MASTER THESIS

Biofuel chain in the Netherlands and its potential as an alternative for fossil fuels in the future

Final Version

August 2018

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Energy specialization

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LIST OF ACRONYMS

BioHeating oil	BHO
Bioprocess Pilot Facility	BPF
Combined Heat and Power	CHP
Energy for Transport Registry	REV
European Union	EU
European Union´s Emission Trading System	EU ETS
Fuel Quality Directive	FQD
Greenhouse Gas	GHG
Hydroprocessed Esthers and Fatty Acids	HEFA
Indirect Land Use Change	ILUC
International Energy Agency	IEA
International Maritime Organization	IMO
Liquefied Petroleum Gas	LPG
Member State	MS
Municipal Solid Waste	MSW
Potassium Hydroxide	KOH
Renewable Energy Directive	RED
Renewable Energy Source	RES
Renewable Energy Unit	HBE
Research and Development	R&D
Social and Economic Council	SEC
Sustainable Aviation Fuel	SAF
Substitute Natural Gas	SNG
United States	US
Used Cooking Oil	UCO
Tank-to-Wheel	TTW
Transport and Environment	T&E

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ABSTRACT

Fossil fuels have been much more reduced during these las two centuries and new alternatives are being searched to fulfil the population growth in the future and reduce the greenhouse gas (GHG) emissions. Biofuels are being implemented and since more than a decade ago, the European Union (EU) and other countries have already implemented policies including tax exemptions and other sources to promote biofuels and make a change in the use of fossil fuels. The intention of this master thesis is making an assessment of the state of the art and analysis of biofuel supply chain and situation in the Netherlands and the EU and see whether it is feasible for the future to promote biofuels and what kind of new alternatives can be achieved to reduce such a high consumptions of fossil fuels both in industry, transport, heating and electricity.

1. INTRODUCTION

1.1 BACKGROUND

Nowadays, we are looking for a pathway to a sustainable energy supply with high reductions in GHG emissions a less dependency on fossil fuels. Biomass is expected to be a good solution for energy purposes in Member states (MS) (Dafnomilis et al., 2017). The table 1 shows the share of renewable energy sources (RES) in electricity, heat and transport in some EU countries in 2014.

Table 1. Final energy consumption, overall RES and biomass in 2014 (Dafnomilis et al., 2017).

	Biomass-e		Biomass-h		Biomass-t		Biomass/Total final energy	Biomass/RES
	% RE-e	PJ	% RE-h	PJ	% RE-t	PJ	%	%
Germany	31	169	87.4	425	88.6	112	7.8	61
Denmark	27	12.5	98	43.5	100[a]	10	8.7	65.6
Belgium	35	10.5	77	20.5	100[a]	9	2.7	61
UK	20	47	94	107	100[a]	52	3.4	51.3
Netherlands	50	18.5	86	46.5	100[a]	15	4.6	75.4
NW EU	32.6	258	88.5	642.5	97.7	198	5.5	62.9
EU28	17.7	565	89	3282	100[a]	548	9.5	61.3

The interest in biofuels is directed to address challenges of decreasing fossil resources and rising levels of GHG emission. Moreover, unconventional oil resources are finite and although the United States (US) and Canada made an increase in exploitation, the size of the reserves still remains uncertain. Biofuels look like a great alternative because it creates employment and improve energy security of oil and gas importing countries. Figure 1 gives an overall view of liquid biofuel production situation in the world (Azadi et al., 2017).

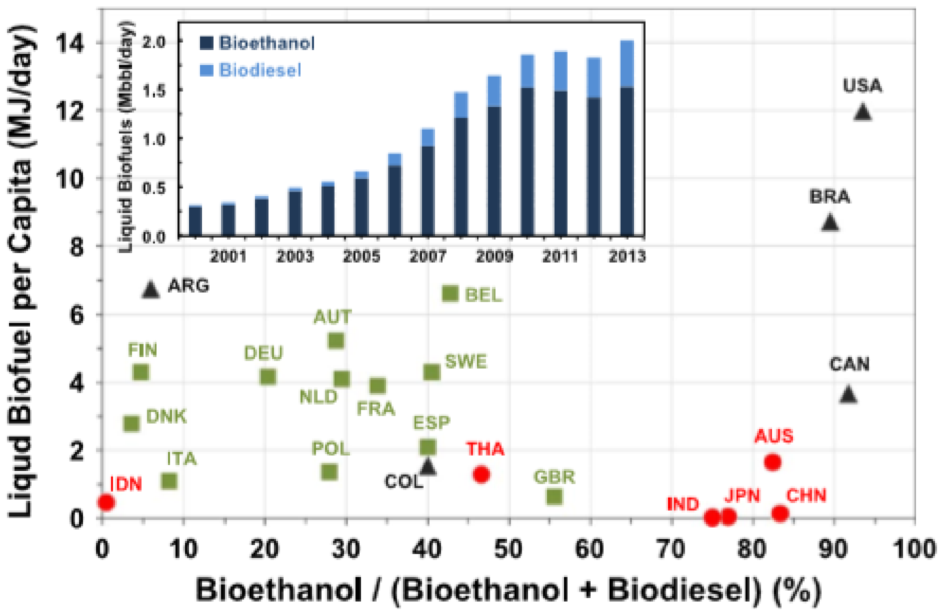

Figure 1. Liquid biofuel production of selected countries (MJ per capita and day) vs. the ratio of bioethanol to total liquid biofuels produced in that country in 2011 on an energy basis. The inset plot shows global annual production volume of bioethanol and biodiesel. Different symbols represent different world regions. (Azadi et al., 2017).

Since 2010, biofuels have less carbon as the University of Illinois at Chicago has shown in their research. For instance, they conducted a research in which they showed that corn ethanol industry´s electricity use has declined between 2001 and 2013, while yields have been increasing by 7%. Sustainable agricultural practices have been adopted increasingly (“Biofuels versus Gasoline: The Emissions Gap Is Widening | Article | EESI,” 2016).

1.2 PROBLEM STATEMENT

In the past decades, an energy crisis happened owing to a huge decrease of unsustainable resources like fossil fuels. The big amount of use of all fossil fuels for transportation and power generation has caused a very big increase in carbon dioxide (CO_2) emissions in the atmosphere and there is a need to reduce its emissions to avoid global warming. High demands of energy for the future, a higher concern of environmental hazards and national security have given attention to production of clean liquid fuels, such as biofuels, as a suitable alternative source of energy (Milano et al., 2016).

Biofuels were already used in the Second World War in many countries in Europe, but just as emergency fuels, such as wood gas and ethanol. Apart from the oil crises of the 1970s, research for alternative fuels started because of urban smog due to huge traffic. Despite a big effort, there has always been big difficulty to find new policy initiatives to promote biofuels (Ulmanen et al., 2009). However, new ways to produce biofuels might appear from waste in Europe regarding at figure 2.

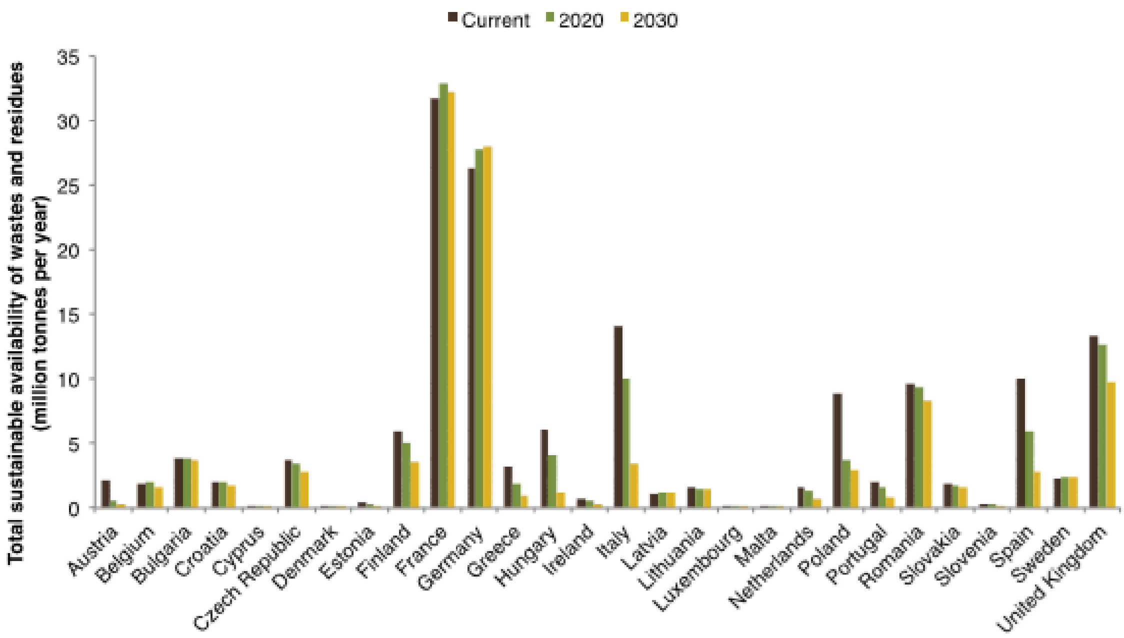

Figure 2. High and low estimates of potential biofuel production from sustainably available wastes and residues compared to a 0.5% advanced biofuel in transport fuel target (%) and the number of biorefineries that would be needed to meet the 0.5% target (Searle and Malins, 2016).

As we are looking for alternatives for fossil fuels, new policies should be made to be able to promote the future towards biofuels, for instance by subsidies or tax exemption. Fossil fuels are finite and very contaminating so it is very important to make a serious assessment of possibilities of promoting alternatives of fossil fuels.

1.3 RESEARCH GOALS AND QUESTIONS

The main research objective of this project is a contribution to the knowledge on the potential of biofuels´ production and application in the Netherlands. Therefore, 2 main sub-objectives are to be reached in the project:

- Making an assessment of the state of the art of current situation of biofuels and its whole production chain from resource to end product in the Netherlands.

- Looking for future developments of biofuels in the Netherlands.

1.3.1 Central research question

What is the biofuel potential in the Netherlands till 2030/50 and what is needed in terms of bioresources, technologies and support policies for its harvesting?

It is already known that the Renewable Energy directive has been applied in all the EU countries, aiming for a 10% of transport from renewable energy until 2020. Before this Directive, the Renewable Fuels for transport directive was applied, and nowadays, new ways have to be found until years 2030/50 to have a replacement for fossil fuels, and biofuels are thought to be a good choice. The potential of biofuels in the Netherlands is analyzed and then future developments are researched in this topic to learn if it will be possible to replace fossil fuels in the future by biofuels and if it is, to what extent.

1.3.2 Sub-questions

The central research question is the main question of the research in this work. To answer it, firstly, there are 3 sub-questions that have to be answered to get to the final conclusion. The answer of these 3 questions lets getting to an answer to the central research question.

- What is the current state of the art of biofuels in the Netherlands?

- What are the potential and ambitions of biofuels till years 2030/50 in the Netherlands?

- How can the potential and ambition of biofuels be harvested and achieved given the resources, technologies and support policies?

1.3.3 Research approach

The research approach is further specified for each of the research questions in table 2 below. All the research questions in this topic are based on the data and information found in the research, the sources or the findings used to achieve the answer of these questions and how the method to answer all respective research questions has been, either by observation and/or analysis.

Table 2. Data, information and accessing methods.

Research question	Data/Information required	Sources	Accessing method
What is the biofuel potential in the Netherlands till 2030/50 and what is needed in terms of bioresources, technologies and support policies for its harvesting?	Potential of biofuels in the Netherlands	Answers to sub-questions	See below for the sub-questions
What is the current state of the art of biofuels in the Netherlands?	Current biofuel situation in the Netherlands	scientific articles, Journals, Policy documentation, webpages	Observation and content analysis
What is the potential of biofuels in the Netherlands and its ambitions till years 2030/50 in the Netherlands?	Potential of biofuels (Consumption, production…) Future goals of Netherlands for biofuels	Dutch government webpage, scientific articles.	Observation and Content analysis
How can potential of biofuels be harvested in terms of resources, technologies, applications and support policies?	Information about resources, technology and applications of biofuels in the Netherlands	Dutch government webpage, scientific articles, journals	Content analysis

1.4 OUTLINE OF THE RESEARCH

In Chapter 2, an introduction to the topic of biofuels will be presented. This introduction includes the types of biofuels that exist currently, why they are important, why they can be useful and in which sectors they are used. Moreover, a comparison between fossil fuels and biofuels is made.

Chapter 3 explains what the current state of the art is in terms of technology, resources and application in the Netherlands. Furthermore, data such as net imports of biodiesel and other resources for biodiesel production in the Netherlands in relation to other countries will be shown, such as consumption data of certain biofuels in the Netherlands for applications such as transport and heating. The biofuel supply chain in the Netherlands will be taken as a reference too.

The chapter 4 shows the potential and ambitions of biofuels in the Netherlands in terms of resources, technologies and applications (especially transport sector). Based on literature, what the thinking of the Netherlands is in this topic is will be explained, making clear what the lowest and highest expectations and points are.

The chapter 5 answers the Research question "How can potential of biofuels be harvested in terms of resources, technologies, applications and support policies?". This chapter is a comparison between chapters 3 and 4 to find efficient solutions for the harvesting of biofuels in the Netherlands in the future.

The chapter 6 refers to the discussion and conclusion of the research, which is the answer of the whole research questions in the thesis and tells whether there are suitable resources and technologies to harvest the biofuel potential in the Netherlands until years 2030-2040. Therefore, the goal of chapter 6 is to make a summary of the major findings of the research and answer the main question of the thesis: "What is the biofuel potential in the Netherlands till 2030/40 and what is needed in terms of bioresources, technologies and support policies for its harvesting?".

2. BIOFUELS

2.1 GENERAL INFORMATION

Biofuels are referred as fuels made from biomass or fuels created from living plant matter which is opposed to ancient plant matter in hydrocarbons (“Biofuels | Student Energy”, n.d.). They are created to deliver benefits, including an improved economy and a positive impact on the environment. Moreover, they are aimed to be the best substitute possible for the extension of longevity of diesel (Fuels, 2016). The 6 main reasons why biofuels are needed are:

- <u>They are easy to use</u>: They can be used in today´s engines with no need to change them and be burned, stored and pumped as petroleum diesel fuels. Furthermore, biofuels are able to release fuel tank deposits and the user will be capable of changing between biofuel and petroleum without any problems.

- <u>Energy security</u>: Nowadays, many countries support the idea of using biofuels from local sources to be used as fuel alternatives. Many of the risks for energy security are the disruption of fossil fuel supply, energy price hikes and limited sources of fuel.

- <u>Building economic development</u>: The increase of investments of biofuels is expected to mean a growth in economy. Therefore, more jobs and new sources of income for farmers will appear.

- <u>GHG emission reductions</u>: If appropriate methods of production are used, biofuels will produce a significant amount of GHG emissions than what is currently being produced by biofuels.

- <u>Energy balance</u>: It is the ratio of the amount of energy required to produce, manufacture and distribute to the amount of energy released when fuel is burned.

- <u>Recyclable and Biodegradable</u>: Biofuels are less toxic than diesel as they are natural and non-toxic vegetable oil. Furthermore, they are shown to be safer to handle than petroleum owing to their low volatility.

2.2 BIOFUELS VS FOSSIL FUELS

Fossil fuels are carbon-based energy sources, such as oil, coal and natural gas. These sources have been created over the millennia from sea creatures and decayed plants that have been formed in the oceans, whereas biofuels are any fuels made from plan materials (“The Differences Between Biofuel & Fossil Fuel | Bizfluent”, n.d.). The two most common biofuels are biodiesel and ethanol. Over these last two decades, interest has been rising on biofuels to reduce the dependency on fossil fuels and develop renewable and environmentally friendly energy. The resources used for their production are composed of a variety forestry and agricultural resources, industrial-process residues, municipal-solid and urban-wood residues (An et al., 2011).

One great promise of biofuels is that they will provide an environmentally friendly alternative to petroleum fuels. The ability to reduce pollution of biofuels can also bring environmental problems if they are not developed carefully. One great concern about biofuels is the net energy balance, which for instance, shows whether the fuel production requires more energy inputs than the contained in biofuels themselves. The new advanced in technology so far have improved production efficiency and that is the reason why biofuels have a positive fossil energy balance.

Table 3. Fossil energy balances of selected fuel types (“Worldwatch Institute”, n.d.).

Fuel (Feedstcock)	Fossil Energy Balance
Cellulosic ethanol	2--36
Biodiesel (Palm oil)	9
Ethanol (sugar cane)	8
Biodiesel (waste vegetable oil)	5--6
Biodiesel (soybeans)	3
Biodiesel (rapessed, EU)	2.5
Ethanol (wheat, sugar beets)	2
Ethanol (corn)	1.5
Diesel (crude oil)	0.8--0.9
Gasoline (crude oil)	0.8
Gasoline (tar sands)	0.75

However, there are also some negative points on the use of biofuels. Although many bioenergy forms play a very helpful role for sustainable energy, the dedication of land only for biofuel and bioenergy production is not wise at all, as it requires a very large amount of area to generate small amounts of fuel, it uses land needed for carbon storage and food production and that wouldn´t surely mean a decrease in GHG emissions because the production of food crops means a great amount of them (Steer and Hanson, 2015).

2.3 TYPES OF BIOFUELS

2.3.1 First-generation biofuels

The first generation biofuels are fuels that have been derived from sources such as sugar, starch, vegetable oils and animal fats. Some of the most used biofuels are biodiesel, vegetable oil, biogas, bio-alcohols and syngas (“First generation Biofuels - BioFuel Information”, n.d.).

The system that produces first-generation biofuels has 2 main stages that consist of agricultural production and biorefinery plants. In this process, the crop is devoted to the production of energy, which means that it is the main input of the biorefinery where biomass is converted into biofuel (Saladini et al., 2016). The figure 3 shows a scheme of a process of bioethanol production.

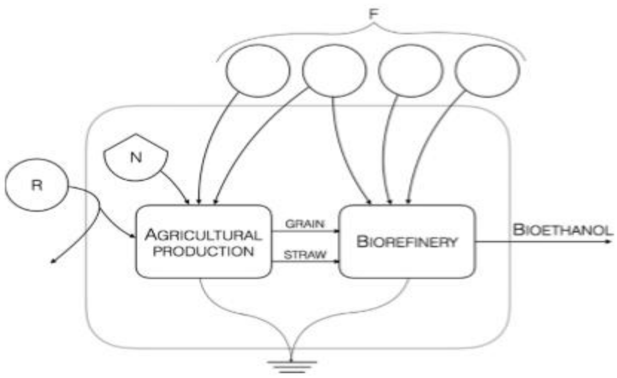

Figure 3. Energy system diagram of a first-generation bioethanol plant based on wheat feedstock (Saladini et al., 2016).

2.3.2 Second-generation biofuels

Second-generation biofuels, also known as advanced biofuels, are fuels manufactured by many kinds of non-food biomass. This type of biomass refers to plant materials and animal waste especially for this kind of biofuel.

These fuels originate from the main product of a production system and they are firs-generation in terms of energy. They rely on feedstocks specifically produced for energy. However, there are other second-generation biofuels are produced using a by-product of agricultural production, such as straw. The figure shows a system with an agricultural production and biorefinery plant for the production of biorefinery plant for the production of second-generation bioethanol.

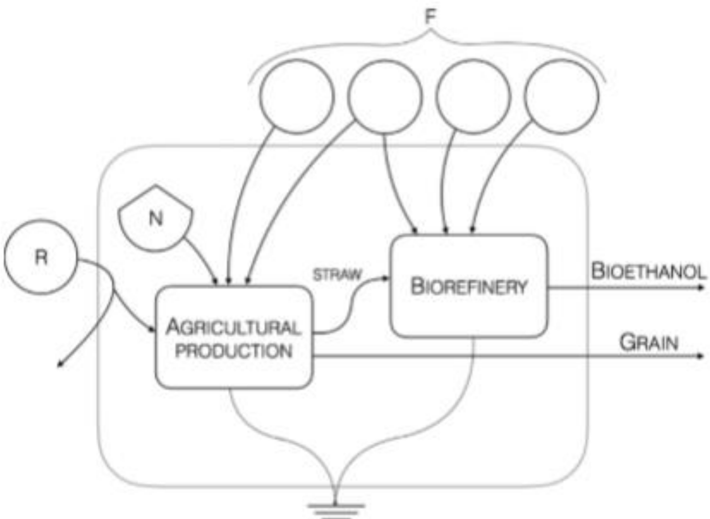

Figure 4. Energy system diagram of second-generation bioethanol from residues of grain production (Saladini et al., 2016).

2.3.3 Third-generation biofuels

The International Energy Agency (IEA) describes the third-generation biofuel as bio-based fuels produced from aquatic feedstock, usually algae. In this case, the system that produces this type of biofuel consists of 2 stages, as well as for first and second-generation biofuels. The first stage consists of the cultivation of aquatic biomass and the second one is made of the operations from harvesting of feedstock to produce the biofuels.

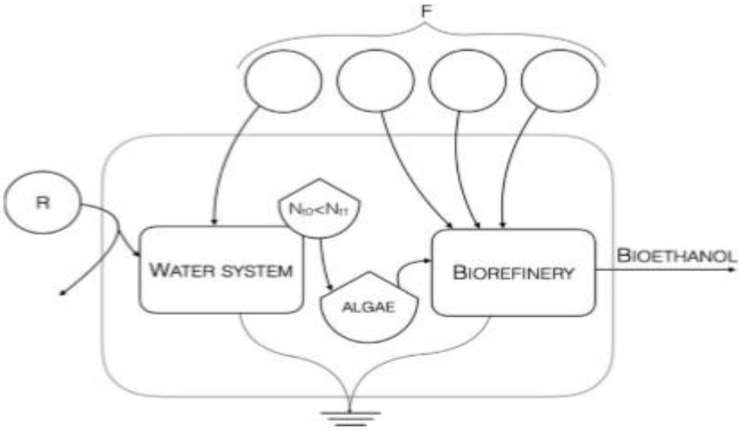

Figure 5. Energy system diagram of third-generation bioethanol from algae feedstock (Saladini et al., 2016).

2.4 APPLICATIONS

2.4.1 Transportation

The main use of biofuels in society is for transportation. Biofuels are dense and they are easy to distribute with small modifications and as they are very similar to petroleum fuels, little modifications are needed so that biofuels work with vehicles ("Biofuels - Uses of Biofuels - Transport", n.d.). The motor vehicles are the most important issues of biofuels because they are the largest conventional fuel consumers and they cover almost all research and development done in biofuels so far. The most used biofuels in transportation sector are:

- Biodiesel: Biodiesel is a very important biofuels because his reaction is very big similarities with diesel fuel. Biodiesel is usually burned through compression-ignition processes and moreover, it is more prepared to be gelled than standard diesel. Therefore, biodiesel is less suitable to cold climates.

- Ethanol: It is popular as a fuel additive and known for being easy to produce and non-toxic. It has low energy density, which means that four times as much ethanol is needed to meet current fuel demands in comparison to gasoline. Moreover, ethanol is corrosive to some rubbers and then, gaskets and seals in engines have to be modified depending on the increase of the level of ethanol.

- Butanol: Butanol is more energy-dense than ethanol and less corrosive to rubbers. The only drawback to butanol is the difficulty to be produced in large quantities.

The second transport sector that consumes the most energy is aviation although it is very difficult to find a highly pure and chemically stable fuel. However, many companies in Europe have started to produce jet fuel from Jatropha and are set to begin supplying several major airlines in the near future. Other areas that are taken into account for biofuels are shipping and rail transport. These industries are not very targeted industries yet. Nevertheless, their low fuel quality standards, the fuel produced for other industries should be useful for these ones as well.

2.4.2 Heating and electricity

Biofuels such as biodiesel can gel in very cold weather, which means it should be possible to store it underground or indoors ("Using biofuel to heat your home", n.d.). High concentrations of biodiesel can also wear out rubbers seals. Biofuels seem a good choice for heating due to its low cost and easy availability but it has some disadvantages ("Biofuels - Uses of Biofuels - Heating", n.d.). Biomass also pollutes as burning solid biomass brings carbon monoxide, nitrogen oxide, and volatile organic compounds with it.

The best step taken in biofuel heating is the combined heat and power (CHP), in which both heating and electricity are harvested from the same biomass reaction. These systems are more efficient as harvesting the wasted heat allows the plants to be more efficient and prevents the discharge of heat into the environment. This technique is especially used in paper production, oil refining and chemical plants.

2.5 DISCUSSION

The main issue for biofuels is that there are many resources and technologies for their production and generally, they are considered a good alternative for fossil fuels. Nevertheless, it is clear that second and third generation biofuels are a better choice than first-generation ones due to the indirect GHG emissions that are emitted because of food production.

3. CURRENT SITUATION OF BIOFUELS IN THE NETHERLANDS

The aim of chapter 3 is to answer the first sub-question: “What is the current state of the art of biofuels in the Netherlands?”. The structure of this answer takes the biofuel supply chain as a reference and is measured from the resources to the end products and regulations.

3.1 RESOURCES

In the Netherlands there is a variety of feedstocks used per company, as some fuel suppliers use many feedstocks and others just use one. Figure 6 gives a very clear overview of all feedstocks used per fuel supplier, where the most notorious issue is that the corn is the most used material.

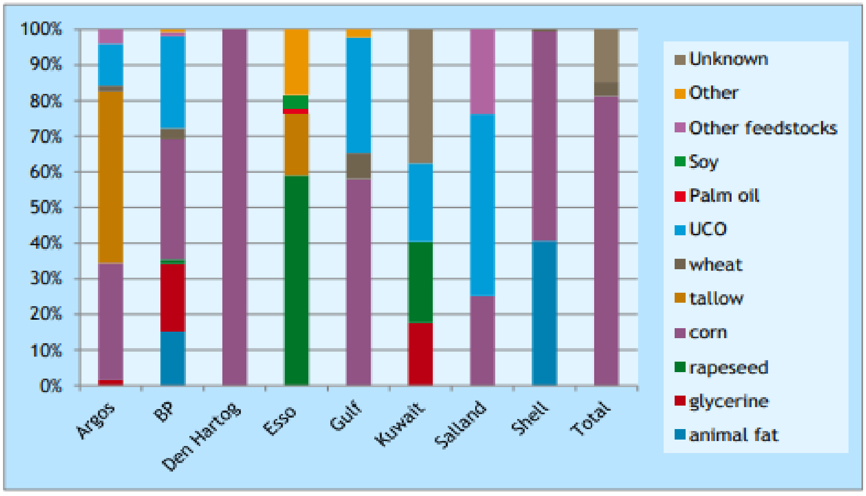

Figure 6. Overview of feedstocks used per fuel supplier (“Biofuels on the Dutch market. Update,” n.d.)

The figure 7 shows the share of biodiesel and bioethanol from food crops, as well as biofuels that come from waste and residues in the Netherlands.

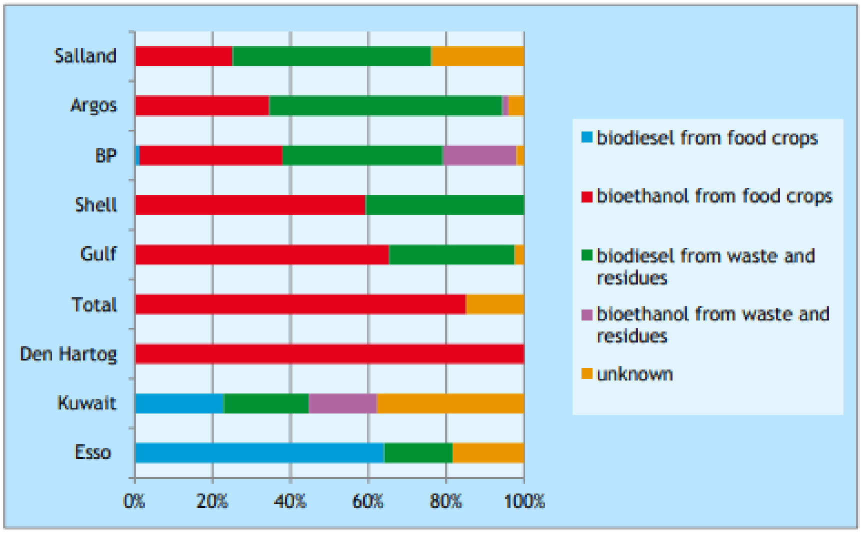

Figure 7. Share of biofuels from food crops and biofuels from waste and residues (“Biofuels on the Dutch market. Update”, 2013).

Most of the shares came from food crops in 2013. This is a problem because due to the indirect land use change (ILUC) directive just 7% of biofuels must come from crops from agricultural land. The Netherlands makes many trades with other countries all over the world. The origin of the feedstocks between 2011 and 2013 are shown in figure 8. The percentage of the feedstocks that are originated in the Netherlands ranges from 20-23% and most of them are imported from Western Europe.

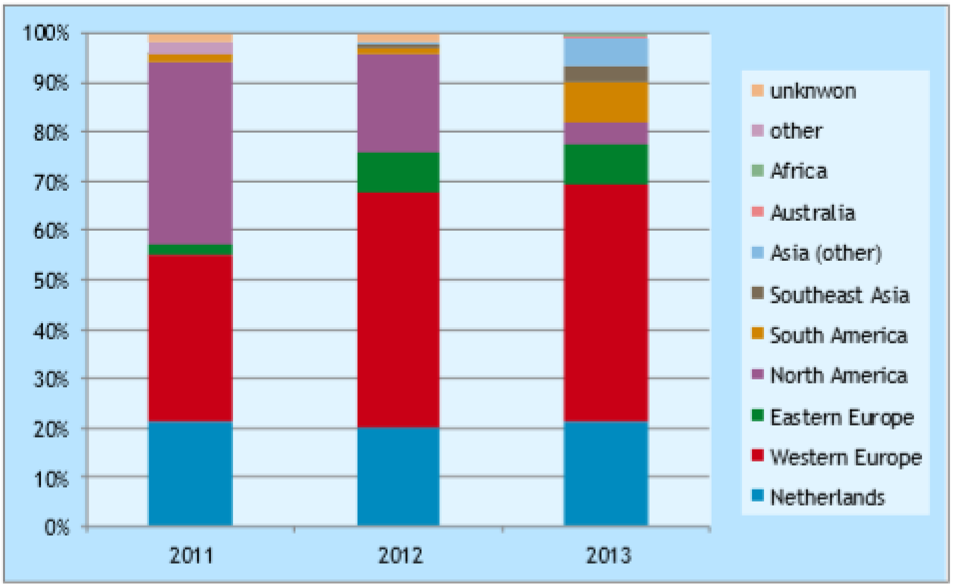

Figure 8. Origin of the seven feedstocks mostly used in 2011-2013 ("Biofuels on the Dutch market. Update", n.d.).

In figure 9, it is noticed that most of the origin of waste for biofuels (starch production and municipal waste) was from the Netherlands in 2013 and used cooking oil (UCO) only accounted for 19%, which is a positive point as it means that the double counting system on biofuels works well in the Netherlands.

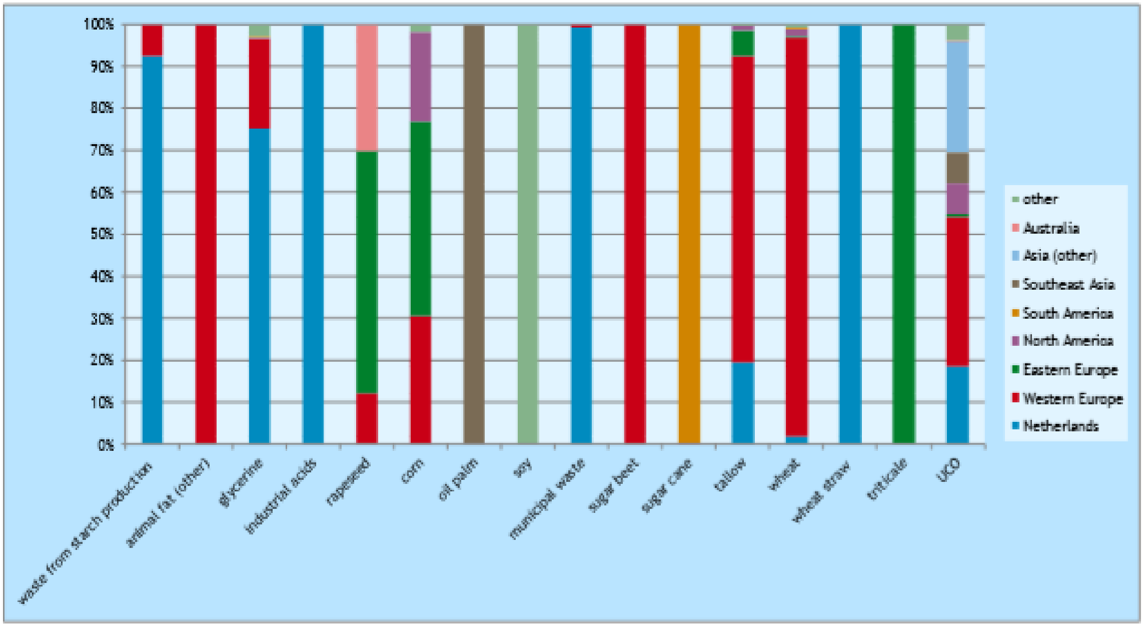

Figure 9. Origin of feedstocks used for biofuels brought on the dutch market ("Biofuels on the Dutch market. Update", n.d.).

3.2 TECHNOLOGY AND PRODUCTION

3.2.1 Bioenergy facilities and Biorefineries

There are many Bioenergy facilities in the Netherlands which are used for different purposes. Figure 10 shows all bioenergy facilities in the Netherlands and they are classified in different types of bioenergy ("Country Reports", 2013). The different points in figure 10 are described as:

- Red bullets, which refer to combustion facilities. There are 228 facilities of this type in the Netherlands nowadays.

- Yellow bullets, used for domestic waste combustion. There are 12 facilities of this kind in the Netherlands.

- Green bullets, which are facilities that produce gas from landfills. 1625 of Nm^3/h of green gas are produced by these facilities in the Netherlands and there are 41 locations of this kind.

- Blue bullets, which refer to waste water treatment plants. There are 82 plants of this kind and they produce 470 Nm^3/h of green gas.

- Purple bullets, which are manure co-digestion facilities. There are 105 facilities of this kind and they produced 606 c.

- Grey bullets, which are facilities that produce 5312 Nm^3/h of green gas from food industry residues and the Netherlands has 13 installations of this kind.

- Black bullets, which are GTF/ONF digestion facilities. There are 11 installations of this type in the Netherlands and 3892 Nm^3/h of green gas are produced from these facilities.

Figure 10. Bioenergy facilities in the Netherlands ("Country Reports", 2013).

Biorefineries are integrated facilities which are used for co-production of chemicals, materials, green gasses, fuels for transportation, power, heat from biomass and they are also similar to today´s petroleum refineries. In the Netherlands, biorefineries are focused specially on certain domestic crops, aquatic biomass (usually algae), imported biomass, biomass-derived intermediates in large scale and valorization of residues. They are classified in 2 types: commercial and pilot biorefineries (“Country Reports”, 2013).

Commercial biorefineries are the refineries that are already working in large-scale (industry-scale) and they appear in red colour in figure 11. Nowadays, there are 5 in the Netherlands:

- BioMCN is a biorefinery that was officially opened on 25th of June 2010. It upgrades by-product glycerine from biodiesel production to biomethanol for transport. It has a production capacity of 250 million litres (“Our Vision | BioMCN”, n.d.).

- Cargill/Nedalco is an integrated biorefinery that produces bioethanol, formed by Cargill starch industry and Royal Nedalco companies. Cargill´s wheat processing plant is Nedalco´s raw materials´ supplier for its alcohol production process. It is a second generation plant and it produces 2 ML/a of bioethanol (“Ethanol | Cargill”, n.d.).

- Empyro pyrolysis plant is a pyrolysis plant whose construction started in February 2014 and it produces 20 million of litres of pyrolysis oil per year. This pyrolysis oil is used for bioenergy (ST) and chemicals (LT) (“Home - Empyro - energy & materials from pyrolysis”, n.d.)

- Greenmills is a joint initiative between Rotie, Noba, Biodiesel Amsterdam and Orgaworld BV to integrate processes. It has a production of 113 ML/year of biodiesel, 5 ML/year of bioethanol and 25 m^3/year of biogas (“Country Reports”, 2013).

- VION Ecoson is an integrated plant that produces biogas, CHP and biodiesel from animal waste. They have a big production capacity per year: 9000 MWh from biogas, 50000 tons of refined fat and 5000 tons of biodiesel. Moreover, they officially have a biophosphate plant opened since 6th October 2014 (“Residuals to resources | Ecoson”, n.d.).

Pilot biorefineries are refineries that are specialised in research for new alternatives to obtain biofuels and they appear in blue spots in figure 11. Nowadays there are current pilot projects in the Netherlands:

- ACRRES is an application centre for renewable resources and green raw materials located in Lelystad. It focuses in solar and wind energy, biomass, R&D and teaching. They have a pilot-scale biorefinery facility with multiple purposes and they work with research and testing of new production methods, soil quality issues and nutrient recycling. Furthermore, they have digestable and fermentable feedstocks that come from crops and residues and they work with waste water valorisation as well. Their outputs are proteins, biogas, microalgae and bioethanol (“Acrres ”, n.d.).

- AlgaePARC is a refinery and microalgae production platform that produces lipids, carbohydrates, proteins and pigments, located in Wageningen. It develops processes and technology to fractionate microalgae biomass and to make systems analysis and sustainability assessment (“AlgaePARC”, n.d.).

- Avantium YXY Technology is a chemical catalysis biorefinery located in Geleen. It uses cellulose, hemi-celullose, starch and sucrose as feedstocks. Its outputs are furan based biofuels, monomers for polymers, fine and specialty chemicals and solid fuels (“Home”, n.d.).

- Bioprocess Pilot Facility (BPF) is an open-access facility with multiple purposes. It has a capacity of 5000 m^2, with a complex piloting equipment and supporting labs to investigate scale-up issues (“About the BPF,” n.d.).

- COSUN is a pilot project that uses beet to produce materials, food, chemicals and energy. It processes about 75000 ha beet into sugars and animal feed (“Cosun Corporate - Home”, n.d.).

- CRODA is a residual plant that uses oil to produce biobased polymers, chemicals, coatings and personal care products. Moreover, they also produce green chemical intermediates for polymers by oleochemical refining (“Home - Croda Industrial Chemicals,” n.d.).

- Grassa!! is a green mobile biorefinery that works in small scale and produces high-value sustainable protein (feed) and fibre based products (board). This project uses grasses and protein-rich agroresidues as feedstocks. It has a capacity of between 1 and 5 tonnes of fresh materials per hour (“Country Reports”, 2013).

- Harvestagg is a pilot plant that uses cultivated grass to produce energy and turf. The mobile press is developed to press grass on the harvesting location, aiming to obtain the required quantity of dry matter content. Press cake and Grass juice will be valorised (“HarvestaGG - Rendabel en duurzaam oogsten in energie, landbouw en regio,” n.d.).

- Indugras is a small-scale green biorefinery that take grass from nature management to feed and convert it into chemicals. It has a super-heated steam (SHS) Technology tested for production of animal feed and chemicals (“Indugras | Productie van industriële grondstoffen uit gras,” n.d.).

- Millvision/Greencell-ID is a pilot plant that converts verge and nature grass into fibres for cardboard and paper. In addition, it also transforms protein-poor nature and verge grass into cellulosic fibres and value-added biobased products by mild fractionation (“Welkom op de projectpagina van Greencell-ID,” n.d.).

- Newfoss is a small-scale biorefinery that turns grass and verge grass from nature management to fibres, energy, feed and nutrients. They have a patented mild extraction technology (“Home - NewFoss,” n.d.).

- Purac is a plant that transforms residues from paper in lactic acid and its derivates. The residues that are produced by a paper factory, such as cellulose, are separated and fermented to lactic acid and its derivates and it uses paper sludge as a resource to produce bioplastics. Furthermore, in the fermentation process, when the cellulose´s quality is very low, it can still be converted into lactic acid. It works in the development of technologies that separate chalk from cellulose (“Corbion,” n.d.).

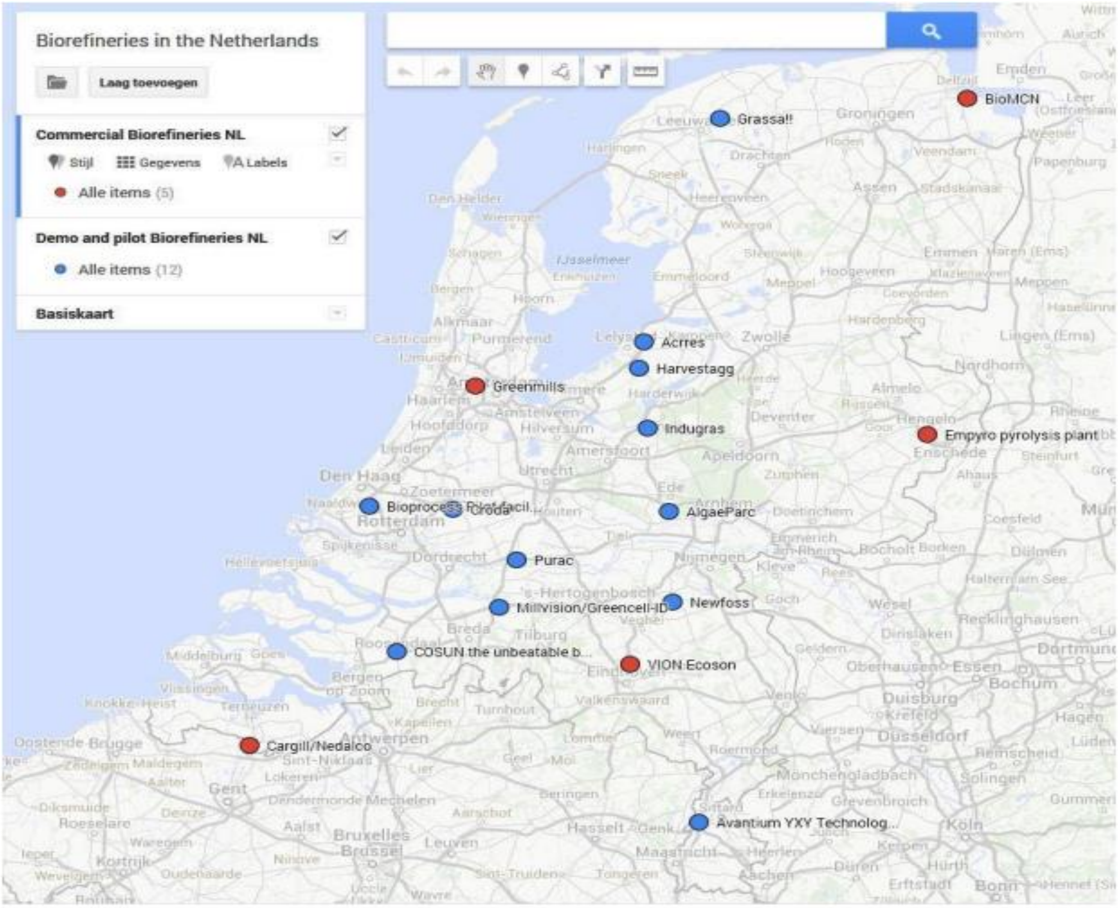

Figure 11. Biorefineries in the Netherlands (“Country Reports”, 2013).

3.2.2 Processes and equipment

In the Netherlands, the biomass conversion technology has been used for electricity production since 1980. Some years later, the thermochemical conversion technology increased (van de Kaa et al., 2017). The aim of these technologies is the conversion of raw materials into intermediate products, so that they are eventually transformed into the end products needed. Biomass can be directly combusted for the production of heat and /or electricity, and even bio-syngas, bio-oil can be converted into biofuels, chemicals, etc. All these applications are comprised into three thermochemical conversion techniques called direct combustion, gasification and pyrolysis (table 4).

Table 4. Characteristics of direct combustion, gasification and pyrolysis (van de Kaa et al., 2017).

	Direct combustion	**Gasification**	**Pyrolysis**
Energy balance	Exothermic	Endothermic	Endothermic
Main products	Steam, heat, electricity	Bio syngas, heat, electricity	bio-oil, heat, electricity, biofuel
Energy efficiency	20-25%	40-50%	85-90% (potential)
Commercially available in the Netherlands since	1980	1990	2015 (demonstration plant)
Scale	1 MW - 100 MW	50 kW - 100 MW	2 MW - 50 MW
Investment cost/kW	€480/kW - €1040/kW	€1280/kW - €1840/kW	ca. €4960/kW

Pyrolysis is the most energy-efficient technique and it is very new as it became a commercial technology in the Dutch market in 2015. Moreover, there are other types of processes, such as anaerobic digestion for biogas production and trans-esterification processes for Biodiesel production, used for the production of biofuels in the Netherlands.

3.2.2.1 Pyrolisis

BTG is the company that works with pyrolysis technology so far in the Netherlands, and its techniques are based in intensive mixing of particles and hot sand particles in a modifier rotating cone reactor (figure 12). The mixture of all particles is reduced to a size below 6 mm before entering the reactor and the moisture content below 10 wt%. In the process, there is no inert carrier. Therefore, the pyrolysis products are undiluted and then, this vapour flow results in minimum size downstream equipment. To sum up with process, a condenser is used to cool the vapour by yielding the oil product and some permanent gases. Some seconds later, the biomass is turned into pyrolysis oil ("Pyrolysis oil and organic acids - Empyro - energy & materials from pyrolysis", n.d.).

The charcoal and sand are recycled to a combustor. After this, the charcoal is burned for the reheat of the sand. The permanent gases are sometimes used in gas engines for electricity generation but not external utilities are usually required. In the whole process, approximately 75 wt% of the primary products is pyrolysis oil and the rest is char and gas.

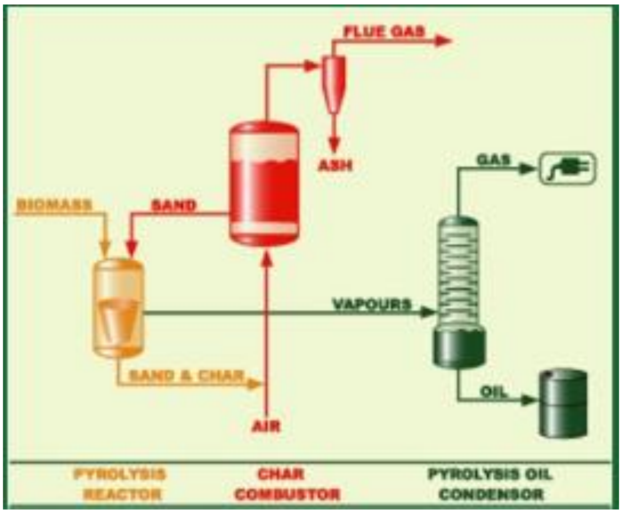

Figure 12. BTG´s pyrolysis process (“Pyrolysis oil and organic acids - Empyro - energy & materials from pyrolysis”, n.d.).

3.2.2.2 Biodiesel production

The production and consumption of biofuels has been reduced during this last period due to the Directive ILUC, as the production of first-generation biofuels has to decrease and therefore, the Netherlands has to look for second-generation biofuels (biofuels made from lignocellulosic biomass, waste oils, fats…). Biodiesel Amsterdam, for instance, is a dutch company that upcycles biodiesel waste oils and fats from companies such as Rotie (“Biodiesel Amsterdam", n.d.). There is a big variety in terms of customers. They come from different companies from the food industry to catering establishments and small hotels. These fats and oils are collected in accordance with the current legislation taking place and from more than 35000 addresses.

When the collection of oils and fats finishes, they transfer them to the high-tech processing hall and they use 4 processes to produce the biodiesel. The first step of the process is the esterification, where the free fatty acids, contained in the waste fats and oils, are converted to biodiesel under acidic circumstances and using methanol. As the reaction takes place in acidic circumstances, sulphuric acid is added as a catalyst. After this, the phase separation takes place, in which the water is formed to be separated and deployed for processing by-products (figure 13).

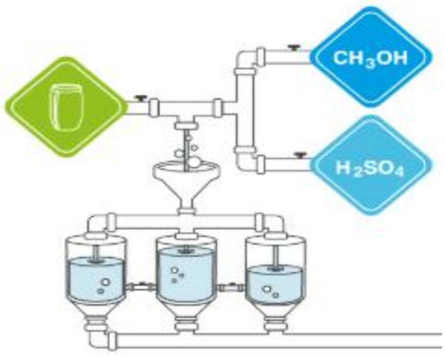

Figure 13. Esterification of waste oils and fats (“Biodiesel Amsterdam | The Process”, n.d.).

The next step is the trans-esterification process. A very important component contained by the raw material is glycerides, as it can react to become biodiesel under basic conditions. Methanol is also used for this. Moreover, Potassium hydroxide (KOH) is also added for the creation of basic conditions. The by-product formed in of this reaction is glycerine. The last step is the phase separation of glycerine and biodiesel in the reactor, which is possible as these products are inmiscible (figure 14).

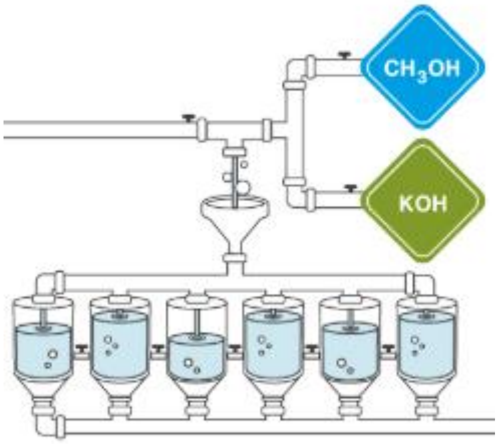

Figure 14. Trans-esterification process ("Biodiesel Amsterdam | The Process", n.d.).

After trans-esterification, in FME distillation, the biodiesel phase that comes from the trans-esterification goes through a purification process that meets the highest standards for the biodiesel. The process used to achieve this is the distillation, which happens in a vacuum. The main goal of this step is to remove the heavy organic particles from the biodiesel and form a stream called Bio Heating Oil (BHO) that can be used as a sustainable fuel for the energy generation in the form of steam (figure 15).

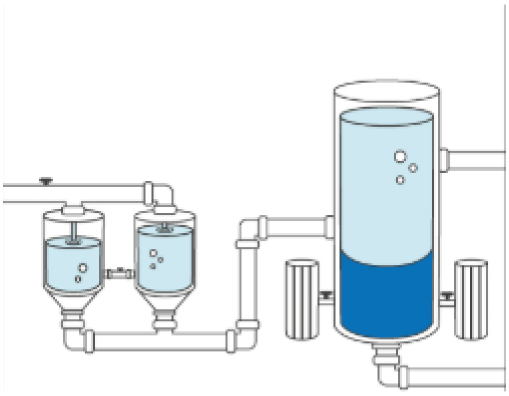

Figure 15. Distillation process ("Biodiesel Amsterdam | The Process", n.d.).

In this last process, both by-products from the esterification (acid water) and trans-esterification (glycerine phase) process are mixed, making a mixture of two fluids and solid matter. After this, the three fluids are separated in a tricanter, which is a centrifugation technology. The fluid phase part containing oil is deployed in the process again and the part that contains water, methanol and mixture of glycerine is then separated by two distillations. Finally, three streams are formed: glycerine, water and methanol, which can be deployed in the process again.

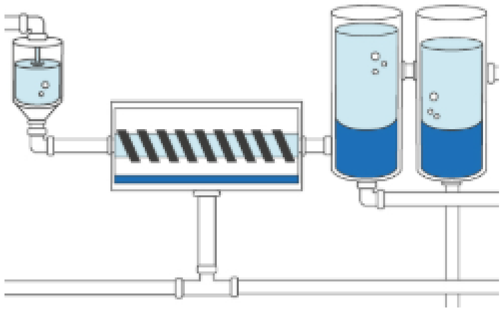

Figure 16. Processing by-products ("Biodiesel Amsterdam | The Process", n.d.).

3.2.2.3 Gasification

As seen in table 4, gasification is a very common commercial technology used in the Netherlands since 1990. There are a lot of companies and universities working with this technology in the Netherlands. However, most of the initiatives taken for the use of this technology are more related to waste the streams, instead of clean biomass ("IEA BioEnergy Agreement Task 33: Thermal Gasification of Biomass", 2013). This makes sense owing to the high population density of such a small country as the Netherlands. Moreover, nowadays Dutch industries and governments are more willing to participate in SNG (Substitute Natural Gas) production from biomass as there have to be new alternatives for natural gas in the Netherlands.

The figure 17 shows that there are 3 universities and other companies working with gasification technology. Nevertheless, the plant NUON/Vatenfall had to be closed in 2013 due to the high operating costs and low energy prices in that time. These factors and the relatively small size of that plant meant it was impossible to make profitable operations.

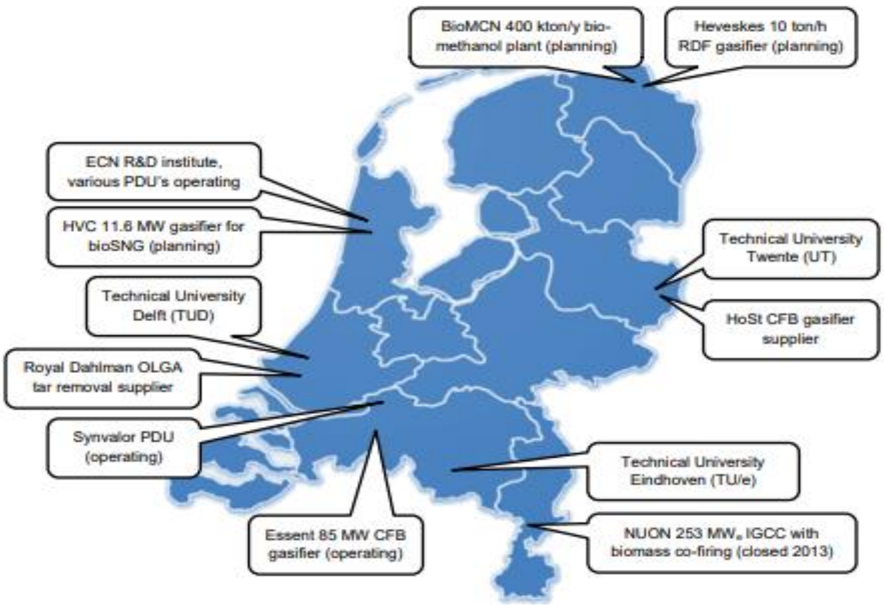

Figure 17. Biomass gasification in the Netherlands ("IEA BioEnergy Agreement Task 33: Thermal Gasification of Biomass", 2013).

In terms of biofuel production through gasification technology, there is a gasification company called BioMCN (figure 11 and 17) which produces biomethanol. At the beginning, BioMCN was a natural gas based methanol plant but they changed production methods and they chose raw glycerine used from biodiesel production as feedstock. Nowadays, they treat up to 200 ktons of bio-methanol per year and they include a raw glycerine purification plant which plays a very important role in the bio-methanol production process ("IEA BioEnergy Agreement Task 33: Thermal Gasification of Biomass", n.d.). The figures 18 and 19 show the bio-methanol plant, raw glycerine purification plant and the methanol storage tanks of BioMCN.

Figure 18. BioMCN bio-methanol plant (left) and glycerine purification plant (right) ("IEA BioEnergy Agreement Task 33: Thermal Gasification of Biomass", n.d.).

Figure 19. Methanol storage tanks in BioMCN ("Hoe Groningen honderden miljoenen en een nieuwe fabriek misliep", n.d.).

3.2.2.4 Bioethanol production

The bioethanol production in the Netherlands is made due to a grain-based bioethanol production technology ("Abengoa Bioethanol Plant - Chemical Technology" n.d.).

There were two large international companies which work with this production technology for bioethanol production in the Netherlands: Arbengoa and Lyondellbasel ("Biofuels on the Dutch market. Update", n.d.). Abengoa was a very powerful bioethanol company but 2 years ago, they were forced to sell their bioethanol-producing plant to four companies called AlcoGroup, Groep Vanden, Avenne Commodities and Vandema ("New owners for Rotterdam bioethanol plant | ENDS Waste & Bioenergy", n.d.).

The facility occupies an area of 23 h and has 8 silos for storing grains and facilities for bioethanol and DGS, distillation units, fermentation tanks, heat exchangers, dryers, decanters and cooling towers. The plant also includes other technologies, such as a grain intake system, a gas turbine and a boiler, a jetty a water treatment plant and an outflows plant. All grain silos have a storage capacity of 55000 tones. Furthermore, the grain intake system includes a 600-meter-long conveyor belt used for carrying the grain from the jetty to the bioethanol plant. The plant´s jetty handles many sizes of ships between 1000 and 60000 tones. There is also a cogeneration plant in the plant used for the production of steam and electricity required for producing the ethanol. When there is extra energy in the plant, it is exported to the Dutch national grid. There is an installation called distributed control system (DCS) for the monitoring and control of all operations taking place at the plant. This system is very helpful for the plant for automating the plant´s information systems and operational cost reductions ("Abengoa Bioethanol Plant - Chemical Technology", n.d.).

Figure 20. Rotterdam´s bioethanol plant in Europoort ("Abengoa Bioethanol Plant - Chemical Technology" n.d.).

3.2.2.5 Anaerobic digestion

This technology is used in the Netherlands for biogas production. In Europe, generally, biogas is basically produced in aerobic digesters by the use of agricultural waste, energy crops and manure (Scarlat et al., 2018). The figure 21 gives an overall overview of the share of biogas technologies for biogas in Europe. The Netherlands has most of its share for biogas processes from anaerobic digestion (75-80%), less than 10% from landfill gas recovery and the rest comes from sewage gas. Therefore, anaerobic digestion is a very common technology in the Netherlands and there is no share of thermal processes for biogas production in the Netherlands.

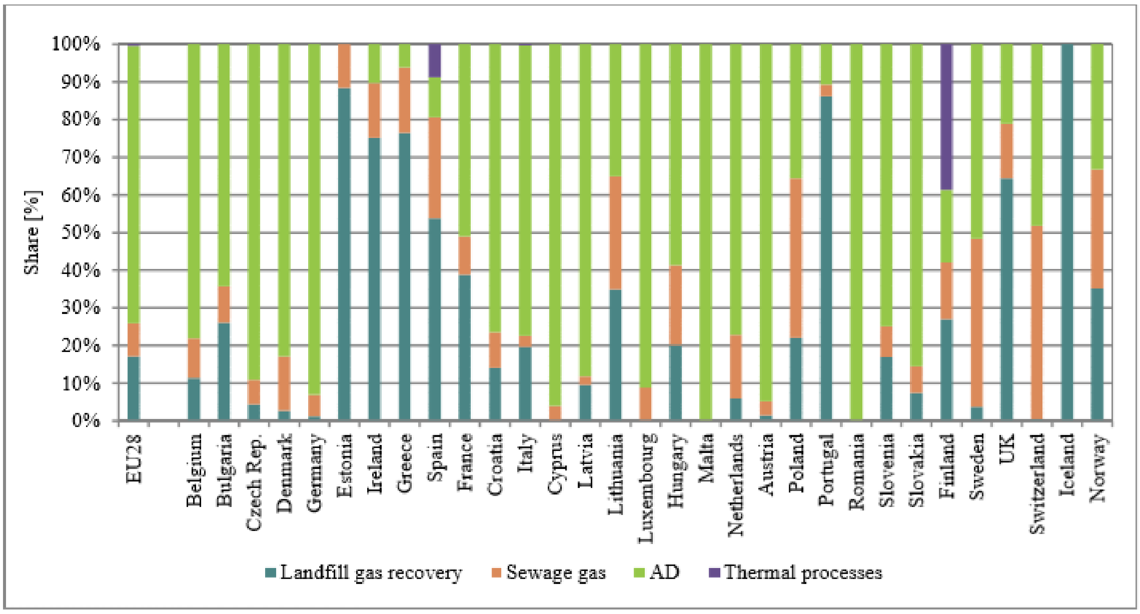

Figure 21. Share of different processes for biogas in Europe in 2015 (Scarlat et al., 2018).

Nowadays, there are between 200 and 300 biogas plants in the Netherlands (Scarlat et al., 2018). These plants use many technologies for biogas production. For instance, In Greenmills plant in Amsterdam, The biogas conversion technology is combined with wet digestion technology (table 10) and is used to create electricity, water purification and heat by a biomembrane reactor. This allows the facilitation of smart synergies with local heat networks, the regional electricity grid and other Dutch companies, such as Cargill and asSimadan, which then provide Greenmills with their waste through a pipeline for their recycling at the plant. The Orgaworld Greenmills plant processes nearly 120000 tons of unpackaged supermarket food and other organic waste, which is digested in tanks and then, the biogas is released. This biogas in turned into heat, steams and green energy. These products are partially used by Greenmills and the rest is sent to the power network. The residual product formed in the process is converted into high-quality fertilizer using the own heat produced by the plant (Table 10) (“Amsterdam, Greenmills | Orgaworld”, n.d.).

The biggest biogas plant in the Netherlands is situated in Veendam, in the North of the country, with a total amount of biomass used of 231000 tons per year (14000 tons of chicken litter and 205000 tons of manure). Many types of residues are processed, such as food production waste. The plant is composed of 2 lines: Firstly, the one running on chicken litter and manure, with an operation temperature of 50 ºC and secondly, the other line, which runs on industrial waste, grain and manure, operating at a temperature of 37 ºC. One of these lines includes and air cleaning system, which cleans at a speed of 40000 m^3/hour (“Veendam - The Netherlands | Biogas and energy production”, n.d.).

Moreover, this plant includes pasteurization technique, included in the pre-treatment system, and which receives 3 animal by-products. The pasteurization of the biomass works for an hour at 70 ºC and the result is a strong reduction of bacteria content in the processed biomass.

Figure 22. Biogas plant in Veendam, the Netherlands (“Veendam - The Netherlands | Biogas and energy production”, n.d.).

3.2.2.6 HEFA technology

Hydroprocessed Esthers and Fatty Acids (HEFA) technology is applied by the company Dutch SkyNRG for the production of Sustainable Aviation Fuel (SAF). With this technology, the triglycerides go through a treatment with hydrogen under increased temperature and pressure, as well as with the presence of a catalyst. In this hydro-treatment, the oxygen contained in the natural oils is removed and pure hydrocarbons remain (“SkyNRG Refining - SkyNRG”, n.d.).

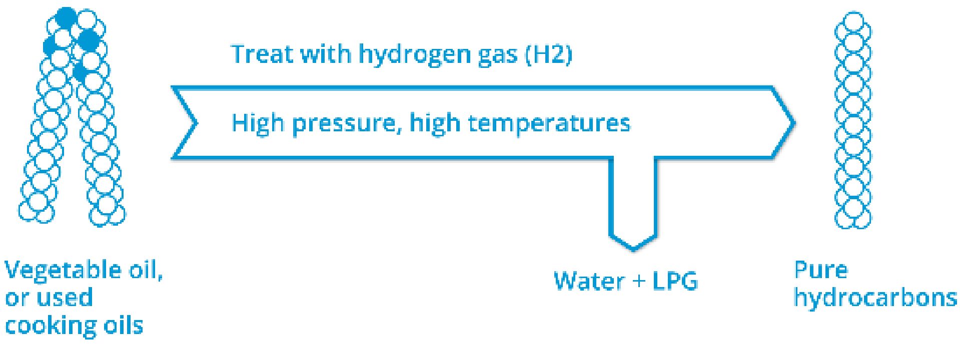

Figure 23. HEFA technology (“SkyNRG Refining - SkyNRG”, n.d.).

Hydrocarbons produced in the process are basically long-chain hydrocarbons and they are used in an extra-treatment to create branch and shorter hydrocarbons, which is called hydrocracking and isomerisation or generally, hydroprocessing. There are other kinds of technologies for SAF that are suitable (table 11).

3.3 PRODUCTS

3.3.1 Biodiesel

After the biodiesel production, many products are achieved, such as the ones from Biodiesel Amsterdam ("Biodiesel Amsterdam | The Process", n.d.).

- Crude biodiesel: It is used as 2G biodiesel in accordance with EN14214 standard.

- Bio-glycerine: Building block for a variety of production processes.

- Bio-heating oil: It is a sustainable fuel that can be used for energy generation (heat).

- Bio-fertilizer: It is used as an environmentally-friendly fertilizer for agricultural purposes.

The company VION Ecoson also produces Biodiesel from animal fats which is used as a sustainable fuel for combustion in diesel engines ("From animal fat to renewable fuel | Ecoson", n.d.).

The Netherlands generally imports a lot of biodiesel (tables 12 and 13). Most Biodiesel is imported from European countries, such as Germany (biggest Biodiesel producer in Europe), Belgium, Italy and Spain. Therefore, despite having enough resources and technologies, a lot of Biodiesel is still imported from other countries in the Netherlands.

3.3.2 Pyrolysis oil

The pyrolysis oil is focused basically on boiler applications from 1 MW to 20 MW. It can replace light and heavy light fuel oils in industrial boiler applications, as well as natural gas but it can also contribute to sustainable transport fuels ("Pyrolysis oil and organic acids - Empyro - energy & materials from pyrolysis", n.d.).

The application of pyrolysis oil in heat and power is dedicated to boilers, gas turbines and diesel engines. Boilers are the simplest applications for pyrolysis oil. In fact, BTG has already demonstrated that (co-) combustion of pyrolysis oil in a natural gas-fired power plant works in industrial scale. Nowadays it can be offered to companies that want to shift from natural gas, Liquefied Petroleum Gas (LPG) or heating oil to a new renewable alternative fuel. Pyrolysis oil has also been tested in stationary diesel engines. BTG expects a market of diesel engines that are able to operate using pyrolysis oil in the future, as these engines can be used for heat and power on ships ("Heat and Power from Pyrolysis oil - BTG Bioliquids BV", n.d.).

3.3.3 Biomethanol

Biomethanol is a very versatile product made using biogas, produced by the company BioMCN, in the Netherlands. It can be used as a fuel and a feedstock for biofuel production. When it works as a fuel, it can be blended with gasoline or be used as a feedstock for other environmentally friendly fuels. Moreover, biomethanol does not require any technological changes to modern vehicles and it can be stored, transported and sold the same way as diesel and petrol. However, they can also be produced for applications such as plastics, paints and as a chemical building block for other future-oriented products, such as Bio-DME, Bio-MTBE, bio-hydrogen and synthetic biofuels ("Methanol and bio-methanol | BioMCN", n.d.). This biofuel is expected be ready by 2030 for its use in shipping industry (table 15), due to the a study made by E4tech ("Documenten voor de leden - Platform Duurzame Biobrandstoffen", n.d.). Moreover, it is proved to reduce CO_2 emissions compared with the current engines and vessels used.

3.3.4 Bioethanol

This biofuel is used basically in combination with gasoline, up to 25% ethanol in low blends. For flex-fuel vehicles, in high blends, bioethanol is usually used at 85% ethanol, which can run any ethanol and gasoline blends ("Biofuels - ALCOGROUP", n.d.).

3.3.5 Biogas

The biogas is a different biofuel, as it does not compete in transportation sector as Biodiesel or biogasoline. In Xergo´s plant, in Vendeem, Biogas is basically used for energy production in CHP, as well as it can be upgraded to natural gas quality and introduced into the gas and electricity grid ("Veendam - The Netherlands | Biogas and energy production", n.d.).

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3.4 CONSUMPTION

Biogasoline, Biodiesel and biogas are the main consumed biofuels in the Netherlands. The table 16 shows that biogasoline is only used in transport sector whereas biodiesel is used in heating sector as well and biogas is used for heating and electricity and a very little amount in transport sector ("CBS StatLine - Renewable energy; final use and avoided use of fossil energy", 2018). Table 16 shows that the most used application for biofuels, in the Netherlands, is transportation sector and this is the reason why ambitions for the future are mostly focused in this application. In addition, the more biofuels are consumed, the more CO_2 emissions are avoided in the atmosphere (Table 13) and this means that the use of biofuels can contribute to the GHG emission reduction targets in the Renewable Energy Directive (RED).

3.5 REGULATION

Nowadays, The Netherlands is following EU targets 2020 to promote the use of renewable energy and reduce GHG emissions. The main objective of following these targets is to become Europe in a greener and more sustainable continent.

3.5.1 Renewable Energy Directive

The Renewable Energy Directive is one of the most important targets in EU countries and it has several objectives concerning transport ("EUR-Lex - 32009L0028 - EN - EUR-Lex", 2009):

- Achieving a minimum of 10% of renewable energy in transport in 2020.
- The promotion of electric vehicles, biofuels and biogas.
- The application of renewable fuels on road transport, as well as in shipping and air transport.
- Using a double counting system for second generation biofuels (waste/residues/cellulosic material).

3.5.2 Fuel Quality Directive

For biofuels, the most important directive in the EU is the Fuel Quality Directive (FQD), which is applied to petrol, diesel and biofuels in road transport and to gasoil used in non-road-mobile machinery ("Fuel Quality | Climate Action," n.d.). This directive requires a reduction of GHG emissions of transport fuels by a minimum of 6% by 2020, which is meant to be achieved by:

- The use of biofuels, less carbon-intensive fossil fuels, electricity and renewable fuels of non-biological origin, such as e-fuels.
- Reductions of venting and flaring at extraction stages of fossil fuel feedstocks.

Biofuels must meet GHG emission reduction targets. Therefore, a sustainability criteria is applied to reduce the undesired impacts from the production of greenhouse gases ("Sustainability criteria - Energy - European Commission," n.d.). Renewable Energy directive and Fuel Quality Directive have some points in common:

- GHG emissions from biofuels must be lower than the fossil fuels they are replacing. At least, they have to be 50% and 60% for new installations. Biofuels have to achieve at least 35% of GHG savings comparing to fossil fuels. When calculating GHG savings, all life cycle emissions are taken into account, which include cultivation, processing and transport.
- Raw materials that are used to produce biofuels cannot be sourced from land high carbon stock, such as wetlands and forests.
- The origin of raw materials to produce biofuels cannot be high- biodiversity lands, such as primary forests or very biodiverse grasslands.

3.5.3 Indirect land use change

However, in 2015 new rules came into play which amended the Renewable energy Directive and Fuel quality Directive, taking into account what is called the indirect land use change (ILUC) and it was created because biofuel production usually takes place on croplands that were previously used for other agriculture uses such as growing food or feed, and as this agricultural production is still necessary, it might be displaced to non-cropland, such as forests and grasslands ("Land use change - Energy - European Commission", 2015). This amendment:

- Puts limits to the share of biofuels coming from crops that are grown on agricultural land that can be counted on the 2020 renewable energy targets to 7%.

- Harmonizes the lists of feedstocks for biofuels within the EU that are contributing in a double way towards the 2020 target of 10% for renewable energy in transport.

- Requires that biofuels that are produced in new installations produce at least 60% fewer GHG gases than fossil fuels.

- Makes stronger incentives for the use of renewable electricity in transport.

- Includes a number of extra-reporting obligations for fuel providers, EU countries and the European Commission.

3.5.4 Double counting system

3.5.4.1 Purpose

Some sustainable fuels might be counted as twice by all companies under renewable Energy for Transport laws and regulations. These biofuels are the ones produced from waste, non-food cellulosic or lignocellulosic biomass. This system is applied so that companies delivering a double-counting biofuel for transport in the Netherlands obtain twice as many Renewable Energy Units (HBEs) when they enter a claim in the energy for Transport Registry (REV) as they would for a single-counting biofuel (Emissieautoriteit, 2015).

The purpose of this double counting scheme is to promote the production of biofuels that offer better environmental performance. It is a product of the RED. The companies that wish to enter a claim in the REV for a biofuel that counts as a double-counting certificate for this biofuel, which proves that the double counting has been confirmed by an independent verifier and meets legal conditions. The latter has to be authorized to count double-counting verification.

Companies entering a claim for biofuels must always prove they are sustainable and it does not matter whether this is related to single-counting or double-counting biofuels (Emissieautoriteit, 2015).

3.5.4.2 Performing double-counting verification

A double counting verifier can be used to perform verification with a 2% materiality threshold and a reasonable degree of certainty. This verifier makes collections of sufficient verification evidence for this purpose and makes sure that verification risks are at an acceptable low level. This situation is applied to deviations in type of materials that are connected to the double counting biofuel as well as in deviations in the amount of material used in relation to the amount of double-counting biofuel produced (Emissieautoriteit, 2016).

Double counting verification takes place at production sites of the double-counting biofuels. These sites must be certified a sustainability system basis, which is recognized by the European Commission. Moreover, this verifier makes sure that the sustainability system that has been applied is adequate for the raw material used to produce the double counting biofuel and it is required to visit the production sites during the initial verification inspection. In any time when the verifier issues a certificate for any site, he also has to visit that site at least once a year.

3.6 DISCUSSION

In terms of resources, the Netherlands uses many resources for biofuels production but only the 20% of the feedstocks are originated in the Netherlands, so it is a country that depends a lot on the imports of other countries. This is due to the small size of the country and its big population density. However, they use a lot of animal fats and UCO for biofuel production, so they are contributing to second-generation biofuel production.

Combustion and gasification techniques are still the most used technologies for biofuels in the Netherlands. BTG´s pyrolysis plant is a positive point for conversion technologies in the Netherlands but this technology is still very expensive and its development needs time and investments. There are already more than one commercial biorefinery and pilot projects for biofuels are very common in the Netherlands.

In terms of products, the most common one is Biodiesel, which is used mainly for transport but also for heating. Bioethanol, Bio-LNG and biomethanol are also produced in the Netherlands but they are not as common as Biodiesel and they have a lot of applications, which is an advantage for the country as it gives hope for the implementation of biofuel application in the future.

The Dutch regulation for biofuels is practically the same as for the whole EU. The Netherlands follows the EU´s targets and the double counting system is a very useful system for the promotion of second-generation biofuels in order to generate biofuels from waste and residues and not from food crops, which are less sustainable as they emit many indirect GHG emissions.

4. POTENTIAL AND AMBITIONS OF BIOFUELS IN THE NETHERLANDS UNTIL 2030/50

The chapter 4 answers the research question: “What is the potential and ambitions of biofuels in the Netherlands until 2030 and 2050?”. The main goal of the chapter is to show the ambitions of biofuels in the Netherlands, how much GHG emissions they intend to reduce with the use of biofuels, how important biofuels are expected to be to achieve them, and based on information in chapter 3 and thee ambitions, analyze how the situation will be in the Netherlands until 2030 and 2050.

4.1 AMBITIONS FOR 2030/2050

4.1.1 Energy consumption targets in the Netherlands

The Netherlands is still consuming a lot of energy from fossil fuels such as oil, natural gas and coal, but due to the policies and directives applied from the EU, energy consumption has been much more reduced from 2000 to 2015 and based on Dutch government´s expectation, it should be even more reduced by years 2020 and 2035. In table 5, the huge decline of natural gas is noticed, as after Groningen´s earthquakes, the government stopped Groningen´s well´s drilling for a while and gave subsidies to all the inhabitants that suffered from the damages. Furthermore, natural gas consumption is thought to decrease in the future as well to change from that source to other ones.

The decline of natural gas consumption has given more space for coal and renewables. Nevertheless, coal is expected to decrease in 2020 and 2035 because of new policies to reduce CO_2 emissions. The Netherlands is very hopeful to meet Renewable Directive and Fuel Quality Directive´s targets and by 2020, they expect to achieve at least a 200 PJ of consumption in Renewable Energy, including transport.

Table 5. Energy consumption in the Netherlands (“Netherlands - Energy | export.gov”, n.d.).

Consumption in Petajoules	2000	2015	2020	2035
Oil	1173	1173	1212	1253
Natural Gas	1517	1191	1040	885
Coal	325	516	326	292
Renewables	52	136	276	491
Miscellaneous	72	88	92	35
Net electricity imports	65 (import)	40 (import)	75 (import)	74 (export)
Total	3204	3144	3020	2882

Although renewable consumption is expected to increase almost 4 times compared with 2015, oil consumption is expected to increase by 2035 due to the reduction in natural gas consumption. This means the oil consumption might increase for transport as well and therefore, more policy work will have to be implemented to change from fossil fuels to biofuels in the Netherlands.

4.1.2 Energy Agreement

Regarding at energy provision and use of fuels, a big number of transitions are being held all over the world. The goals of this vision brings together social issues and climate-related mobility objectives that are related to green growth, energy conservation, sustainable energy, safety and living conditions such as noise pollution and air quality in a global context.

The Netherlands is following the targets taken in the Energy Agreement signed under the rules of the Social and Economic Council (SER) in September 2013 ("Dutch Mobility Innovations", n.d.). In this agreement, in order to reduce CO_2 emissions in mobility and transport sector, Tank-to-Wheel (TTW) objectives were agreed to meet with these targets (Figure 24).

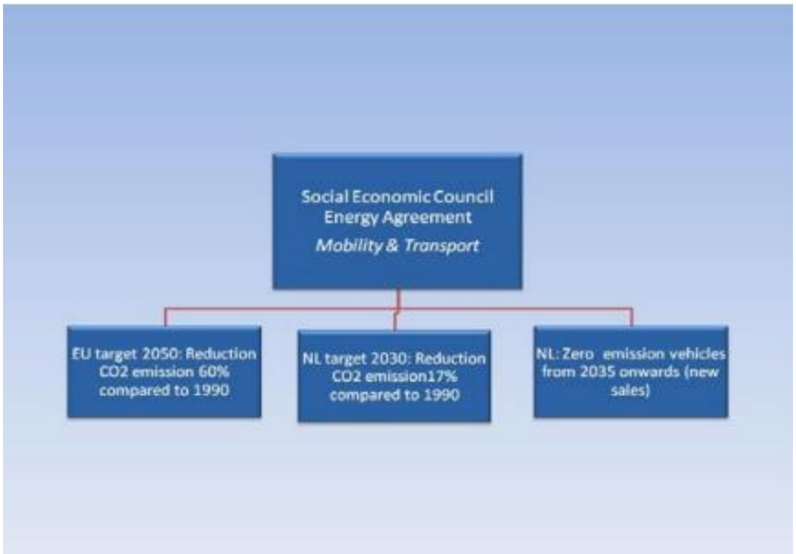

Figure 24. The Energy Agreement´s objectives ("Dutch Mobility Innovations", n.d.).

To achieve the objectives in this Energy Agreement, there should be approximately 3 million zero-emission vehicles in the Netherlands by 2030. This agreement has certain objectives in transport sector ("Agreement on Energy for Sustainable Growth - English | SER," n.d.):

- The emissions cannot exceed 25 Mton CO_2 by 2030, which is less than 17% in 1990. For 2050, all parties involved in the agreement (NGOs, energy sector, Industry and Dutch government) agreed on an overall CO_2 reduction of 60%.

- The contribution to energy savings of between 15 and 20 PJ by 2020 in comparison to 2012 baseline studies conducted by the Energy Research Centre of the Netherlands Environmental Assessment Agency.

4.1.3 Dutch biofuel market in 2030

Good examples of measures taken by the Dutch government to overcome barriers for the promotion of biofuels so far are subsidies and tax exemptions, in addition to the biotickets and double counting systems.

In the EU, up to one quarter of the transport fuel needs can be achieved by CO_2-efficient and clean biofuels by 2030. Biofuels will more likely be used in internal combustion engines, as these technologies will still remain and biorefineries co-producing chemicals, biofuels and other forms of energy will be in full operation ("Biofuels in the European Union - A Vision for 2030 and beyond (BIOFRAC) | Renewable Energy Mapping and Monitoring in Europe and Africa (REMEA)," n.d.).

In 2014, the EC proposed a new policy framework for climate and energy in 2030 ("European Commission - COM(2014)15 - Register of Commission documents", 2014). After this, the EU leaders agreed on plan called Energy and Climate Package on 23rd of October 2014 ("European Council, 23-24/10/2014 - Consilium", 2014). This package is divided in 4 propositions:

- Reducing at least a 40% of domestic GHG emissions in comparison to 1990 by 2030. In order to achieve this percentage, all sectors that belong to the EU emissions trading system (EU ETS) would have to make reductions of their emissions by 43% compared to 2005 and emissions coming from sectors out of the EU ETS (including transport) would need to be cut by 30%, below the 2005 level.

- Achieving at least a 27% of renewable energy by 2030.

- An increase of energy efficiency by at least 27% by 2030 in comparison to the business-as-usual scenario.

- Reforming the EU ETS.

There already have been many publications predicting the future of the shares of renewable energy in transport and biofuels for 2030, despite not being a very clear new policy framework. In the study from (Mitkidis et al., 2017), there is an assessment of the impact of several 2030 targets, including a target of 30%, the closest one to the 27% target in the EU package. According to this report, a stagnation of biofuel consumption can be expected from 2020 to 2030, as can be seen in figure 25, where a biofuel demand of 9.9% is expected for the road transport for 2030.

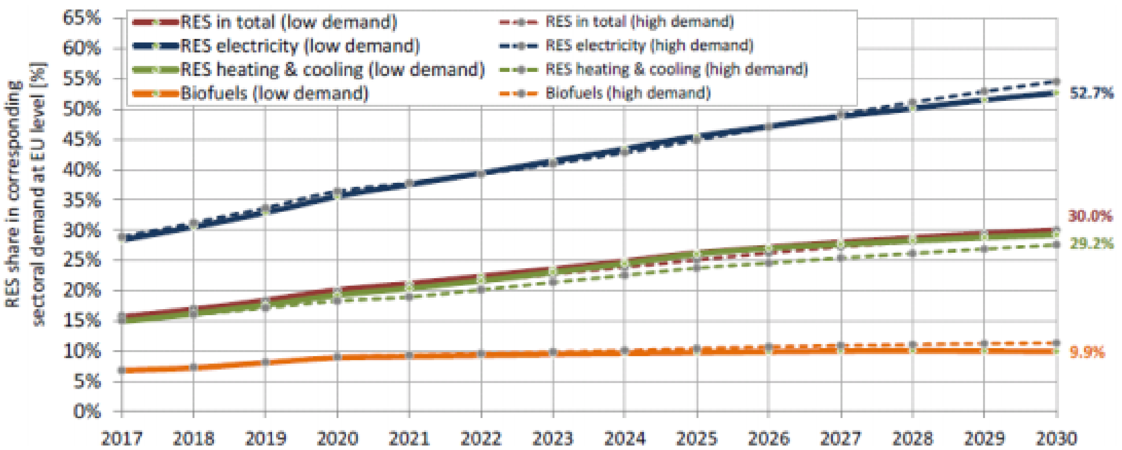

Figure 25. Future renewable sources pathways up to 2030 at EU level, pursuing a 2030 target, in total and per energy sector depending on the future gross final energy demand (Mitkidis et al., 2017).

4.1.4 Aviation for 2050

Partly due to the growing importance of the aviation industry in the world, GHG emissions owing to aviation are expected to be doubled by 2050 if measures are not taken. The figure 26 illustrates all choices available to industry to meet sustainability targets. In order to reduce fuel consumption and GHG emissions, the first priorities are increased energy efficiency and demand. The change from fossil fuels to renewable sources such as hydrogen or electricity are not so easy in aviation industry, so the SAF is considered the most promising alternative to fossil kerosene and reduce carbon footprint in aviation industry. Due to these reasons, SkyNRG has a huge commitment to build this new industry for SAF and create a sustainable future for aviation ("SkyNRG Rationale for sustainable aviation fuel - SkyNRG", n.d.).

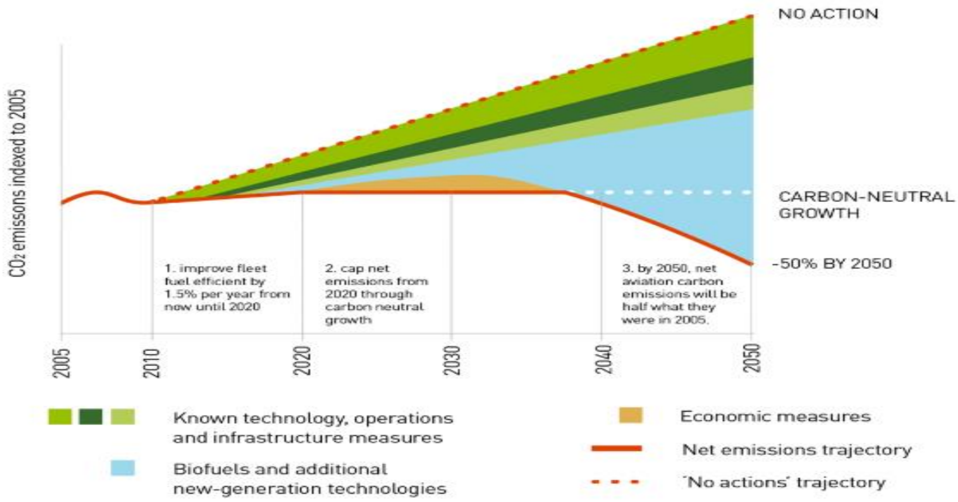

Figure 26. Breakdown of CO2 reduction options for aviation through 2050 ("SkyNRG Rationale for sustainable aviation fuel - SkyNRG", n.d.).

According to figure 26, the current technologies, infrastructures and operations will be very helpful to fight climate change and accumulation of CO_2 in the Earth until 2050, but biofuels and other new-generation technologies would reduce CO_2 emissions more. That is why biofuels are a very good guarantee for aviation sector in the Netherlands for the future.

The Netherlands has great combination of proactive production and distribution businesses product users and developers, who lead public-private partnerships and knowledge centers committed to green growth. The ports of Amsterdam and Rotterdam are of the Europe´s major logistic hubs for kerosene trading and they have a very well developed bio-based infrastructure. Therefore, the Netherlands can continue being the international leader in setting sustainability standards for bio-kerosene ("Duurzame Brandstofvisie met LEF | SER," n.d.). The proposed development path for these standards is aligned with the international objective of carbon-neutral growth from 2020 and 50% emission reduction by 2050:

- Direct market preparation with bio-kerosene through hydrogenated sustainable plant oils and fats, and further development on sustainability standards.

- Until 2020 after and of 2020 large-scale bio-kerosene technology use based on biomass flows.

4.1.5 Shipping ambitions

In Paris Agreement, taken place in 2015, the main goal set was "holding the increase in the global average temperature to well below 2 ºC above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 ºC above pre-industrial levels" ("The Paris Agreement | UNFCCC", 2015). In shipping sector, the International Maritime Organization (IMO) managed to develop a GHG roadmap to agree measures. Transport and Environment (T&E) did research and created a ranking of EU member states regarding at their ambition of past declared national positions on the IMO process.

The ranking made T&E is presented in table 6. Depending on their national policy positions, every member state is assigned primary points for each question on climate ambition in shipping. Positive points are given if any member state has supported on any issue during recent IMO negotiations. Support means 1-5 points and lack of support a penalization of -1 points. Nevertheless, lack of support for 3 different choices for a long-term reduction is not penalized with a negative point.

Moreover, all member states in the EU receive secondary points as a function of their primary options which are weighted by their registered shipping tonnage. Large tonnage gives additional positive points, while climate laggards are penalized with additional negative points. This secondary point allocation system is used to differentiate among member states with very similar rankings based on primary points, as larger tonnage benefits a country vis-à-vis other that have equal primary points.

Table 6. Question to assess climate ambition and primary points awarded for each question ("Shipping climate ambition: ranking of EU member states | Transport & Environment", n.d.).

<table>
<tr><th colspan="2" rowspan="2">Questionnaire</th><th colspan="2">Max primary questions awarded per question</th></tr>
<tr><th>Support</th><th>Lack of support</th></tr>
<tr><td colspan="2">Supporting a long-term reduction target?</td><td>1</td><td>-1</td></tr>
<tr><td rowspan="3">Specific options for a long-term target</td><td>Supporting 100% CO2 reduction by 2035?</td><td>5</td><td></td></tr>
<tr><td>Supporting 70-100% CO2 reduction by volume by 2050 over 2008?</td><td>3</td><td></td></tr>
<tr><td>Supporting 50% CO2 reduction by volume by 2060 over 2008?</td><td>1</td><td></td></tr>
<tr><td colspan="2">Supporting emissions reduction before 2023?</td><td>1</td><td>-1</td></tr>
<tr><td rowspan="2">Specific measure</td><td>Supporting mandatory speed reduction (slow steaming) to reduce GHG?</td><td>1</td><td>-1</td></tr>
<tr><td>Supporting early (2018) decision to tighten EEDI phase 3?</td><td>1</td><td>-1</td></tr>
</table>

The Netherlands is implementing a policy with the aim to reduce CO_2 emissions by 30% by 2020 in comparison to levels in 1990. The Rotterdam Climate Initiative set a goal with the aim to reduce CO_2 emissions by 50% compared with 1990 levels by 2025 and promote 100% climate proofing (Lee and Nam, 2017). The Rotterdam Sustainability mobility and the Rotterdam Energy Port have a direct relation to the harbors that are among those subjects to 50% reduction targets for CO_2 emissions. After the analysis of IMO with the questionnaire in table 6, it was concluded which countries in the EU are the ones that are most willing to achieve this climate ambition and therefore, have the adequate resources and technologies to achieve these targets (figure 27). The Netherlands is considered the 4th country that is most focused on achieving the climate ambition through shipping industry, behind Germany, France and Belgium. This conclusion makes sense, as in tables 12 and 13, it is shown how these 3 countries are the ones that produce and export most Biodiesel, so they are applying the use of these biofuels in shipping industry too.

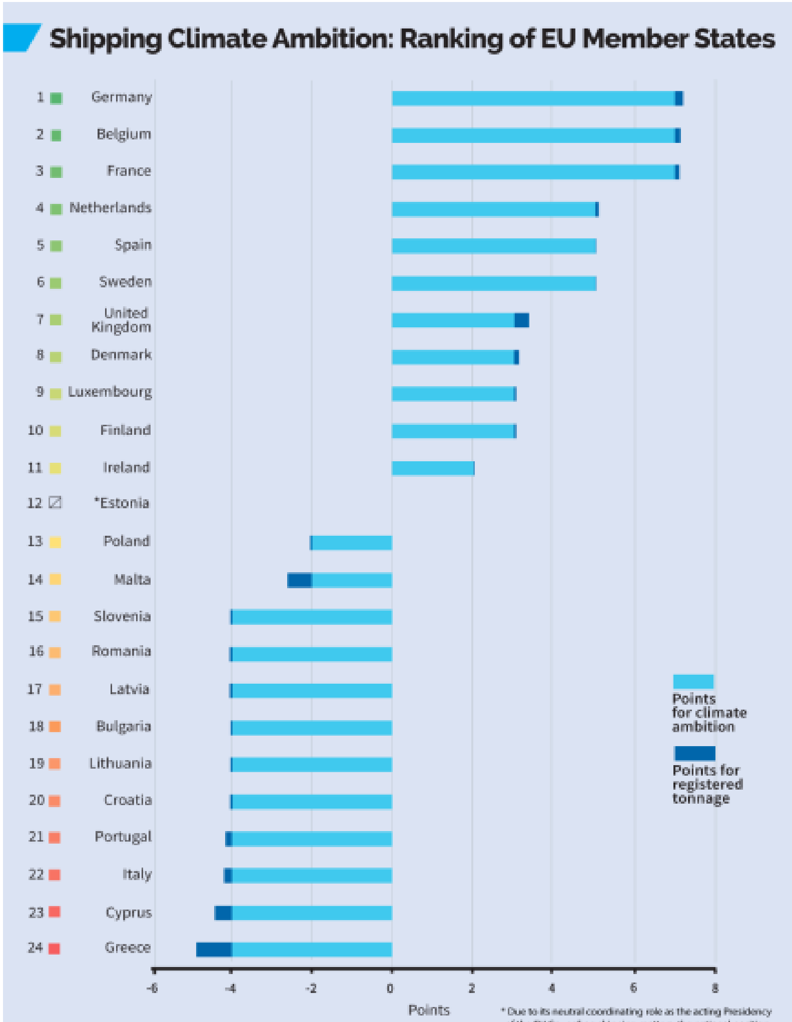

Figure 27. Shipping climate action: Ranking of EU Member States ("Shipping climate ambition: ranking of EU member states | Transport & Environment", n.d.).

Figure 28 shows the currently estimation of CO_2 emission reductions which are attainable implementing measures in the Dutch maritime shipping sector.

It is noticeable that the CO_2 emissions reductions in shipping are expected to be higher year by year until 2050. The use of biofuels will help the decrease in CO_2 emissions but improved efficiency in technology will be more helpful and useful, which means policies and measures in technology development are very necessary for the future.

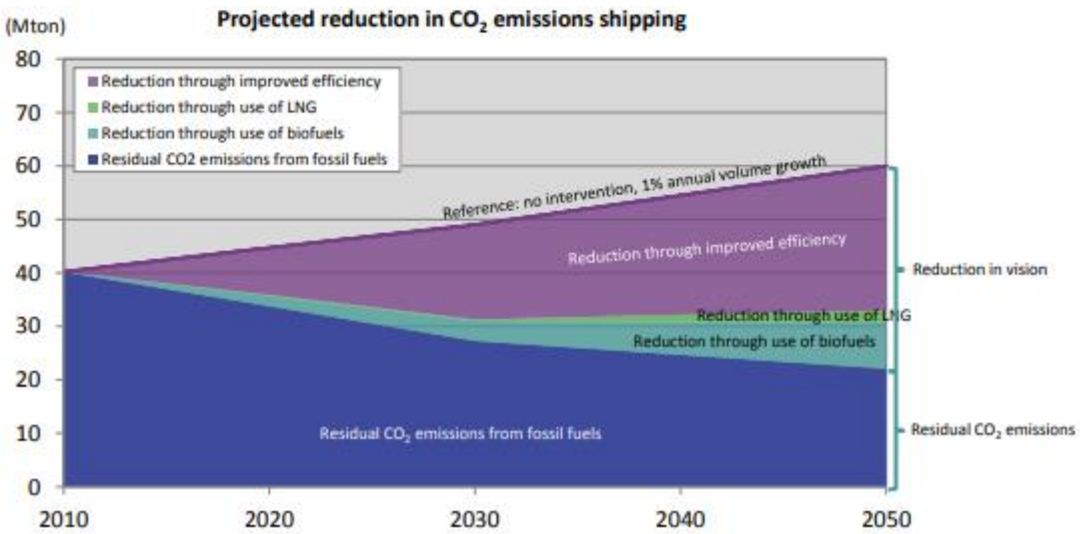

Figure 28. Forecast development of CO2 emissions from maritime shipping ("Duurzame Brandstofvisie met LEF | SER", n.d.).

4.1.6 Road transport ambitions

The Netherlands is preparing a transition in road transport until 2030 and 2050. However, electric vehicles are expected to be the main part of the transition, which means that biofuels are likely to play a secondary role in sustainable road transport (figure 29).

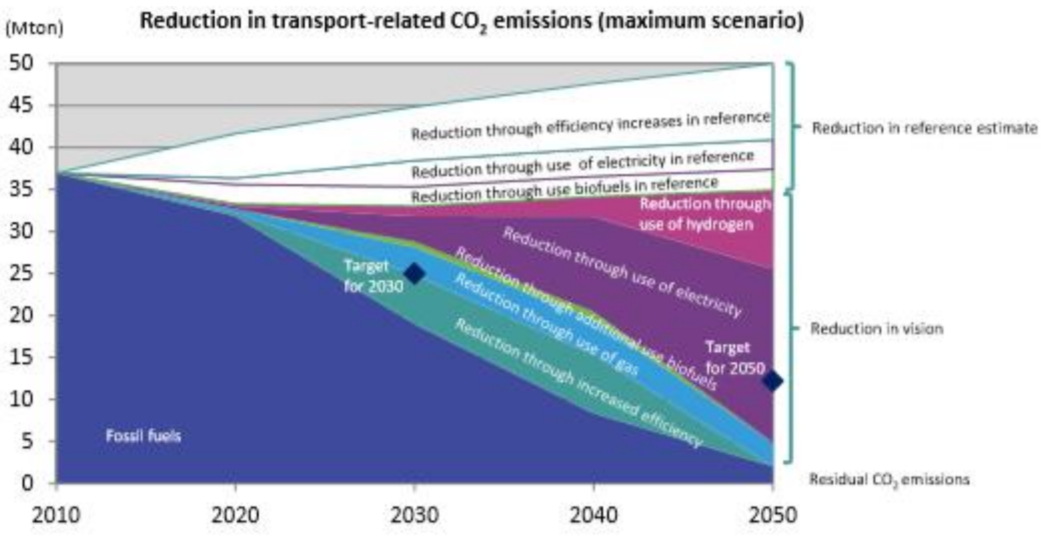

Figure 29. Estimated reduction in CO2 emissions from road transport ("Duurzame Brandstofvisie met LEF | SER", n.d.).

GHG emissions are expected to be reduced with the use of biofuels until 2030 in very small amounts. As figure 29 shows, electricity will be the main source for green cars in the future and as long as electric cars are fully commercially available for the Netherlands, the use of biofuels will decrease. Moreover, cars driven by gas and hydrogen are more likely to play a more important role in road transport than biofuels, as markets are putting more effort on batteries as they think it is more economically feasible for the future.

4.1.7 Rail ambitions

The rail sector is largely electrified nowadays in the Netherlands. Nevertheless, diesel is still used for regional and freight transport, as well as shunting and whenever a small section of a rail section is not electrified, a diesel engine is used for logistic reasons ("Duurzame Brandstofvisie met LEF | SER", n.d.). It is thought that cooperation with shipping and road transport on the use of Bio-LNG could be useful. The Dutch railways company NS intends to use green power without trading any certificate.

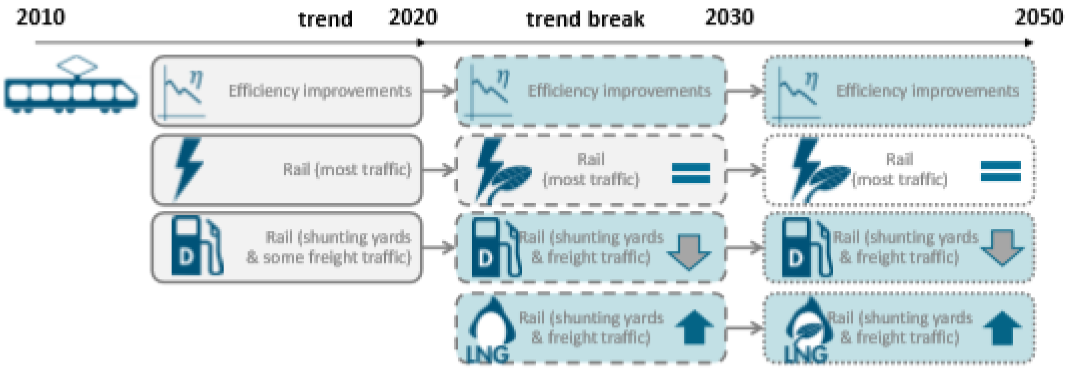

Figure 30. Rail development paths in the Netherlands ("Duurzame Brandstofvisie met LEF | SER", n.d.).

4.2 POTENTIAL FOR 2030/2050

4.2.1 Resources

Regarding at point 3, it is obvious that the Netherlands imports most of their resources for biofuel production, but at the same time, a lot of its local resources are waste. Therefore, the Double counting system in the Netherlands is working well and it can be useful for achieving sustainable targets for 2030 and 2050. Furthermore, due to the ILUC directive, the Netherlands will invest less in food crop imports for biofuel production. There are already companies, such as Rotie, who work in UCO and organic waste collection and supplying other companies that produce biofuels with this waste ("Used cooking oils - Rotie", n.d.).

The most common feedstocks for biofuels originated in the Netherlands are municipal waste, industrial acids, wheat straw, waste from starch production, glycerine, tallow and UCO. All this resources can be considered feedstocks for second-generation biofuels as they do not compete with food crops. Therefore, the Netherlands has a great potential to produce second-generation biofuels and this means that they are taking Red and FQD seriously, as this is a country that produces the most biofuels possible from waste. In fact, there is a Dutch company called SkyNRG, known as the global market leader for SAF, who produces this SAF from waste vegetable oil, UCO, municipal solid waste (MSW), forestry residues and non-food energy crops, such as lingo-cellulosic and non-edible oils (Agency (RVO), 2015). This company shows that it is possible to apply biofuels in aviation sector and that the waste produced in the Netherlands can be useful for airplanes. However, it is easier to make aviation sector green than road transport as all companies are more willing to invest in electrification rather biofuels on road and rail transport.

4.2.2 Technology and production

There is enough potential in terms of technologies for producing biofuels in the Netherlands, but when it comes to biofuel production in large scale, there are some projects that have had to be turned down, such as wordspirit, in which BioMCN intended to build the biggest biomethanol plant in the world ("Hoe Groningen honderden miljoenen en een nieuwe fabriek misliep", 2016). The problem did not involve lack of resources or technologies, but funding. All banks, investors and companies involved in the project considered there was too much investment involved in a plant that was built only as a demonstration project. This means there are very suitable technologies for producing biofuels but investors and organizations are not fully confident of making their production in large scale, as they still rely more on large scale in fossil fuel production. Moreover, the fact that investors are more self-confident in electricity and batteries for road transport does not help at all. The most promising sectors are aviation and shipping, so, technology should be focused especially on these transportation areas. There is also a big variety of technologies for biogas production for heating and electricity, such as anaerobic digestion, which as seen in figure 21, is a very common technology in the Netherlands. Therefore, the targets explained in point 4.1.3, the RED and FQD can be achieved through the current technologies available in the Netherlands for reduction of GHG emissions.

Nowadays, a lot of hope is put on pyrolysis technology as it has very high energy efficiency. Nevertheless, the technology is very new and because of it, the investments costs are still very high. Therefore, today the Netherlands only has a pilot project so far and it works in small scale (2-25 MW). Although pyrolysis is new and expensive, it can co-exist with combustion and gasification technology in the Netherlands, as new applications for pyrolysis are being looked for and some of them are related to engines in transportation sector.

4.2.3 Products and consumption

Biodiesel is the most common product for transportation in the Netherlands but biogas is also very important, as although it is barely used in transportation sector, the consumption is high in heating and electricity sectors. Moreover, biogas is also used for the production of bio-methanol, which means it is a very versatile product.

Although biofuels such as bio-methanol, bio-LNG and bio-ethanol are produced in the Netherlands, their use is still not common in the country. Bio-LNG is being studied in many research centers for their use in shipping industry and as seen in figure 27, the Netherlands is considered to have a very positive future regarding green shipping in terms of climate ambitions. In fact, E4tech did a study on what biofuels are most suitable for their application in shipping industry in the Netherlands according to their readiness of fuel production, compatibility with the current engines and vessels and their potential for CO_2 reduction (table 14). In this study, it turns out that the most suitable and advanced biofuels for this industry are Bio-LNG, Biomethanol and 2G ethanol (table 15). However, although having advanced technologies and sustainable resources, investors still need more confidence to invest in these products for their application in transportation sector. In fact, as table 5 shows, the oil consumption is expected to increase and oil industry is already a very settled industry not only in the

Netherlands, but all over the world. Therefore, this will mean a great competence for biofuels in the Netherlands.

4.3 DISCUSSION

The biofuel supply chain in the Netherlands is well developed and there is potential to produce more biofuels in the future. However, in terms of ambitions, it is obvious that in rail and road transport, biofuel market is not powerful at all as there are other priorities, such as electricity, which is very advanced in rail sector in the Netherlands and it will more likely be in road transport as well.

However, there are very few policies all over the world for making all airplanes and ships electric and it is thought it will be impossible to achieve it. Therefore, the Netherlands has a great potential for biofuels but that is not enough, as the global market does not think biofuels are the best choice for all transport sector.

In terms of green electricity and heating, the Netherlands also has a lot of potential, as they are very concerned of the importance of biogas for these sectors and how useful all types of waste can be for the development of this biofuel. Moreover, it is easier to implement policies for these issues and there is no need to develop new technologies for producing green electricity and heating with biogas.

The regulatory context of the Netherlands is in terms of biofuels is based on the EU legislation. They follow the RED and FQD directives to achieve the targets of the EU and the double counting system for biofuels companies are very suitable for biofuel production. Therefore, although regulation and legislation can always be stricter, it is not the main problem in the Netherlands.

5. HARVESTING POTENTIAL OF BIOFUELS IN THE NETHERLANDS

The chapter 5 answers the question: "How can potential of biofuels be harvested in terms of resources, technologies, applications and support policies?". The main goal of chapter 5 is, based on analysis in chapter 3 and 4, make a comparative analysis and make propositions to harvest the potential of biofuels in the Netherlands until 2030 and 2050.

5.1 RESOURCES

The most important issue is to find ways to promote waste collection for second-generation biofuels, which do not compete with food crops. As seen in chapter 3, the Netherlands imports a lot of food crops for biofuel generation and in order to reduce this, a good method is creating social campaigns and advertisements in public places, on TV and education centers. The main resources to be collected can be UCO, animal fats and oils, food waste, vegetable oils…, basically waste people want to get ride off and can be useful.

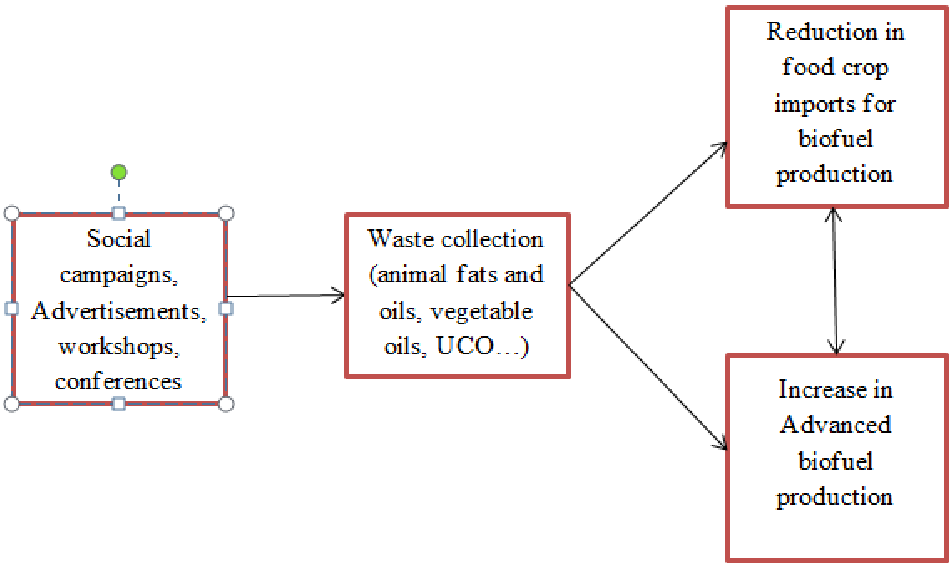

Figure 31. Waste collection methodology for advanced biofuel promotion.

The regulation in the Netherlands already includes the double counting system, which gives benefits for companies that produce biofuels from waste, so, policies should be focused on the importance of making waste useful and promoting the creation of points where waste can be collected by trucks and sent to biofuel companies, where all the waste will be processed and refined.

5.2 TECHNOLOGY

Combustion and gasification are very common technologies in the Netherlands since the 20th century, then, new effort on promoting other technologies has to be made. As seen in table 4, pyrolysis is a very new technique that still needs to be researched. It is a technology that can be very helpful due to its high efficiency and it is important to make it more common and apply it in large scale more, so that in time, the operating and investments costs are not as high as they are nowadays. There is already a company that has a commercial pyrolysis plant (BTG) but it still needs to be more implemented. Moreover, there are already some projects that involve third-generation biofuel technology in which Wageningen university takes part, such as AlgaeParc (figure 11), which are still being researched and are expected to last long.

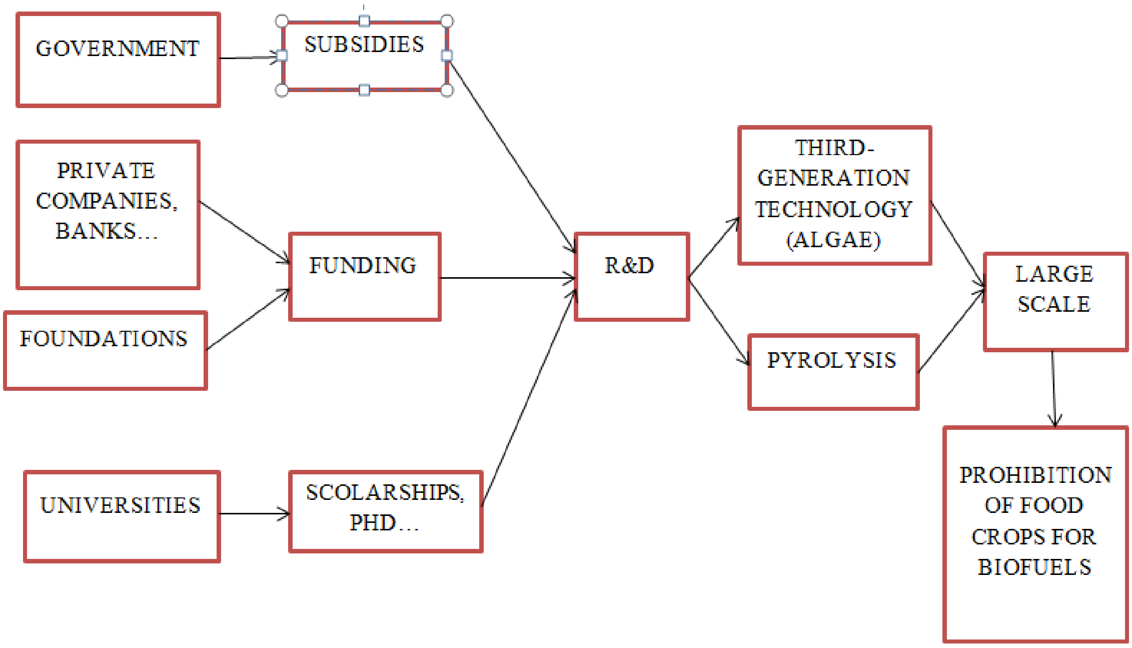

Figure 32. Policy for technology development for biofuels.

In order to harvest the potential of technologies and achieve the ambitions until 2030 and 2050, public and private entities should apply tools to develop new technologies that are energy-efficient and able to be used in large scale in the long run, such as subsidies from the Dutch government, funding from foundations or any private entity and scolarships for PhD students from universities. These economic tools should be invested in Research and Development (R&D) for research in technologies that are still under development, such as third-generation technologies with algae as a resource and pyrolysis which is not still as common as other technologies in the Netherlands. When this technology is proved to useful and suitable for biofuel production, new large-scale plants can be built and this will mean that other resources can be applied instead of food crops. Therefore, when this happens and technologies are fully implemented, the food crop use for biofuels will be able to be banned and the Netherlands won´t have to import food crops for biofuel generation.

5.3 PRODUCTS

In the Netherlands, the biofuels consumed can be classified in 3 types: biofuels under research, such as pyrolysis oil, biofuels that are usually used for transportation sector, such as Biodiesel, bioethanol, biogasoline… and biofuels for electricity and heating generation, which is basically composed of biogas, although tables 16 and 17 show that in 2016 and 2017, a little amount of heating has also been consumed from Biodiesel.

The main tools that should be applied for the promotion of the use of biofuels in the Netherlands are subsidies or tax exemptions, basically mechanisms used by the government.

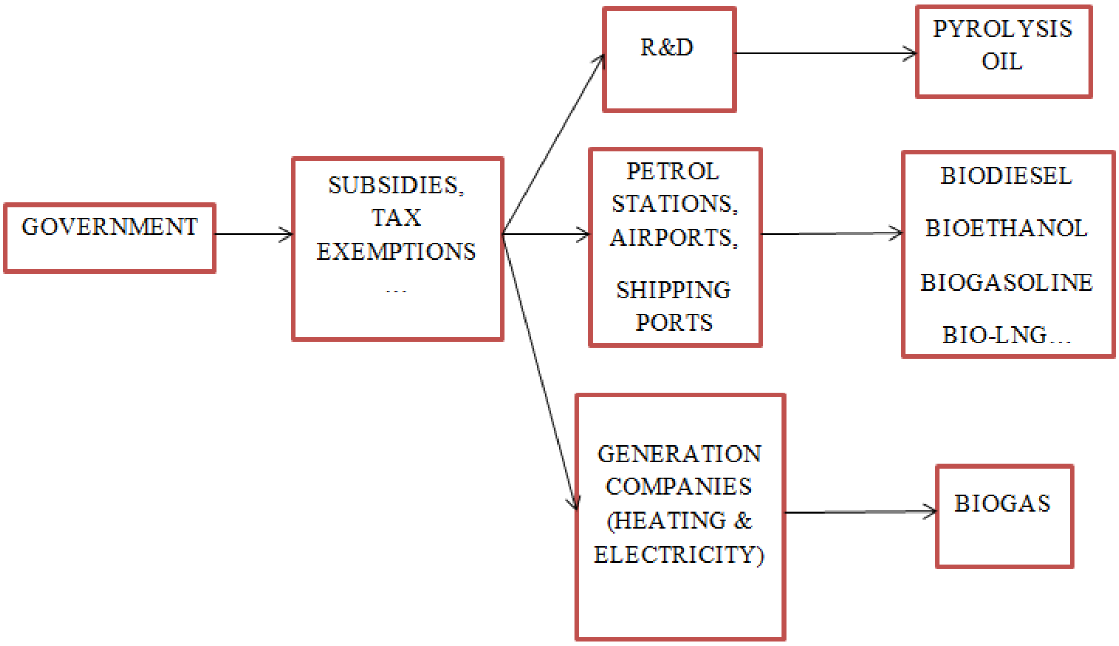

Figure 33. Biofuel promotion methodology.

The main institutions or entities where subsidies and/or tax exemptions should take place especially in R&D centers, such as research centers or universities, in petrol stations and generation companies (heating and electricity). R&D is important to investigate on pyrolysis oil, as they are thought to be useful in engines for transportation, although their main use is for boilers. Giving subsidies in petrol stations, airlines and shipping ports is very important because transportation is a crucial sector for biofuels, especially in road transport, where the effort has to be huge so that biofuel market can compete with electric road transport. In terms of heating and electricity generation, subsidies and/or tax exemptions for generation companies can help them to move form fossil fuels to biogas production using waste, which would be cheaper and more sustainable.

5.4 DISCUSSION

In terms of resources, the most important issue of the supply chain to be able to create a future with only second (or third) generation biofuels is to create a good social and advertising industry in favor of their use and waste collection, so that imports of food crops for biofuel production stop. A very big reduction of food crops imports for biofuels would really mean something positive for promotion of biofuels.

In technical terms, the Netherlands is an advanced country, which means that even if research has to be put into new technology, there is well developed technology in this country. A focus on R&D is very important so that in time, when new technologies are proved to be sustainable and economically feasible, they can be settled in biofuels industry as conventional technologies.

The last step, which is the most difficult one in the Netherlands, is the products and their promotion for consumption. It is very important that companies have a big support economically and socially from the Dutch government or any public institution to purchase biofuels instead of fossil fuels. The case of BioMCN is a very significant example that shows that apart from having a great potential in technology and resources for production, as well as very high expectation and ambitions, it is very important to develop confidence on banks or any private and public entities so that the necessary funding can be applied in new projects. Therefore, R&D, good advertising programs, social campaigns and other issues play a crucial role in biofuel industry overall, not only in the Netherlands. People have to be concerned about GHG emissions, resources scarcity and that new alternatives need to be developed, as long as they are the most sustainable possible.

6. CONCLUSIONS

The Netherlands is still a country that imports a lot of food crops and other resources to produce biofuels although they also use a lot of local waste for this purpose. The best option for promoting more biofuels is the use of social campaigns and advertising in any center, especially public places, companies and education centers to warn about the need to find alternatives for fossil fuels and make sure that biofuels are one of the best solutions, so that people are more concerned and they collect their food waste for the production of transport biofuels or biogas for green electricity or heating. Moreover, by increasing biofuel production by waste collection, the food crops imports for first-generation biofuels would increase and it would be possible to achieve all ambitions and targets for 2030 and 2050.

The technology section is very well developed as combustion, gasification and anaerobic digestion technologies are very common in the Netherlands. Furthermore, pyrolysis technology is increasing and by 2030 and 2050, this technology will very likely be used in the Netherlands, depending on whether this technique can already be used in large scale. Therefore, a lot of investments have to be put into R&D, such as conceding scolarships to PhD students in universities to investigate on this technology or putting funding for any other research center.

There are a lot of different kinds of biofuels produced in the Netherlands, but many of them are imported as well. The most common ones are Biodiesel, biogasoline, bioethanol for transportation sector and biogas for heating and electricity. The most feasible applications are shipping and aviation and the future looks very promising for them, whereas in road and rail transport sector, the ambitions are more negative as electricity looks a more feasible choice than biofuels. In order to compete in with all markets in all the applications possible, the Dutch government should concede tax exemptions and subsidies to all entities that are will be sell business with biofuels.

Overall, the potential for biofuels in terms of bioresources, technologies and support policies for its harvesting in the Netherlands until 2030 and 2050 are very positive, but they are not still mature enough to look as an alternative for fossil fuels in the future in all applications. It will be very difficult to match all the potential with all the sectors, both in transportation or heating and/or electricity.

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APPENDIX: TABLES

Table 7. Biodiesel production companies in the Netherlands ("Biofuels on the Dutch market. Update", n.d.)

Company & location	Type Biodiesel	Capacity (kton)	Feedstock	Since
Land based feedstocks (food crops)				
ADM, Rotterdam	FAME	3000*	Rapeseed, canola, soybean (oilseeds)	<2009
Biopetrol Industries, Rotterdam	?	400	Rapeseed, canola, soybean , palm, sunflower, free fatty acids	2008
CLeanerG, Zwijndrecht	FAME*	200	Rapeseed, soybean, palm	>2011
Cooperatie Camola, Limburg	PPO	2,5**	Rapeseed	2006
Ecopark, Harlingen	PPO	32 (only small % for fuels)***	Rapeseed	2007
OIO/Loders Crocklaan	Palm oil	10000*	Palm	<2009
Wilmar/KOG	Palm oil	500*	Palm	
Waste and residues based feedstock				
Biodiesel Amsterdam, Amsterdam	FAME (UCE)	110	UCO (Benelux), Animal fat cat. 1	2010
Biodiesel Kampen, Kampen	UCE		UCO (local), Animal fat cat. 1	N/A
Eco Fuels, Eemshaven	UCOME	50	UCO	2007
Ecoson (VION), Son	FAME*	5	Animal fat cat. 1, 2, 3	<2011
SunOil, Emmen	FAME*	70	UCO (Animal fats)	<2012
SES International, Moerdijk	?	NA	UCO, vegetable oils, fats	>2007
Multifeedstock				
Ekectrawinds Greenfuel, Sluiskil	FAME*	250	Multifeedstock, vegetable oils, UCO, animal fat	<2011
Neste Oil, Rotterdam	HVO	800	Multifeedstock; vegetable oils, UCO, rape, canola, animal (fat) waste residues, palm oil, stearine	>2011

Table 8. Bioethanol production in the Netherlands ("Biofuels on the Dutch market. Update," n.d.).

Company & location	Type Bioethanol	Capacity (kton)	Feedstock	Since
Land based feedstocks (food crops)				
Arbengoa, Rotterdam	Bioethanol	480	corn, wheat	<2011
LyondellBasell, Rotterdam	Bio-ETBE	600**	unknown	2008
Waste and residues based feedstock				
Cargill, Bergen op Zoom/Sas Van Gent	?	32	Palm oil, starch slurry	<2011
SABIC, Geleen	ETBE/MTBE	unknown	?	Unknown

Table 9. Other biofuel production in the Netherlands ("Biofuels on the Dutch market. Update," n.d.).

Company & location	Type Biofuel	Capacity (kton)	Feedstock	Since
Waste and residues based feedstock				
Bioethanol Rotterdam, Rotterdam	Bio-LNG	Unknown	Biomass waste	Unknown
BioMCN, Farmsum	Biomethanol	200	Crude glycerine	<2011

Table 10. Set-up characteristics in anaerobic biogas composting in the Netherlands ("Amsterdam, Greenmills | Orgaworld" n.d.).

Technology	Wet anaerobic digestion
	Sediment drying facility
	MBR aerobic + anaerobic water purification
Input	Food and kitchen waste
	Supermarket waste
	Organic, polluted industrial waste water
Biogas conversion	Biogas buffer, 3 CHPs + 1 torch
Waste gas treatment	Air purification (+ stack)
Number of digestion reactors	3
Volume of fermentation	75000 tons a year
Reactors	10000 m^3
Capacity for digestion	120000 tons/year
Volume of water purification	7000 m^3
Time spent on water purification	7 days
Capacity of water purification	350000 m^3/year
Energy output	5.5 MW electric + 5.5 MW thermal
Product output	3500 tons of fertilizer
Size of location	1.5 ha
Construction year	2010

Table 11. Technological development of Sustainable Aviation fuel (SAF) ("SkyNRG Technology Section - SkyNRG", n.d.)

Pathway	ASTM	Description	Production capacity
Fischer-Tropchs Synthesis (FT-SPK and FT-SPK/A)	++	Converts any carbon-rich material into syngas which is then catalytically converted to bio jet	0; only fossil capacity in place (e.g. coal or natural gas)
Hydrotreated Esters and Fatty Acids (HEFA) HRJ	+	Converts oils and fats to hydrocarbons via deoxygenation with hydrogen and cracking	40 k ton HRJ
Alcohol to Jet (ATJ)	+	Sugars (from celullosic materials or syngas) converted to jet through an alcohol intermediate	Only at demonstration scale
Synthesized Iso-Paraffins (SIP)	+	Ferments plant sugars to hydrocarbons which are thermochemically upgraded to jet fuel	25 k; facility of Amyris, not dedicated to jet; current supplies the chemical market

Table 12. Major trade flows (net import) of FAME and biodiesel (mixtures including HVO) for the Netherlands from 2012-2013 (ktonnes) ("Sustainable biomass and bioenergy in the Netherlands", 2016).

Country	**2012**			**2013**		
	Oils containing biodiesel	**Biodiesel mixtures**	**FAME**	**Oils containing biodiesel**	**Biodiesel mixtures**	**FAME**
Argentina	0	0	551.3211	0	0.3535	155.16
Austria	3.3028	0.8273	-4.3479	0.0001	-6.5134	-2.921
Belgium	-199.4893	-48.2513	-64.5587	178.4648	-67.525	-200.64
Brazil	0	0	2.467	0	0	9.0324
Czech Republic	-0.0008	0	0.4022	0	-15.426	4.1528
Germany	-1651.1963	-143.5604	-35.3829	-942.9404	-102.49	-32.082
Spain	-76.9083	-36.8923	-27.9286	8.0262	-17.616	-21.17
France	-307.4748	-32.4423	-60.7913	-291.773	-14.476	-104.89
UK	81.6138	-12.8367	-92.4476	280.0272	-55.512	-144.91
Indonesia	0	8.9692	364.1652	0	7.5314	109.5
Ireland	-6.262	0.006	-1.7941	-6.9487	-4.616	-6.45
India	22.3028	0	4.7532	0	0	43.045
Italy	-36.795	-28.8146	-74.8426	-0.0014	-82.164	-55.746
South Korea	-0.0005	0	30.9126	-0.0048	0	63.729
Malaysia	0	5.0095	15.1782	0	0	167.54
Norway	-0.0017	0	9.2364	-0.001	0	-38.401
Portugal	0	0	0	7.1762	0	1.9994
Romania	-0.0094	0	-0.9873	-0.2279	0	-0.9997
Russia	-0.0054	0	0	-0.0313	0	0
United States	0.0793	0.0002	-6.5908	71.0447	0	-39.944

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Table 13. Major trade flows (net import) of FAME and biodiesel (mixtures including HVO) for the Netherlands from 2014-2015 (ktonnes) ("Sustainable biomass and bioenergy in the Netherlands", 2016).

Country	2014			2015		
	Oils containing biodiesel	Biodiesel mixtures	FAME	Oils containing biodiesel	Biodiesel mixtures	FAME
Argentina	0	0	0	-5.6739	-0.0041	0
Austria	0.0002	0.0017	-6.6101	0	-0.0064	1.6481
Belgium	-46.7256	-80.8266	-270.3319	-985.5513	11.141	-296.4
Brazil	-0.0068	0	12.9549	-4.9423	0	0
Czech Republic	0.0352	0	12.1974	0.0122	-0.0003	22.343
Germany	-711.2201	-146.6699	58.6071	-695.5595	22.396	-95.733
Spain	-0.1112	7.5539	-2.0158	-0.002	2.6508	-20.505
France	-273.0933	-33.9315	-142.477	-137.5495	-5.9926	-170.07
UK	5.8812	-71.8574	-290.4085	-17.1332	0.1773	-217.88
Indonesia	-0.0002	0	0	-0.0006	0	0
Ireland	0	0	-37.6655	0	0.0022	-18.232
India	0	0	6.5128	0	-0.0021	7.3499
Italy	-0.0061	-24.0128	-89.8862	-0.0018	-4.5043	-88.145
South Korea	0	0	51.4611	0	-1.25	27.941
Malaysia	0.0001	0	265.6286	0	0	207.54
Norway	-0.0004	-0.0289	-8.1189	-0.0019	0.5165	-8.6552
Portugal	-0.0007	0	4.1937	-0.0002	-0.0056	5.6998
Romania	-0.0895	0	-0.7906	-0.0023	-0.0012	1.5266
Russia	71.6662	0	0	0	-2.5733	0
United States	0.001	0	-0.0208	0.002	-0.0002	0

Table 14. Indicators for biofuels in dutch shipping sector ("Documenten voor de leden - Platform Duurzame Biobrandstoffen", 2017).

Indicator	Readiness of fuel production	Compatibility with current engine and vessel (typical to sector type)	CO_2 reduction potential
1	Established and used widely, readily available and fully developed	No modification to engine or infrastructure - Drop in fuel or low blends	>90% GHG savings
2	Commercially available but not in wide use; could be further development	Considerable changes to engine, fuelling system and/or storage/infrastructure	75-90% GHG savings
3	Working demonstration plant	New vessel	<75% GHG savings

Table 15. Biofuel evaluation per dutch sipping sector ("Documenten voor de leden - Platform Duurzame Biobrandstoffen", n.d.)

Biofuel	Shipping sector	Readiness of fuel production		Compatibility		CO_2 reduction potential
HVO	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
FAME	Inland	Today	2030	Today*	2030*	
	Short sea			Today*	2030*	
	Deep sea			Today*	2030*	
SVO	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
1G Ethanol	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
2G Ethanol	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
Bio-Methanol	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
Bio-LNG	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
FT-Diesel	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	
Upgraded pyrolisis oil	Inland	Today	2030	Today	2030	
	Short sea			Today	2030	
	Deep sea			Today	2030	

Table 16. Consumption of biofuels in the Netherlands ("CBS StatLine - Renewable energy; final use and avoided use of fossil energy", 2018).

			Gross final consumption biofuels	
			Final consumption	**Final consumption relative**
Energy sources	**Application**	**Periods**	**TJ**	**%total energy cons.**
Biogasoline	Transport	2016	4752	0.23
		2017	5399	0.26
Biodiesel	Heat	2016	718	0.03
		2017	1021	0.05
	Transport	2016	4966	0.24
		2017	7063	0.34
	Total	2016	5683	0.27
		2017	8084	0.39
Biogas	Transport	2016	2	0
		2017	2	0
	Heat	2016	6554	0.31
		2017	6683	0.32
	Electricity	2016	3982	0.19
		2017	3854	0.18
	Total	2016	10537	0.51
		2017	10539	0.50

Table 17. Avoided carbon dioxide emissions by biofuels in the Netherlands ("CBS StatLine - Renewable energy; final use and avoided use of fossil energy", 2018).

			Avoided carbon dioxide emissions	
			Avoided emissions	**Avoided emission relative**
Energy sources	**Application**	**Periods**	**kton**	**% of total CO2 emission**
Biogasoline	Transport	2016	257	0.15
		2017	314	0.19
Biodiesel	Heat	2016	55	0.03
		2017	78	0.05
	Transport	2016	381	0.23
		2017	542	0.33
	Total	2016	436	0.26
		2017	620	0.38
Biogas	Transport	2016	0	0
		2017	0	0
	Heat	2016	251	0.15
		2017	253	0.15
	Electricity	2016	612	0.37
		2017	588	0.36
	Total	2016	864	0.52
		2017	842	0.51