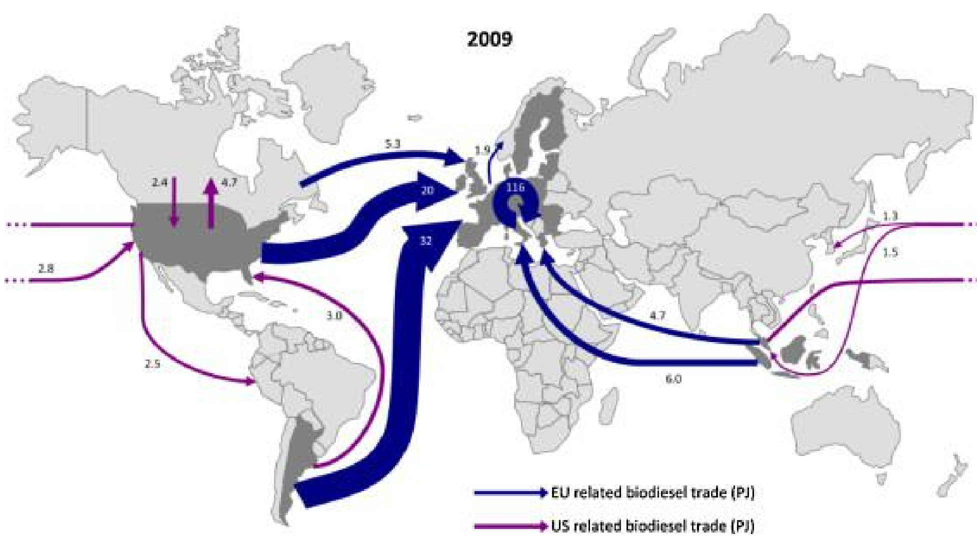

Fig. 28. Biodiesel trade route flows to and fro from the EU in 2009 (Lamers et al., 2011).

The internal trading of biodiesel is rife among the EU member states and it accounts for the highest share of biodiesel trading. Germany has the highest production rate of biodiesel and also exports to other countries such as Norway. The multitude of incoming arrows in the EU also accounts for relatively higher consumption of biodiesel than bioethanol in the EU.

Figure 29 shows the trade pattern for ethanol. The trade route flows to and fro from the EU in 2009 were mainly from Brazil and also a large trade was internal, within the EU.

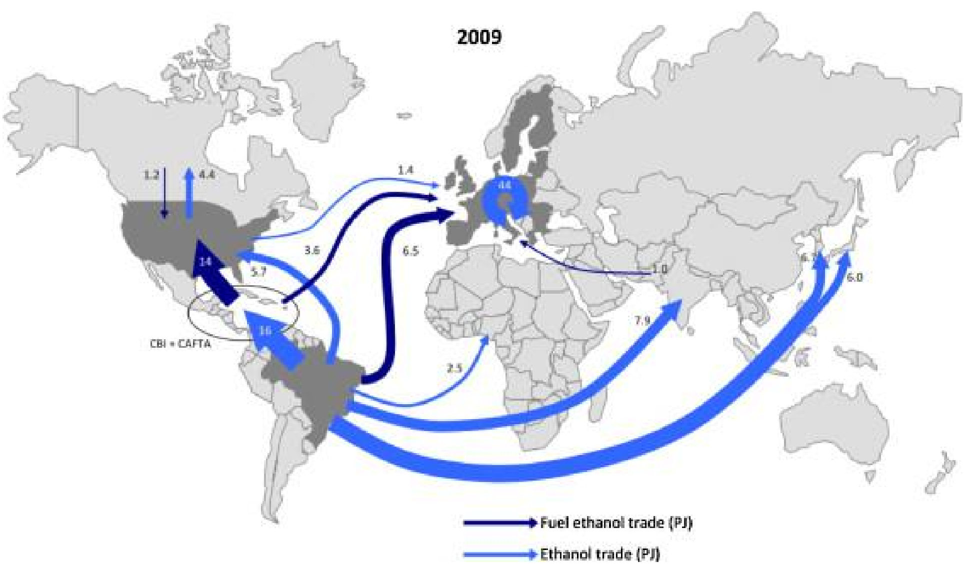

Fig. 29. Ethanol trade route flows to and fro from the EU in 2009 (Lamers et al., 2011).

Whereas the consumption and, therefore, the import was more for biodiesel in the EU compared to ethanol, the global production was also dominated by biodiesel.

Figure 30 (below) shows the current energy dependencies of EU member states on imports. The dark red areas show a heavy dependency on imports bordering over 50% to satisfy domestic energy consumption. Italy and Belgium have the darkest red areas, showing dependencies on import in excess of 75%, while Romania needs under 25% imports to fulfill its energy demands.

Naturally, the dependencies would change with bioenergy and many EU members that are heavy importers now could end up becoming net exporters and vice versa. The figure also indicates the level of preparedness or unpreparedness and indicate whether the EU member states find themselves having to import or export to account for their energy consumption in case of change of energy policies.

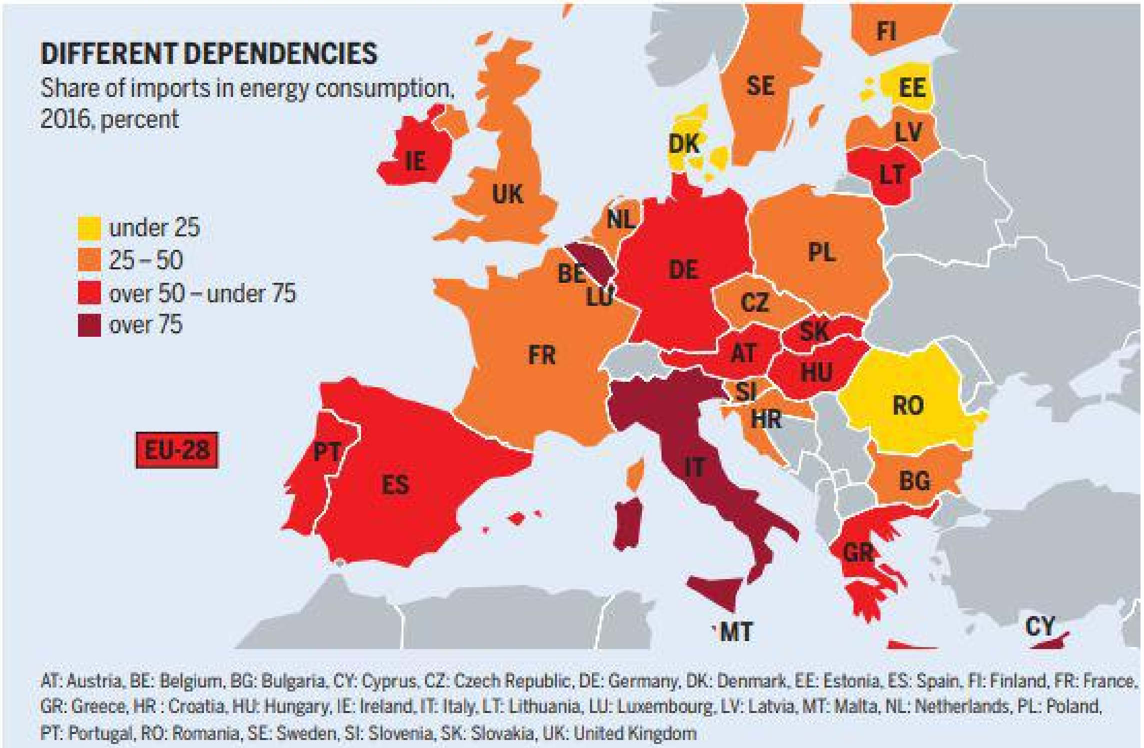

Fig. 30. EU member states share of imports in energy consumption, 2016 (%) (Energy Atlas, 2018).

Bioenergy accounts for 1% of import dependence of the EU for its primary production. The figure below captures this energy dependency of bioenergy in the EU. Biomass contributes to 4.4% of the gross

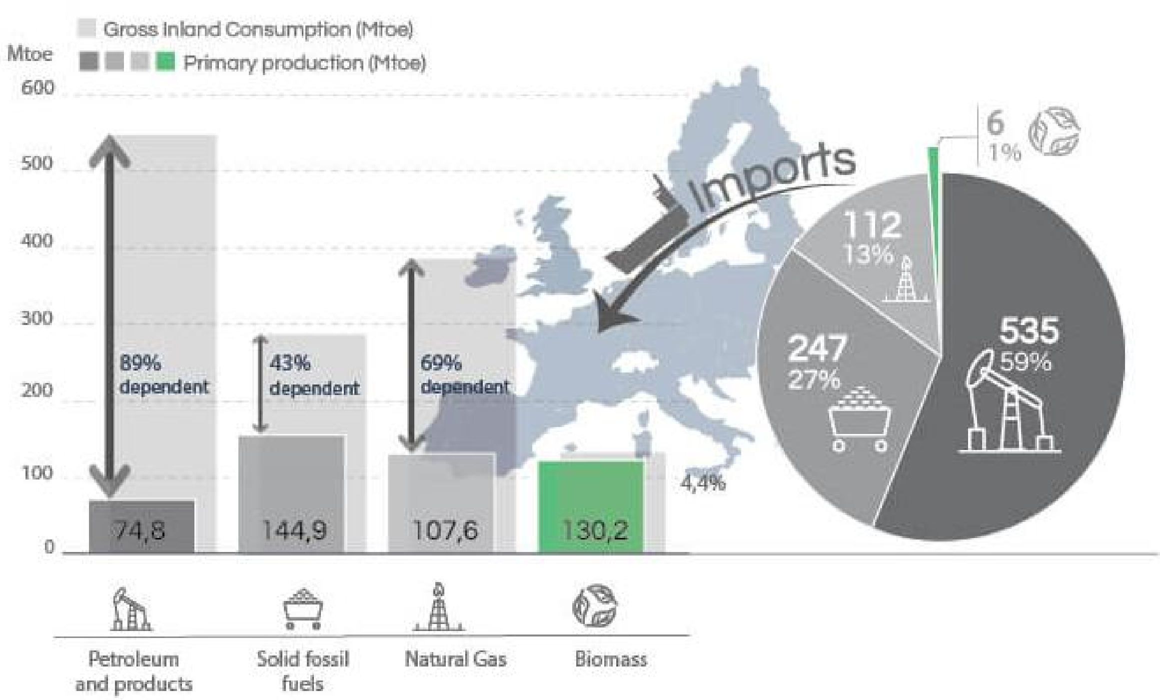

Fig. 31. EU energy dependence and imports (in 2015, Mtoe, %) (Eurostat, 2017). I

inland consumption and has a less share of imports compared to other fossil fuels as shown in the above figure 31.

The related indicators are as follows:

***% of imports coming from outside the region (*Solid biomass, biogas, biomethane)**

The EU has been a net importer of biomass (Matzenberger et al., 2014). The import of sea-based products like seafood, algae for biofuels, biofuels (mainly solid) were far higher than the exported products of forestry and animal based products like pulp and paper industrial products, wood, and other processed items (Lilliestam and Ellenbeck, 2011).

Although the EU is a net importer of biomass, this balance depends on the type of biomass. For paper and solid wood products as well as the animal and processed products, the EU is a net exporter. However, for solid biofuels, aquaculture and f plant-based food, the EU is a net importer (JRC Science, 2018). The annual consumption of dry biomass in the EU is more than 1 billion tonnes. Of this biomass, the feed and food sector uses 60%, bioenergy accounts for 19.1% and biomaterials uses 18.8% (JRC Science, 2018).

As the EU has been a net importer of bioenergy despite the potential (Lilliestam and Ellenbeck, 2011), and bioelectricity is predominately obtained from two major bioenergy sources. The first is the solid biomass (wood chips, pellets, straw, dry manure) can be co-fired in conventional coal-fired power plants, and second being biogas and biomethane (AEBIOM Statistical report, 2017). Some of the bioenergy have been locally available and but most of it was imported (EEA, 2013). This indicator scores a 2 on the rating scale, which implies a slightly negative effect for the indicator.

Diversification of fuels for transport (biofuels)

The most widely used bioenergy source in the EU is liquid biofuels i.e. biodiesel and bioethanol, which are usually blended with fossil fuels. To comply with the 2020 transportation goals, liquid biofuels have seen increase in the production, especially biodiesel (Hombach et al., 2018), followed by bio-gasoline and other liquid biofuels.

The cost advantage of conventional aviation fuels has not deterred the growing interest in biofuels in the market. There has been a rapid expansion in biojet fuels with more than 20 airlines used it in more their 2500 commercial flights in 2016 (IATA, 2016).

Dedicated energy crops, like reed canary grass, willows, poplars, etc., have been used for energy production across the EU. As is the case for fossil fuels, some of these bio-resources are available throughout the year like the municipal waste and forest residue (Eurostat: European Statistics, 2017). While the agricultural and pellet etc. have been dependent directly or indirectly on the prevailing climate or weather conditions affecting daily as well as seasonal supply (Searle et al., 2016).

The figure below (fig. 32) shows the various types of biomass used for biofuels for transport in 2015 in the EU. Biodiesel shares the highest contributor with 74.68%, and for biodiesel production rapeseed is the highest contributor.

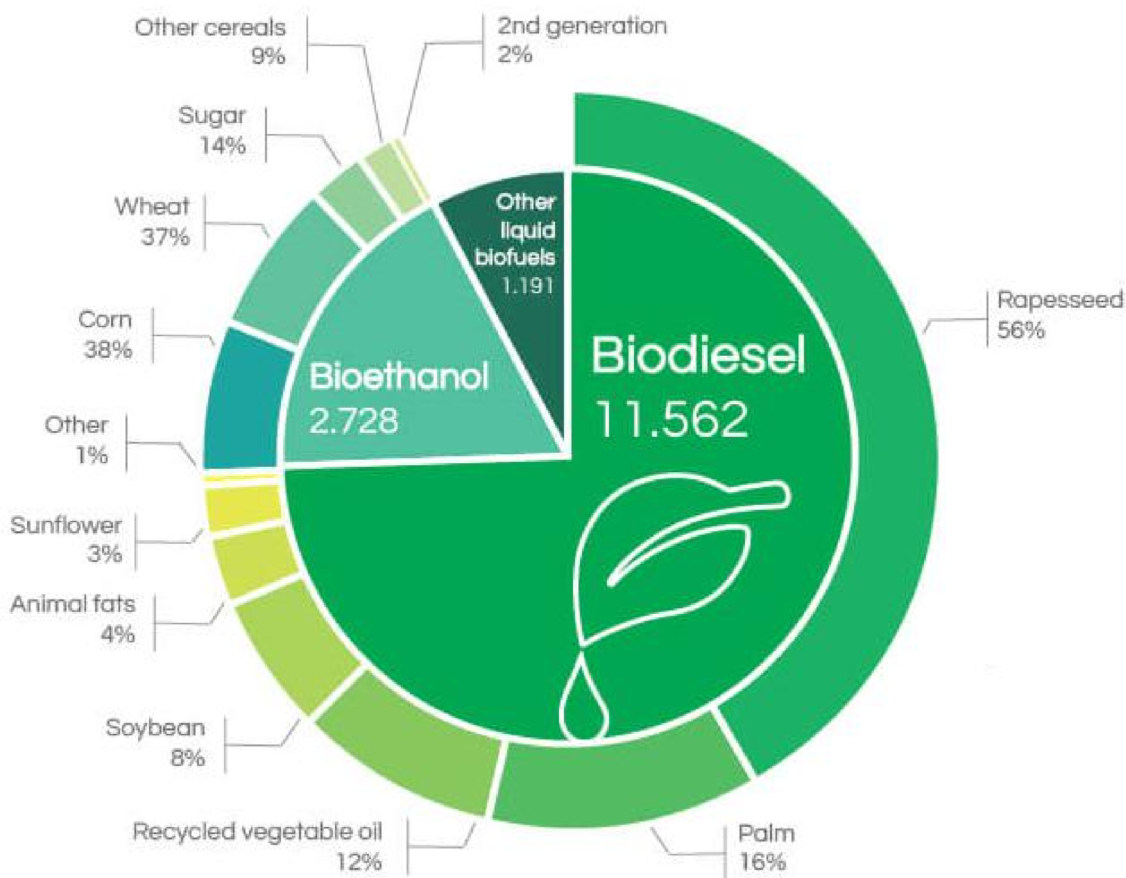

Fig. 32. Types of biomass used in the EU for biofuels for transport (in 2015, ktoe, %) (Eurostat, 2017).

This has added to the diversification option for transport fuels and hence, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

Diversification of fuels for heating and cooling(Biofuels, waste biomass)

Dry biomass has been transported over long distances in the EU for various applications. Biofuels are mainly deployed for road transport, with significant potential for shipping and aviation sectors still there to be utilized (European Commission, 2018). Waste biomass has been used for electricity and for heating directly or indirectly for CHPs (combined heat and power plants) (K.Sipilä, 2016). Bioenergy in the EU is both geographically constrained as well as geographically independent to a degree. Each of the EU member states has some kind of bioenergy resource available at its disposal (Andrew Welfle, 2017). Domestic energy production sites like food crop, waste plants, etc., vary across the region. Given the myriad number of sources of biomass and its diversity, the possibilities of diversification have been very large both as raw material and the obtained end products (Lamers et al., 2011). The ability of biomass to get converted into heat, electricity and transport fuels, has made bioenergy very versatile in its sourcing and applications in the as two decades.

This shows, a varied diversification of biofuels and waste biomass had been taking place in the EU and as a result, this indicator scores a 4 on the rating scale, which implies a positive effect for the indicator.

The indicators and the effects have been summarized in table 9 below:

Table 9: Energy security indicators and their ratings for availability dimension.

Indicator	Effect (Rating)
% OF IMPORTS COMING FROM OUTSIDE THE REGION	2
DIVERSIFICATION OF FUELS FOR TRANSPORT	3
DIVERSIFICATION OF FUELS FOR HEATING AND COOLING	4

4.4 Energy security dimension of 'Environmental & social sustainability'

The indicators and metrics for 'Environmental & social sustainability' will be discussed in this section. To start with, the biggest debate of fuel vs food for growing energy crops has been for biofuels, and biofuels have seen a complete change of public perception and policy implementation. So, the following section starts with the question of how biofuels have performed in the EU in the last 18 years.

4.4.1 Biofuels in the EU

Demand for heat has been the largest of all energy services in the EU. Bioenergy used in boilers and wood stoves for both water and space heating. For industrial applications, furnaces, boilers, and combined heat and power plants are used for all operating temperatures. Biogas and solid biomass are used for cooking in advanced cookstoves. Biofuels consumption comprises 3% of the total market in 2016.

Figure 33 (below) details the contribution of renewable energy to the transport sector of each and every EU member state in terms of their percentage share of the total gross final energy consumption in the year 2016. The member with the highest share of energy from the renewable sources in transport in 2016 was Sweden, followed by Austria, France, and Finland. Sweden fulfills almost 30% of its transport sector energy needs from renewable energy sources like bioenergy. This has led it to have a well-established bioenergy transportation sector along with its heating sector which also consumes a large amount of bioenergy.

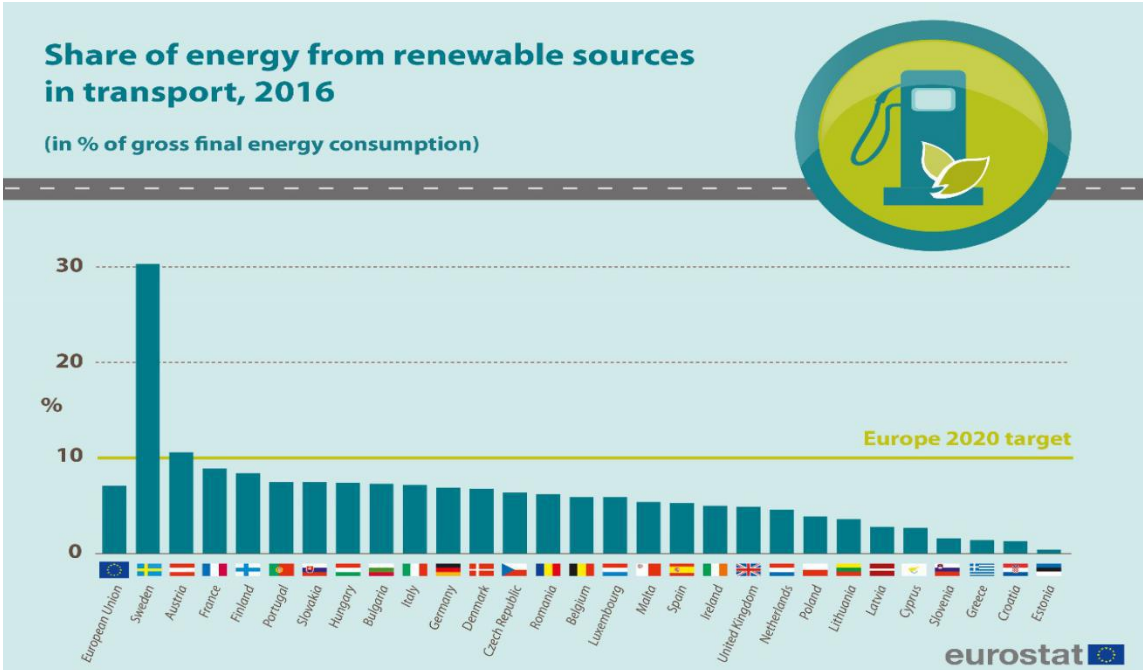

Fig. 33. The contribution of renewable energy to the transport sector across EU nations in terms of % of total gross final energy consumption (Eurostat, 2016).

The International energy agency its 2016 edition of world energy outlook made some projections regarding the demand for biofuels worldwide especially in the European Union and the United States. Figure 34 shows the demand for bioethanol and biodiesel by sector and region starting from 2000 and 2018, also projecting up to 2040. Biodiesel demand is led by the United States and the European Union. The European Union has now become both the largest producer and largest user of biodiesel in the world (Souza et al., 2018).

Biofuels enjoys the advantage of having a broad range of potential feedstock and production processes. Another major factor that works in favor of biofuels is that it does not need completely new infrastructure, the present infrastructural system can use biofuels instead of fossil fuels.

Research conducted by Hover and Abraham (2009) for replacing petroleum-based fuels with biofuels concluded that it was not advisable to use good cropland for biofuels. However, if the crops that were grown were not to be used for commercial purposes, the resultant fuel would be much more sustainable than fossil fuel (petroleum in this case) (Hover and Abraham, 2009).

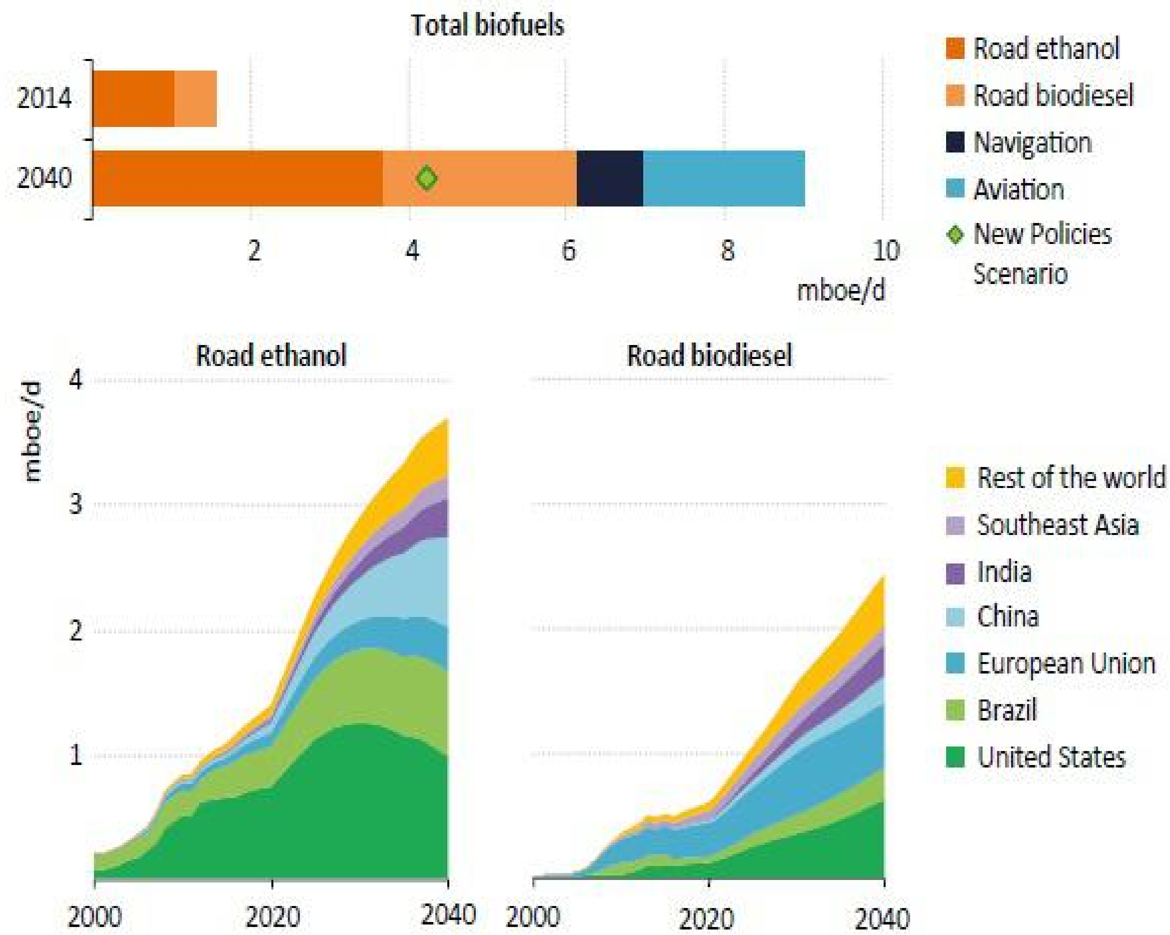

Fig. 34. Demand for bioethanol and biodiesel in 2000 and 2018 by sector and region (WEO, 2016).

The requirements for this is to find clean crops that will not depend on a lot of fertilizer, water, or other inputs. A bad choice, in this case, would be corn ethanol, as it requires large inputs of fertilizers, costs and water, which does not make it either economically or ecologically sustainable. On the other hand, switchgrass and other such crops, which could be grown on waste lands, with promising results (Souza et al., 2018). These lands could also be used for growing plants that can be converted to biofuels. According to the IEA 2011 roadmap, liquid biofuels are providing more share to the global transportation fuel consumption and have to a less extent replaced diesel, kerosene, and jet fuel (IEA 2011).

4.4.2. Sustainability concerns

Sustainability concerns regarding the use of bioenergy especially biofuels have caught the imagination of the public as well as policymakers in recent times. The potential of bioenergy is closely linked to sustainability. Most of the bioenergy potential data that has been used in the study has been classified under sustainable.

Many factors influences the sustainable availability of biomass (ECN, 2011):

• A major requirement for the production of biomass is land. It comes at a comprise of other land-use functions, and in practice, it results in disrupting natural systems. With productivity improvements in the agricultural sector, there can be a higher potential for land usage for biomass, however, this involves a trade-off between meeting the growing demand for food and biomass energy crops. Therefore, there can be a lot of assumptions which would result in different calculated potential. Discarded land or degraded and poor quality soil can be used for growing dedicated energy crops. However, it is to be seen whether from an agricultural economics point of view, would this make any sense, and meanwhile land with better soil quality remains the preferred option.

• Some EU nations have higher biomass but these nations tend to have a poor organizational structure. A lot of institutional changes need to be implemented in time in order to achieve the calculated potential.

• Bioenergy can also be produced without biomass from land, an example of this is biofuels from algae. However, to date, biofuels from algae haven't captured the market, as it was once estimated. It remains unfeasible economically. The learning curve can help in the development and better economics in the future, however, much uncertainty hangs over the probable outcomes.

Other features that have identified with respect to the sustainability are:

- The fermentation potential can be exploited in a much efficient way.
- Setting a clear benchmark for bioenergy sustainability criteria, including biofuels and biomass alike, delineating both the indirect and direct effects.
- Research and development in the optimization of processes and analysis of pilot projects to map out the most promising pathways for further scale-up.
- Planning and preparation for larger processing of biomass for import into biofuels and biogas. A few features of such a process would be the selection of location and technology, bioenergy trade contracts, licenses, and Carbon capture and storage (CCS) locations. (ECN, 2011)

Agricultural resources serve as the main feedstock for biofuels. More demand for biofuels directly competes with agricultural outputs I.e food, feed, processed food and industrial use, resulting in a direct impact on food security, livestock as well as community markets (Tatsuji Koizumi, 2015). This competition can be further categorized into direct and indirect competition. The substitution to alternative commodities is an example of indirect competition. It entails a competition for the usage of land and water, labour and capital, fertilizers and pesticides, etc. The competition of biofuels with natural and agricultural resources is shown in the figure below.

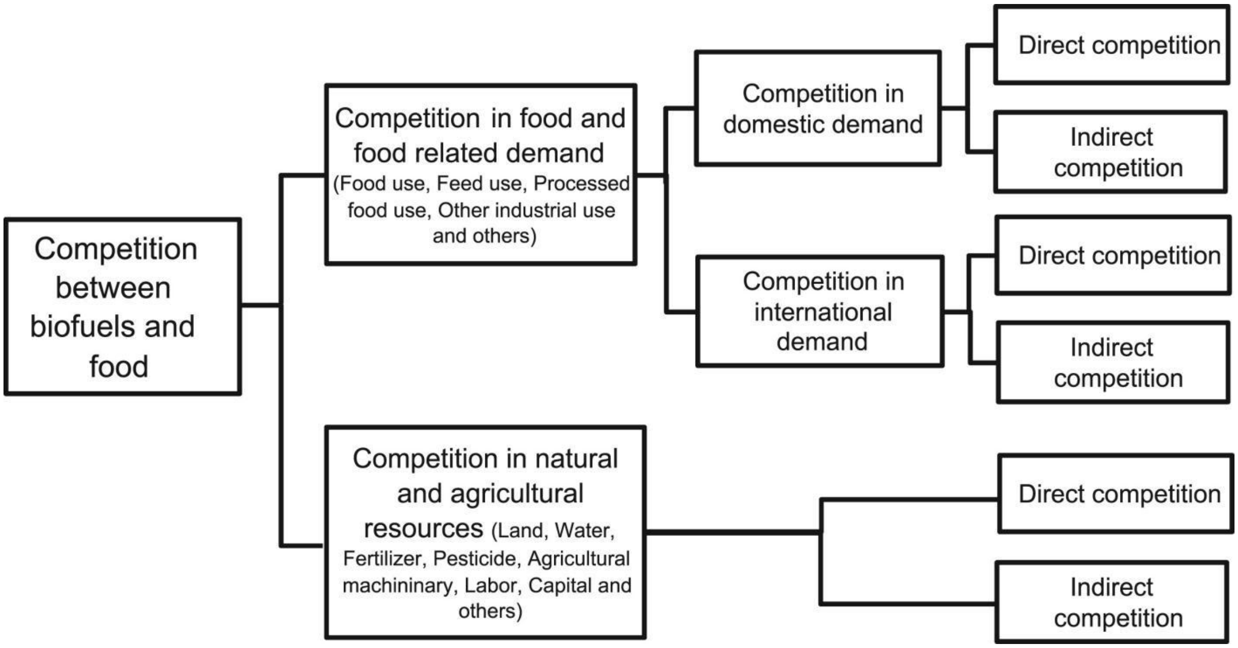

Fig. 35. Direct and Indirect competition between biofuel and food (Tatsuji Koizumi, 2015).

The use of food crops for energy production has been a controversial issue for the EU policymakers. Figure 36 (below) illustrates the use of food and cereal crops in the EU member states in 2014. 3.9% of the total food crops in the EU are used for energy generation. While 3.1% of the total cereal crops are used for the production of biofuels. This implies that although not a substantial percentage of food and cereal crops are used for bioenergy production, still the number is also not negligible and has its own consequence.

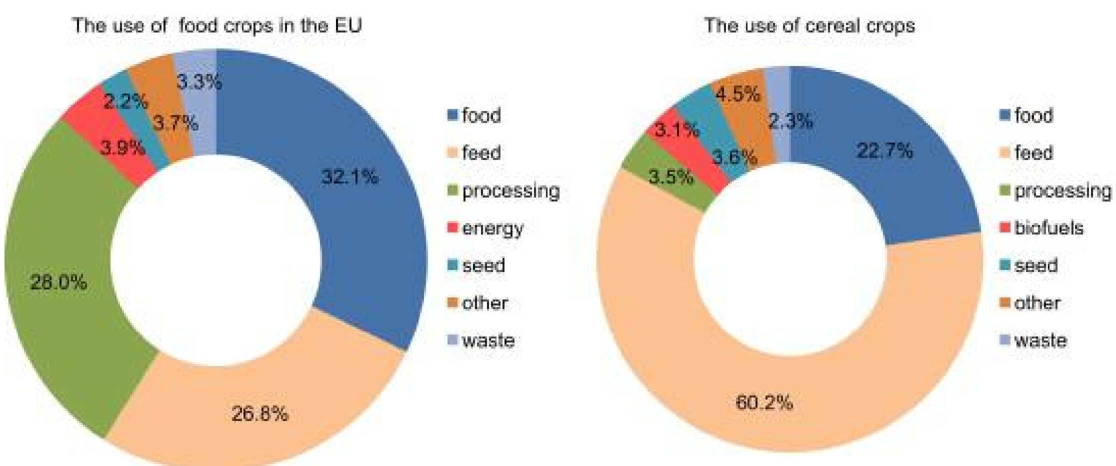

Fig. 36. The use of food and cereal crops in the EU in 2014 (Scarlat et al., 2015).

In figure 37 (below), the Food Price Index is representative of the average of five (cereals, vegetable oil, sugar, meat, and dairy) commodity group price indices weighted per the average export fractions of each of the groups for 1990 to 2015 (Araujo et al., 2017). This study suggests that during the indicated increase in food price food, there was a simultaneous escalation in the production of biofuels, which may confirm what many believe to as a direct connection between the food and fuel prices.

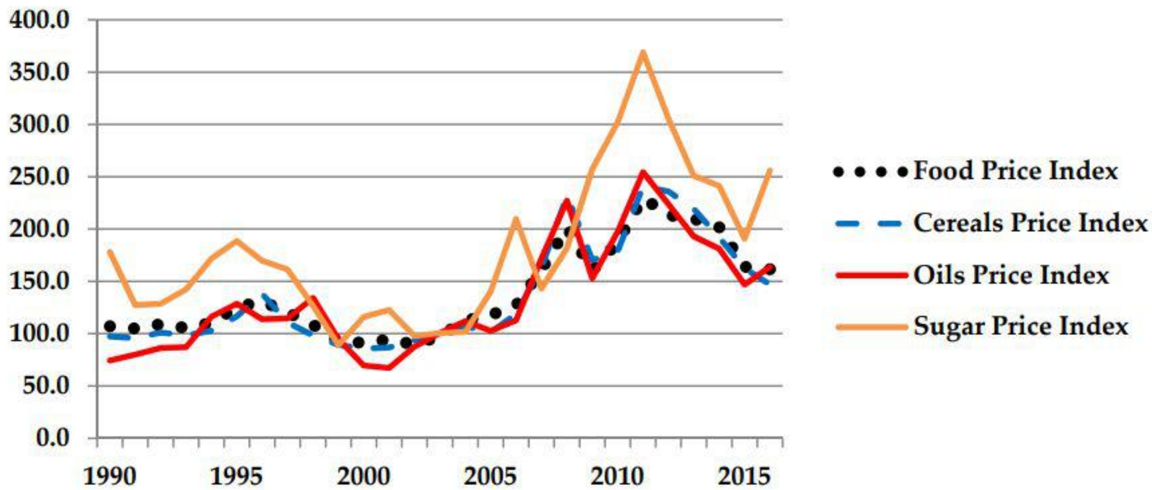

Fig. 37. Food vs Fuel. Food price index and key constituents (Araujo et al., 2017).

4.4.3. Conflicts: Effects on the environment

Second generation biofuels are controversial in nature and their sustainability is questioned. Gamborg et al. (2011) state that the production of biomass for second-generation biofuels has an adverse impact on to environmental conservation and biodiversity, hence it cannot be sustainable (Gamborg et al., 2011). The argument being that the use of biomass from crop and forest residues affects the localized carbon cycles along with the quality of fertile soil. Furthermore, the widespread use of artificial fertilizers lead to the eutrophication and do not lead to any potential GHF emissions savings (Doornsbosch and Steenblik 2008).

Although the claim that the 2nd-generation biofuels have less GHG emission than their 1st Generation counterparts (Delshad et al. 2010), these potential emissions reductions have been just being lost or absorbed in the form of land use change. This happens as land that would act as a carbon sink, for example, patches of forest and pastures, would be substituted by the cropland used for the bioenergy generation (Melillo et al. 2009).

For countries with high biofuel potential, some conflicts have come to light with small land holders and farmers are forced to sell their lands or forced to grow these energy crops. Land conflicts and grabbing have become real concerns (Johansson, 2013).

4.4.4 Biofuel market structure

Figure 38 (below) tries to capture the complex interconnection between trade streams of biofuels and biomass that can encapsulate either local, regional or full EU trade. Biomass can be imported or exported directly either as raw biomass or finished products like pellets. Given the impetus that biofuels got at the turn of the century and its fossil-fuel like market structure, the development of biofuel market could be sustained through the trading of biomass for the production of biofuels in the bio-refineries for the transport sector (Heinimo and Junginger, 2007).

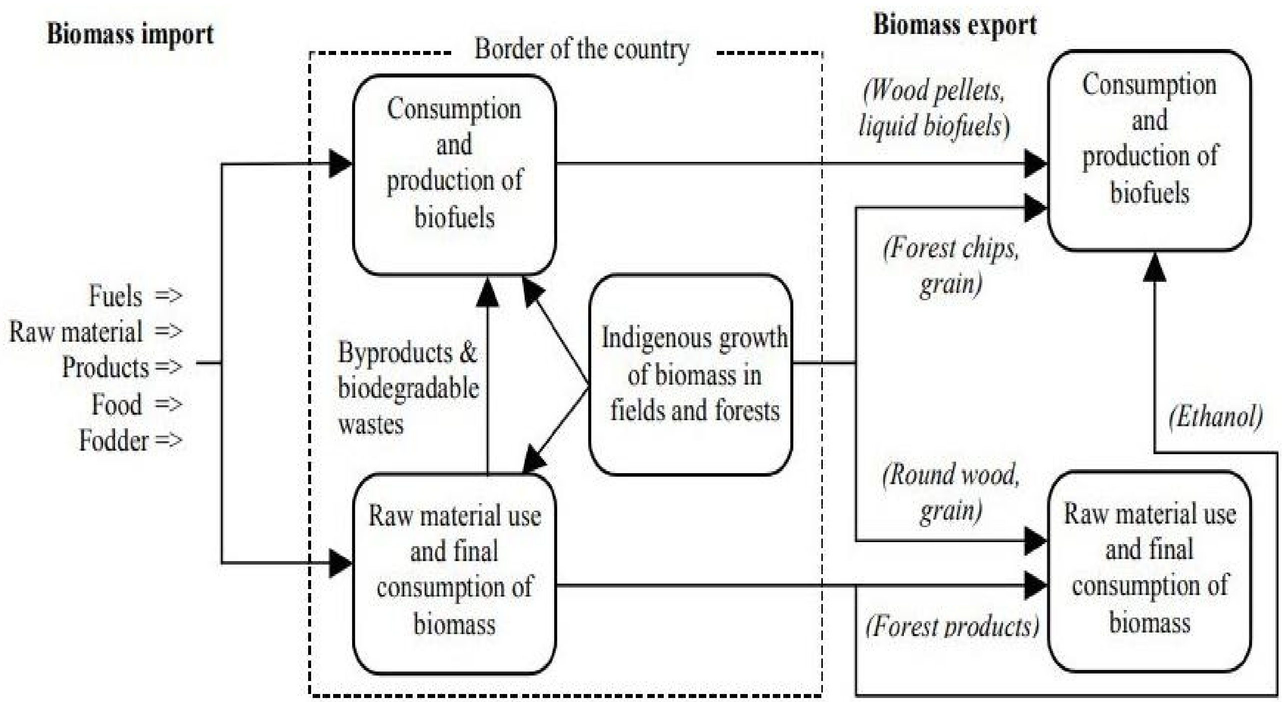

Fig. 38. Biomass trade flow within a particular region/country or the full EU member states (Heinimo and Junginger, 2007).

4.4.5 Consumption of different forms of bioenergy

Solid biomass is the biggest source of gross inland consumption of biomass for energy in the EU-28 in 2015 with 70% (95.285 ktoe) of the total gross inland consumption of bioenergy. The next on the list is biogas with 11.5% of the total contribution. Liquid biofuel follows with 11.4%. The contribution of municipal waste for energy was 7.1%. Wood pellets contribute 6.3% of the total. For the solid biomass, the residential consumption of solid biomass, with 41%, is the biggest contributor (AEBIOM, 2017).

Biodiesel has the biggest consumption for the liquid biofuels in the EU with a 75% contribution of the total consumption. There was a fourfold increase in the use of recycled vegetable oil between 2010 and 2015, which accounts for the main development of biodiesel during that period. The other major liquid biofuel in the EE is Bioethanol, which accounts for 18% contribution of the total consumption. The 2nd generation biofuels account for 2% of all biofuels generation. The agricultural sector and food industries account for more than 70% of the total use of biogas (AEBIOM, 2017).

Figure 39 (below) shows the gross inland consumption EU-28 of biomass per use and feedstock in 2015.

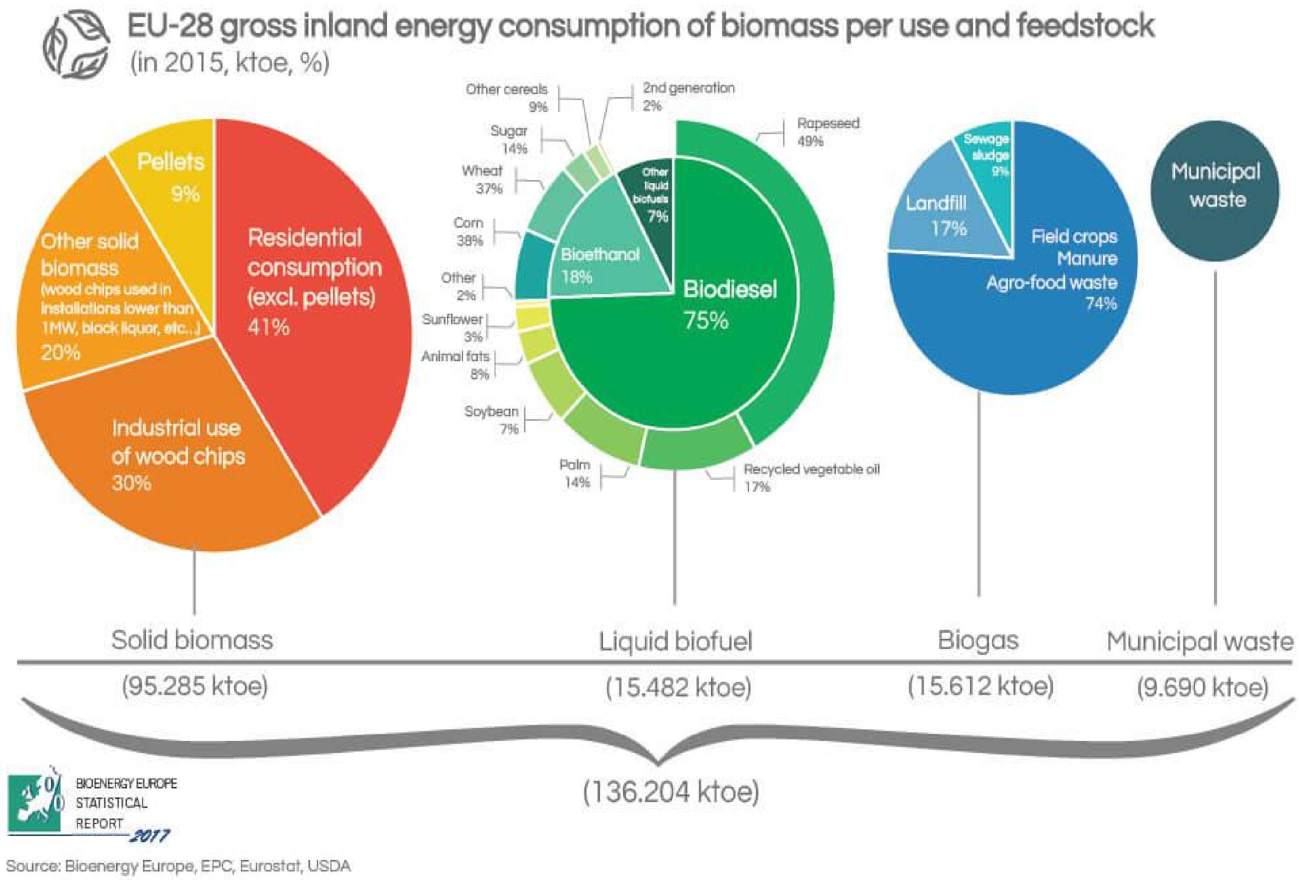

Fig. 39. The gross inland consumption EU-28 of biomass per use and feedstock in 2015 (in Ktoe, %) (AEBIOM, 2017)

Indicators and Effects:

It follows from above that biofuels have had certain adverse and some positive effects since their widespread application in the EU. Indicators like deforestation and impact on habitat have had negative impacts and hence gets a low rating. While indirect employment in this sector and diversification of fuels for transports get a positive rating. Similarly, other indicators and effects of bioenergy on energy security for the EU in the last decade can be derived from the above data and the effects are shown on the rating scale that was derived in section 2.

Deforestation related to energy use and fuel collection (Biofuels and Biomass)

The overall effects of bioenergy on deforestation, according to Johansson (2013), "depend on the incentives for improvements of productivity, developments on other markets such as those for food and fiber and the possibility to use degraded land for marginal production increases instead of forest land." (Johansson, 2013).

Even with the policies and directives like the zero landfill and a Waste Framework Directive (WFD), the total quantity of the energy recovered from the non-recyclable municipal waste of the EU-28 countries in 2010 was only about 6% (EuroStat 2014).

Rafiaani et al., (2018) state that there are many environmental, social and economic implications of growing biomass at mass scale. These include loss of ecosystems, global warming, labour rights, employment, food security, etc.

Biofuel market is prone to conflicts, especially when large-scale and industrial plantations are concerned. These are often achieved at the loss of the local, small farmers and communities (Jonasson, 2013). Land-grabbing is another potential abuse which is shown to be connected not only to biofuels use but also to boost export at the expense of domestic consumption (Blanchard et al., 2014).

Trading energy crops for food crops may become a threat to food security. It is depended on many variables like changing crop production technology and changing diets. Displacement of food crops could trigger a chain reaction that has adverse effects on areas with high biodiversity and potential loss of carbon to the atmosphere (Jonasson, 2013). The debate over the use of energy crops in the EU has led to change in the EU policy, with more stringent criteria for the use of biomass and biofuels (European Commission, 2018). This indicator scores a 2 on the rating scale, which implies a negative impact on the indicator.

Generation of energy-related industrial and municipal solid waste (MSW)

Biomass waste usage, particularly from industries, homes and waste products from agriculture and forestry residues, has no land issues to deal with. However, these products have the potential for other applications, for example in cattle feeding. It is unclear what percentage of bio-waste can be reserved for energy applications (Scarlet et al., 2018). Figure 40 shows the municipal solid waste operations in the EU from the year 1995 and 2015.

One of the trends is that the EU countries have changed their focus increasingly from the disposal of municipal solid waste to its prevention and reuse. The quantity of recycled municipal waste tripled and landfill plummeted to half in a decade. Yet, currently in the EU, more than 30% of the municipal waste continues to be and filled (Eurostat: European Statistics, 2017).

Due to the EU's waste and renewable energy legislation, a large amount of energy has been produced from the renewable municipal solid waste. On account of bioenergy sector, the total share of renewable waste was, in 2015, at 7.2%, that, in 1995, was at 5.1%. (Eurostat, 2017).

On account of the above industrial and MSW policies, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

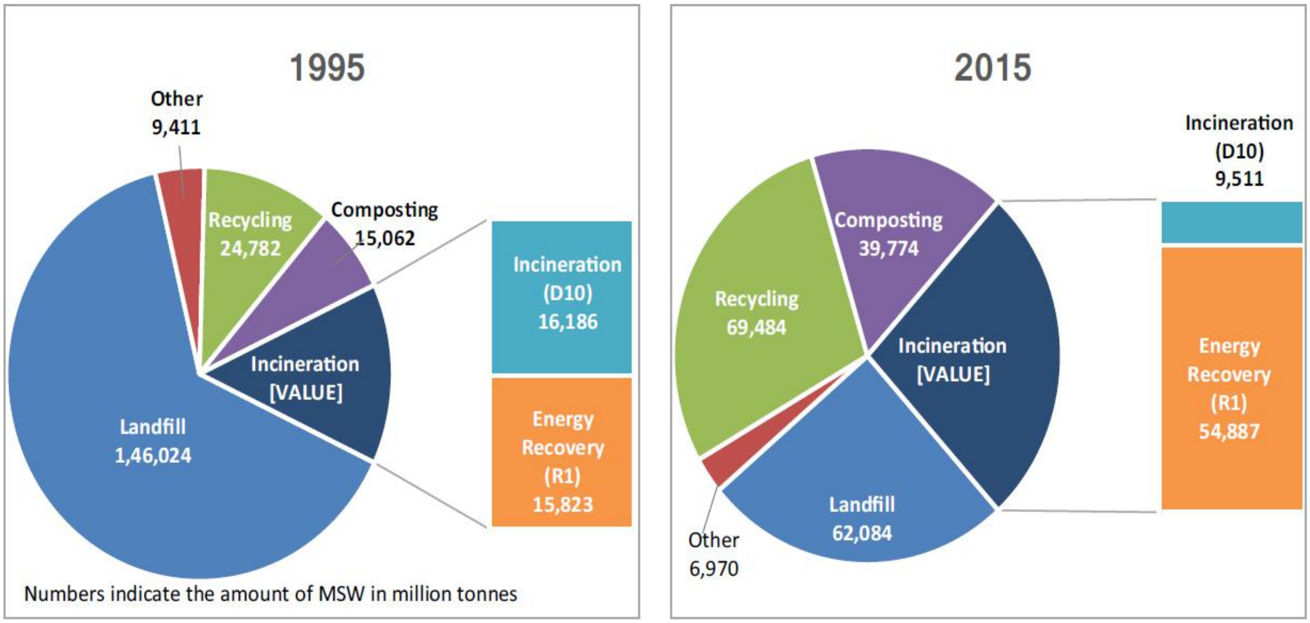

Fig. 40. Municipal Solid waste operations in the EU in 1995 and 2015 (Eurostat, (2015)

Energy pollution's impact on habitats (Solid Biomass)

Production of biomass for energy in the EU has resulted in reducing the land which could have been used for growing food crops. This shows the imminent danger that energy crops have for the food production (Jonasson, 2013). This conflict over the use of land for energy or food depends on several external drivers like the increase in efficiency in both food and energy crop production and the global and local dietary habits. Increased demand for bioenergy could lead to increased food prices, which itself is a critical indicator of food security (Ondrej et al., 2017). Thus there are winners such as the landowners and the losers who belong to a particular section of society, who are not so well-do to and, and as a result, new conflicts have arisen among these groups.

The direct and indirect effect of land use on account of bioenergy production has been shown in figure 41. It is clear from figure 41 (below) that the extent of the trickle-down impacts indirect effects can be difficult to quantify in the long run. How the change in consumption will shape or to what extent the conversion of non-farmed land would take place is difficult to predict accurately (EEA, 2013).

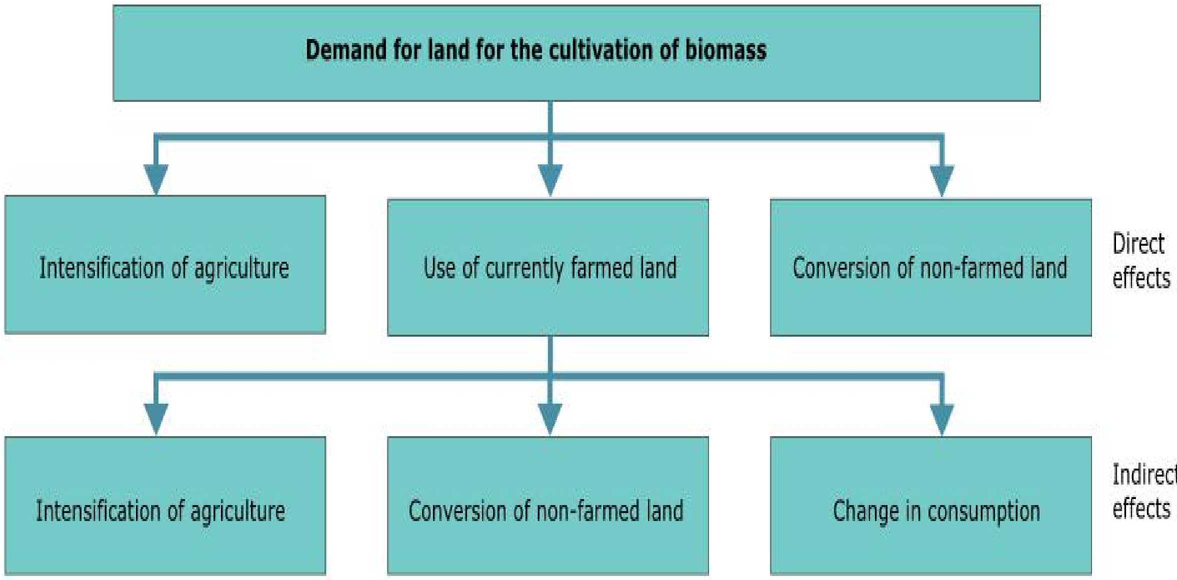

Fig. 41. The direct and indirect effect of land use for bioenergy (EEA, 2013).

Land use and the associated changes that a massive development and deployment of bioenergy would bring with it would be an important point in sustainably obtaining bioenergy as the availability of land could end as putting a restraint or a boundary condition (Bentsen et al., 2012).
This indicator scores a 2 on the rating scale, which implies a negative effect for the indicator.

Expenditures on financial support mechanisms for renewable energy (Biofuels)
The EU has continuously provided funding for many bioenergy based research and technology development (RTD) over the many successive policy-making phases. These have included the complete chain i.e. starting from the feedstock production to the end use applications.

More than 100 projects were initiated under 'Framework Programme FP5' between the period of 1998 and 2002 with a total budget of €140 million (Lengefeld and Lies, 2018). The successive policy 'Framework Programme FP6' supported over 40 projects between the period 2002 to 2006 with a total budget of €150 million Continuing with the trend, the funding is continued and in 2018, for liquid biofuels, seven 2nd generation biofuel projects were funded (IEA, 2018). This indicator scores a 4 on the rating scale, which implies a positive effect on this energy security indicator.

Planned new energy projects including construction status of approved project (Solid Biomass)
112 projects related to bioenergy have been sanctioned under the horizon 2020 by the EU in the last 4 years. Furthermore, many novel initiatives were taken in order to increase the potential of biomass such as the 'Bio-Based Industries Public Private Partnership' which falls under the scope of horizon 2020 (EUBIA, 2018). The ability to make use of the existing infrastructural setup for bioenergy in the EU, which has improved with time, has helped in implementing the new projects quickly. The continuous existence and planning of bio-based energy projects, although not on a massive scale, give this indicator a score of a 3 on the rating scale, which implies a little or no effect for the indicator.

The indicators and effects have been summarized in table 10 below:

Table 10: Energy security indicators and their ratings for environmental & social sustainability dimension.

Indicator	Effect (Rating)
DEFORESTATION RELATED TO ENERGY USE AND FUEL COLLECTION	2
GENERATION OF ENERGY-RELATED INDUSTRIAL AND MUNICIPAL SOLID WASTE	3
ENERGY POLLUTION'S IMPACT ON HABITATS	2
EXPENDITURES ON FINANCIAL SUPPORT MECHANISMS FOR RENEWABLE ENERGY	4
PLANNED NEW ENERGY PROJECTS INCLUDING CONSTRUCTION STATUS OF APPROVED PROJECT	3

Total greenhouse gas emissions from energy production and use (Solid biomass, biofuels)

In this study, bioenergy has been assumed to be sustainably available as per the current data and studies. However, with the pace of bioenergy having exceeding far more than the projections made, there have been major conflicts with other land use i.e. food production (Ondrej et al., 2017), material requirements, agricultural land, biodiversity, etc (European Commission, 2016).

The criteria for biomass and bio-liquid fuels for the GHG emissions saving and sustainability criteria has been laid out by the European Commission in its energy directive(COM/2016/0767 final/2 - 2016/0382 (COD)) had a draft rule stating that the electricity generated from the biomass fuels, for plants with or 20 MW capacity or more, would be seen as renewable source, given that it is obtained by newer and cleaner technology like the new efficiency co-generation (EU Carbon Market Glossary, 2016). Furthermore, the use of dedicated energy crops, which are carbon neutral, has have helped the stated aim of the EU to curb greenhouse emissions.

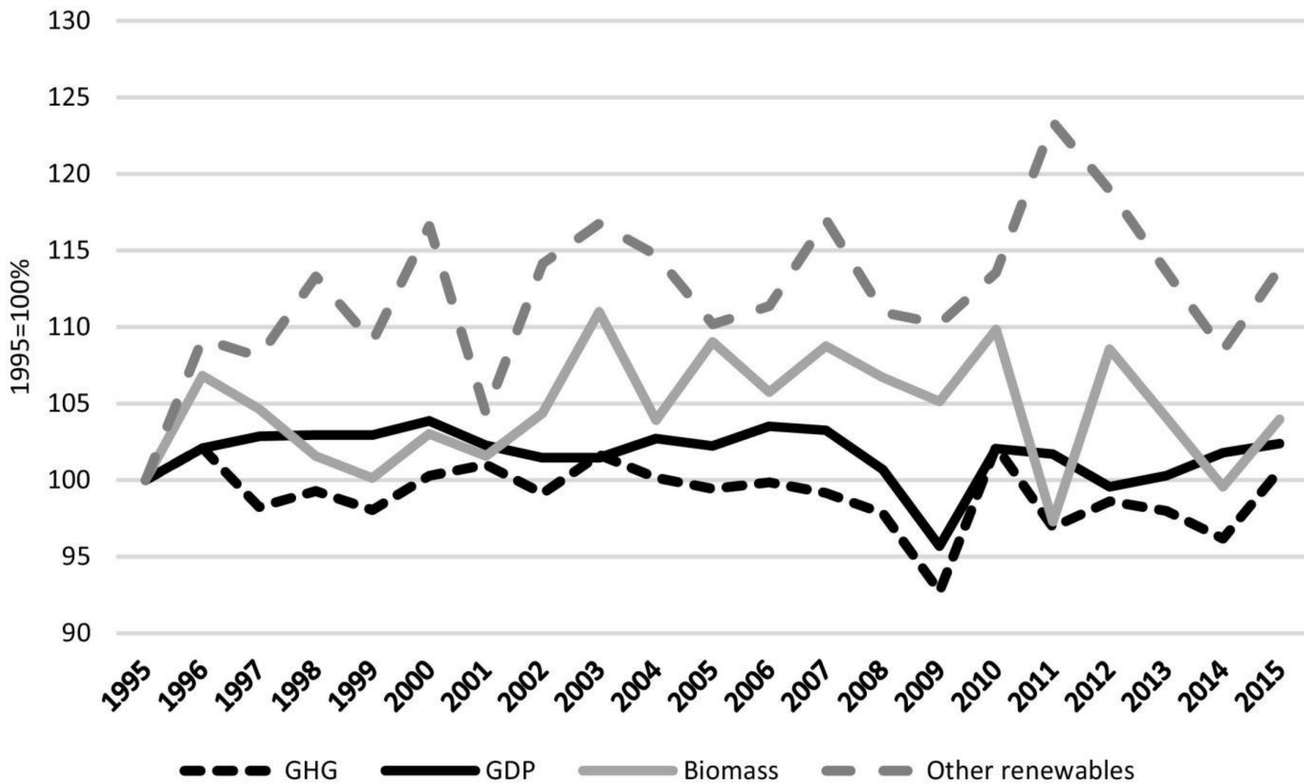

Fig. 42. Changes in the biomass GHG emissions and GDP in the EU from 1995 to 2015 (T. Baležentis et al., 2019).

In the above figure, the benchmark for the GHG emission from biomass has been kept at 100% in 1995. The figure captures both the subsequent increase and decrease in emission in the following years. The total GHG emissions from biomass from 2000 to 2015 increased by 2%. The emission from biomass was at its peak in 2003. It was also comparatively high in 2010 and 2012. After the recession of 2008-09, for the economic recovery period (2010–2015) there a reduction in GHG emissions. There were shifting changes in biomass, from 2000 to 2015, the production of biomass increased by 3% (T. Baležentis et al., 2019).

With the emissions from biomass being constantly above the above GHG, Therefore, with this data, this indicator scores a 2 on the rating scale, which implies a negative effect for the indicator.

Generation of energy-related hazardous waste (Bioenergy crops)

Unlike solar and wind technologies, there are not very strict criteria and the requirements for critical materials. However, with plantation of dedicated bioenergy crops, there will be a high demand for fertilizers, both organic and artificial. For large-scale crop production, artificial fertilizers are bound to be the main suppliers. The total demand will vary according to the prevailing product requirements, management, regional and technological development. The three major constituents of artificial fertilizers are phosphorus, potassium, and nitrogen (World Wildlife Fund and Ecofys, 2014). Nitrogen fixation ensures that atmospheric nitrogen is converted to nitrogen, so for applications in fertilizers, that would be sufficient nitrogen available. Hence nitrogen has not been a bottleneck or generated extra pollutants. Potassium and phosphorus, on the other hand, need to be mined from the earth in the form of potash and phosphate rock, which has its own environmental implications (World Wildlife Fund and

Ecofys, 2014). This indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

CO_2 reduction targets (Solid biomass, biofuels)

In June 2018, the EU governments reached a political agreement to raise renewable energy targets to 32% by 2030 (European Commission, 2018). This is seen as an ambitious target which would further spur the growth of renewables. The RES policy framework of the EU had started to take shape in March 2007 when the 27 EU members agreed on a binding target of at least 20 percent renewable energy from final energy consumption by 2020 (European Commission, 2018).

In 2016 for the total gross inland energy consumption of the EU, the renewable energy sources (RES) amounted up to 13.2 %. Wood and other solid biomass accounted for the highest share of all the RES (EEA, 2018).

With the implementation of the EU RED certificate requirement for bio-liquids, other such certification systems began to mushroom with their specialization for biofuels such as ISCC, RSB, REDCert, and 2BSvs**.** Contrary to the prevalent agricultural certification systems, these ones had to directly tackle carbon emissions as per the EU RED requirement that the biofuels cause fewer emissions than the petroleum-based fuels (European Commission, 2018). Due to these stringent actions taken, particularly for the new revised and updated standard for biofuels, this indicator scores a 4 on the rating scale, which implies a positive effect for the indicator.

Share of zero-carbon fuels in energy mix (biofuels, solid biomass)

In the stated policy of e the EU, biofuels would have to account for 35 % reduction in greenhouse gases emission than the current emissions from fossil-based fuels. And in 2018, the target is to achieve 50 % reductions in GHG emissions. Similarly, for new installations , i.e. the ones installed after 2015, would have to show 60 % GHG emissions reductions (EUBIA, 2017).

The EU Renewable Energy Directive (RED) mandated that by 2020, around 10% of the energy used in the transportation sector should come from renewable energy sources (RES). In 2011, the initial requirement was set at 5% blending by energy in 2014. In 2015, the RED was amended by the EU Indirect Land Use Change (ILUC) directive, which introduced a 7% cap on the contribution that conventional food and feed-based biofuels could make to the RES-transport target (ICCT, 2018). This indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

Carbon content of primary fuels (biofuels)

The EU Renewable Energy Directive (RED) mandated that by 2020, 10% of the energy used in the transportation sector should come from renewable energy sources (RES). In 2011, the initial requirement was set at 5% blending by energy in 2014. In 2015, the RED was amended by the EU Indirect Land Use Change (ILUC) directive, which introduced a 7% cap on the contribution that conventional food and feed-based biofuels could make to the RES-transport target (ICCT, 2018).

Biofuels, along with electric vehicles, considered low-carbon fuels, has been envisaged as important tools to make the transport sector sustainable (IRENA, 2016). The second generation biofuels are being beefed up as the capacities are on the incline, however, there still exists a steep technology learning curve (Araújo et al., 2017).

This indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

The indicators and effects have been summarized in table 11 below:

Table 11: Energy security indicators and their ratings for environmental & social sustainability dimension.

Indicator	Effect (Rating)
TOTAL GREENHOUSE GAS EMISSIONS FROM ENERGY PRODUCTION AND USE	2
GENERATION OF ENERGY-RELATED HAZARDOUS WASTE	3
CO_2 REDUCTION TARGETS	4
SHARE OF ZERO-CARBON FUELS IN ENERGY MIX	3
CARBON CONTENT OF PRIMARY FUELS	3

4.5 Energy security dimension of 'Regulation and Governance'

Presence of climate change goals or targets (Biofuels, solid biomass)

The targets for climate change has become more stringent over the last decade. In the EU, 10% of the energy obtained from the RES in the transportation sector by 2020 is the target of the renewable energy directive, which currently stands at 5%. With concerns regards to the sustainability in the EU, the emphasis has been on the development and acceleration of the 3rd generation of liquid biofuels. In 2016, the biofuels industry was the second largest renewable energy employer after the solar PV industry. In June 2018, the EU governments reached a political agreement to raise renewable energy targets to 32% by 2030 (European Commission, 2018). This is seen as an ambitious target which would further spur the growth of renewables. The RES policy framework of the EU had started to take shape in March 2007 when the 27 EU members agreed on mandatory count of 20 % of the total energy consumption to be met from the RES (European Commission, 2018).

According to European Commission (2016), “”In 2016 renewable energy represented 17 % of the energy consumed in the EU, on a path to the 2020 target of 20 %. The share of energy used in transport activities from renewable sources almost tripled in 10 years to reach 7.1 % in 2016”” (European Commission, 2016).

Also in 2016, for the total gross inland energy consumption of the EU, the renewable energy sources (RES) amounted up to 13.2 %. Wood and other solid biomass accounted for the highest share of the renewable energy sources.

Under the EU directive of 2015/1513, the RED and the Fuel Quality criteria were addressed to increase GHG savings. Furthermore, the indirect land use was put under the restriction of 7 % share of the conventional biofuels in the transportation sector for 2020 sustainable energy goals and it also includes

0.5% use of 2nd and 3rd generation biofuels (EUBIA, 2018). Furthermore, these biofuels also need to measure up to the sustainability criteria set up the renewable energy directive. The following are some of the criteria to be meet (IEA, 2016):

1. Compared to fossil fuels, biofuels should account for more than 35 % GHG savings and the value has risen to 50% from 2018.
2. All the installations set up after October 2015 must account for a minimum of 60 % GHG savings.
3. Biofuels cannot be grown in areas such as wetland, forests, and areas which had other high carbon stock areas.
4. The raw materials procured for biofuels cannot be obtained from land with high biodiversity which includes grasslands and forests.

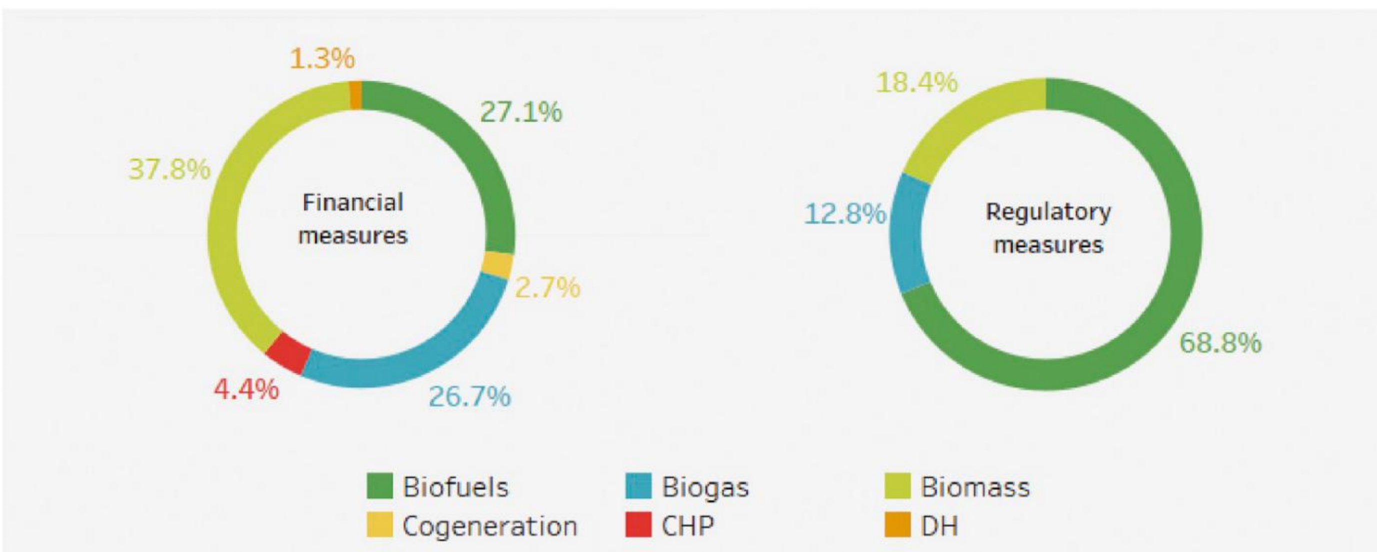

Fig. 43. Breakdown of financial and regulatory measures upon bioenergy sources (2005–2015) (M. Banja, et al., 2019).

As seen from the above figure, from 2005 to 2015, 325 support measures had been issued for the bio-sector in the EU, mainly in the energy sectors of transportation, heating/cooling and electricity (M. Banja, et al., 2019). Around 60% of these measures are for financial measures, other measures included were that for the soft and regulatory measures. The financial measures, which account for 60 %, included all the types of biomass.

Biofuels, over these years, have been subjected to all kinds of measures, including soft, financial and regulatory. For the biomass employed for electricity production, more than 20% of the measures (particularly financial) were implemented in this time period (M. Banja, et al., 2019).

Due to these stringent goals and targets, this indicator scores a 4 on the rating scale, which implies a positive effect on this energy security indicator.

The indicators and the effects have been summarized in table 12 below:

Table 12: Energy security indicators and their ratings for regulation and governance dimension.

Indicator	Effect (Rating)
PRESENCE OF CLIMATE CHANGE GOALS OR TARGETS	4

4.6 Energy security dimension of 'Technology development and efficiency'

The direct and indirect employment induced in the EU in the bioenergy sector from 2010 to 2015 as shown in the figure (fig. 44) below. Solid biomass sector is the highest employer with around 30000 jobs in 2015.

Fig. 44. Evolution of bioenergy employment sector in the EU from 2010-2015(Indirect and Direct jobs) (BESR, 2017).

Induced employment in the energy sector (Solid biomass, biofuels, biomaterials)

Mengal et al., (2018) estimated that in 2013, the EU bioeconomy was estimated at EUR 2.1 trillion. It also accounted for 10% of the total jobs in the EU, which was 22 million. These bio-based sector accounts for the production of all bio-based products ranging from bio-chemicals, solid and liquid biofuels, energy crops, bio-materials, to paper industry to fisheries (Mengal et al., 2018).
This indicator scores a 4 on the rating scale, which implies a slightly positive effect on this indicator.

Research budget for biofuels (Biofuels)

Under LC-SC3-RES-23-2019 and LC-SC3-RES-24-2019, up to € 40 million budget is allocated to renewable Fuels for transports in the EU. This includes the development of next-generation biofuel and advanced aviation biofuels in the EU (European Commission, 2018). Bioenergy has always attracted a lot of attention as well as investment. Within the EU, the focus has been mainly on biodiesel. There are many member states which take the initiatives to promote bioenergy like mandating fuel mixing. Within the EU, there is a 7% mandate for biodiesel mixing (SETIS, 2014).

The principal instrument for funding research and development of the EU is the 'Horizon 2020'. It has a budget of nearly €80 billion over 7 years. It has been granted funding over 3,7€ billion which would aim at boosting the investment in the development and strengthening of a sustainable bio-based industry sector in the EU (EUBIA, 2018). In December 2017, Bioenergy further received loans amounting to €45 million. On account of continuous funding, this indicator scores a 4 on the rating scale, which implies a positive effect on this indicator.

Indirect employment in the energy sector (Biofuels, biomass)

According to the research by Rafiaani et al., (2018), the EU has created a total of 520,000 jobs in the bio-sector, this includes both indirect and direct jobs and amount up to EUR 78 billion (Rafiaani et al., 2018). In 2010, the global ethanol and biodiesel production produced around 1.4 million jobs in all sectors of the global economy according to The Global Renewable Fuels Association (GRFA) (Urbanchuk 2012), and out of which, the EU had a share of estimated 221,183 jobs (Suarez eta., 2015). Because of all these impacts on employment, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

Research budgets for renewable sources of energy (All bioenergy)

The principal instrument for funding research and development of the EU is the 'Horizon 2020'. It has a budget of nearly €80 billion over 7 years. It has been granted funding over €3,7 billion which would aim at boosting the investment in the development and strengthening of a sustainable bio-based industry sector in the EU. In December 2017, Bioenergy further received loans amounting to €45 million (EUBIA, 2018). On account of continuous funding, this indicator scores a 3 on the rating scale, which implies a little or no effect for the indicator.

The indicators and effects have been summarized in table 13 below:

Table 13: Energy security indicators and their ratings for technology development and efficiency dimension.

Indicator	Effect (Rating)
INDUCED EMPLOYMENT IN THE ENERGY SECTOR	4
RESEARCH BUDGETS FOR BIOFUELS	4
INDIRECT EMPLOYMENT IN THE ENERGY SECTOR	3
RESEARCH BUDGETS FOR RENEWABLE SOURCES OF ENERGY	3

4.7 Conclusion

As in this chapter, the ratings were awarded for every selected energy security indicator, an average of all the energy security dimension would help present a clearer picture of the analysis. Some of the energy security dimensions have performed positively, while some others have scored an overall negative score.

Although the weight of every energy security dimensions and indicators have been kept the same for the purpose of this study, this may not be the case, and this is further explored under the 'discussion' chapter

The overview and the average rating for all the ratings of energy security dimensions of energy security for this study are as follows:

For the 'Availability' dimension, the average rating of all the energy security indicators and metrics rating is 3.0/5

For the 'Regulation and governance' dimension, the average rating of all the energy security indicators and metrics rating is 4.0/5.

For the 'Environmental & social sustainability' dimension, the average rating of all the energy security indicators and metrics rating is 2.9/5.

For the 'Technology development and efficiency' dimension, the average rating of all the energy security indicators and metrics rating is 3.5/5.

Therefore, for all the energy security indicators and metrics of each dimension, the average of the ratings of all the 22 energy security indicators come up to 3.09/5. The detailed implications of all the ratings and scores for these energy security indicators and metrics are done in chapters 5 and 6.

The overall average of all the for this analysis rating is 3.09. This suggests that bioenergy in the EU has had a very slightly positive effect, for the selected indicators, on energy security in the last 18 years. This score on our rating scale is a lot closer to no or little effect than a positive effect but falls in the positive bracket. Therefore, by the rating scale criteria, the effect of bioenergy on the energy security of the EU has been slightly positive for the selected indicators for this study. Although, the weight for all the indicators has been assigned the same value. Their weight may not be the same as some indicators have more impact than others. The assigning of equal weight to different dimensions and their indicators have been discussed in chapter 5. The consequence and a detailed analysis of this result for all the energy security dimensions have been discussed in the following chapters.

The summary of the rating table of all the energy security indicators and metrics measured in this section has also been provided in Appendix III. The rating scale and the ranges of the energy security indicators and metrics have been provided in Appendix IV.

Chapter 5

Discussion and reflections

This chapter reflects on and discusses the research. Many choices have been made in all the phases of the research process. In this chapter, the reflections on the most important decisions are presented along with the limitations of the research. The first part of the discussion is dedicated to the discussion of the results of this research thesis. Then, the themes of energy security and the theory are discussed and analyzed. The second part discusses the outline drawn in chapter 3 for biomass and the methods employed, and the last part focuses on the earnings from the bioenergy experience in the EU and a link is formed between future bioenergy potential in the EU and policy directions.

5.1 Results

The thesis provided with a new framework for the assessment of bioenergy implication on energy security for the EU. The framework can be used for any number of studies by changing certain parameters like the geographical scope, the energy security indicators selection, the timescale of the research, etc. In this section, the effect of chosen energy security dimensions, indicators, and metrics on the results are discussed.

For the 'Availability' dimension, the average of all ratings is 3.0/5. For the 'Regulation and governance' dimension, the average of all ratings is 4.0/5. For the 'Environmental & social sustainability' dimension, the average of all ratings is 2.9/5. For the 'Technology development and efficiency' dimension, the average of all rating is 3.5/5. Therefore, for the 22 ES indicators and metrics, the overall average rating for the selected ES indicators and metrics stands at 3.09/5. These implications of these results are discussed in the following sections.

The effects of a 3.09 score can be broken down and studied individually for each dimension of energy security. Some dimensions are positive, like the dimension for regulation and governance and technology development and efficiency. While some have no major effect on the energy security, like the dimension, while the dimension for environmental & social sustainability had a negative impact. Therefore, overall, most of the ratings are better, hence a positive impact would be expected from the bioenergy on the ES.

From these results and implications, the policymakers and government can better perceive the ramifications of the future policies and the direction that should thus be adopted. For example, the ratings of the dimension related to 'Environmental & social sustainability' implies that a mass scale deployment of bioenergy on the EU would not have a positive effect on the energy security of the EU. Therefore, policy considerations have to be made in regards to percentage allotted to bioenergy and future criteria for sustainably of bioenergy.

Another important implication from the rating is the importance of financial thrust on technological advancement. The dimension, 'Technology development and efficiency', with the highest rating, shows research budget for biofuels and bioenergy, in general, have had a positive impact on the bioenergy sector. The indirect and induced employment generated has boosted the bioeconomy. Therefore, more funds for research and development for bioenergy would have a positive effect for more than one dimension and overall energy security.

Given, the overall rating is only slightly positive, a large inclusion of bioenergy in the energy mix of the EU by the policymakers would be less likely. Other neutral implication may not turn out to be positive in the on run. The environmental effects have not improved with the increased use of bioenergy. The long term viability and sustainability also depend on how other renewables like solar and wind perform on these indicators. The implications for the continuous long-term application of bioenergy are difficult to draw from these results.

The positive implications include employment generation related to bioenergy sector. The availability of raw biomass ensures a secure supply of energy. These would induce more confidence in the social sustainability of bioenergy. These entail that the EU could have more bioenergy in its energy mix. However, the practical scenario of a large-scale inclusion of bioenergy, at present, seems unlikely on account of its questionable sustainability and availability of other renewables options like solar energy and wind energy. Development of 3rd generation biofuels along with the use of refined and treated solid biomass could be help overcome these problems. For these, again, the policies will have to be more benign towards subsidies, and research and funding.

The exact scope of bioenergy in the results is not limited to liquid biofuels or solid biomass. As the data used is for all the major types of bioenergy, in which, biofuels have the highest representation and occurrence due to its widespread use in the EU, it may tend to indicate that the major findings are based on and would be most applicable for biofuels. However, this is not the goal of the study, it tries to indicate the implications of all bioenergy as a whole rather than one particular form of bioenergy. This new framework fills the void for the study of energy security in the context of bioenergy. This research helps connect the dots between the indicators, components, and dimensions of energy security and also provide insight into their relationship with a broader system in the EU. The implications of only the liquid biofuels or only the solid biomass on the energy security for the EU can also be carried out using this new framework.

5.2 Theory

Energy security is a broad term that can be viewed and defined in several ways depending on the approach, scope, and type of study. Therefore, several different definitions of energy security exist and are used in a different context. All the major definitions and themes of energy security were described in table 1 of chapter 2.

As the EU has shifted its policy towards more sustainable energy, it becomes imperative to investigate the effects of these new renewable and sustainable energies for the energy security. Although, wind and solar energy have received all the limelight, discussions and researches on bioenergy has been mainly limited to biofuels and its environmental effects. The concept of bioenergy as a whole coupled with the energy security of the EU has not been investigated. Thus, the selection of bioenergy for this study provides insights into the effects of bioenergy on the energy security in the EU and by the formulation of a new energy security framework.

For the research approach of this thesis, the term ‘energy security’ has been used in many ways, mainly derived from the studies of Sovacool & Mukherjee (2011), to keep continuity with the literature that definition has been adopted. This had an impact on the result of the effects on all the indicators and metrics, as they conform to the applied definition and approach. The components and dimensions were selected from that paper. The selected dimensions are as follows: availability, regulation and governance, technology development & efficiency, and environmental & social sustainability, and regulation and governance. These dimensions and their indicators and metrics constituted the main framework and were tested upon. Adopting a different approach and definition of energy security would have resulted in different dimensions and subsequent indicators and metrics.

PEST tool has also been adopted for the study. It helps to group the various energy security indicators and metrics under the broader categories of political, economic, social, and technological indicators respectively. The link between the PEST and the ES was derived in chapter 2. PEST has added value in terms of figuring out the most suitable and relevant energy security indicators and metrics for this study. Starting with the political elements of the PEST analysis tool, the indicators and metrics from ES dimensions of ’availability’, and ‘regulation and governance’ fall under it. The economic element of the PEST broadly includes the dimension of ‘technology development and efficiency’. The social elements included the dimensions of ‘environmental and social sustainability’. The technological elements include the dimension of ‘technology development and efficiency’, and ‘availability’.

Although the dimension and their indicators cover the wide range of energy parameters, some of them may be overlapping and a few indicators and metrics may fall under two different dimensions. ‘Presence of climate change goals or targets’ is one such indicator which could be categorized under the dimensions of ‘regulation and governance’ as well as ‘Environmental & social sustainability’. The stringency and application of this indicator directly affect the dimension of environmental & social sustainability, hence it has been used under the same. As the average rating of all the indicators are taken and ‘regulation and governance’ has only one indicator under it, therefore it has been listed under ‘Environmental & social sustainability’ dimension for better accuracy and coherence of results.

The energy security literature, though thorough, does not provide all the relevant indicators that might better reflect and help to gauge the impact on energy security. For assessing the environmental effect of bioenergy, there is a gap between the existent energy security indicators and metrics. To capture the intricate details, more and varied indicators and metrics need to be defined. Therefore, energy security literature has to capture more indicators from the current realities. Moreover, the framework is confined to the broader categories it encompasses. A new framework or a modified version of this framework could be employed for studying new dimension and new elements such as the study of ‘legal’ aspects of energy security and this would, in turn, entail a new set of energy security indicators and metrics.

5.3 Methods

To access the energy security indicators and metrics, qualitative research has been employed for this study on account of the vague definitions and interpretations of every energy security indicator and metric involved. The indicators and metrics provide quantifiable results to understand comprehensively the energy security effects. The scope of the study allows for an overview and selection of the ES indicators and metrics and not a detailed analysis of every indicator of energy security defined as it would be beyond the scope of the study. By defining the characteristics of bioenergy, a more thorough understanding of bioenergy was obtained. The abstractness and complexity of the topic required detailed analyses of data, information, and trends which were derived from studies and existing knowledge on the bioenergy based on literature research. Adaptation of qualitative, descriptive, and exploratory procedures was incorporated.

The research does not carry any interviews to validate findings or to find information on many accounts. Firstly, this being total desk research, the data needed was readily available from the literature study, and the findings and conclusion are derived from the latest data which is available. Secondly, this kind of research is being conducted for the first time for the theme of bioenergy and energy security in the EU, no such study exists. So, it was difficult to find an authority which could validate the research in its entirety. Thirdly and finally, interviewing a company or a stakeholder could have a more subjective point of view, a bias or an inclination for some specific policies. So, in order to make the process more transparent and objective, a through and multiple interviews of many stakeholders, ministries and companies had to be conducted. This does not align with the end goal of this research and perhaps would be more relevant if the study was to be carried out in collaboration with a specific partner or a target group.

However, the inclusion of interviews before and after carrying out this research could have resulted in the selection of a new set of energy security indicators. Although, it is not certain if that would have been more relevant as the current study already incorporates 22 indicators and metrics from all major energy security dimensions and components. Perhaps, more insight could have been thrown on the weight and importance of the indicators from the interviews as this is one of the possible shortcomings of this research and has been discussed later in the section.

The mapping of bioenergy potential in the EU has been undertaken in various shapes and forms, including forestry biomass potential, industrial waste potential, biofuel potential. A lot of estimates made by different organizations, governments, authors, etc. tend to contradict each other, and the scope and definition of as to what bioenergy accounts for also differ. In this study, official data published and used by government agencies in the EU has been used as the reference point. In the earlier sections, the various biomass potentials were discussed. The theoretical biomass potentials thus have been estimated from these data. However, as the full implications of employing these resources are not known or tested, so there remains a high level of ambiguity attached to it. All the biomass resource have been discovered, if not developed, which is not the case for conventional fossil fuel resources.

Figure 14 shows one of the ways that is possible to map bioenergy resource estimates. Established bioenergy industries, like the widely available biofuels, provide a better probability if any new biofuel plant would be able to match the expected fuel delivery. Moving left of the graph, there is increasing confidence for recovery of biomass resources based on social and political conditions. The difference in the theoretical and realistic or implementable sociopolitical conditions for the extraction and recovery of resources remains large. Given the questions over sustainability, dedicated land use or energy crops for bioenergy has become more difficult, therefore, in this case, the realistic (or implementable) biomass resource has been shifted more towards the ambiguity quadrant relative to the probabilities for conventional fuels.

The current study provides only an overview of the selected dimension. For example, under the dimension of 'technology development & efficiency', the indirect employment generation indicators have been analyzed in the study and the results were positives. However, to give further insight into the long-term employment, short-term employment, skilled and unskilled labour, loss of old employment, etc. These need to be recognized under different suitable indicators. Indicators like these can be introduced for other dimensions as well as for more comprehensive research. Although the range of indicators covers the major implications of bioenergy in the energy security in the EU, for a more detailed and robust analysis, additional dimensions, indicators and metrics need to be introduced. This constituent some of the limitations of the current framework.

One of the possible shortcoming and challenge for this research is the vague definitions and scope of both bioenergy and energy security, and the combination of both implies difficulties and limitations to the study. One such challenge was to accurately select and categorize the energy security dimension. In this study, 22 Indicators and metrics that were selected cover the major implications of the bioenergy on the energy security. More indicators would result in a more comprehensive but also a more complex and long study. Therefore, instead of selecting more indicators, specific focus on a particular energy security dimension would provide better insights. For example, instead of choosing 22 indicator and metrics across 4 dimensions of energy security, all the indicators and metrics under one dimension could be chosen and that would result in a study of only one aspect of energy security. This can be taken in future studies, for example, the standalone and absolute effect of 'availability dimension' or 'technology development and efficiency' dimension could be studied using this framework and approach. Particularly for the study of bioenergy, more indicators related to the environment can be added.

One drawback of this analysis would be that all the indicators have been given the same weight, the same importance. This may actually not be the case as some indicators tend to affect more than others for a given adopted policy. From the average ratings of each dimension, it is clear that the effects are not the same on the energy security as a whole, as some aspects of it are benefited, some suffer while others have negligible impact.

So, the average rating of every dimension should be seen just as an indicative result but it is still important as no single indicator with a greater weight can form a comprehensive energy security assessment. The weight if each indicator would most likely to be context driven. If the focus is n the environmental aspects of a study, then the environmental indicators and metrics take precedence and its indicators and metrics should be given a higher weight. The rating scale used for this study has the ratings from 1-5 in whole numbers. Therefore, with an absence of intermediate decimal rating leaves a degree of ambiguity and fallibility. The indicator which may have an exact value of 2.8 will be scored as a 3. Similarly, an indicator of absolute value 2.2 will be recorded as a 2 on the rating scale. One drawback of this approach is that this may also lead to an oversimplification of the results and ratings.

However, it is very difficult to score any indicator with absolute accuracy and precision. Therefore, an indicative rating suffices for the purpose of this study. Exact and accurate rating of 2.25 rather a 2 falls out of the scope of this study, is rather cumbersome, and would not provide any distinct advantage to the end aim of this study. Then there could be the arguments that any rating scale is liable to error and more changes, however precise with its rating, and it is extremely difficult to come up with an absolute objective rating.

Furthermore, for some of the ES indicators and metrics, some of the data for the studied time period is not precisely available. For example, for the changes in GHG emissions, the data is accurately available for the period from 2000 to 2015, and has a projection to 2020 but not till 2018. So, this may slightly affect the accuracy of the results and ratings for some of the indicators.

What has worked well in this research is the development of a working framework for bioenergy in the EU. However, whether it will be useful as it is for a specific type of bioenergy, say forest residues, may not be entirely true. Some changes will have to be made in terms of selection and weight of indicators. Although, it does give a ready framework to apply these changes and it appears to be flexible to accommodate these changes.

If the research was to be undertaken again or furthered on, now with hindsight, a specific bioenergy sector or application, involving the stakeholders, would be taken on board in the form of a case study. For example, a case study can be included for the effects of biofuels for the energy security of the Netherlands while researching for the broader theme of the EU. The ranges for all energy security indicators proved difficult to measure accurately. There are no references to some of the indicators and metrics from which to gauge it.

5.4 Lessons from the EU experience

There have been some learning from the EU bioenergy experience in the last 18 years. In the energy mix of the EU, the role of bioenergy, as a whole, has been getting a more measured and calculated share, primarily on account of its sustainability credentials, this has been particularly true for biofuels. Biofuels had huge impetus during the first decade of the 21st century i.e. from 2000 to 2010, it was included widely in the policy framework of the EU. However, the sustainability criteria for biofuels is now a lot more thorough and rigorous than it was a decade ago (European Commission, 2018). The food vs fuel debate has also raised serious questions about the cost of wide applications of bio-based energy crops. This has been reflected in the latest policy framework of the EU, where apart from new strict standards, development and deployment of advanced biofuels is given importance (EUBIA, 2018).

Bioenergy has had a big role in securing the energy security of the EU in the last 20 years and the present share of bioenergy in the energy mix of the EU suggest that it will continue to have an important role in immediate future despite the above-mentioned sustainability debate. The availability potential has been adequate over the last two decades as seen in chapter 4. Furthermore, the effect on direct and indirect employment has been positive, which shows that the bioenergy sector has been a direct contributor to the EU economy.

The contribution of 'sustainable biomass' has been getting a larger share in the renewable energy targets of the EU. Although, the regulation and governance and social indicators have been slightly positive for bioenergy in the EU, the larger negative impacts and ratings for the environmental indicators necessarily imply that a large-scale deployment of bioenergy in the EU must not be hurried. These negative effects on environment balance out most of the positives offered by the bioenergy, hence the EU has seen even more rigorous sustainability criteria for applications based on bioenergy as reflected in RED II (European Commission, 2018).

As shown in section 3.3, the bioenergy potential of the EU in the immediate future is sufficient to meet the demands as well as the financial support mechanisms for bioenergy continue to be part of the EU's energy future sustainable energy development goals. If the current policies continue, then bioenergy would have an important part to play in the future EU energy security. Bioenergy, especially the advanced biofuels, has the potential to prove to be a cleaner and more efficient alternative to fossil fuels and add to the EU energy security. However, it also has to compete with other, much cleaner, renewables like solar and wind energy.

The recommendations for the future policy actions in regards with bioenergy in the EU has been given at the end of chapter 6 in case of a continuous role of bioenergy as an alternative source of energy in the EU's future energy policy and energy source.

Chapter 6

Conclusion

The objective of this thesis is to understand the possible implications that the bio-based energy systems have had on energy security in the EU from the time period 2000 to 2018. The main focus of the thesis is on the energy security indicators and their implications for the member states of the EU. In the process, a new working and comprehensive energy security assessment framework has been developed keeping bioenergy in the EU in mind.

The research question, along with sub-questions, aims to fully understand the possible implications of bioenergy systems and economy on the energy security for the EU, and obtain clearer insights into the effects.

The structure of this chapter follows the general structure of the thesis. The research question and the accompanying sub-questions help to draw conclusions from this research. The conclusion starts with a short summary of the research question and a detailed list of the conclusion drawn are given. Effects of every energy security dimension are presented and the conclusions are drawn. the thesis ends with recommendations and directions that may be employed for future policy actions in the EU as well as further academic research related to bioenergy in the EU.

6.1 Comprehensive energy security assessment framework

The analysis of bioenergy and its implications on energy security for the EU has led to several interesting findings.

The new framework developed in this thesis has moved beyond the traditional oil and gas frameworks. This framework combines the elements of bioenergy-related indicators and metrics of sustainability, climate change goals, economic, political, and technological elements, which allow for exploring the comprehensive implications of bioenergy based systems. Given the intricacies of bioenergy and its wide sources and applications, bioenergy systems are different from the current oil and gas systems. Therefore, it was needed to develop a new framework for the energy security of bioenergy systems, and in this study, that framework has been developed.

The important and relevant energy security dimensions and their indicators and metrics are taken from the previous studies. These indicators and metrics form a new comprehensive energy security assessment framework for bioenergy in the EU.

Taking the help of the PEST tool, the new energy security framework has been developed as to investigate the energy security implications under the broader categories of political, economic, environmental, and technical effects of bioenergy on the energy security for the EU.

The four dimensions of availability, regulation and governance, environmental and social sustainability, and technology development and efficiency, are the main dimensions of the energy comprehensive energy security assessment framework. Therefore, there are 4 energy security dimensions, 12 ES components, and 22 ES indicators and metrics that have been broadly classified under the four elements of the PEST analysis tool.

6.2 Conclusions of the research

The main research question for this study is:

What has been the impact of bioenergy on the energy security for the EU from 2000 to 2018?

The answer to this main research question is given as conclusions obtained from the analysis. The following are the conclusion that help assess the impact of bioenergy on the energy security for the EU.

General Conclusions:

• The widespread availability of bioenergy has made for secure energy supply with a slightly positive effect on raw material, storage, stable prices, and transportation.

• There are tougher climate goals in place enforced by the EU in an effort to reduce GHG emissions. This has given impetus to more sustainable bioenergy in the final energy mix.

• Food vs fuel debate has had a negative impact both on the perception of bioenergy as well as its large-scale application. Damage to habitats, ecology, and land use changes had implied more negative ratings. It thus has severe repercussions attached.

• The sustainability of bioenergy has been questionable, and the ratings suggest it is not a very clean alternative fuel. Although most of the bioenergy production has been carbon neutral and new stringent laws adopted by the EU employs more sustainable bioenergy.

• Diversification indicators related to bioenergy have largely positive ratings, making it a more reliable and safe source of energy resource.

• Bioenergy has given a boost to the local economy. The effects on local industries, direct and indirect employment, capital generation have been positive. The ratings for related indicators and metrics are mostly positive.

• Non-energy raw material and critical materials are not the bottlenecks deployment of bioenergy at present or in the past. Components of artificial fertilizers are nitrogen, phosphorus, and potassium are available in large quantities to meet the existing demand.

On average, all the energy security dimensions score positive ratings and the comprehensive energy security effects thus are positive.

The indicators of ‘environmental & social sustainability‘ generally come worse off and on average have scored the least ratings of all the indicators and metrics. On the other hand, the availability dimension scores the maximum average rating.

The conclusions from the effects of all the energy security dimensions have been given below. The PEST indicators, with its broader umbrella and categorization, has also been discussed.

Effects of indicator and metrics of availability dimension

With an overall rating of 3.0, the availability dimension scores an average on the rating scale. The indicators and metrics such as the energy reserves and net imports score particularly well on the scale. This indicates a secure source of energy with less dependency on imports outside the EU.

The availability dimension, which includes the indicators and metrics such as 'total energy demand', get an average rating of 3.3. With a rating of '3.0' implying no or little change, a score of 3.3 demonstrates a positive improvement in this area of the energy security. For the policy considerations, in the long run, this could mean that more investment towards bioenergy could be made but a heavy investment may not be advisable on the grounds of availability. This could help policymakers to decide upon the contribution of bioenergy on the future energy mix of the EU.

Effects of indicator and metrics of Regulation and Governance

This dimension has an important ES indicator of 'Presence of climate change goals or targets'. It has a score of a 4.0 on the rating scale mainly based on the stringent climate goals set by the EU in the last 10-12 years. For the development of biomass in the EU especially for the power and heat sectors, there have been many support measures in place like the economic, financial, regulatory, and administrative support. The effects have been more resources for bioenergy as well as more stronger sustainability criteria. This has been particularly true for the biofuels, new sustainability criteria were set up under the revised renewable energy directive. The rating shows bioenergy has had an overall slightly positive effect on the energy security of this dimension over the last 18 years.

Effects of indicator and metrics of environmental & social sustainability dimension

Given that the sustainability of bioenergy is widely debated, this dimension has particularly high relevance. The average rating of the indicators and metrics of this dimension comes up to 2.9, which shows it has a slightly negative effect. The indicators like the 'presence of climate change goals', 'CO_2 reduction goals', and 'targets and expenditures on financial support mechanisms for renewable energy' get the highest score with a rating of 4. These signify the stringency policy actions taken at the EU level to tackle climate changes. While the indicators and metrics of 'deforestation related to energy use and fuel collection' and 'total environmental footprint of energy facilities', score the least with a rating of 2. Bioenergy has had a detrimental effect on deforestation and land-use change with the poor performance of energy companies in the field of sustainability.

Effects of indicator and metrics of technology development & efficiency dimension

With an average score of 3.5, this dimension has a slightly positive effect, especially in the field of direct and indirect jobs. It includes indicators and metrics like the indirect employment generation or the induced employment in the bioenergy sector and research budgets for biofuels and bioenergy. The indicators and metrics of 'Indirect employment in the energy sector', 'Induced employment in the energy sector' get a rating of 4.0 and for the ' Research budgets for renewable sources of energy' and 'Research budget for biofuels' get a rating of 3.0. It shows the positive impacts on the employment sector related to bioenergy. The rating shows that technological advancement has had a positive effect on many sectors of bioenergy.

Effects of the selected energy security dimensions under the PEST elements.

As PEST has been employed for the broader categorization of the results, figure 45 (below) illustrates the interaction between the selected energy security indicators and metrics for this study and the elements of PEST. They have been deduced from the literature and study in previous sections. The PEST elements form an overarching umbrella for the dimensions and the subsequent energy security indicators and metrics. The elements of the PEST that most closely follow the selected dimensions of energy security has been categorized accordingly. Therefore, a link has been formed between the selected energy security indicators (and dimensions) and PEST elements for the broader categorization of this study.

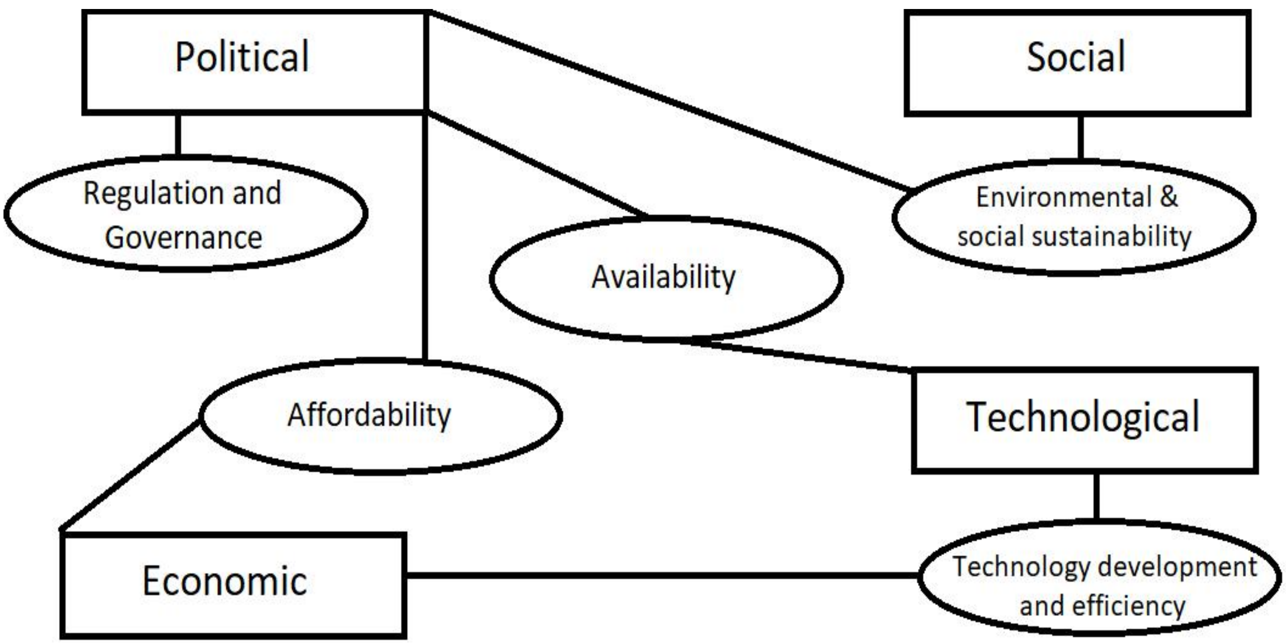

Fig. 45. Interaction between the selected energy security dimension and the PEST elements used in this study.

Most of the selected ES indicators and metrics from the dimension of 'Availability' tend to falls under both the political and technological elements of PEST. Most of the selected ES indicators and metrics from the dimension of 'Regulation and governance' tend to fall under the political element. Most of the selected ES indicators and metrics from the dimension of 'Regulation and governance' tend to fall under the political and economic elements. The selected ES indicators and metrics from the dimension of 'environmental and social sustainability' fall under political and social elements. And finally, most of the selected ES indicators and metrics from the dimension of 'technological development and efficiency' tend to fall under the technological and economic elements.

For the energy security indicator 'Diversification of fuels for transport', which falls under the dimension of 'Availability', both the 'political' and 'technological' changes will affect it directly. Similarly, for the ES indicator 'Research budget for biofuels', which falls under the dimension of 'technological development and efficiency', both the 'economic' and 'technological' elements will directly influence it and hence the final ratings.

Therefore, the dimensions of energy security and their respective indicators and matrices now can be analyzed in the light of their socio-economic and political context of the EU and bioenergy.

Along with these major conclusions, the ratings can also be seen under the broader categories of Political, economic, social, and technology elements. The overall political indicators (under P-E-S-T) have an average rating of 3.63 and has a positive effect on the energy security. The economic elements have an average rating of 3.0, and it has neutral to little effect on the energy security. Therefore, economically the effect of bioenergy on the ES in the EU has been almost neutral. The social indicators get a rating of 3.34 and have a neutral to a positive effect on the energy security. The technological indicators have a rating of 3.68 and can be classified as relatively positive for the energy security.

The average rating under the P-E-S-T categorization is 3.3/5. It shows an overall positive impact on the energy security. The most positive impact has been on the technological indicator with a rating of 3.68/5, while the economic indicator has the least a little or no impact on the energy security with a rating of 3.0/5. The social indicator is slightly positive with a rating of 3.34/5, and the political indicator is relatively more positive with a rating of 3.63/5.

6.3 Recommendations for future research

This study provides an opportunity for subsequent research and pathways. Bioenergy is a broad term comprising of biomass, biofuels, biomaterials, etc. In this section, recommendations are made for further academic research and future policy actions in the EU.

A short list of recommendations is provided for the research findings and conclusion, the recommendations for possible future policy actions and further academic research, followed by their elaboration.

6.3.1 Recommendation from this research findings

Some of the recommendations based on the findings and conclusions of this research thesis are as follows:

- Conduct research on the sustainability aspect of bioenergy with the relevant energy security indicators and metrics for all types of bioenergy. With changing policies and differing criteria, more indicators relating to sustainability could be studied.
- Research into the effects on the ES indicators for more imports from outside the EU and for more percentage of bioenergy in the EU energy mix. Imports of both the raw biomass as well as electricity.
- Conduct more expert interviews with the bio-industry and carry out such research in co-operation with governments co-operations or bio-industry.

- Carry out research for one type of specific bioenergy for all the energy security components, dimensions, indicator and metrics to provide a thorough review.
- The ranges for many energy security indicators and metrics are not clearly defined with no benchmarks. Further research could be conducted into the benchmarking of ES indicators with respect to bioenergy.
- The selection of a different set of energy security indicators and metrics for the same ES components and dimensions could produce a different result. This aspect can be further researched on as to how the results differ with the selection of ES indicators and metrics.

6.3.2 Recommendations for future policy actions in the EU

The recommendations on the future policy regarding the energy security of the bioenergy in the EU could look into the following:

- The comprehensive energy security effects of bioenergy on every member state of the EU;
- The comprehensive energy security effects of a specific type of bioenergy like biofuels, forestry residues, municipal waste, etc. or their combinations;
- The social and environmental impact of bioenergy on different member states of the EU;
- More budget allocation for research and development for bioenergy as it directly affects several key dimension of energy security as concluded from this study.

The framework can be used for studying the effect of bioenergy for a specific member state of the EU or a region. The study itself can be either a holistic one or more detailed one for a particular dimension or indicator. For a more in-depth approach, a specific type of bioenergy can be chosen for the study. Biofuels and biogas have separate market dynamics, so insightful study in either would form a research topic.

As bioenergy covers a wide array of industries and applications that currently stand at various junctures of technological advancement and value chains, wide use of bioenergy in the future would introduce the working and execution of generic biotechnology into all other existing industries. The implications of such a bioenergy application in these sectors could reshape the working of industrial processes. The study of these consequences could be taken up in case of favourable bioenergy policies.

6.3.3 Recommendations for further academic research

Recommendations for future academic research are as follows:

- Find what energy security components, dimensions, and indicators carry the most significance for bioenergy in the EU and conduct a study on them.
- Research into a comprehensive energy security study for all the indicators and metrics of every energy security component and dimension for bioenergy;

- For a more comprehensive or narrow field of study, add more components, dimensions and additional indicators and metrics to the energy security framework.
- Research into a comprehensive energy security study with each type of biomass and assess its impact;
- Perform a region specific or country-specific analysis for bioenergy. It could be a region like north-West Europe or a country, like, Germany.
- Perform a comprehension energy security study for each type of bioenergy, biomass (solid/wet), biogas, and biofuels (algae/solid), separately.

The weight of individual energy security indicator and metric could be assigned for a particular study. As an example, for the study of sustainability for bioenergy in the EU, environmental indicators may have more significance than social indicators. Such a study would then also merit an additional number of indicators and metrics related to the environment, that could be another field of research.

6.4 Scientific Relevance and contribution

The energy security framework developed in this thesis has elements of both existing features and a bespoke selection of indicators for every energy security dimension. These indicators have been applied on a new rating scale. Defining the scope and the selection of energy security indicators relevant to bioenergy in the EU along with its application on a rating scale, as to gauge its implications, is the principal academic contribution of this research. The thesis does intent to open a new area of research on the impact of bioenergy in the EU, with the perspective of energy security. Furthermore, it could add to the academic contribution as it has relevance to both current and future bioenergy scenarios that could open a pathway for future research.

Some salient features to the contribution to the field of energy security are as follows:

- Developing bespoke energy security indicators.
- Defining the scope for bioenergy in terms of energy security.
- Using a rating scale for energy security dimension i.e. new assessment criteria.
- Introduction of flexibility and simplicity in the otherwise intricate and often inelastic energy security framework.
- Incorporation of feedback circuit into the framework.
- Given the scope and application of both ES and bioenergy, the framework can be used for numerous comparative study and for evaluation of many different scenarios.

Energy security and bioenergy are both very broad terms encompassing numerous definitions and wide interpretations with an even wider scope of its constituents. On this very account, they also suffer from a certain vagueness, which is not very acute to fossil fuel or even other renewable energy like solar energy and wind energy. This has also given an opportunity to develop and contribute to this specific line of research. The framework developed in this thesis is the first of its kind for the evaluation of bioenergy in the EU. Under the energy security section (section 2.2), a complete chronological order of definition of energy security has been provided as to reflect upon the growth of the concept and the way it is headed to.

With the current ES literature being focused on conventional energy systems, PEST has been employed to narrow down the data gathering and relevance of energy security indicators for bioenergy. The use of the PEST analysis tool also offers a unique combination of elements in the framework and a boarder categorization, which in traditional energy security is often not employed. With the PEST, the results can be viewed under the broader elements of P-E-S-T. Sections on energy security and bioenergy (section 2 and 3 respectively) provide a base and tool for further research into the link between energy security and bioenergy, which is absent from the current work of research.

There is a dearth of research in the field of energy security of bioenergy sources. The concepts of current energy security for conventional energy sources are incorporated in the energy security of bioenergy sources, thereby classifying some of the traditional concepts as critical, less, important, obsolete or irrelevant. In the process, a relationship among various parameter of energy security such as the components, dimensions, and indicators gain more clarity.

Therefore, there was a space and need for a new framework that could encapsulate the impacts on energy security in energy systems that employ and run on different forms of bioenergy, and this study has tried to provide that.

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APPENDICES

APPENDIX I: Energy Security dimensions and indicators

APPENDIX II: Abbreviation

APPENDIX III: Summary of all the energy security Indicators and metrics ratings

APPENDIX IV: Rating scale and ranges of select energy security indicatos

APPENDIX I: Energy Security dimensions and indicators

Sovacool and Mukerjee (2011) have divided the energy security indicators for energy security into simple and complex indicators. Where a complex indicator was defined as "if it is an established aggregate indicator that includes the measurement of multiple variables or if it involves time intensive, detailed means of measurement." Complex indicators are better suited for in-depth assessment of few indicators. By contrast, simple indicators are those that are more suitable for an overview and view of energy security.

Sovacool and Mukerjee (2011) have selected 372 indicators and metrics for 20 energy security dimensions. These have been provided in this appendix as below:

Simple and Complex Energy Security Indicators and Metrics.

Dimension	Components	Simple Indicators and Metrics	Complex Indicators and Metrics
Availability	Security of supply and production	• Total energy reserves • Total energy reserves per capita • Proven recoverable energy reserves • Proven recoverable energy reserves per capita • Average reserve-to-production ratios for the four primary energy fuels (uranium, coal, natural gas, and oil) in remaining years • Coal reserves per capita • Oil reserves per capita • Uranium reserves per capita • Natural gas reserves per capita • Total oil reserves • Total uranium reserves • Total natural gas reserves • Total coal reserves • Total renewable energy resource endowment • Total energy supply (including imports) • Self Sufficiency (% demand met by domestic production) • Strategic fuel stock ratio • Total primary energy supply per capita • Total primary energy supply per GDP • Reserve-to-production ratio for uranium • Reserve-to-production ratio for petroleum • Reserve-to-production ratio for coal • Reserve-to-production ratio for natural gas • Average field recovery rate for oil • Average field recovery rate for natural gas • Total installed electricity generation capacity	• Supply/Demand (SD) Index • Willingness to pay for security of supply

		• Total electricity demand • Peak-load electricity demand • Base load electricity demand • Refining capacity (as percentage of production) • Refining capacity (volume refined per year) • Percent served by residential solar home systems • Percent served by cogeneration or CHP • Percent served by alternative transport fuels • Annual amount of coal production • Number of oil wells drilled for exploration • Number of coal mines • Growth in energy production per year • Total energy consumption per capita • Annual electricity consumption per capita	
	Dependency	• Oil import dependence ratio • Coal import dependence ratio • Natural gas import dependence ratio (including liquefied natural gas) • Uranium import dependence ratio • Net electricity imports • Annual change in net electricity imports • Annual change in net fuel imports • Ratio of exports and imports to consumption • Number of international electricity interconnections • Total oil imports (barrels of oil) • Ratio of value of oil imports to GDP • Oil consumption per unit of GDP • % of imports coming from the Middle East • % of imports coming from outside the region • Annual transfers of wealth to oil producers (in USD) • Balance of payments related to energy	• Stability of exporting countries • Transparency International corruption rating for exporting countries • Historical relationship with exporting countries • State Fragility Index rating of exporting countries • Worldwide Governance Indicator rating of exporting countries
Affordability	Price Stability	• End-use energy prices by fuel • End-use energy prices by sector (residential, commercial, industrial) • Regional price differences (average price in most expensive/cheapest deciles) • Electricity and petrol price volatility (annual % change) • % energy use covered by long-term contracts • Fuel price volatility • Carbon price volatility • Currency exchange rate volatility	• Price of macroeconomic shocks caused by volatility
	Access and Equity	• Percent of households with high quality connections to the electricity grid • Rate of electrification (number of new connection per year) • Percent of population reliant on charcoal, dung, and biomass for cooking • Percent of people that use mechanical power for productive, non-industrial applications, such as water pumping, agricultural mechanization, and grinding and milling • Rate of electrification expansion (annual % change) • Annual number of new electricity customers served (number of new customers served) • Revenues lost from electricity theft • Average number of household electric appliances • Vehicle ownership • Income distribution tied to energy use, lowest quintile • Average household expenditure on energy • Annual household electricity consumption (in kWh) • Average kilometers driven per private automobile per capita • % of total dwelling areas that are air conditioned	• Burden threshold variable • Energy GINI coefficient

	Affordability	• Share of household income spent on fuel and electricity • Public expenditure on subsidies as percent of GDP • Industrial energy prices • Residential energy prices • Retail gasoline prices • Price of 1 kg of fuel wood • Price of 1 kg of charcoal • Price of 1 L of kerosene • Market prices for coal • Market prices for uranium • Market prices for oil • Market prices for natural gas • Average price of residential electricity per GDP • Sales of industrial electricity per industrial GDP • Inflation caused by import fees • End-use energy retail prices by fuel and sector • Avoided cost of power generation • Marginal cost of electricity power generation • Fuel cost for electricity generation • Transmission and distribution cost for electricity • Carbon price • Wholesale price of electricity	• Ratio of daily disposable income to energy consumption • Equity of access to grid/transmission system • Household energy use for each income group and corresponding fuel mix
Technology Development and Efficiency	Innovation and Research	• Total energy research expenditures • Annual number of new energy patents • Total number of energy patents • Public research intensity (government expenditures on energy research compared to all government expenditures) • Private research intensity (private expenditures on energy research compared to all expenditures) • Research budgets for renewable sources of energy • Research budget for fusion • Research budget for advanced fission • Research budget for hydrogen • Research budget for biofuels • Overall research expenditures (public + private) as a percentage of GDP • Research consistency (% change from year to year in expenditures)	• Research intensity (% government expenditures on energy research comparedto all expenditures)
	Safety and reliability	• Frequency of electric power grid • Voltage control of electric power grid • Number of hours homes have electricity per year • Cost of interruptions • Voltage control of electric power grid • Number of major energy sector accidents and failures (defined as accidents involving at least one fatality and/or $50,000 of property damage) • Number of annual terrorist attacks and disruptions on energy infrastructure • Number of natural disasters • Number of coal mining accidents or deaths per year • Cases of pneumoconiosis (black lung disease) • Frequency of electricity blackouts or supply interruptions • Duration of electricity blackouts or supply interruptions • Annual revenues lost due to electricity blackouts or interruptions • Interruptions in electricity supply per year per customer • Hours of availability of electricity per day • Annual accident fatalities per specific fuel chain • Value of lost load for electricity	• System Average Interruption Duration Index (SAIDI) • System Average Interruption Frequency Index (SAIFI) • Customer Average Duration Index (CAIDI) • Breakdown of energy supply per energy carrier (in MJ) • Crisis Capability Index (CCI) • Average time required to restore service to the average customer per sustained interruption
	Resilience and adaptive capacity	• Gas capacity margins (maximum supply versus maximum demand) • Electricity capacity margins (maximum supply versus maximum demand)	• Emergency preparedness measures • Generator profile (seasonal) • Availability of trained repair personnel

Dimension	Components	Simple Indicators and Metrics	Complex Indicators and Metrics
		• Secondary frequency control reserve (for electricity transmission) • Tertiary frequency control reserve (for electricity transmission) • Critical electricity surplus • Percentage of energy capacity actually utilized • Peak-load to base load ratios • Generator profiles summer/winter • Emergency stockpiles for oil (days meet demand) • Emergency oil stockpiles (% imports) • Emergency stockpiles for coal (days meet demand) • Emergency coal stockpiles (% imports) • Emergency stockpiles for natural gas (days meet demand) • Emergency natural gas stockpiles (% imports) • Availability of trained repair personnel • Availability of spare parts and supplies • Generation adequacy • System adequacy	• Availability of spare parts and supplies
	Efficiency and energy intensity	• Energy intensity (number of BTUs needed for US$1 of GDP) • Number of LEED certified buildings • Average thermal efficiency of power plants • Fuel economy for new vehicles • Fuel economy for on-road vehicles • Fuel economy for rail (megajoules per ton-kilometer traveled) • Fuel economy for aviation • Fuel economy for freight and heavy trucks (megajoules per ton-kilometer traveled) • Fuel economy for marine transport (megajoules per ton-kilometer traveled) • Electricity transmission and distribution losses • Space heating efficiency • Annual energy efficiency savings (revenues) • Annual energy efficiency savings (billion kWh) • Energy intensity for total manufacturing • Energy intensity for chemicals manufacturing • Energy intensity for primary metals manufacturing • Energy intensity for paper, pulp, and print • Energy intensity for non-metallic minerals • Energy intensity for metal products and equipment • Energy intensity for food, beverages, and tobacco • Energy intensity for cement manufacturing • Energy intensity for iron and steel • Energy intensity for aluminum	• Energy payback ratio for total energy sector • Energy end use efficiency for buildings • Standard Assessment Procedure rating for households
	Investment and employment	• Planned new energy projects including construction status of approved projects • Direct employment in the energy sector • Indirect employment in the energy sector • Induced employment in the energy sector • Technical expertise (number of engineers or energy employees) • Unemployment in the energy sector (%) • Expenditures on financial support mechanisms for renewable energy • Investment in electricity transmission (billions of dollars/year) • Net capital investment in energy infrastructure • Total amount of stranded costs or sunk costs • Average age of energy capital stock • Average power plant age • Planned new generation capacity • Average rate of return on energy investments	• Average construction lead time for new energy infrastructure • Net total investments in energy infrastructure (billions of dollars)
Environmental and social sustainability	Land use	• Total environmental footprint of energy facilities • Energy pollution's impact on habitats • Generation of energy-related industrial and municipal solid waste • Generation of energy-related hazardous waste	• Cost of noise pollution • Loss of farmland due to decline in soil quality

Dimension	Components	Simple Indicators and Metrics	Complex Indicators and Metrics
	Water	• Energy-related mercury discharges to water supplies • Occurrence of annual climate-changed related droughts • Thermal discharges to water sources • Water withdrawals per kWh • Water consumption per kWh • Water use per kWh • Water use efficiency • Energy intensity of water treatment • Volume of tritium leaked into local water supplies • Water used per ton of coal mined • Water used per ton of uranium mined • Water used per barrel of oil refined	• Annual economic damages from energy-related water contamination • Economic damage to fisheries from energy production
	Climate change	• Share of zero-carbon fuels in energy mix • Total greenhouse gas emissions from energy production and use (including land use changes) • Per capita greenhouse gas emissions from energy production and use (including land use changes) • Total greenhouse gas emissions from energy production and use (excluding land use changes) • Per capita greenhouse gas emissions from energy production and use (excluding land use changes) • Energy-related methane emissions • Energy-related nitrous oxide emissions • Carbon content of primary fuels • Annual revenue related to carbon credits • Presence of climate change goals and targets • CO_2 emissions from fuel combustion • CO_2 emissions from electricity sector	• Carbon dioxide intensities of transport (per km driven) • Carbon dioxide intensity of electricity (per kWh) • Carbon dioxide intensity of industrial output • Carbon dioxide intensity of buildings (per square foot)
	Pollution	• Annual nitrogen oxide emissions • Annual sulfur dioxide emissions • Annual emissions of volatile organic compounds • Annual benzene emissions • Annual emissions of particulate matter • Annual emissions of lead • Annual emissions of mercury • Annual emissions of carbon monoxide • Annual emissions of cadmium • Annual emissions of black carbon • Per capita nitrogen oxide emissions • Per capita nitrous oxide emissions • Per capita sulfur dioxide emissions • Per capita emissions of volatile organic compounds • Per capita benzene emissions • Per capita emissions of particulate matter • Per capita emissions of lead • Per capita emissions of mercury • Per capita emissions of carbon monoxide • Per capita emissions of cadmium • Per capita emissions of black carbon • Number of annual oil spills (greater than 50 barrels) • Volume of oil spilled each year • Percent of power plants equipped with pollution abatement equipment • Number of households with improved cook stoves • Annual volume of sales from woodlots	• Ratio of waste to units of energy • Economic damage from annual oil spills (USD) • Disability adjusted life years associated with biomass use/indoor energy combustion
Regulation and governance	Governance	• Number of electricity system regulators • Percent government revenue dependent on energy • Provision of priority grid access to renewable energy • Strength or sufficiency of environmental permitting and impact assessment requirements • Length of time it takes new business to get electricity service • Frequency of changes in regulatory or institutional mechanisms • Frequency of review of country energy profile	• Transparency International Corruption Index • Worldwide Governance Indicators (CIGI/World Bank) • State Fragility Index • UN Human Development Indicators (HDI) • Satisfaction (share of adult population satisfied with policy and planning

Dimension	Components	Simple Indicators and Metrics	Complex Indicators and Metrics
		• Completeness of existing legislation • Estimated annual revenues lost to corruption in the energy industry • Country credit rating	
	Trade and regional interconnectivity	• Amount of transnational electricity trading (kWh) • Volume of natural gas/oil exported • Annual revenue from exports of energy fuels and technology • Number of free trade agreements signed related to trade of energy fuels • Total electricity interconnection capacity (installed) • Amount of interconnector trading of electricity (kWh traded) • Number of flagged LNG tankers • Number of flagged very large crude carriers (oil tankers) • Volume of energy imports via pipeline • Volume of energy imports via rail • Number of attacks or acts of piracy on flagged marine vessels carrying energy fuels and/or equipment • Number of transnational natural gas pipelines • Number of LNG ports • Number of existing production sharing agreements in the oil sector • Volume of energy shared during emergencies • Foreign direct investment in the energy sector	
	Competition and markets	• Market share by largest three energy suppliers or companies • Rate of return for energy companies • Percent of generation capacity owned by independent power providers • Average annual change of GDP energy intensity • Tax burden of energy sales volume • Ratio of accounts receivable to annual production volume of energy industries • Total amount of annual public energy subsidies • Total amount of annual public energy subsidies per capita	
	Knowledge and access to information	• Periodic publication of official energy planning documents and/or statistics • Number of customers served by net metering • Number of customers served by real time pricing or smart grids • Annual cost of energy-related externalities (to inform policymakers) • Annual cost of automobile accidents (to inform policymakers) • Annual deaths from automobile accidents (to inform policymakers)	• Public resistance to new power generating units • Energy literacy of users

APPENDIX II: Abbreviations

Following are the abbreviations used throughout the thesis.

CBD: Convention on Biological Diversity

FCCC: United Nations Framework Convention on Climate Change

BE: Belgium

BEE: Biomass Energy Europe

BEFSCI: Bioenergy and Food Security Criteria and Indicators

C&I: criteria and indicators;

CDM: Clean Development Mechanism

CEN: European Committee for Standardization

CFS: Committee on World Food Security

CO:P Conference of the Parties

EC: European Commission

EEA: European Environment Agency

EEA: The European Economic Area

ELCD: European Reference Life Cycle Database

EMEP: European Monitoring and Evaluation Programme

ES: Energy security

ETS: Emissions Trading System

EU: European Union

EUCAR: European Council for Automotive R&D

EUTR: EU Timber Regulation

FAO: Food and Agriculture Organization of the United Nations

FAO: Food and Agriculture Organization of the United Nations

FLEGT: Forest Law Enforcement: Governance and Trade

GBEP: Global Bioenergy Partnership

GBS: Global Bioenergy Statistics

GDP: Gross domestic product

GEF: Global Environment Facility

GHG: Greenhouse gas

GIS: Geographic information system

GRFA: Global Renewable Fuels Association

GVA: Gross value added

GWP: Global warming potential

ICCT: International council on clean transportation

ICLS: International Conference of Labour Statisticians

IDB: Inter-American Development Bank;

IEA: International Energy Agency

ILO: International Labour Organization

ILUC: Indirect land-use change

IPCC: Intergovernmental Panel on Climate Change

IRENA: International Renewable Energy Agency

JRC: Joint Research Centre

LUC: Land-use change

M-RQ: Main Research Question

MS: member states

MSW: Municipal solid waste

Mt: Million tonnes

NGO: Non-governmental organization

NL: Netherlands;

NLBI: Non-Legally Binding Instrument on All Types of Forest;

OECD: Organization for Economic Co-operation and Development

R&D: Research and development

RD&D: Research, development and demonstration

RED: Renewable Energy Directive;

RQ: Research Question

RFS: US Renewable Fuel Standard;

RPS: Renewable Portfolio Standards;

RSB: Roundtable on Sustainable Biofuels

RTD: Research and technology development

SFM: sustainable forest management;

SFU: Solid fuel use

SQ: Sub-Question (research)

TPES: Total primary energy supply

UNCED: United Nations Conference on Environment and Development

UNDP: United Nations Development Programme

UNECE: United Nations Economic Commission for Europe

UNED: United Nations Environment and Development

UNEP: United Nations Environment Programme

UNFCCC: United Nations Framework Convention on Climate Change

USDA: United States Department of Agriculture

VGGT: Voluntary Guidelines on the Responsible Governance of Tenure of Land: Fisheries and Forests.

WB: World bank

WBA: World Bioenergy Association

WFD: Waste Framework Directive

WHO: World Health Organization

WWF: World Wildlife Fund

Appendix III: Summary of the ratings of all the energy security Indicators and metrics with ratings.

Energy security indicators and metrics for 'Availability' dimension

Indicator	Effect (Rating)
PROVEN RECOVERABLE ENERGY RESERVES	**3**
AVAILABILITY OF RENEWABLE ENERGY RESOURCE	3
SHARE OF RENEWABLE ENERGY IN TOTAL PRIMARY ENERGY SUPPLY	3
TOTAL ENERGY SUPPLY	3
% OF IMPORTS COMING FROM OUTSIDE THE REGION	2
DIVERSIFICATION OF FUELS FOR TRANSPORT	3
DIVERSIFICATION OF FUELS FOR HEATING AND COOLING	4

Energy security indicators and metrics for 'Regulation and Governance' dimension

Indicator	Effect (Rating)
PRESENCE OF CLIMATE CHANGE GOALS OR TARGETS	4

Energy security indicators and metrics for 'Technology development and efficiency' dimension

Indicator	Effect (Rating)
RESEARCH BUDGET FOR BIOFUELS	4
INDIRECT EMPLOYMENT IN THE ENERGY SECTOR	3
INDUCED EMPLOYMENT IN THE ENERGY SECTOR	4
RESEARCH BUDGETS FOR RENEWABLE SOURCES OF ENERGY	3

Energy security indicators and metrics for 'Environmental & social sustainability' dimension

Indicator	Effect (Rating)
DEFORESTATION RELATED TO ENERGY USE AND FUEL COLLECTION	2
GENERATION OF ENERGY-RELATED INDUSTRIAL AND MUNICIPAL SOLID WASTE	3
ENERGY POLLUTION'S IMPACT ON HABITATS	2
EXPENDITURES ON FINANCIAL SUPPORT MECHANISMS FOR RENEWABLE ENERGY	4
PLANNED NEW ENERGY PROJECTS INCLUDING CONSTRUCTION STATUS OF APPROVED PROJECT	3

TOTAL GREENHOUSE GAS EMISSIONS FROM ENERGY PRODUCTION AND USE	2
GENERATION OF ENERGY-RELATED HAZARDOUS WASTE	3
CO_2 REDUCTION TARGETS	4
SHARE OF ZERO-CARBON FUELS IN ENERGY MIX	3
CARBON CONTENT OF PRIMARY FUELS	3

Appendix IV: Ratings Scale and ranges for some selected ES indicators and metrics

The ranges of all the energy security indicators and metrics are given below:

Availability dimension

The share of renewable energy in total primary energy supply (AEBIOM, 2017) (Indufor, 2017), (IEA Bioenergy, 2018).

Ratings	1	2	3	4	5
Ranges (%)	**.01-1**	**1-5**	**5-10**	**10-20**	**20+**

According to the estimates made by GBS (2017), AEBIOM (2017), and Indufor, (2017), the share of renewable energy in total primary energy supply fell between 50 EJ to 100EJ in 2018. The EU had a share of almost 30% renewable electricity in 2016, out of which 20% electricity came from biomass. During the same period, the share of biofuels for transport amounted to 4.4%. The share of biomass for heating in all sectors amounted to 15%. Furthermore, 24% of the total heat was generated by CHP and other heat plants was produced from biomass. Finally, in the residential sector use of biomass accounted for 20% of the total consumption of heat/fuel (IEA Bioenergy, 2018).

The consumption of all forms of bioenergy for the EU increased from 3.8 EJ in 2005 to 10.0 EJ by 2018 as indicated in figure below. In 2009, for the EU member states, the primary production of bioenergy in the form of biomass and waste stood at 4.2 EJ (Bensten and Felby, 2012).

Availability of renewable energy resource (BEE, 2010), (JRC, 2015) and (Scarlat and Dallemand, 2019).

Ratings	1	2	3	4	5
Ranges (EJ)	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**

The raw fuel for bioenergy had always been in abundant supply because of its large potential. Along with the bioenergy potential, the potentials of agricultural residues varied between 1.8 and 3.8 EJ in 2010 (BEE, 2010). For forestry and forest residues, the potential was between 1.4 and 4.0 EJ in 2015 (JRC, 2015). Although, the availability estimates differs from study to study, the most approximate estimates made by BEE (2010), JRC (2015) and Scarlat and Dallemand (2019) for the availability of bioenergy resource had been between 15-20 EJ. This shows a continues availability and potential throughout.

Although, the availability estimates differs from study to study, the most approximate estimate made by BEE, (2010), JRC, (2015) and Scarlat and Dallemand, (2019) for the availability of renewable energy resource has been between 15-20 EJ. And for continuation of the bioenergy availability, according to latest report by P.C. Faaij (2018), the potential estimates of all possible biomass categories tends to roughly vary between over 6 EJ (143 Mtoe) up to 30 EJ (717 Mtoe) in 2050.

% of imports coming from outside the region (European Commission, 2018), (Matzenberger et al., 2014), (Lilliestam and Ellenbeck, 2011), (JRC Science, 2018)

Ratings	1	2	3	4	5
Ranges (%)	**80-100%**	**60-80%**	**40-60%**	**20-40%**	**20-0%**

The EU has been a net importer of biomass (Matzenberger et al., 2014). The import of sea-based products like seafood, algae for biofuels, biofuels (mainly solid) were far higher than the exported products of forestry and animal based products like pulp and paper industrial products, wood, and other processed items (Lilliestam and Ellenbeck, 2011).

Although the EU is a net importer of biomass, this balance depends on the type of biomass. For paper and solid wood products as well as the animal and processed products, the EU is a net exporter. However, for solid biofuels, aquaculture and f plant-based food, the EU is a net importer (JRC Science, 2018). The annual consumption of dry biomass in the EU is more than 1 billion tonnes. Of this biomass, the feed and food sector uses 60%, bioenergy accounts for 19.1% and biomaterials uses 18.8% (JRC Science, 2018).

Proven recoverable energy reserves (BEE, 2010), (JRC, 2015) and (Scarlat and Dallemand, 2019).

Ratings	1	2	3	4	5
Ranges (EJ)	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**

It is calculated that the maximum limit in primary energy to the total biomass availability in the EU has been between the range of 60–120 EJ/yr (Elbersen et al., 2012). Biomass is available widely across the EU, from the findings, it is observed that the maximum limit in primary energy to long-term total biomass availability in the EU is 60–120 EJ/yr. The estimates of total biomass potentials range between 8.5–24 EJ for the period 2030 and between 18–59 EJ around 2050 (Eurostat, 2017).

The proven recoverable energy reserves of biomass vary a lot from study to study. As the biomass resources in the EU are abundant but finite in nature, the situation has not been very different from the current fossil fuel scenario (BEE, 2010). As shown in chapter 3, the technical potential has been calculated by many studies and is found to be on par with the current demand (JRC, 2015).

Diversification of fuels for heating and cooling (K.Sipilä, 2016), (Andrew Welfle, 2017, (Lamers et al., 2011)

Ratings	1	2	3	4	5
Ranges (no. Of fuels)	**1**	**1-3**	**3-5**	**5-7**	**7+**

Dry biomass has been transported over long distances in the EU for various applications. Biofuels are mainly deployed for road transport, with significant potential for shipping and aviation sectors still there to be utilized (European Commission, 2018). Waste biomass has been used for electricity and for heating directly or indirectly for CHPs (combined heat and power plants) (K.Sipilä, 2016). Bioenergy in the EU is both geographically constrained as well as geographically independent to a degree. Each of the EU member has some kind of bioenergy resource available at its disposal (Andrew Welfle, 2017). The domestic energy production sites like food crop, waste plants etc. varies across the region. Given the myriad number of sources of biomass and its diversity, the possibilities of diversification have been very large both as a raw material and the obtained end products (Lamers et al., 2011). The ability of biomass to get converted into heat, electricity and transport fuels, has made bioenergy very versatile in its sourcing and applications in the as two decades.

Total energy supply (JRC Science, 2018), (IEA Bioenergy, 2018), (Eurostat, 2018)

Ratings	1	2	3	4	5
Ranges (EJ)	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**

The total bioenergy consumption in the EU increased two-fold between 2000 and 2010; An average growth of further 3% was recorded for the period 2011-2016. During this period, the share of bioenergy in total primary energy supply increased from 7.0% to 8.8%.

According to JRC science policy report for EU (2018), 1466 Mt of dry matter of biomass are produced annually by the land-based sectors of the EU, of which agriculture accounts for 956 Mt and forestry amounts to 510 Mt (JRC Science, 2018). The marine-based sectors that included algae-culture, aqua-culture and fisheries supply around 2 Mt of dry biomass annually.

In 2015, around 64% of the total primary energy production of renewable energy in the EU-28 was generated from biomass (Eurostat, 2018). Table 7 shows the total primary energy supply figures per capita for the EU for 2016, to which bioenergy contributed to 11.5 GJ/capita (IEA Bioenergy, 2018).

Diversification of fuels for transport fuel (Hombach et al.,2018), and (IATA, 2016)

Ratings	1	2	3	4	5
Ranges (no. Of fuels)	**1**	**1-3**	**3-5**	**5-7**	**7+**

The most widely used bioenergy source in the EU is liquid biofuels i.e. biodiesel and bioethanol, which are usually blended with fossil fuels. To comply with the 2020 transportation goals, liquid biofuels have seen increase in the production, especially biodiesel (Hombach et al., 2018), followed by bio-gasoline and other liquid biofuels.

The cost advantage of conventional aviation fuels has not deterred the growing interest in biofuels in the market. There has been a rapid expansion in biojet fuels with more than 20 airlines used it in more their 2500 commercial flights in 2016 (IATA, 2016).

Dedicated energy crops, like reed canary grass, willows, poplars, etc., have been used for energy production across the EU. As is the case for fossil fuels, some of these bio-resources are available throughout the year like the municipal waste and forest residue (Eurostat: European Statistics, 2017). While the agricultural and pellet etc. have been dependent directly or indirectly on the prevailing climate or weather conditions affecting daily as well as seasonal supply (Searle et al., 2016).

Regulation and Governance Indicators

Presence of climate change goals or targets (European Commission, 2016), (EC, 2018), and (IEA, 2016), (EUBIA, 2018).

Ratings	1	2	3	4	5
Ranges	No targets	Less ambitious targets	Well defined goals	Stringent goals	Ambitious goals with follow-ups

The targets for climate change has become more stringent over the last decade. In the EU, 10% of the energy obtained from the RES in the transportation sector by 2020 is the target of the renewable energy directive, which currently stands at 5%. With concerns regards to the sustainability in the EU, the emphasis has been on the development and acceleration of the 3rd generation of liquid biofuels. In 2016, the biofuels industry was the second largest renewable energy employer after the solar PV industry. In June 2018, the EU governments reached a political agreement to raise renewable energy targets to 32% by 2030 (European Commission, 2018). This is seen as an ambitious target which would further spur the growth of renewables. The RES policy framework of the EU had started to take shape in March 2007 when the 27 EU members agreed on mandatory count of 20 % of the total energy consumption to be met from the RES (European Commission, 2018).

According to European Commission (2016), “”In 2016 renewable energy represented 17 % of the energy consumed in the EU, on a path to the 2020 target of 20 %. The share of energy used in transport activities from renewable sources almost tripled in 10 years to reach 7.1 % in 2016”” (European Commission, 2016).

Also in 2016, for the total gross inland energy consumption of the EU, the renewable energy sources (RES) amounted up to 13.2 %. Wood and other solid biomass accounted for the highest share of the renewable energy sources.

Under the EU directive of 2015/1513, the RED and the Fuel Quality criteria were addressed to increase GHG savings. Furthermore, the indirect land use was put under the restriction of 7 % share of the conventional biofuels in the transportation sector for 2020 sustainable energy goals and it also includes .5% use of 2nd and 3rd generation biofuels (EUBIA, 2018). Furthermore, these biofuels also need to measure up to the sustainability criteria set up the renewable energy directive.

Environmental & social sustainability Indicators

Planned new energy projects including construction status of approved project (EUBIA, 2018), and (European Commission, 2016)

Ratings	1	2	3	4	5
Ranges	**0-10**	**10-20**	**20-40**	**40-60**	**60+**

(No. Of projects approved/yr)

112 projects related to bioenergy have been sanctioned under the horizon 2020 by the EU in the last 4 years. Furthermore, many novel initiatives were taken in order to increase the potential of biomass such as the ‘Bio-Based Industries Public Private Partnership’ which falls under the scope of horizon 2020 (EUBIA, 2018). The ability to make use of the existing infrastructural setup for bioenergy in the EU, which has improved with time, has helped in implementing the new projects quickly. The continuous existence and planning of bio-based energy projects, although not on massive scale.

Expenditures on financial support mechanisms for renewable energy (Lengefeld and Lies, 2018), (IEA, 2018)

Ratings	1	2	3	4	5
Ranges	**0-5**	**5-10**	**10-20**	**20-50**	**50+**

(Million €/Year)

The EU has continuously providing funding for many bioenergy based research and technology development (RTD) over the many successive policy-making phases. These have included the complete chain i.e. starting from the feedstock production to the end use applications.

More than 100 projects were initiated under 'Framework Programme FP5' between the period of 1998 and 2002 with a total budget of €140 million (Lengefeld and Lies, 2018). The successive policy 'Framework Programme FP6' supported over 40 projects between the period 2002 to 2006 with a total budget of €150 million. (IEA, 2018).

Energy pollution's impact on habitats (Araujo et al., 2017) (Helmut Haberl, 2015) (Röder and Welfle, 2019) , (EEA, 2013) and (Rathmann et al., 2010).

Ratings	1	2	3	4	5
Ranges	**Very negative**	**negative**	**neutral**	**positive**	**very positive**

Biomass production have resulted in loss of land. This shows the imminent danger that energy crops have for the food production (Jonasson, 2013). This conflict over the use of land for energy or food depends on several external drivers like the increase in efficiency in both food and energy crop production and the global and local dietary habits. Increased demand for bioenergy could lead to increased food prices, which itself is a critical indicator of food security (Ondrej et al., 2017). Thus there are winners such as the landowners and the losers who belong to a particular section of society, who are not so well-do to and, and as a result, new conflicts have arisen among these groups.

The direct and indirect effect of land use on account of bioenergy production has been shown in figure 41. It is clear from figure 41 that the extent of the trickle-down impacts indirect effects can be difficult to quantify in the long run. How the change in consumption will shape or to what extent the conversion of non-farmed land would take place is difficult to predict accurately (EEA, 2013).

Total greenhouse gas emissions from energy production and use (Popp et al., 2011) (Searchinger et al., 2008), and (Haberl, 2013).

Ratings	1	2	3	4	5
Ranges	**Very Low**	**Low**	**High**	**Very High**	**Critically High**

The increase in total GHG emissions not only come from the direct use of energy crops and energy consumption but also brought indirect means. The surges in food prices, has led to an increased rental prices of land, would only get worse on account of increasing food demand, coupled with demand for bioenergy and protection of ecosystem and forests (Popp et al., 2011). This would further restrict the use of land for food crops/production (Wise et al., 2009). This price rise would have a detrimental effect on food security and environmental (Lambin and Meyfroidt, 2011). Deforestation, ecological damages, and increased GHG emissions, may even negate, in the first place, the very aim of mitigating climate change of the EU (Searchinger et al., 2008, Haberl, 2013).

CO_2 reduction target (European Commission, 2018), (EEA, 2018)

Ratings	1	2	3	4	5
Ranges	**No targets**	**Less ambitious targets**	**Well defined goals**	**Stringent goals**	**Ambitious goals with follow-ups**

In June 2018, the EU governments reached a political agreement to raise renewable energy targets to 32% by 2030 (European Commission, 2018). This is seen as an ambitious target which would further spur the growth of renewables. The RES policy framework of the EU had started to take shape in March 2007 when the 27 EU members agreed on a binding target of at least 20 percent renewable energy from final energy consumption by 2020 (European Commission, 2018).

In 2016 for the total gross inland energy consumption of the EU, the renewable energy sources (RES) amounted up to 13.2 %. Wood and other solid biomass accounted for the highest share of all the RES (EEA, 2018).

With the implementation of the EU RED certificate requirement for bio-liquids, other such certification systems began to mushroom with their specialization for biofuels such as ISCC, RSB, REDCert, and 2BSvs**.** Contrary to the prevalent agricultural certification systems, these ones had to directly tackle carbon emissions as per the EU RED requirement that the biofuels cause fewer emissions than the petroleum-based fuels (European Commission, 2018). Due to these stringent actions taken, particularly for the new revised and updated standard for biofuels.

SHARE OF ZERO-CARBON FUELS IN ENERGY MIX (EUBIA, 2017), (ICCT, 2018)

Ratings	1	2	3	4	5
Ranges	**Very Low**	**Low**	**High**	**Very High**	**Extremely High**

In the stated policy of e the EU, biofuels would have to account for 35 % reduction in greenhouse gases emission than the current emissions from fossil-based fuels. And in 2018, the target is to achieve 50 % reductions in GHG emissions. Similarly, for new installations , i.e. the ones installed after 2015, would have to show 60 % GHG emissions reductions (EUBIA, 2017).

The EU Renewable Energy Directive (RED) mandated that by 2020, around 10% of the energy used in the transportation sector should come from renewable energy sources (RES). In 2011, the initial requirement was set at 5% blending by energy in 2014. In 2015, the RED was amended by the EU Indirect Land Use Change (ILUC) directive, which introduced a 7% cap on the contribution that conventional food and feed-based biofuels could make to the RES-transport target (ICCT, 2018).

Deforestation related to energy use and fuel collection (EuroStat 2014), (Rafiaani et al., 2018), (Jonasson, 2013), (Blanchard et al., 2014).

Ratings	1	2	3	4	5
Ranges	**Very Low**	**Low**	**High**	**Very High**	**Critically High**

The overall effects of bioenergy on deforestation, according to Johansson (2013), "depend on the incentives for improvements of productivity, developments on other markets such as those for food and fiber and the possibility to use degraded land for marginal production increases instead of forest land." (Johansson, 2013).

Even with the policies and directives like the zero landfill and a Waste Framework Directive (WFD), the total quantity of the energy recovered from the non-recyclable municipal waste of the EU-28 countries in 2010 was only about 6% (EuroStat 2014).

Rafiaani et al., (2018) state that there are many environmental, social and economic implications of growing biomass at mass scale. These include loss of ecosystems, global warming, labour rights, employment, food security, etc.

Biofuel market is prone to conflicts, especially when large-scale and industrial plantations are concerned. These are often achieved at the loss of the local, small farmers and communities (Jonasson, 2013). Land-grabbing is another potential abuse which is shown to be connected not only to biofuels use but also to boost export at the expense of domestic consumption (Blanchard et al., 2014).

Trading energy crops for food crops may become a threat to food security. It is depended on many variables like changing crop production technology and changing diets. Displacement of food crops could trigger a chain reaction that has adverse effects on areas with high biodiversity and potential loss of carbon to the atmosphere (Jonasson, 2013). The debate over the use of energy crops in the EU has led to change in the EU policy, with more stringent criteria for the use of biomass and biofuels (European Commission, 2018).

Generation of energy-related industrial and municipal solid waste (Scarlet et al., 2018), and (Eurostat, 2017)

Ratings	1	2	3	4	5
Ranges	**Very Low**	**Low**	**High**	**Very High**	**Extremely High**

Biomass waste usage, particularly from industries, homes and waste products from agriculture and forestry residues, has no land issues to deal with. However, these products have the potential for other applications, for example in cattle feeding. It is unclear what percentage of bio-waste can be reserved for energy applications (Scarlet et al., 2018). Figure 40 shows the municipal solid waste operations in the EU from the year 1995 and 2015.

One of the trends is that the EU countries have changed their focus increasingly from the disposal of municipal solid waste to its prevention and reuse. The quantity of recycled municipal waste tripled and landfill plummeted to half in a decade. Yet, currently in the EU, more than 30% of the municipal waste continues to be and filled (Eurostat: European Statistics, 2017).

Due to the EU's waste and renewable energy legislation, a large amount of energy has been produced from the renewable municipal solid waste. On account of bioenergy sector, the total share of renewable waste was, in 2015, at 7.2%, that, in 1995, was at 5.1%. (Eurostat, 2017).

Generation of energy-related hazardous waste (World Wildlife Fund and Ecofys, 2014)

Ratings	1	2	3	4	5
Ranges	**Very Low**	**Low**	**High**	**Very High**	**Critically High**

Unlike solar and wind technologies, there are not very strict criteria and the requirements for critical materials. However, with plantation of dedicated bioenergy crops, there will be a high demand for fertilizers, both organic and artificial. For large-scale crop production, artificial fertilizers are bound to be the main suppliers. The total demand will vary according to the prevailing product requirements, management, regional and technological development. The three major constituents of artificial fertilizers are phosphorus, potassium, and nitrogen (World Wildlife Fund, 2014) (Ecofys, 2014). Nitrogen fixation ensures that atmospheric nitrogen is converted to nitrogen, so for application in fertilizers that would be sufficient nitrogen available. Hence Nitrogen will not be a bottleneck. Potassium and phosphorus, on the other hand, need to be mined from the earth in the form of potash and phosphate rock.

Carbon content of primary fuels (IEA0OECD, 2016), (IRENA, 2016) (ICCT, 2018)

Ratings	1	2	3	4	5
Ranges (%)	**80-100%**	**60-80%**	**40-60%**	**20-40%**	**20-0%**

The EU Renewable Energy Directive (RED) mandated that by 2020, 10% of the energy used in the transportation sector should come from renewable energy sources (RES). In 2011, the initial requirement was set at 5% blending by energy in 2014. In 2015, the RED was amended by the EU Indirect Land Use Change (ILUC) directive, which introduced a 7% cap on the contribution that conventional food and feed-based biofuels could make to the RES-transport target (ICCT, 2018).

Biofuels, along with electric vehicles, considered low-carbon fuels, has been envisaged as important tools to make the transport sector sustainable (IRENA, 2016). The second generation biofuels are being beefed up as the capacities are on the incline, however, there still exists a steep technology learning curve (Araújo et al., 2017).

Technology development and efficiency dimension

Induced employment in the energy sector (S. Piotrowski, et al., 2016), (Mengal et al., 2018)

Ratings	1	2	3	4	5
Ranges (Million jobs/yr)	<.01	0.01 - .1	0.1 - 0.5	0.5 - 1	> 1.0

Mengal et al., (2018) estimated that in 2013, the EU bioeconomy was estimated at EUR 2.1 trillion. It also accounted for 10% of the total jobs in the EU, which was 22 million. These bio-based sector accounts for the production of all bio-based products ranging from bio-chemicals, solid and liquid biofuels, energy crops, bio-materials, to paper industry to fisheries (Mengal et al., 2018).

Research budgets for renewable sources of energy (EUBIA, 2018)

Ratings	1	2	3	4	5
Ranges (Budget/yr)	**<€ 1 Mn**	**€ 0-1 Mn**	**€ 1-10 Mn**	**€1Mn 1- 1 bn**	**> € 1 bn**

The principal instrument for funding research and development of the EU is the 'Horizon 2020'. It has a budget of nearly €80 billion over 7 years. It has been granted funding over €3,7 billion which would aim at boosting the investment in the development and strengthening of a sustainable bio-based industry sector in the EU. In December 2017, Bioenergy further received loans amounting to €45 million (EUBIA, 2018).

Indirect employment in the energy sector (Rafiaani et al., 2018), (Urbanchuk 2012)

Ratings	1	2	3	4	5
Ranges	<.01	0.01 - .1	0.1 - 0.5	0.5 - 1	> 1.0
(Million jobs)	**Very few**	**A Few**	**Medium**	**Large**	**High**

According to the research by Rafiaani et al., (2018), the EU has created a total of 520,000 jobs in the bio-sector, this includes both indirect and direct jobs and amount up to EUR 78 billion (Rafiaani et al., 2018). In 2010, the global ethanol and biodiesel production produced around 1.4 million jobs in all sectors of the global economy according to The Global Renewable Fuels Association (GRFA) (Urbanchuk 2012), and out of which, the EU had a share of estimated 221,183 jobs (Suarez eta., 2015).

Research budget for biofuels (European commission, 2018), (SETIS, 2014)

Ratings	1	2	3	4	5
Ranges (Budget/yr)	**< € 1 Mn**	**€ 0-1 Mn**	**€ 1-10 Mn**	**€ Mn 10- 1 bn**	**> € 1 bn**

Under LC-SC3-RES-23-2019 and LC-SC3-RES-24-2019, up to € 40 million budget is allocated to renewable Fuels for transports in the EU. This includes the development of next-generation biofuel and advanced aviation biofuels in the EU (European Commission, 2018). Bioenergy has always attracted a lot of attention as well as investment. Within the EU, the focus has been mainly on biodiesel. There are many member states which take the initiatives to promote bioenergy like mandating fuel mixing. Within the EU, there is a 7% mandate for biodiesel mixing (SETIS, 2014).

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