Aalto-yliopisto
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Biofuel legislation implications on biofuel markets in Finland, Sweden, and Norway

Thesis submitted for examination for the degree of Master of Science in Technology

Espoo 3.3.2020
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Diplomityön tiivistelmä

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Työn nimi Biopolttoainelainsäädännön erojen vaikutukset Suomen, Ruotsin ja Norjan biopolttoainemarkkinoihin	
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Tiivistelmä

EU on asettanut tavoitteita uusiutuvan energian osuudelle liikenteessä ja polttoaineiden päästöintensiteetin vähentämiselle. Yksi näiden tavoitteiden päämääristä on vähentää liikenteen päästöjä ja eräs tapa saavuttaa tavoitteet on luovuttaa biopolttoaineita kulutukseen. Jokainen jäsenvaltio voi implementoida tavoitteet haluamallaan tavalla. Vaikka Norja ei ole EU:n jäsenvaltio, se on sopinut toteuttavansa tavoitteet. Kun biopolttoainelainsäädäntö pannaan täytäntöön eri tavoin kunkin maan kansallisessa lainsäädännössä, biopolttoaineiden ja niiden ominaisuuksien arvostus vaihtelee maittain. Tämä luo arbitraasia biopolttoaineiden markkinoille ja voi johtaa maidenväliseen biopolttoainekauppaan.

Tämän diplomityön tarkoituksena on arvioida, luovatko erot Suomen, Ruotsin ja Norjan biopolttoainelainsäädännössä arbitraasia ja siten maidenvälistä biopolttoainekauppaa. Työn painopiste on kansallisten lakien luomassa toimintaympäristössä. Tämän vuoksi biopolttoaineiden maastaviennin ja -tuonnin tutkiminen on rajattu pois tämän diplomityön aihepiiristä.

Suomen, Ruotsin ja Norjan välisiä eroja biopolttoaineiden arvostuksessa tutkitaan arvioimalla polttoaineiden toimittajien maksuhalukkuutta erityyppisistä biopolttoaineista. Tulokset osoittavat, että maksuhalukkuus biopolttoainevelvoitteita täyttävistä biopolttoaineista on korkein Suomessa ja alhaisin Norjassa. Lisäksi havaittiin eroja biopolttoaineiden kestävyysominaisuuksien arvostuksessa, mikä viittaa siihen, että lainsäädäntöympäristö luo suotuisat puitteet biopolttoaineiden maidenväliselle biopolttoainekaupalle.

Avainsanat Biopolttoaineet, lainsäädäntö, arbitraasi, maksuhalukkuus

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Abstract of master's thesis

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Abstract

The EU has set targets for renewable energy share in transport and emission intensity reduction of fuels. One of the aims of these targets is to decrease emissions in transport. One way to achieve these targets is to supply biofuels to consumption. Each member state can choose the way of implementing these targets. Even though Norway is not an EU member state, it has agreed on implementing the targets in its national legislation. When biofuel legislation is implemented in a different way in each country's national legislation, the valuation of biofuels and their attributes differs from country to country. This creates arbitrage in the biofuel market and may lead to intra-industrial trade of biofuels.

The aim of this master's thesis is to assess if the differences in the Finnish, Swedish, and Norwegian biofuel legislation create arbitrage and thus intra-industrial trade of biofuels. The emphasis is more on the operating environment created by national legislations. Therefore, the actual amounts of biofuels traded is out of the scope of this thesis.

The differences in biofuel valuation in Finland, Sweden, and Norway are studied by estimating fuel suppliers' willingness to pay for different types of biofuels when supplying biofuel to the market. As a result, the willingness to pay for biofuels fulfilling the biofuel obligation is highest in Finland and lowest in Norway. Furthermore, differences in biofuel sustainability characteristics valuation were found, implicating that the legislative environment is favourable for intra-industrial trade of biofuels.

Keywords Biofuels, legislation, arbitrage, willingness to pay

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I would like to thank my supervisor Martti Larmi for the supporting and encouraging supervision and my advisor Timo Huhtisaari for giving me the freedom to choose a topic of my interest and giving me insights on the subject. I want to thank Roland Magnusson for helping me to find and refine the topic and scope of the thesis and for giving valuable comments. I would also like to thank my colleagues Chad Edwards and Miika Johansson for taking time to explain me about the topic. Furthermore, I would like to thank my other colleagues in NEOT and St1 for all the help.

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Symbols

B_O	[%]	Biofuel obligation
C	[€]	Cost of not supplying biofuel
C_D	[€]	Cost of filling biofuel obligation with double countable biofuel
E	[gCO_{2ekv}/GJ]	Emission intensity of fuel supplier
E_b	[gCO_{2ekv}/GJ]	Emission intensity of biofuels
E_f	[gCO_{2ekv}/GJ]	Emission intensity of fossil fuels
E_{b_red}	[%]	Emission reduction of biofuel
E_{red}	[%]	Emission reduction of fuel supplier
P	[€/GJ]	Fuel price
P_b	[€/GJ]	Biofuel price
P_f	[€/GJ]	Fossil fuel price
F	[€/GJ or €/$kgCO_2$]	Penalty fee
Q	[GJ]	Total fuel amount
Q_b	[GJ]	Biofuel amount
Q_f	[GJ]	Fossil fuel amount
T_b	[€/GJ]	Biofuel tax
T_f	[€/GJ]	Fossil fuel tax
W_D	[€/GJ]	Fuel supplier's willingness to pay for double countable biofuels
W_O	[€/GJ]	Fuel supplier's willingness to pay for biofuel when fulfilling biofuel obligation
W_S	[€/GJ]	Fuel supplier's willingness to pay for surplus biofuel overfilling the obligation

Definitions

Advanced biofuels	Biofuels made from feedstocks listed in RES-directive Annex IX
Biodiesel	FAME (Fatty Acid Methyl Ester)
Biobased diesel	Biobased components blended to diesel: renewable diesel and biodiesel
Food and feed crops	Cereal and other starch-rich crops, sugars and oil crops and crops grown as main crops primarily for energy purposes on agricultural land (RES-directive)
GHG	Greenhouse gas
HVO	Hydrotreated vegetable oil
PFAD	Palm fatty acid distillate
Renewable diesel	Paraffinic biobased diesel fuels such as HVO (Hydrotreated Vegetable Oil), and Fischer-Tropsch biofuels
WTP	Willingness to pay

1 Introduction

In the EU, the transport sector's greenhouse gas emissions counted for 27 % of all the emissions in 2017. 72 % of these emissions came from road transport. (EEA 2019.) This is one of the main reasons the EU aims to increase the energy efficiency and the use of low-emission fuels and vehicles in transport.

As part of the EU's policy in achieving these targets, the EU has set targets for renewable energy share and fuel emission reduction in transport sector. A target of 10 % renewable energy share in transport in 2020 and 14 % in 2030 have been set with the renewable energy directive (RES directive, 2009/28/EC) and its recast version (RED II, 2018/2001/EU). The fuel quality directive (2009/30/EC) sets a 6 % greenhouse gas reduction target for transport fuels in 2020 compared to the 2010 level.

The EU directives must be implemented in the member states' national legislation. In addition, Norway and Island have agreed on implementing the directives. Each country has created their own country-specific rules and approaches in the implementation. Many countries are fulfilling the targets mainly with biofuels and calculating their contribution in a different way. For example, the Finnish biofuel obligation sets an energy-based obligation for biofuels, while in Norway the biofuel obligation is volume based. Both countries have set a sub obligation for advanced biofuels, and Finland has a cap for biofuels made from food and feed crops. Furthermore, advanced biofuels are counted twice on filling the biofuel obligation. Sweden has taken a different approach by setting an emission reduction obligation for biofuels, not considering the total volume, energy content, nor feedstock of biofuels supplied. In addition to these biofuel obligations, all the three countries have set a different kind of tax exemption system for biofuels.

Differences in biofuel policies between countries may impact on biofuel markets and trade. Biofuel policy implications to biofuel markets and trade have been studied in the literature review part of this thesis. The literature review also introduces an example of a biofuel policy driven arbitrage situation between the US and Brazil, which lead to the trade of bioethanol between the two countries.

The objective of the thesis is to assess how the differences in the Finnish, Swedish, and Norwegian biofuel legislation influence biofuel markets. The research question this master's thesis aims to answer is the following:

- Can the differences in the Finnish, Swedish, and Norwegian biofuel legislation create arbitrage and thus intra-industrial trade of biofuels?

The question can be divided into the following sub questions:

- How the valuation of biofuels differs in Finland, Sweden, and Norway?
- How much can a fuel trader profit by trading biofuels inside Finland, Sweden, and Norway?

The policy impact on biofuel valuation in Finnish, Swedish, and Norwegian markets is evaluated from a perspective of a fuel trader supplying fuels to consumption. As legislation creates value for different attributes of biofuels, a fuel trader operating in many countries can optimise its operations by choosing where to supply which biofuel batch. The assessment is conducted by quantifying the value of biofuels in the three countries and calculating the economic value of optimising where biofuels are supplied to. Fuel suppliers' willingness to pay (WTP) for biofuel they are supplying to consumption is used to estimate the biofuel valuation in Finland, Sweden, and Norway.

Different ways of implementing the EU biofuel policy to member states' national legislation is discussed in Peixoto et al. (2019) and Drabik et al. (2019). By conducting a longitudinal qualitative analysis, the study of Peixoto et al. (2019) demonstrates that the different order in biofuel valuation is an important element shaping the biofuel market. However, values for the valuation of biofuels are not calculated. Furthermore, both Peixoto et al. (2019) and Drabik et al. (2019) conclude that often occurring changes in legislation creates uncertainty in the markets, not least because changes in the legislation in one area might have an impact on the market in other parts of the world.

Rosero Abad (2018) explores the policy instruments used in the EU for promoting biofuels and analyses their performance. The paper points out lessons to be learned from each assessed country's policy instruments. However, it does not consider how the differences in the national legislations affect their performance or markets.

Intra-industrial trade of biofuels due to differences in legislation has been studied in the US. For example, Meyer et al. (2013) studied the biofuel obligations in the US and Brazil and concluded that the bioethanol trade between the countries is happening due to the legislative differences. They also discussed chain of custody methods' influence on the physical trade of biofuels.

De Gorter et al. (2009b) used the concept of willingness to pay to explain the economics of biofuel tax credits and mandates. They introduced the mechanism how customers' WTP for biofuel is formed when a biofuel tax credit, mandate, or both of them are in place. The purpose of the study was to explain how biofuel tax credits and mandates work and influence on economics and environment.

It is possible to conclude that this study about the differences between Finnish, Swedish, and Norwegian biofuel legislation and its implications on biofuel markets is unique. This thesis adds a new point of view on top of the previously conducted research by assessing closely the differences in biofuel legislations in three Nordic countries with high biofuel obligations and calculating fuel supplier's WTP's for biofuel.

The structure of the remainder of this thesis is as following. A literature review of biofuel policy implications to markets is conducted in section 2. In section 3, the EU biofuel policy and the biofuel legislation in Finland, Sweden, and Norway are introduced. Section 4 introduces the biofuels commonly used to fulfil the biofuel obligations and section 5 estimates the price of different fuels in the market. Section 6 acts as an introduction to the assessment conducted in section 7, and introduces the way biofuel suppliers are evaluating how biofuel obligations should be filled. The biofuel valuation in Finland, Sweden, and Norway is quantified in section 7. In the second part of section 7, the assessment is made further for different sustainability characteristics of renewable diesel. The results are discussed in section 8, and the results are evaluated from the point of view of chain of custody methods, emissions, and future changes in legislation. Finally, conclusions are provided in section 9.

2 Background

2.1 Biofuel policy and markets

In this subsection a literature review is conducted on biofuel tax exemptions and obligations as policy instruments to promote biofuels. The subsection aims to introduce how biofuel tax exemptions and obligations work and influence the market.

2.1.1 Policy instruments to promote biofuels

There are various kinds of policy instruments which can be used to promote the use of biofuels. Examples of those are tax exemptions, obligations for blending or supplying biofuels, import tariffs and quotas, and production subsidies. (De Gorter et al 2009b.)

Widely used policy instruments to support biofuels are tax exemptions for biofuels and biofuel obligations. Tax exemptions and biofuel obligations can be assigned for example to biofuel blenders for blending biofuels in diesel or gasoline, or to fuel suppliers for supplying biofuels to consumption as a blend with diesel and gasoline. Many countries, such as many of the EU member states and the US, have implemented both the biofuel obligation and tax exemptions.

The EU has set directives regarding the promotion of renewable energy and energy taxation. However, the directives allow the member states to implement the targets and rules in their own way. This allows the member states to use the most effective policy instruments in their country. The best ways to achieve the targets may differ country by country depending on the objectives and natural resources.

2.1.2 Economics of biofuel policies

When there is a biofuel obligation in place, the fuel suppliers need to buy a certain amount of biofuel instead of petrol and diesel. The resulting cost is directed to the fuel consumers. As a result, the fuel price at the pump includes the price of the biocomponent and fossil component in the fuel. De Gorter et al. (2009b) suggest that the fuel price for customers is the weighted average of the biofuel and fossil fuel components in the fuel blend. When a biofuel obligation is implemented, the fuel price at the pump can change to either direction depending on fuel supply elasticities. (De Gorter et al. 2009a.)

Introducing a biofuel tax exemption will set the biofuel wholesale price to the level of the fossil fuel price plus the biofuel tax exemption. This happens because the fuel suppliers will bid the biofuel price up until it is in the same level with the cost of fossil fuel. As they get a tax exemption from biofuels, they can afford to pay that amount more to the biofuel producers, assuming consumers will not pay extra for the biofuel content in the fuel. Therefore, the tax exemption acts as a subsidy to biofuel producers. If there is only tax exemption in place instead of biofuel obligation, the biofuel suppliers do not have an incentive to supply biofuels if their price is higher than the cost of supplying fossil fuels. (De Gorter et al. 2009a.)

The final price and consumption of fuel depends on the supply of fossil fuel. According to the calculations of De Gorter et al. (2009b), if the supply is perfectly elastic (horizontal supply curve, significant response in demand to small changes in price), a tax exemption does not change the fuel consumption. In that case, the fossil fuel consumption decreases by the amount that biofuel is introduced to the market. However, if a mandate is in place instead of a tax exemption, the total fuel consumption decreases. This leads to lower fossil fuel consumption.

If the supply is less elastic (upward sloping supply curve, smaller response in demand to changes in price), a tax exemption leads to increased fuel consumption and oil price decrease. In the case of a mandate, the fuel prices depend on other market parameters. All in all, De Gorter et al. (2009b) conclude that biofuel obligations lead to increased fuel prices, lower consumption, and lower taxpayers' costs, and therefore should be a preferred policy instrument compared to tax exemptions.

As many countries have both biofuel obligation and tax exemption in place, it is important to understand how they work together. De Gorter et al. (2009a & 2009b) argue, that biofuel tax exemption and obligation work in a different way separately than together. When both the biofuel obligation and tax exemption are implemented, the fuel suppliers need to supply the obligated amount of biofuel, so there is no incentive to bid the biofuel price up. As described above, with a biofuel obligation the fuel price at the pump is the weighted average of fossil and biofuel, and the customers are paying the bill for biofuels. With a mandate the price of biofuel compared to the price of fossil fuel is higher than with tax exemption. Therefore, when a tax exemption is implemented with a biofuel obligation, the supplier does not have an incentive to pay even more for the biofuel. Instead, the tax exemption added to the biofuel mandate allows biofuel suppliers to lower the fuel price at the pump. This allows the suppliers to compete with lower prices at the pump. Therefore, the prices in the pump can be lowered all the way the amount of the tax exemption. However, lower prices result in increased consumption. In this case, not only the biofuel consumption, but the consumption of the fuel blend increases. Thus, it can be concluded that tax exemption together with a biofuel obligation subsidises both biofuel and fossil fuel consumption. It is important to note that increase in fuel consumption is against the purpose of biofuel mandates and tax exemptions. (De Gorter at al. 2009a & 2009b.)

2.1.3 Bindingness of targets

Renewable energy targets are made to be able to ensure the continuous and growing supply of renewable energy to consumption. When targets are binding, they create incentives to invest in research, development and market-scale projects.

Targets can be written as indicative targets or legally binding targets in legislation. Also, consequences, such as penalty payments, for not achieving the targets can be set. The EU has over time tightened its environmental legislation to be more legally binding. According to Johnston et al. (2016) the targets set in the RES directive are in principle legally binding, yet there are features, such as unprecise language and no clear penalties, which lower the bindingness. (Johnston et al. 2016.)

Thompson et al. (2009) write about the bindingness of a target more from an economical point of view. According to them, an obligation is binding, when it forces companies to act in a different way than without the obligation. The obligation has to create an economical incentive to change the actions of companies in order to be binding. (Thompson et al. 2009.)

An example of an economically unbinding biofuel obligation is the US renewable fuel standard when it was just established. After establishing the obligation in 2005, more biofuel was supplied into consumption in 2006-2008 than what was required by the obligation. Because of the high oil price, high biofuel supply in the markets and biofuel tax credits, it was economically profitable to supply more biofuels than the law obligated. This means, according to Thompson et al. (2009), that the obligation was not binding. However, as the obligation has grown every year, faster than the biofuel supply, fulfilling the obligation has become more binding than in the beginning (Guidice 2013). When an obligation is binding, fulfilling it is more as an economical loss than a gain for an economical operator because supplying biofuel under a binding obligation is more expensive than supplying its fossil alternative. (Thompson et al. 2009.)

2.1.4 Biofuel price leading country

According to Rajcaniova el al. (2013), the world biofuel wholesale prices are determined by one policy in one country. As described before, a biofuel tax exemption and obligation are not additive when working together. If a country has both tax exemption and biofuel obligation in place, only one of them can be binding and set the market price for biofuel (De Gorter et al. 2011). The fact that the world biofuel wholesale prices are determined by only one country, can be rationalized with a basic economic theory on arbitrage and the law of one price.

An arbitrage situation occurs when there is a price difference in two different markets of a commodity. Traders benefit from the situation by buying from the cheaper market and selling where the commodity has a higher price. In an arbitrage situation the profit of the traders is guaranteed and thus it is risk free. However, as traders are exploiting the situation, the demand grows in the cheap market while supply grows in the more expensive market. This leads to the convergence of prices in the two markets. Therefore, arbitrage is always only a temporal situation. This leads to the law of one price according to which the price of a commodity should always be equal in every location. This is explained by the fact that every time there is an arbitrage, traders, called arbitragers, take advantage of the situation, which leads to the convergence of prices.

Following the theory on arbitrage and the suggestion that only one type of policy can be binding at a time, it is possible to conclude that the world biofuel wholesale prices are determined by one country, and one type of policy in that country. When it is a binding tax policy determining the biofuel price, the biofuel price is linked to oil price by the tax exemption. The price determining country is then the country where the diesel or petrol price is the highest, fuel tax lowest and the tax exemption for biofuel the highest. When it is a biofuel obligation determining the world biofuel price, the biofuel price in the price leading country is higher than in the case of the binding tax policy. (Rajcaniova el al. 2013.)

The calculations of Rajcaniova el al. (2013) suggest that the US and Brazil together were the price leaders of ethanol in 2002-2010. The tax exemptions in both countries were the determining policy. However, according to the results of Kliauga et al. (2011), the ethanol price leader was only the US. In addition to investigating slightly different years (2004-2008), their calculation methods differed slightly from the methods of Rajcaniova et al. (2013). The price leader of biodiesel was found to be the EU in 2005-2010 (Rajacaniova et al. 2013 & De Gorter et al. 2011). According to the results of Rajcaniova el al. (2013) the EU biofuel mandate seems to be the price determining policy, but the results on the determining policy in the EU are quite uncertain. When saying that the world biofuel prices are determined by one country, Rajacaniova et al. (2013) and De Gorter et al. (2011) argue also that other countries' tax exemptions do not affect the world price. As the world biofuel price is already determined by another country's policy, the other countries' tax exemptions do not affect the price anymore, instead they only act as subsidies.

The studies of Rajacaniova et al. (2013) & De Gorter et al. (2011) calculated the ethanol and biodiesel price leading countries for the years 2004-2008 and 2005-2010. As the biofuel legislation and targets have already changed from those years, the results should not be trusted anymore. More up to date research would be needed to determine the current price leaders of biofuels.

2.1.5 Biofuel policy implications to trade

When biofuels get benefits in one country, but not elsewhere, it encourages to transport biofuels to the area with the highest economical support, other things being equal and taking the cost of transportation into account. Swinbank (2009) argues that this is especially disadvantageous for developing countries, because they cannot compete with wealthier countries with the economic support for biofuels. This can lead to export of biofuels to the EU to fetch a premium in the EU whereas biofuels and fossil fuels are treated equal in the domestic markets. Fossil fuel might be imported to replace the exported biofuel in order to fulfil the fuel demand.

A policy implication to biofuel trade was witnessed in the 2000's, when the so called "splash and dash" program took place in the US resulting to biodiesel exports from the US. In 2004, a tax credit of 1 \$/gal was implemented for the fuel blenders blending biodiesel to fossil fuel in the USA. The tax credit was paid for both domestic and imported biodiesel. As the tax credit was payed for blending, it permitted fuel blenders to blend and then export the fuel blend to the EU, where a tax exemption for supplying biodiesel was given. To get the maximum benefit of the blending tax credit, fuel suppliers blended 99,9 % of biodiesel with 0,1 % fossil diesel and sold that to the EU. Biodiesel could have even been shipped from the EU to the USA to be blended, and then shipped back to the EU to be distributed. The incentive for "splash and dash" was eliminated when in 2008 the US prohibited biodiesel imports to be exported again and in 2009 the European Commission set duties on biodiesel imports from the US. (De Gorter et al. 2011.)

Another biofuel policy implication to trade is the intra-industrial trade of biofuels due to differences in biofuel legislations. The following subsection explains in more detail the ethanol intra-industrial trade phenomenon in the US and Brazil. The phenomenon is based on the differences in the biofuel legislation in the US and Brazil, which leads to ethanol trade between the two countries.

In addition to tax exemptions and biofuel obligations, import tariffs influence biofuel trade. However, this thesis concentrates only on tax exemptions and biofuel obligations, while import tariffs are excluded from the scope of the thesis.

2.2 Case US-Brazil

This subsection introduces an example of a biofuel policy driven arbitrage situation between the US and Brazil, which lead to the trade of bioethanol between the two countries. The first part describes the ethanol trade between the US and Brazil. The second part introduces the biofuel legislation leading to the intra-industrial trade of ethanol.

2.2.1 Trade in US-Brazil

Intra-industry trade is the two-way trading of similar products from the same industry i.e. exporting and importing of similar products. There is intra-industry trade of bioethanol between the US and Brazil, and this subsection aims to explain that the reason for this is the dissimilar environmental regulations in the US and Brazil.

The US and Brazil are the biggest ethanol producers in the world, the US counting for 56 % (16 billion gallons) and Brazil 28 % (8 billion gallons) of the world ethanol production in 2018. The EU is the third biggest ethanol producer counting for 5 % of the world's production in 2018. (RFA 2019.) The US ethanol is principally made from corn starch, while the Brazilian ethanol comes mostly from sugar cane (RFA 2018 & Babcock et al 2017).

As seen in Figure 1, the US has been importing ethanol more than exporting until 2011, when the ethanol exports from the US grew drastically, however still continuing to import (RFA 2018). Since the beginning of 2000s, almost all ethanol imports to the US came from Brazil. In 2010 the US started to export ethanol to Brazil while continuing the imports from Brazil. The exports have grown since, and in 2017 most of the US ethanol exports (33 %) were exported to Brazil. The ethanol imports to the US in 2017 came almost solely from Brazil, when 80 million gallons of sugarcane ethanol were imported because of the high appreciation of sugarcane ethanol due to the US legislation. (RFA 2018 & Babcock et al 2017.) Figure 1 represents the US ethanol exports and imports in the 21st century.

It is clear, that there is intra-industrial trade occurring between the US and Brazil. Some of the US corn starch based ethanol is shipped to Brazil while Brazilian sugarcane based ethanol is shipped to the US, even though the ethanol is chemically equal, regardless of the feedstock used.

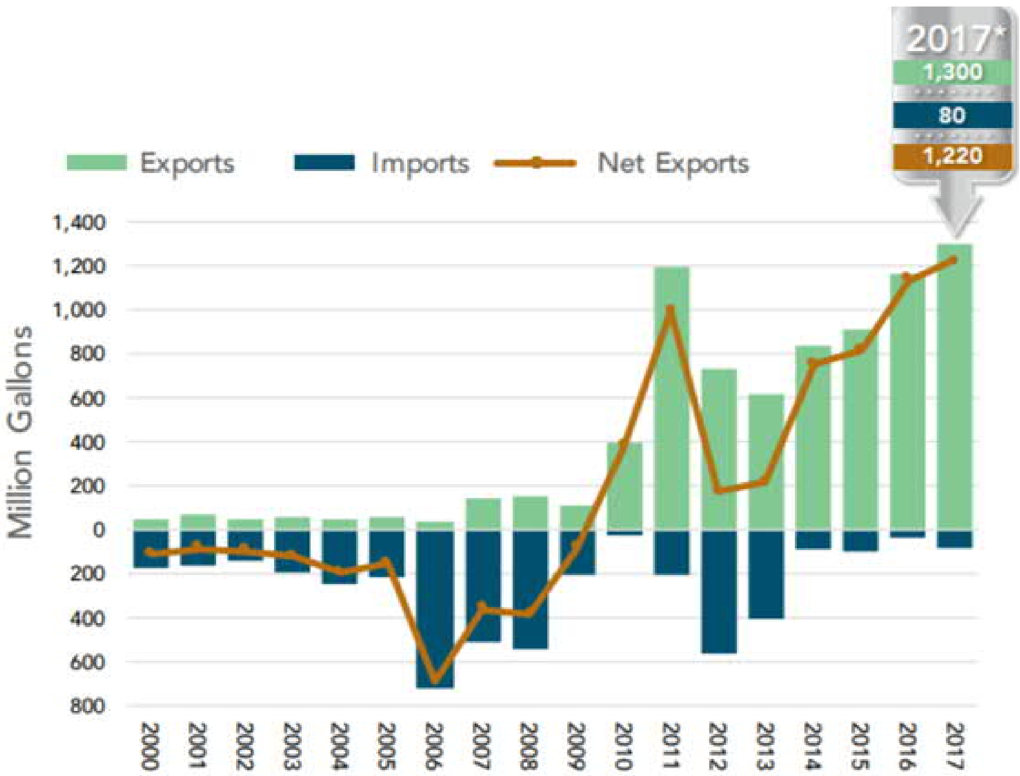

Figure 1 US ethanol exports and imports (RFA 2018)

Typical reasons driving to intra-industry trade are for example differential natural endowments, quality and capital intensity of production, economic specialization, economies of scale, aggregation or classification issues in trade data, seasonality, and border trade. However, according to Meyer et al. (2013) the reason behind ethanol trade between the US and Brazil lies in the environmental legislation. (Meyer et al. 2013.) In the following subsection the biofuel related legislation in the US and Brazil is explained.

2.2.2 Biofuel legislation in US and Brazil

The US has an overall obligation for biofuels, as well as sub obligations for more specifically defined biofuels. One of the sub obligations concerns advanced biofuels, which according to the legislation include ethanol made from sugarcane and exclude ethanol made from maize starch.

The US has the following obligations in its biofuel legislation (Guidice 2013):

- The overall obligation concerns renewable fuels which meet 20 % emission reduction. Obligation for 2022: 36 billion gallons (EPA 2019a).
- The sub obligation for advanced biofuels is for biofuels from other feedstocks than corn starch, meeting an emission reduction of 50 %. Obligation for 2022: 21 billion gallons (EPA 2019a).
- The sub obligation for cellulosic biofuels is for biofuel derived from cellulose, hemicellulose, or lignin. The emission reduction must be at least 60 %. Obligation for 2022: 16 billion gallons (EPA 2019a).
- The sub obligation for biomass-based diesel is for biodiesel achieving at least 50 % emission reduction. Obligation for 2022: 1 billion gallon (EPA 2019a).

All the US obligations grow, but in different rates at each year (Thompson et al. 2011). Figure 2 represents the nesting structure of the obligations.

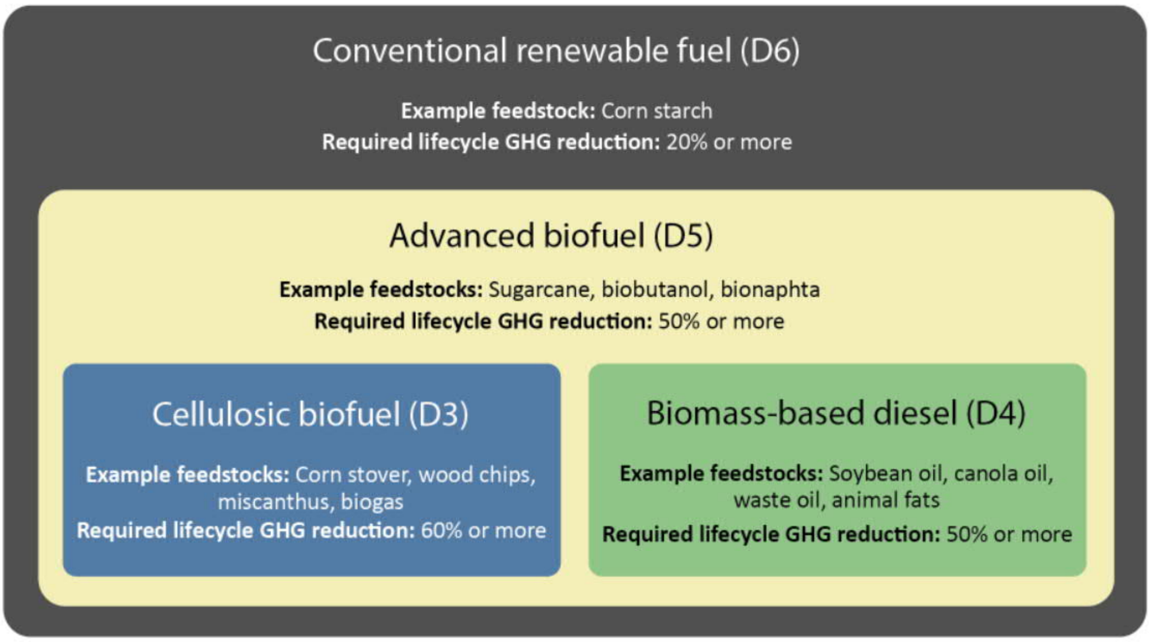

Figure 2 Nesting structure of the US biofuel mandates (EPA 2019b)

Most biofuels can be used to fulfil the overall obligation on renewable fuel. Corn starch is excluded from the advanced biofuel obligation, whereas sugar cane ethanol among other biofuels and feedstocks can be used to fill the sub target.

Based on the renewable fuel obligation, fuel blenders have to supply renewable fuels a certain percentage of their total supplied amount (Guidice 2013). Renewable fuels are certified with a renewable identification number (RIN) when the fuel is bought or imported to the country. The fuel suppliers can then use these RINs to fulfil their obligation. The RINs are tradable, so a fuel supplier can choose to buy more renewable fuels than it needs and sell the extra RINs to other fuel suppliers who have not bought enough renewable fuels to fill their obligation. The fuel suppliers must then take into account the price of RINs and the price of physically supplying renewable fuels when evaluating the way of filling its renewable fuel obligation. An advanced RIN can be used to fill the advanced biofuel obligation and the overall obligation. That is why the advanced RIN will always be more expensive than a normal RIN. (Thompson et al. 2011.)

In Brazil, ethanol policies have been implemented already in the 70s. Currently, there is a blending obligation of 27 % for ethanol in gasoline and 10 % for biodiesel in diesel. There are also tax reductions and exemptions in place for biofuels. However, certain types of biofuels or feedstocks are not valued over other as in the US. (USDA 2018 & Dimaranan et al. 2012.)

As Brazil produces ethanol mostly from sugarcane and the US from corn-based feedstocks, the factors driving to intra-industrial ethanol trade are evident. Even though ethanol produced in Brazil and the US are chemically equal, the US policy has created value for different ethanol attributes like feedstocks, therefore creating a hierarchy structure for ethanol. For that reason, ethanol made from sugarcane is more valuable in the US than ethanol made from corn starch. (Meyer et al. 2013 & Babcock et al 2017.)

Often the purpose of laws on promoting the use of biofuels is replacing fossil fuels, decreasing emissions, and increasing energy independency. However, biofuel legislation which creates value for different attributes of biofuels in different areas, creates intra-industry trade, which in turn increases transportation, which leads to emissions. (Meyer et al. 2013.)

2.3 Suggested solutions

Some problems resulting from the 21st century's biofuel legislation have been introduced in this literature review. Differences in biofuel legislation in different countries can lead to export of biofuels and import of fossil fuels, intra-industrial trade of biofuels, and tax benefit "shopping" by shipping biofuels around the world. All these may increase emissions due to emissions from transporting biofuels and fossil fuels. Furthermore, unintended support to fossil fuels by taxation might increase fuel consumption and thus emissions.

According to Swinbank (2009) in the optimal world all countries would have equal or similar biofuel policies. In this way, differences in legislations would not create arbitrage between countries. However, as this will most likely not happen, Swinbank (2009) suggests EU to reduce the financial incentive for biofuels. Swinbank introduces this as a way to address the problem that developing countries do not afford to support biofuels in the way the EU does.

Meyer et al. (2013) proposes a system of tradable obligations as a solution for biofuel intra-industrial trade between the US, Brazil, and the EU. If biofuel sustainability certificates (such as RIN's) could be traded between countries, sustainable biofuels could be produced and consumed in one country, and the sustainability certificates used in another country. In this way, the need to transport the physical biofuel in order to fulfil with the biofuel obligation would be removed. This could be achieved by allowing book and claim as a chain of custody method. The chain of custody methods are introduced in subsection 3.5, where also the reason for the EU choosing the mass balance method instead of the book and claim method is discussed.

3 EU biofuel policies

Policy is the main driver for biofuels in the EU. As described earlier, policy can have a significant impact on the kinds of biofuels consumed in a country and on the trade between countries. Therefore, it is essential to understand the legislative environment when analysing the biofuel supply and markets. The following subsections introduce the EU level biofuel legislation and the Finnish, Swedish, and Norwegian biofuel legislation.

3.1 EU legislation

The EU climate policy follows the Kyoto protocol commitment, which defines emission reduction targets until 2020. Inside the EU, the climate and energy packages for 2020 and 2030 also set binding targets and obligations for emission reductions. According to the 2030 climate and energy package, the EU has engaged to reduce greenhouse gas emissions at least 40 % by 2030 compared to 1990 level (EUCO 169/14). To achieve this target, the EU has committed to make a 30 % reduction compared to the 2005 level in the emissions in the sectors outside the EU emission trading system. The target is shared between the member states in the effort sharing regulation ((EU) 2018/842). The target share for Finland (outside the EU emission trading system) is 39 % reduction in greenhouse gases by 2030 compared to the 2005 level.

To achieve the high targets on emission reductions, the EU has given directives about renewable energy and fuel quality. The Renewable Energy Directive (RES directive, 2009/28/EC) sets the targets for 2020 and the recast Renewable Energy Directive, called RED II ((EU) 2018/2001), sets the targets for 2030. According to the RES directive, the EU must have 20 % renewable energy share in the total energy consumption by 2020. RED II sets the target of renewable energy share to 32 % by 2030. The renewable energy directives set targets also to the renewable energy share in transport. For 2020 the target for renewable energy share in transport is 10 % and for 2030 it is 14 %. With the Fuel Quality Directive (2009/30/EC), a target for fuel emission intensity reduction of 6 % is set for 2020, compared to the 2010 levels.

According to the RES directive, biofuels must meet certain sustainability criteria to be counted towards the renewable energy obligation and emission reduction obligation. The sustainability criteria have to be met also when financial support from the government is applied for the production of biofuels or bioliquids and when biofuels or bioliquids are combusted in a facility under EU emission trading system to avoid the need to buy emission rights for biofuels. The sustainability criteria are the following:

1. The GHG emissions of the biofuel life cycle must be lower than the life cycle emissions from an equivalent fossil fuel. The reduction must be
    - 65 % for biofuels produced in installations starting operation on or after Jan 1st 2021
    - 60 % for biofuels produced in installations starting operation between Oct 5th 2015 and Dec 31st 2020.
    - 50 % for biofuels produced in installations in operation on or before Oct 5th 2015.

2. The raw material shall not be obtained from land with high biodiversity value

3. The raw material shall not be obtained from land with high carbon stock

4. The raw material shall not be obtained from land that has been peatland

5. Agricultural raw material shall be cultivated in accordance of the requirements of certain agricultural regulation

The RES directive sets sustainability criteria only for biofuels and bioliquids. RED II sets sustainability criteria also for biomass fuels. Biomass fuels are solid and gaseous fuels produced from biomass. This means that after 2020 the sustainability of e.g. wood, when combusted, must be demonstrated.

The RES directive allows three ways for calculating the GHG emission reductions of biofuels. Easiest is to use default values for different biofuel pathways given in the RES directive. However, for example the default value for ethanol produced from wheat is 16 %, when the GHG emission reduction limit for sustainable biofuel is 50-60 % depending on the plant the biofuel was produced in. Alternatively, the actual values of GHG emissions from each step of the supply chain can be calculated. The RES directive provides calculation methodology for calculating the actual GHG emission reductions. The third way is to use actual values and disaggregated default values provided in the RES directive. The disaggregated values are useful when for example the emissions from cultivating the raw material are unknown and knowing them would require too much effort. Then disaggregated values could be used for cultivation but actual calculated values would be used for production, transportation, and other relevant parts of the supply chain.

The RES directive and RED II set rules for biofuel feedstocks. A minimum share of biofuels must be produced from certain feedstocks and there is a cap for other kind of feedstocks. Biofuels produced from certain feedstocks can be counted double when calculating the share of biofuels in transport.

Annex IX of the directives lists renewable transport energy forms and biofuel feedstocks which are here called advanced biofuel feedstocks. Most of the biofuel feedstocks mentioned in Annex IX are wastes and residues which require advanced technology. According to the RES directive, 0.5 % of the renewable transport fuel obligation must be filled with the energy forms and biofuel feedstocks listed in the Annex IX part A. In the recast RED II, the Annex IX includes only advanced biofuel feedstocks and the obligation grows to 3.5 % in 2030. RED II sets a 1.7 % cap for biofuel feedstocks mentioned in Annex IX part B, which include used cooking oil and animal fat.

The RES directive and RED II set a cap for “biofuels produced from cereal and other starch-rich crops, sugars and oil crops and from crops grown as main crops primarily for energy purposes on agricultural land”. These feedstocks are here called food and feed crops. Up to 7 percentage points of the transportation renewable energy obligation can be filled with food and feed crops until 2020. After 2020 the cap becomes stricter and is bound to the amount of food and feed crops used for fulfilling the transport renewable energy obligation in 2020.

Biofuels with high risk of indirect land use change are not calculated towards the renewable transport fuel mandate anymore in 2030.

Biofuels can be counted to fill the transportation renewable energy obligation twice of their energy content when they are produced from advanced feedstocks listed in annex IX.

The RES directive gives alleviations for wastes, process residues and residues as biofuel feedstocks. The life cycle emissions of waste, residues and process residues is calculated only from the point of collection. This means that for example emissions from cultivation are not included in the life cycle emissions of straw. The first point where emissions are formed in the life cycle of straw would then be when the straw is collected from the field. Another alleviation is that waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, need to fulfil only the sustainability criteria concerning GHG emissions.

The RES directive and RED II set the boundaries for the biofuel legislation in the EU member states. RED II entered into force in December 2018. The EU member states must implement the directive on their legislation and regulation by 30th June 2021, so the RED II was not yet implemented when this master's thesis was written.

As the RES directive was implemented, the EU member states created their own legislation concerning biofuels. Even though the RES directive sets obligations and rules, the member states had space to create their own kind of legislation and regulation. This can be seen in the following subsections, where the special features of biofuel legislation in Finland, Sweden, and Norway are described.

3.2 Biofuel obligations in Finland, Sweden, and Norway

Even though the RES directive allows the inclusion of any form of renewable energy in the transportation renewable energy obligation, Finland, Sweden, and Norway have decided to fill the obligation with biofuels. All three countries have established a biofuel obligation, which is set to increase over time. However, the details in the biofuel obligations in the three countries vary significantly.

In this subsection the biofuel related legislation in Finland, Sweden, and Norway is explained.

3.2.1 Finland

The Finnish biofuel legislation sets an energy-based obligation for biofuels. The biofuel obligation for 2019 is 18 % and for 2020 is 20 %. The obligation grows yearly, being 30 % in 2029 and after. (446/2007.)

In Finland the double counting of biofuels produced from feedstocks mentioned in the RES directive annex IX is allowed. However, the double counting will be seized after 2020. (446/2007.)

The obligation for advanced biofuels (RES directive annex IX part A) starts in 2020, growing yearly from 0.5 % in 2020 to 10 % in 2030 and after. The double counting concerned earlier biofuels made from waste, residue, inedible cellulose, and lignocellulose, and therefore they are grandfathered to the current advanced biofuel's sub obligation in 2020. The cap for food and feed crops is implemented from 2020 as stated in the RES directive: maximum 7 % of the biofuels supplied can be produced from food and feed crop feedstocks. (446/2007.)

In the Finnish biofuel obligation, the excess biofuel supplied can be carried over (with certain limitations) to fill the next year's obligation (446/2007). That is why also it might seem that some years the biofuel obligation has been overfilled extensively, while some years the target has not been reached. In reality, the overfill has been used to fill part of next year's obligation.

In Finland the excise duty of fuels consists of energy tax and CO_2 tax. Sustainable biofuels get 50 % deduction from the CO_2 tax and further 100 % from the CO_2 tax when they are made of waste, residue, inedible cellulose of lignocellulose. (1472/1994.)

The feedstock classification is based on case-by-case interpretation depending on the process and location. This is why a feedstock with a same name could be assessed differently depending on the location it is produced for example. A certain feedstock could be assessed for example as a process residue if it was produced in a place with no markets for end use and as a side product if it was produced in another place with possibilities to further utilise it.

3.2.2 Sweden

In Sweden the biofuel obligation is emission-based. The biofuel suppliers are obligated to blend biofuels in petrol and diesel to achieve emission reductions. In 2019 the emission reduction obligation is 2.6 % for petrol and 20 % for diesel. From 2020 onwards the reduction obligation is 4.2 % for petrol and 21 % for diesel. The emission reduction is calculated by comparing the biofuel life cycle emissions to default values of petrol and diesel emissions. (2017:1201.) High-blend biofuels, such as HVO100, FAME100, E85 or ED95 cannot be used to fill the biofuel obligation. Instead, the high-blend biofuels get exempted from excise duty. (Swedish Energy Authority 2019a.)

In Sweden there is a list of feedstocks which normally are classified as waste, agricultural, aquaculture, fisheries and forestry residues, process waste, and co-products. According to the Swedish regulation on biofuel sustainability the market price is also considered in the classification of feedstocks. Too high market price of a feedstock might mean that it is not considered as a process residue, but a co-product. Thus, those feedstocks do not get any alleviations when calculating the emissions. (2011:1088.)

The cap on food and feed crops, the minimum share of advanced biofuels nor double counting have been implemented in Sweden.

According to the Swedish energy tax law (1994:1776), the excise duty of fuels consists of energy tax and CO_2 tax. Biofuels do not get any tax exemptions anymore after 2018, unless they are supplied as high-blends such as HVO100, FAME100, E85 or ED95. The high-blend biofuels get a full exemption from the energy and CO_2 taxes. (Swedish Energy Authority 2019a & Swedish Tax Agency 2019) Food based biofuel plants may be exempted from the excise duty only if the plant was in operation before 31.12.2013 and if the plant is not fully depreciated. (2010:598.)

3.2.3 Norway

Norway has implemented the biofuel obligation as volume-based. In 2019 the share of biofuels in transport is targeted to 12 % by volume. In 2020 the mandate is 20 %. The aforementioned being the overall biofuel obligation for transportation, minimum 4 % of the gasoline in transportation has to be replaced by biocomponents like ethanol. (1731/2018.)

In 2019 minimum of 2.25 % of the biofuels supplied have to be made from feedstocks mentioned in the RES directive annex IX parts A and B. In 2020 the share shall be 4 %. Biofuels made from feedstocks mentioned in the RES directive annex IX parts A and B should also be counted double as their volume. (1731/2018.)

The Norwegian law of excise duty (1451/2001) sets a CO_2 tax and road tax for transport fuels. Sustainable biofuels are exempted from the CO_2 tax. When the biofuel obligation has been filled by a fuel supplier, the biofuel exceeding the obligation will be exempted from both the CO_2 tax and road tax. (1451/2001.)

The cap for food and feed crops is not implemented in Norway.

The Norwegian Environment Agency maintains a list of feedstocks classified as waste and residues (Norwegian Environmental Agency 2019a).

3.2.4 Summary of biofuel obligations

Table 1 summarizes the rules and targets in the Finnish, Swedish, and Norwegian biofuel legislations.

Table 1 Characteristics of the country-specific systems in 2020.

	Finland	**Sweden**	**Norway**
Biofuel share calculated by	Energy (MJ)	GHG emissions (gCO_2/MJ)	Volume (NL)
Biofuel obligation in 2020	20 % (energy based)	4.2 % for petrol, 21 % for diesel (emission based)	20 %-vol overall, 4 %-vol for components blended to petrol (volume based)
Double counting	Yes	No	Yes
Obligation for advanced biofuels	0.5 % Feedstocks in RES-directive annex XI part A can fulfil.	No	4 %-vol Feedstocks in RES-directive annex XI parts A and B can fulfil.
Cap for food and feed crops	7 %	No	No
Tax exemption	50 % exemption on CO_2 tax. Full exemption on CO_2 tax for waste, residues, inedible cellulose or lignocellulose based biofuels.	Full tax exemption for high biofuel blends	Biofuels fulfilling the obligation are exempted from CO_2 tax. Biofuel exceeding the obligation is fully tax exempted.

3.3 Sustainability schemes

Companies can demonstrate the sustainability of biofuels by establishing a sustainability scheme. Sustainability schemes are similar to quality systems or management systems which can be certified by third party certification bodies. According to the Finnish, Swedish, and Norwegian regulation the sustainability scheme must be approved and/or audited.

The voluntary and national schemes recognised by the EU are valid in all the EU member states when companies want to demonstrate sustainability of their biofuels (2009/28/EC). By the time writing this thesis, the EU had recognised 14 voluntary schemes and one national sustainability scheme being the Austrian national scheme (European Commission 2019).

Voluntary schemes are private certification bodies which verify that companies comply with the sustainability criteria in RES directive. Even though a national sustainability scheme would not be recognised by the EU, it can still be used to demonstrate the sustainability of biofuels to the national authorities. However, the proofs of sustainability would not be valid in other countries.

Finland and Sweden have their own national sustainability schemes not recognised by the EU. However, Finland and Sweden have made a bilateral agreement, according to which economic operators can use their sustainability schemes approved by either of the countries to demonstrate the sustainability of biofuels in both of the countries.

The companies allowed to demonstrate biofuel sustainability are biofuel suppliers paying excise tax and operating under the biofuel obligation, biofuel producers receiving state aid for investment, and heat and/or power plants combusting biofuels or bioliquids such as tall oil. (2009/28/EC.)

Companies are not obligated to demonstrate the sustainability of biofuels. Companies can also choose to not to demonstrate biofuel sustainability. However, unsustainable biofuels cannot be used for filling the biofuel obligations or claiming tax exemptions. Also, state aid cannot be payed. If the sustainability of biofuels is not demonstrated, they are treated as fossil fuels. (2009/28/EC.)

Companies must report the authorities about the biofuels and bioliquids claimed sustainable each year. Depending on the company and the nature of operation, these are the biofuels and/or bioliquids produced, supplied to consumption or combusted. The companies must be audited by an external independent auditor yearly. (393/2013 & 2010:598 & FOR-2004-06-01-922.)

In Norway sustainability schemes are not approved by national authorities. Therefore, if a company does not have a sustainability scheme under a voluntary scheme, the Norwegian authorities require heavier auditing every year. The auditing is required for all the functions not covered by sustainability certificates. (Norwegian Environmental Agency 2019a.)

The sustainability schemes of companies must be approved or audited to those parts which are not already certified. For example, if an economic operator buys biofuels with a voluntary scheme sustainability certificate, only the operations after receiving the certificate, for example mass balance and documentation have to be approved or audited.

Once the sustainability scheme of a company has been approved, the company is able to provide proofs of sustainability to anyone it is selling biofuels. A proof of sustainability includes the sustainability information of a certain batch of biofuel.

3.4 Feedstocks

As described previously, biofuel derived from waste, residue, process residue, inedible cellulose or lignocellulose or feedstocks mentioned in the RES directive annex IX A and B get alleviations in sustainability criteria and taxes. Table 2 summarises the benefits concerning feedstocks in the three countries.

Table 2 feedstock benefits for 2020

	Finland	Sweden	Norway
Waste	• Only GHG emissions sustainability criteria • Emissions calculated from the point of collection • 100 % deduction from CO_2 tax	• Only GHG emissions sustainability criteria • Emissions calculated from the point of collection	• Only GHG emissions sustainability criteria • Emissions calculated from the point of collection
Process residue	• Only GHG emissions sustainability criteria • Emissions calculated from the point of collection • 100 % deduction from CO_2 tax	• Only GHG emissions sustainability criteria • Emissions calculated from the point of collection	• Only GHG emissions sustainability criteria • Emissions calculated from the point of collection
Residue	• Emissions calculated from the point of collection • 100 % deduction from CO_2 tax	• Emissions calculated from the point of collection	• Emissions calculated from the point of collection
Inedible cellulose and lignocellulose	• 100 % deduction from CO_2 tax	-	-
RED annex IX part A	• Double counting • 0.5 % obligation	-	• Double counting • 4 %-vol obligation
RED annex IX part B	• Double counting	-	• Double counting • 4 %-vol obligation
Food and feed crops	• 7 % cap	-	-

The classification of feedstocks is done differently in the three countries, and therefore not all the feedstocks are classified in a same way in the three countries. Among other parameters, Sweden considers the price of the feedstock in the feedstock classification. Sweden and Norway have a public list of feedstocks which have been already classified and which are automatically classified as in the list (Swedish Energy Authority 2012 & Norwegian Environmental Agency 2019a). In contrast, in Finland the feedstock classification is a case by case interpretation and therefore a feedstock with the same name can be classified differently depending on the other parameters considered, such as origin of the feedstock. In Finland companies have to apply for a classification of feedstock from the Finnish Energy Authority. (Finnish Energy Authority 2019.)

3.5 Chain of custody

To be able to verify that the biofuels supplied in the EU fulfil the sustainability criteria, the origin of every biofuel batch must be known. To acquire this information, there has to be some kind of traceability system to trace the fuel through its supply chain. These kinds of systems are called chain of custody. Identity preservation, mass balance, and book and claim are examples of chain of custody methods. They differ in that which level the sustainable and non-sustainable matter can be mixed. (Kormann et al. 2016.)

In the chain of custody methods, biofuel batches get sustainability characteristics. A batch of biofuel has always the same sustainability characteristics. Sustainability characteristics may contain for example evidence on fulfilment of the sustainability criteria, value of GHG emission reduction, information on under which sustainability scheme the sustainability has been granted, and the country of origin of the feedstock. (2010/C 160/01.) This is the information documented on the proof of sustainability of a biofuel batch.

In the identity preservation method, sustainable and unsustainable fuel batches are kept physically separated from each other (Kormann et al. 2016 & Laurent 2015). According to the UN Global Compact & BSR (2014) definition of identity preservation, even batches with different sustainability characteristics must be physically separated. The identity preservation method requires separate locations, such as silos or tanks, for storing sustainable and unsustainable feedstocks and fuels, and separate containers for transporting the batches separately. In this way, the customers can be sure that the product they are buying is physically what is sold. The amount of biofuel in a fuel blend could be verified for example by performing a radiocarbon analysis. (Kormann et al. 2016.)

In the mass balance system, the sustainable and unsustainable batches can be mixed. However, the amount and sustainability characteristics of material taken out from the mixture have to be equal to the amount and sustainability characteristics put into the mixture. In reality, when the sustainable and unsustainable batches are mixed together in a tank for example, a batch removed from the tank consists of partly sustainable and partly unsustainable fuel. However, the mass balance bookkeeping enables the operator to take fully sustainable and fully unsustainable fuel batches out of the tank in a paper, as long as the amount and sustainability characteristics of the fuel batches remain equal to the ones entered in the mixture. This means, that a fuel batch can have a sustainability certificate stating it is 100 % sustainable biofuel, even though it is only partly sustainable biofuel, while some batches don’t get sustainability certificate at all. (Kormann et al. 2016.) Figure 3 presents the mass balance approach on bookkeeping.

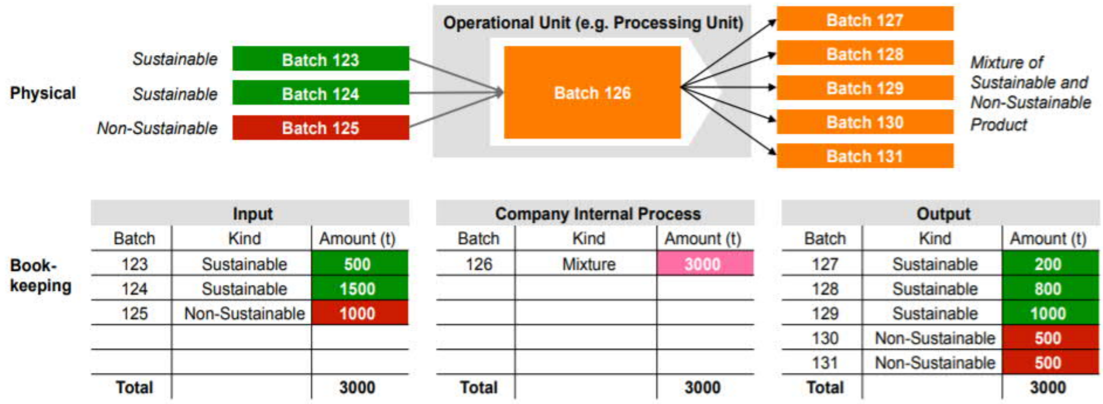

Figure 3 (ISSC 2018)

In the book and claim method the physical material supplied and the sustainability certification can be totally separated. A company could then supply fossil fuels to consumption but fill their biofuel obligations by buying sustainability certifications. Book and claim system is used for example in the clean development mechanism (CDM) where projects with GHG-reductions produce certified emission reductions (CER) which can be bought and used to claim emission reductions in emission trading systems. (Kormann et al. 2016.)

When preparing the RES directive, the European Commission assessed all the three above mentioned chain of custody methods. The book and claim system was discarded because it was seen that it would not increase the investments on sustainability in the EU. The economic operators need an economic incentive to start investing on sustainability. This would not happen in the book and claim system, as instead, those already producing sustainable biofuels elsewhere in the world could be certified an EU sustainability certificate which could be sold to the EU. In other words, with the book and claim system, economic operators in the EU could buy credits for sustainable biofuels from outside the EU and claim them to fulfil their obligation in the EU. With the mass balance system in place, the proofs of sustainability must always be attached to a batch of fuel, so physical movement of fuel is required. Therefore, producing biofuels inside the EU saves in transportation expenses. (SEC(2008)85.)

In addition to evaluating the sustainability effects, the Commission estimated administrative costs falling on fuel suppliers from using the different chain of custody methods. The identity preservation system was estimated to have more than 50 times higher cost than mass balance, and the mass balance system had 4 times higher cost than book and claim. (SEC(2008)85.)

The mass balance system was chosen in a way as a compromise, to avoid the low effectiveness of the book and claim method and the high cost of the identity preservation method (SEC(2008)85).

3.5.1 Mass balance systems in the EU

According to the RES directive, it must be possible to mix biofuel batches with different sustainability characteristics, but at the same time be able to attach the different sustainability characteristics in the mixture. Furthermore, the amount of the fuel withdrawn from the mixture cannot be more than what has been entered. In the same way all the sustainability characteristics withdrawn from the mixture must be equal to the sustainability characteristics entered to the mixture. This is essentially the definition of mass balance method. The RES directive, however, does not set more detailed rules on mass balance.

In a mass balance system, the timeframe and the borders of the system should be defined. In a European Commission communication (2010/C 160/01) for voluntary schemes, the Commission has defined these in more detail. The borders of a mass balance system limit the physical area inside which the sustainable and unsustainable batches can be mixed. According to the Commission "A 'mixture' can have any form where consignments would normally be in contact, such as in a container, processing or logistical facility or site (defined as a geographical location with precise boundaries within which products can be mixed)." (2010/C 160/01.) At greatest this could mean for example a biofuel production site or a terminal with several fuel tanks.

According to the communication of the commission, the mass balance system can be either continuous in time or it can be achieved in set time periods (2010/C 160/01). For voluntary schemes, there is a maximum limit of 3 months for the time period of mass balance (European Commission 2015).

One way to choose the sustainability characteristics for a batch which is taken out from the mixture is the first in-first out (FIFO) method. In the FIFO method the sustainability characteristics enter the mix at the same time with the physical material. Every time a batch is removed from the mixture, the sustainability characteristics are chosen in order. In this way, the sustainability characteristics of the batch last entered in, are attached to a batch taken out only when all the characteristics entered in before this one have been already taken out of the mixture. However, the FIFO method is not required in the RES directive, so other methods (including random picking) are also possible.

Finland, Sweden, and Norway have different rules for the mass balance calculations. As the RES directive does not give very strict rules on how the mass balance calculation has to be performed, the member states have been able to give more detailed regulation on it.

The European Commission communication (2010/C 160/01) is addressed to voluntary schemes, so the national sustainability schemes are not obligated to follow it. According to the communication, the mass balance boundaries must be site-specific in the voluntary schemes. The Finnish and Norwegian regulation refer to the communication (2010/C 160/01) of the Commission in their definitions on the mass balance borders (Finnish Energy Authority 2019 & Norwegian Environmental Agency 2019a). In Sweden the mass balance boundaries can be extended to all of the company storages in Sweden. Thus, all the biofuels inside Sweden with similar physical characteristics can be merged in the bookkeeping (for example ethanol with ethanol or renewable diesel with renewable diesel) as long as the sustainability information of different biofuel batches is kept separately in bookkeeping. This allows swapping of proofs of sustainability between two biofuel batches which are physically in different locations inside Sweden. (Swedish Energy Authority 2012.)

If the mass balance is not even in every moment (inputs=outputs), the mass balance has to be balanced in certain time periods. The time period can be maximum one year in the Finnish, Swedish, and Norwegian systems. (Finnish Energy Authority 2019 & Swedish Energy Authority 2012 & Norwegian Environmental Agency 2019a.) In the voluntary schemes it can be maximum 3 months. Table 3 summarizes the different mass balance rules of Finland, Sweden, Norway, and voluntary schemes.

The mass balance cannot be negative when it is balanced. This means, that more sustainable material cannot be dispatched than was received. However, the balance can be positive. In this case the positive credit can be transferred to the next mass balance period. (Finnish Energy Authority 2019 & Swedish Energy Authority 2012 & Norwegian Environmental Agency 2019a.)

Table 3 Mass balance rules for timeframe and system boundaries

	Finland	**Sweden**	**Norway**	**Voluntary schemes**
Timeframe	3-12 months	Max 12 months	Max 12 months	1-3 months
Boundaries for fuel supplier	Terminal	Sweden	Terminal	Terminal

A batch of biofuel has always the same sustainability characteristics. For example, the feedstock and GHG emission reduction is the same. Batches of biofuels can be merged in the bookkeeping if they have the same sustainability characteristics. However, if the GHG emission reduction value is the only differentiating value, the batches can be still merged if certain rules are followed. According to Finnish and Swedish schemes' rules, the smaller GHG emission reduction value is used for the mixture of the batches (Finnish Energy Authority 2019 & Swedish Energy Authority 2012). In Norway, a weighted average of the GHG emission reduction values can be used for the whole mixture (Norwegian Environmental Agency 2019a). All the batches should naturally fulfil the minimum requirement for the GHG emission reduction value before merging the sustainability information of the batches.

The EU Commission ordered an analysis of the operation of mass balance systems in the EU in 2012, when there was already some experience on using the systems in demonstrating sustainability of biofuels. The report also provided the Commission information on whether other chain of custody methods should be allowed. The methods of the analysis included interviews with market players and experts, an expert workshop and a desk study. The analysis found out that there are differences in the mass balance systems of different member states and voluntary schemes. This has led to for example confusion and the need to operate more than one mass balance, which is why harmonisation of mass balance rules was wished by the interviewees and recommended by the report. However, the interviews revealed that the current mass balance systems are still preferred over the option of making expensive changes in the systems and having many chain of custody systems to choose form. (Ecofys 2012.)

4 How biofuel obligations can be filled

Several different kinds of biofuels can be used to fill the biofuel obligations. At the moment, most of the Finnish, Swedish and Norwegian biofuel obligations are filled with bioethanol, biodiesel and renewable diesel. Bioethanol is blended to petrol, whereas biodiesel and renewable diesel are blended to diesel. Other biocomponents used in transport sector are for example biomethane and bionaphta.

The fuel quality directive (2009/30/EY) and fuel standards restrict the amount that certain biofuels can be blended with petrol and diesel. This is called blend wall. The restrictions are based on the usage qualities and emissions of fuels and the current engine technology which is originally designed for conventional petrol and diesel. For example, high amounts of biofuel in a diesel engine might cause corrosion and other problems in engines.

In the next subsections the usage and restrictions of ethanol, biodiesel, and renewable diesel is discussed. Furthermore, the blend wall of these fuels in Finland, Sweden and Norway is estimated.

4.1 Ethanol

Ethanol is commonly produced in a fermentation process, which is a very simple method also used in alcohol production. In fermentation the sugars in the feedstock are converted to alcohol with the help of yeast. Most of fuel ethanol is produced from sugar and starch rich feedstocks such as sugar beet, corn, sugarcane, and wheat. Ethanol can be also produced from cellulosic feedstocks such as wood and inedible parts of plants. However, sugar is more difficult to extract from cellulose, because cellulose is tightly bound with lignin and hemicellulose. To be able to extract the sugar in cellulose and hemicellulose, the lignin must be first removed. Therefore, the process yields lignin as a side product, which can be used for example for heat and power production.

According to the fuel quality directive (2009/30/EC), ethanol can be blended max 10 %-vol to petrol. Petrol containing max. 5 %-vol ethanol is called E5 and petrol containing max. 10 %-vol ethanol is called E10. In addition to using pure ethanol, ethanol and methanol can be used to make ethers, which have better qualities as a petrol component compared to ethanol. The most commonly used biobased ether used in Finland, Sweden, and Norway is ethanol based ETBE (Neste 2015).

Due to their production process, ethers cannot be fully biobased. The RES-directive has given default values for the bio content in ethers, which is 37 % for bio-ETBE. The fuel quality directive sets a limit of 15 %-vol of ETBE in E5 and 22 %-vol of ETBE in E10. However, maximum shares of both ethanol and ethers cannot be blended to petrol, because the oxygen content limit will be met earlier. Either maximum ethanol share or maximum ether share in the fuel will fill up the maximum oxygen content.

In addition to E5 and E10, ethanol can be used as high-blend fuels E85 and ED95. E85 contains min 15 %-vol and max 85 %-vol ethanol, while ED95 contains max 95 %-vol ethanol, the rest being additives. Both fuels require a special engine. E85 can be used in flexfuel vehicles, and ED95 can be used in Scania’s modified busses’ or lorries’ diesel engines. (Sekab 2019.)

Below, the ethanol blend wall in Finland, Sweden, and Norway is estimated for fuel fulfilling the biofuel obligation. As the ethanol blend wall depends on the final fuel blend, each country has a different ethanol blend wall depending on the car fleet and fuels supplied. Table 4 lists the ethanol blend walls in Finland, Sweden, and Norway for fuel fulfilling the biofuel obligations.

In Finland, ethanol is blended to gasoline as E5 and E10. The ethanol blend wall in Finland can be estimated by using the fuel supply distribution of E5 and E10. In 2017, 67 % of the petrol supplied to consumption was E10 and 33 % was E5. Using these shares, a blend wall of 8.37 %-vol for Finland is derived.

Sweden and Norway have not introduced E10, so ethanol can be blended to gasoline only up to 5 %-vol in E5 and as ethers in the Swedish and Norwegian markets. Therefore, a blend wall of 5 %-vol can be used in Sweden and Norway.

The high-blend ethanol fuels can be excluded from the blend wall calculations of Finland, Sweden and Norway. At the moment, there are around 10 ED95 trucks in Finland, Scania being the only provider of them (Sipilä et al. 2018). The share of flexfuel cars of the total gasoline and flexfuel cars Finland was 0.2 % in 2018 Sipilä et al. (2018). In Norway, E85 is not supplied anymore (Ramboll 2016). However, in Sweden there are more cars capable of using high ethanol blends than in Finland and Norway. There are more than 800 ED95 busses (Sekab 2019) and 7 % of petrol cars are flexifuel cars in Sweden (Statistics Sweden 2019). However, as E85 and ED95 are considered as high-blend fuels in Sweden, and thus they are not part of the Swedish biofuel obligation, they have been excluded from the calculation of the blend wall.

Table 4 Ethanol blend wall in fuel filling the biofuel obligations in Finland, Sweden, and Norway

Country	**Max. ethanol content in fuel filling the biofuel obligation (%-vol)**
Finland	8.37
Sweden	5
Norway	5

It is possible, that the use of E20 (20 %-vol ethanol in petrol) will be allowed in the EU in the near future. E20 should not cause any technical problems at least in new cars. (Sipilä et al. 2018)

Besides ethanol, bionaphta can be blended to petrol to increase the biofuel content. Bionaphta does not have a blend wall, but its supply is still very small. Therefore, bionaphta cannot be used in bigger shares, but it can be used to increase the bio content in petrol over the ethanol blend wall. This will be even more important in the future, as the biofuel obligations for petrol are growing each year.

4.2 Biodiesel

In this master's thesis the term biodiesel is used to describe FAME (Fatty Acid Methyl Ester). Biodiesel can be produced from vegetable and animal oils and fats, such as rapeseed oil, palm oil, and tallow. Also wastes, such as used cooking oil can be used for biodiesel production. Biodiesel is derived from transesterification of oils, which yields FAME and glycerol.

Some properties of biodiesel, such as impurities leading to deposits in engine and higher NOx emissions, limit its usage in conventional diesel engines (Nylund et al. 2008). According to standards and the EU fuel quality directive, the maximum share of FAME in diesel fuel is limited to 7 %-vol.

4.3 Renewable diesel

In this master's thesis renewable diesel is used to describe paraffinic biobased diesel fuels such as HVO (Hydrotreated Vegetable Oil), and Fischer-Tropsch biofuels. These fuels are similar to conventional diesel in their chemical properties. Therefore, there is no blending limit on renewable diesel, and it can be used 100 % in normal diesel engines.

The production of HVO uses the same feedstocks as the production of biodiesel. Hydrogen is required for the hydrotreatment process. Fischer-Tropsch diesel and other synthetic diesels are produced by first gasifying biomass, after which it is liquefied. A variety of feedstocks, such as lignocellulosic wood-based biomass, can be used.

As biofuel obligations are very high in Finland, Sweden, and Norway, they are not possible to be fully met with biofuels with blending walls. Therefore, renewable diesel demand is high in those countries. For example, around 75 % of the biofuels supplied in Finland and Sweden in 2017 was HVO (Swedish Energy Authority 2019b & IEA 2018). The Norwegian biofuel obligation is 20 %-vol for 2020, of which slightly more than 5 %-vol can be fulfilled with ethanol and biodiesel. As ethanol can be only blended to petrol and biodiesel to diesel, minimum of a bit less than 15 %-vol renewable diesel of the total diesel and petrol demand is required to fulfil the entire obligation. Approximately the same share of renewable diesel is needed in Finland, since the biofuel obligation is around the same size (20 %, energy based), and the maximum amount of ethanol in petrol and biodiesel in diesel is between 7 and 8 %-vol.

5 Biofuel prices

Until 2012 the price of biofuels was strongly linked with oil prices. However, this link has weakened over time and today the price of biofuels made from food and feed crops is steered by the feedstock prices. Advanced biofuels made from waste, residues and non-food crops are highly valued in global biofuel obligations and thus their demand is high. As their demand is growing faster than their availability, their price is mainly steered by scarcity. Therefore, advanced biofuel sellers can increase their prices to near the penalty fee levels of not fulfilling biofuel mandates, as it is the highest price that obligated parties will pay. For this reason, biofuel legislations have a great impact on biofuel price formation. As the supply of advanced biofuels is, and will be, scarce, countries are able to compete for them by setting such biofuel legislation that values advanced biofuels more than in other countries. (Sipilä et al. 2018.)

Sipilä et al. (2018) estimate fuel wholesale prices until 2030. Their graph on fuel prices is presented here in Figure 4. The price estimate on fossil fuels was conducted based on the IEA oil price predictions in its World Energy Outlook 2017. The price of food and feed crop-based biofuels was estimated based on historical price data and a modelling of agricultural product production rates and prices. The price of advanced biodiesel price was estimated based on waste feedstock prices and the relation of historical price data of food and feed crop based biofuels and advanced biodiesel. The price of renewable diesel was estimated based on revenue and sales volumes of Neste (the world's biggest HVO producer), biofuel tax break in Sweden and price of fossil fuels, waste feedstocks price development and the production costs and refining margins of HVO.

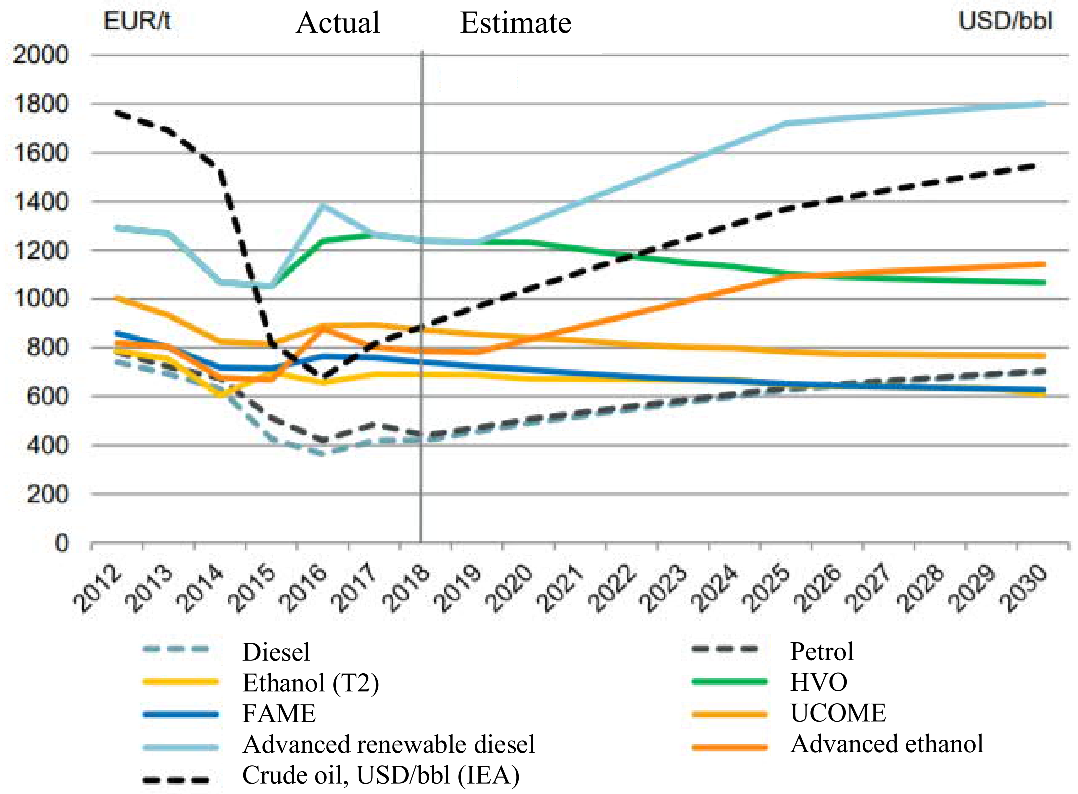

Figure 4 Fuel prices (Sipilä et al. 2018)

Figure 4 shows that feedstock affects to the biodiesel prices. UCOME refers to FAME biodiesel made from used cooking oil, which can be classified as a waste. According to the figure, the price of UCOME is higher than of FAME. This could be due to feedstock availability, but also because of the appreciation of waste as a biofuel feedstock in biofuel legislations over the world.

The fuel prices in 2020 have been derived from Figure 4 and listed in Table 5. These prices are used in the calculations in section 7. The price estimations here do not reveal the emission intensity of the fuels. In reality, the price might differ depending on the emission intensity of the fuel, because legislation in some countries values biofuels with lower emission intensity. Furthermore, fuel prices change every day depending on the market situation. Regardless, in this thesis, the price estimations listed in Table 5 are used in the calculations, as they were the most comprehensive and clear price estimations available.

Table 5 Fuel prices in 2020. Fuel densities and lower heating values are used to convert prices to €/GJ and M€/m3. Used values and their sources are listed in Appendix 1.

Fuel	**€/t**	**€/GJ**	**M€/m³**
Diesel	500	11.59	416.00
Petrol	500	11.57	372.50
Ethanol	700	26.09	547.86
Advanced ethanol	850	32.14	674.90
FAME (biodiesel)	710	18.88	623.00
UCOME	850	22.92	756.50
HVO (renewable diesel)	1220	27.99	951.60
Advanced renewable diesel	1310	30.05	1021.80

6 Optimizing biofuel obligation fulfilment

This section introduces the way fuel suppliers can optimize the fulfilment of biofuel obligations. The differences in the biofuel obligations in Finland, Sweden, and Norway have created such a legislative environment, that a fuel supplier can save significant amount of money by optimizing how the biofuel obligations are filled. The aim of this section is to explain how fuel suppliers operating in various countries can save money by choosing the right country to supply its biofuels. Biofuel traders and a sustainability director at NEOT have been interviewed to get a clear understanding of the way a fuel supplier is filling its biofuel obligations.

If a fuel supplier is filling a binding biofuel obligation, there are costs on filling the obligation. These costs are naturally transferred to customers, but to maintain its competitiveness, the fuel supplier will try to fill its biofuel obligation with as low cost as possible. The fulfilment of the obligation is a cost which has to be met, but which can be optimised. If a fuel supplier is able to fill its biofuel obligation with a lower price than its competitors, profit is made. When money is saved in filling the biofuel obligation, the fuel price at the pump can be lowered to get competitive advantage towards other fuel suppliers. Thus, in a competitive market lower costs for meeting the obligation result in lower price at the pump.

The cost of filling the obligation depends highly on the prices of biofuels but also on how each biofuel batch is valued in the policy. This valuation is based on the sustainability characteristics of biofuels. For example, as the Swedish biofuel obligation is based on emission reductions, biofuels with low emission intensity are more appreciated than biofuels with high emission intensity. In Finland and Norway, the emission reduction value of biofuels does not matter as long as the minimum requirement of 50 % or 60 % reduction is met. Advanced biofuels are appreciated in Finland and Norway, as they are double countable and they have a sub mandate.

A fuel supplier supplying fuels to more than one country has the opportunity to compare the value of each biofuel batch in each country it is supplying to. Assume a fuel supplier has 1 GJ of advanced ethanol and 1 GJ of crop based ethanol with high emission reduction in its storage tanks. By supplying the advanced ethanol to Finland, it will fill its biofuel obligation in Finland by 2 GJ's due to double counting. By supplying the high emission reduction ethanol in Sweden, it will fill its biofuel obligation in Sweden by the amount of emission reduction. Therefore, the fuel supplier will probably benefit the most by supplying the advanced ethanol in Finland and the high emission reduction ethanol in Sweden, and not the opposite.

The tax levels and penalty fees in Finland, Sweden, and Norway are listed in Table 6. In Finland there are different tax levels for diesel and paraffinic diesel as paraffinic diesel gets a tax reduction. For fossil diesel only the tax level for paraffinic diesel is used in this thesis. The paraffinic tax level was chosen because majority of the fossil diesel supplied in Finland is paraffinic and because if a fuel supplier does not supply biofuel, the next reasonable choice would be to supply paraffinic fossil diesel because of the tax exemption, which makes it more comparable with the biofuel tax levels. As renewable diesel is paraffinic fuel, the tax exemption is taken into account for renewable diesel.

Table 6 shows that the highest tax benefit is acquired in Norway when overfilling the obligation (tax premium of 20.53 €/GJ for bioethanol and 14.78 €/GJ for bio-based diesel). Sweden encourages fuel suppliers to supply high blends by offering a tax benefit of 19.79 €/GJ for bioethanol and 12.49 €/GJ for bio-based diesel. Finland gives waste and residue based biofuels a bigger tax exemption than for conventional biofuels, which implicates that the valuation of waste and residue based biofuels is greater.

Table 6 Excise duty levels and biofuel obligation penalty fees (Finnish Tax Administration 2020 & Swedish Tax Agency 2020 & Norwegian Tax Administration 2020) converted to €/GJ. Conversion factors used can be found from Appendix 1.

	Tax (€/GJ)	**Tax reduction in comparison to fossil fuel tax (€/GJ)**
Finland		
Diesel	12.56	
Bio-based diesel:		
FAME	11.97	0.59
Waste & residue FAME	9.21	3.36
Ren. diesel	10.50	2.06
Waste & residue based ren. diesel	7.74	4.82
Petrol	21.82	
Bioethanol:		
Bioethanol	19.35	2.47
Waste & residue based bioethanol	16.63	5.18
Penalty fee	40	
Sweden		
Diesel	12.49	
Bio-based diesel:		
Low blends (filling obligation)	12.49	0
High blends (not filling obligation)	0	12.49
Petrol	19.79	
Bioethanol:		
Low blends (filling obligation)	19.79	
High blends (not filling obligation)	0	19.79
Penalty fee (Dependent on the biofuel GHG value):		
Diesel	0.38 €/kgCO_{2ekv}	
Petrol	0.48 €/kgCO_{2ekv}	
Norway		
Diesel	14.78	
Bio-based diesel:		
Filling obligation	11.52	3.26
Overfilling obligation	0	14.78
Petrol	20.53	
Bioethanol:		
Filling obligation	25.70	-5.17
Overfilling obligation	0	20.53

When a biofuel supplier is facing a biofuel obligation, it has two options: supplying biofuels and filling the obligation or not supplying biofuels and paying a penalty fee. Finland has set a fixed 40 €/GJ penalty fee, and the Swedish penalty fee depends on the fuel GHG emission reduction value (0.48 €/kgCO_{2ekv} for petrol and 0.38 €/kgCO_{2ekv} for diesel). Norway has not implemented a penalty fee. In theory, the highest price a fuel supplier might pay for filling the biofuel obligation is the level of the penalty fee. In other words, a fuel supplier should plan its operations so that the expenses on procuring the biofuel and supplying it does not exceed the level of the penalty fee. Following this reasoning, the positive difference between the penalty fee and the price of supplying the batch of biofuel can be seen as the money saved or profit gained. A fuel trader could "earn money" by making a good deal on buying a cheap biofuel batch instead of paying the penalty fee for not filling the biofuel obligation.

In reality, even though biofuel prices would be higher than the penalty fees in Finland and Sweden, fuel suppliers will most probably fill the fuel obligations. This is due to the fact that all the costs of filling the obligations can be transferred to customers. Furthermore, there are also other costs such as the bad reputation a fuel supplier would get from not filling the obligation.

As the biofuel obligation in Norway has been overfilled in few previous years (Norwegian Environmental Agency 2019b), it can be assumed that the Norwegian tax policy is determining the amount of biofuels supplied to consumption in Norway. Norway has set an excise duty of 14.78 €/GJ for diesel and 11.52 €/GJ for biobased diesel when filling the obligation. When overfilling the obligation, the excise duty is 0 €/GJ. Clearly, the zero tax when overfilling the excise duty is driving fuel suppliers to quickly fill their obligation and then to benefit from the tax benefit by supplying even more biofuels.

The blend wall of ethanol and biodiesel forces fuel suppliers to supply renewable diesel in Finland, Sweden, and Norway to meet the biofuel obligations. In addition to renewable diesel, fuel suppliers must supply advanced biofuels in Finland and Norway because of the sub mandates. As the biofuel obligations and sub mandates are growing every year, it is possible that the scarcity of renewable diesel and advanced biofuels will determine their price. That means, that their price can grow close to the penalty fee levels.

7 Biofuel valuation assessment

In this section, the valuation of biofuels and their different sustainability characteristics in Finland, Sweden, and Norway is assessed. The assessment is done in two phases. First, the overall biofuel valuation in each country is evaluated. The country that values biofuels most, will probably continue consuming biofuels even though the biofuel supply would be small. In this case, the country with the least biofuel valuation might end up consuming zero biofuels.

In the next phase, the biofuel sustainability characteristics valuation in each country is assessed. The differences in the biofuel valuation between countries can create intra-industrial trading discussed in the literature review of this thesis. As explained in section 3, Finland and Norway value advanced biofuels, and therefore they have set sub mandates and count the amount of some of the advanced biofuels twice towards the biofuel obligation. Instead, Sweden values the emission reduction of biofuels, as biofuels are calculated to the emission reduction obligation according to their emission reduction value. In subsection 7.2 the valuation of biofuel sustainability characteristics is attempted to quantify. The money that biofuel suppliers will earn or save by supplying biofuels to one country instead of another country, will direct them to supply certain types and amounts of biofuels in certain countries.

The valuation of biofuels is evaluated by estimating the fuel suppliers' willingness to pay (WTP) for biofuels. According to Breidert (2005) WTP can mean either the maximum price or the reservation price of a commodity. However, he argues that often the difference between maximum price or reservation price cannot be distinguished, so WTP can be either of them. The circumstances determine if buyer's WTP is the maximum price or the reservation price. Maximum price refers to the price a buyer is willing to pay for a certain product instead of buying an alternative product. Reservation price refers to the price a buyer is willing to pay for a product instead of not buying it. Reservation price can be applied when there is no alternative product to choose. (Breidert 2005.)

A fuel supplier has the possibility to choose from different types of biofuels until the blend wall of ethanol and biodiesel has been met. After that, a fuel supplier has only the option of buying renewable diesel or paying the penalty fee (except in Norway, where penalty fee is not implemented). As the biofuel obligations in Finland, Sweden, and Norway are quite high, the blend walls of ethanol and biodiesel are met quite fast. Therefore, the fuel supplier's WTP for the renewable diesel in Finland and Sweden will the reservation price for most of the time when filling the biofuel obligation and it will be tied to the cost of not fulfilling the obligation. In Norway, the WTP for renewable diesel will be tied to the cost of fossil fuels, and therefore, depending on if biofuel and fossil fuel are seen as alternative products it could be also seen as the maximum price instead of reservation price. After the biofuel obligations are fulfilled, the supplier has the option to either continue supplying renewable diesel or supplying fossil fuels. The cheaper option will win, so the fuel suppliers' WTP for the biofuel overfilling the obligation is determined through the cost of supplying fossil fuels. Again, depending on the way biofuel and fossil fuel are viewed, the fuel supplier's WTP for biofuel could be seen as the maximum price instead of reservation price, because it is dependent on the fossil fuel price.

The amount that fuel suppliers benefit from supplying biofuels depends on the country the biofuels are supplied to. Therefore, the amount that fuel suppliers are willing to pay for a batch of biofuel depends on the country they are supplying the biofuel to.

WTP is not the same as the price of biofuel, as it only tells how much a fuel supplier is ready to pay for biofuel. However, when biofuel demand is high and supply low, their prices will probably be near the WTP levels. As discussed before, it is possible that there is one country, whose policy defines the world biofuel price. The objective in this thesis is not to find which country is the price steering country and what is the biofuel price, instead, the valuation of biofuels according to the biofuel policies is evaluated and discussed.

The assessment is done for year 2020, using the tax levels and targets for 2020. 2020 was chosen because Sweden and Norway have not yet set a legislative pathway for biofuels beyond 2020. The fuel prices and demand have been expressed in energy (GJ) instead of volume (m^3) where it is possible because fuel demand is energy based even though fuels are sold in litres. All the calculation factors used in the calculations are listed in Appendix 1.

7.1 Country level biofuel valuation

In this subsection the fuel suppliers' willingness to pay for biofuels is estimated for Finland, Sweden, and Norway. The WTP's are then used to evaluate if there are differences in the biofuel valuation in these countries.

By comparing WTP's of different countries, it is possible to estimate which country values biofuels more. The country with highest WTP is probably the country where biofuel obligations are filled first if the absolute amount of biofuels in a given time period is low. Higher WTP means higher biofuel valuation, so there would be high expenses (penalty fee) or loss of benefits (tax benefits) if biofuels were not supplied.

7.1.1 Finland

Finland has set a penalty fee for not filling the biofuel obligation, so the penalty fee is the main determinant of the WTP of biofuels in Finland. If a fuel supplier chooses to pay the penalty fee instead of supplying biofuels, it will have to pay the price of the penalty fee and the expenses for supplying fossil fuel instead of biofuel. The biofuel tax exemption is added to the WTP, because it is a benefit that fuel suppliers receive after purchasing the biofuel. The following equation is obtained for the biofuel WTP in Finland:

$$W_O = F + P_f + (T_f - T_b) \tag{1}$$

Where W_O = Fuel supplier's willingness to pay for biofuel when fulfilling biofuel obligation (€/GJ)
F = Penalty fee (€/GJ)
P_f = Price of fossil fuel (€/GJ)
T_f = Fossil fuel tax (€/GJ)
T_b = Biofuel tax (€/GJ)

By supplying double countable biofuel, the fuel supplier avoids paying two units of penalty fee. Therefore, the penalty fee term in equation 1 is doubled:

$$W_D = 2 * F + P_f + (T_f - T_b) \tag{2}$$

The tax exemption for waste renewable diesel is used in the calculations, because it is the highest possible tax exemption and therefore leads to the highest possible WTP. As a result, WTP in Finland for single counting biofuel is 56.41 €/GJ and for double counting biofuel 96.41 €/GJ.

When the biofuel obligation has been fulfilled in Finland, the only incentive a fuel supplier has to supply even more biofuel is the tax exemption for biofuels. The WTP for biofuel overfilling the biofuel obligation is calculated according to equation 3. As a result, a fuel supplier is willing to pay maximum 16.41 €/GJ for biofuel overfilling the Finnish biofuel obligation.

$$W_S = P_f + (T_f - T_b) \tag{3}$$

7.1.2 Sweden

In Sweden, there is no tax benefit for biofuels filling the obligation, so the WTP is formed only from the penalty fee and fossil fuel price. However, the penalty fee in Sweden is set in SEK/kgCO_2, which makes it more difficult to compare the value with the Finnish penalty fee. This is demonstrated in the following example.

As different fuel batches have different emission reduction values, the amount of biofuel needed to fulfil the Swedish biofuel obligation depends on the emission reduction values of the biofuel batches supplied. The lower the emission reduction of the supplied biofuel is, the more biofuel is needed to fulfil the emission reduction obligation. Thus, the higher the biofuel emission reduction, the more the supplier can supply cheaper fossil fuel. Therefore, the fuel supplier is willing to pay more for the biofuel with higher emission reduction, because it will then spend less money by supplying fossil fuel instead of biofuel.

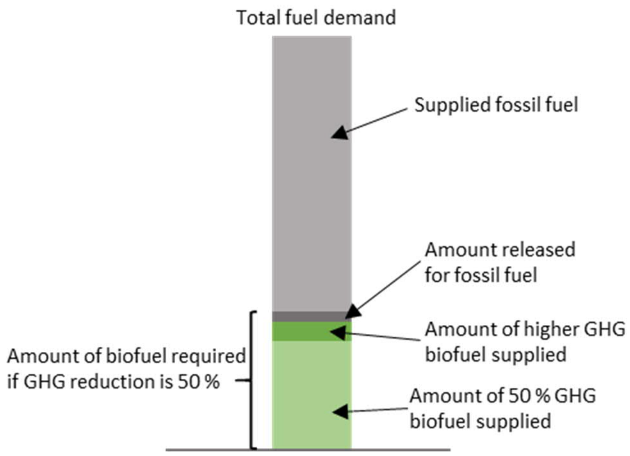

Figure 5 Representation of the Swedish biofuel obligation. The maximum amount of required biofuel is the amount of biofuel required if GHG reduction is 50 %. If a batch of biofuel with higher GHG emission savings is supplied, less biofuel is needed to fulfil the obligation and more fossil fuel can be supplied.

Figure 5 represents a comparison of two situations: a) a fuel supplier meets the obligation only with biofuel with 50 % emission reduction, and b) the obligation is met with 50 %

emission reduction biofuel and a small amount of biofuel with a higher emission reduction. The figure shows that in the latter example the fuel supplier can supply more fossil fuels instead of biofuels. Fossil fuel being cheaper than biofuel, the fuel supplier saves money by not needing to supply as much biofuel.

As explained, 1 GJ of biofuel gets a different WTP depending on the emission reduction value of the biofuel. Therefore, it is possible to draw a curve where WTP is shown for every emission reduction value. In this thesis it is assumed, that the emission reduction can be between 50 % and 100 %. In reality, it is possible to exceed the 100 % emission reduction with technologies such as CO_2 capture. However, it is still quite rare and therefore excluded from this thesis.

The WTP in Sweden can be estimated by calculating the cost (penalty fee + fossil fuel price) and dividing it by the amount of biofuel that can be used to fulfil the obligation.

The amount of biofuel needed to fill the biofuel obligation can be calculated by giving a fixed emission reduction value for the biofuel supplied. According to the Swedish Energy Authority's guidance for emission reductions (Swedish Energy Authority 2018), the total emission reductions are calculated using equations 4-6.

Amount of fuels supplied to consumption:

$$Q = \sum Q_b + \sum Q_f \tag{4}$$

Where Q = Total fuel amount (GJ)
Q_b = Amount of biofuel (GJ)
Q_f = Amount of fossil fuel (GJ)

Emission intensity of fuel supplier:

$$E = \frac{\left(Q_f * E_f\right) + \left(Q_b * E_b\right)}{Q} \tag{5}$$

Where E = emission intensity of fuel supplier (gCO_{2ekv}/GJ)
E_f = emission intensity of fossil fuels (gCO_{2ekv}/GJ)
E_b = emission intensity of biofuels (gCO_{2ekv}/GJ)

Emission reduction of the fuel supplier:

$$E_{red} = \frac{E_f - E}{E_f} \tag{6}$$

Where E_{red} = emission reduction of fuel supplier (%)

The amount of biofuel needed to fulfil the biofuel obligation can be then calculated by combining the equations 4, 5, and 6:

$$Q_b = \frac{-E_{red} * E_f * Q}{E_b - E_f} \tag{7}$$

The calculations are done for the diesel emission reduction obligation (21 % in 2020), so the emission reduction of the fuel supplier E_{red} is equal to the biofuel obligation B_O.

Finally, the WTP for a certain biofuel emission reduction is obtained by dividing the cost of penalty fee and fossil fuel price with the needed biofuel amount. This is shown in equation 8.

$$W_O(E_b) = \frac{C}{Q_b} = \frac{B_O * Q * \left(E_f * F + P_f\right)}{\frac{-B_O * E_f * Q}{E_b - E_f}} \tag{8}$$

Where: $W_O(E_b)$ = Fuel supplier's willingness to pay for a biofuel with fixed emission reduction (€/GJ)
C = cost of not supplying biofuel (€)
B_O = biofuel obligation (% emissions)
F = penalty fee (€/kgCO_2)
P_f = diesel price (€)

The equation 8 is simplified to equation 9.

$$W_O(GHG_b) = \frac{\left(E_f * F + P_f\right) * (E_b - E_f)}{-E_f} \tag{9}$$

Graph in Figure 6 has been drawn for WTP in Sweden for biofuel with emission reduction between 50 % and 100%. Emission intensities used in the calculations are listed in Appendix 1. When the emission reduction of biofuel varies between 50 % and 100 %, the WTP of the biofuels is 23.91 – 47.82 €/GJ.

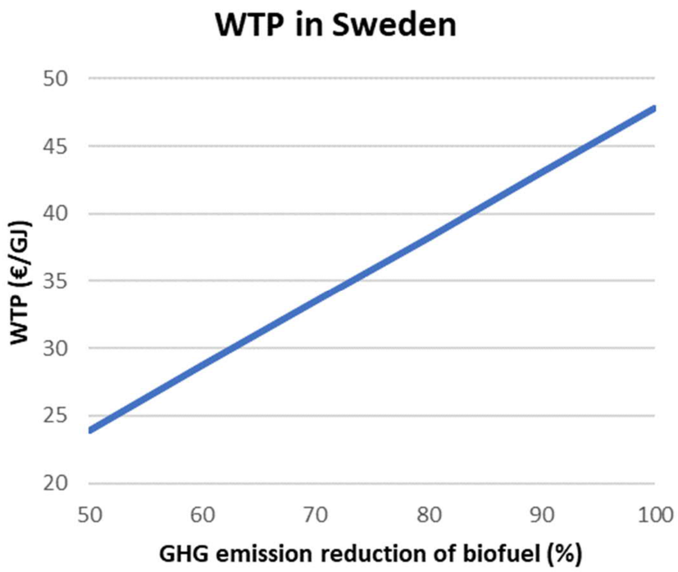

Figure 6 WTP in Sweden according to emission reduction level of biofuel

After the emission reduction obligation is fulfilled in Sweden, a biofuel supplier does not have a further obligation to supply more low blend biofuels. However, high blend biofuels get a tax exemption and fuel suppliers even have an obligation to have them in retail stations to fulfil their possible demand. The WTP for biofuels used for high blend fuels is calculated based on their tax exemption. Equation 3 is used for calculating the WTP for high blends and for low blend biofuels used for overfilling the obligation in Sweden. As a result, the WTP for high blends is 24.08 €/GJ and for low blends used for over blending is 11.59 €/GJ, which is equal to the fossil diesel price as low blend biofuels do not get any tax exemption in Sweden.

7.1.3 Norway

A penalty fee of not fulfilling the biofuel obligation has not been implemented in Norway. However, the biofuel obligation in Norway has been filled every year with even overfilling. Biofuel obligation fulfilment and overfilling has not been done due to low prices of biofuels but due to the tax policy in Norway. Biofuels overfilling the obligation get full exemption from the excise duty, which acts as an incentive to quickly fulfil the biofuel mandate to be able to benefit from overfilling.

The WTP for Norway is calculated in the same way as for Sweden and Finland, but only the fossil fuel price and biofuel tax exemption when filling the biofuel obligation are taken into account. Accordingly, the equation for Norwegian WTP is as following:

$$W_O = P_f + (T_f - T_b) \tag{10}$$

By supplying double countable biofuel in Norway, a fuel supplier can fulfil part of the obligation with only half of the amount of biofuel. Therefore, the benefit of supplying double countable biofuel is that more fossil fuel can be supplied and therefore money saved. As here it is assumed that the biofuel supplier would not meet the total fuel demand with extra cost just to supply biofuels, the WTP of double countable biofuel cannot be higher than the equation 10 suggests. Otherwise the fuel supplier would need to pay more for meeting the overall fuel demand.

According to equation 10, the WTP of renewable diesel for Norway is 14.85 €/GJ. This is below the price of biofuel prices shown in Table 5 in section 5, the lowest biofuel price being 18.88 €/GJ for FAME. This does not, however, mean that the Norwegian biofuel obligation would not be fulfilled in the future. First of all, the tax exemption for biofuels overfilling the biofuel obligation will grow the fuel suppliers' WTP for biofuel. Even without the tax exemption for overfilling biofuel, the costs a fuel supplier will face because of breaking the law (not fulfilling the obligation) and bad reputation will most probably drive fuel suppliers to spend more money on fulfilling the biofuel obligation.

After the biofuel obligation has been fulfilled in Norway, fuel suppliers get a tax exemption for overfilling the obligation. WTP for biofuel overfilling the obligation is calculated with equation 10, using the biofuel tax level (0 €/GJ) for overfilling the obligation. As a result, a fuel supplier is willing to pay maximum 26.37 €/GJ for biofuel overfilling the Norwegian biofuel obligation.

7.1.4 Conclusion of biofuel valuation

Table 7 lists the acquired values for WTP in Finland, Sweden, and Norway. To acquire more accurate value for the WTP in Norway would require more complicated assessment.

Table 7 WTP of renewable diesel in Finland, Sweden, and Norway when fulfilling biofuel obligations

	WTP (€/GJ)
Finland, single counting biofuel	56.41
Finland, double counting biofuel	96.41
Sweden, 50 % emission reduction	23.91
Sweden, 100 % emission reduction	47.82
Norway	14.85

The WTP in Finland is significantly greater than in Sweden and Norway. This is due to the higher penalty fee and the 11.61 €/GJ tax exemption on waste and residue based renewable diesel in Finland. The values calculated suggest that in a situation where biofuel absolute amount available at a given time is too low to meet all the three biofuel obligations, the Finnish biofuel obligation would be filled first in order to avoid the high penalty fee payment.

As mentioned before, the Norwegian WTP value is not accurate, as it is not taking into account the tax benefit of 14.78 €/GJ when overfilling the obligation. However, if biofuel availability were to be low, the tax exemption for overfilling the obligation would probably not be enough to shift the biofuel supply from Finland to Norway.

In a situation that the amount of biofuel available is too low to fulfil all the biofuel obligations, the biofuel demand is first met in Finland. In such a situation, biofuel produced in Sweden and Norway would be transported to Finland. However, in a situation that the available biofuel amount is enough to cover the biofuel obligation in each country, all the biofuel obligations will be filled to avoid the penalty fees and other costs such as image losses.

It is possible that biofuel is supplied to Finland, Sweden, and Norway more than the biofuel obligations oblige. Biofuel suppliers get tax exemption in Norway for overfilling the obligation and in Sweden for supplying high blend biofuels which do not count towards the biofuel obligation. These tax exemptions act as an incentive to supply biofuels more than the biofuel obligations require. Therefore, after the biofuel obligations are fulfilled in Finland, Sweden, and Norway, the order of countries valuating biofuels will change. Table 8 lists the WTP's of biofuels used for overfilling the biofuel obligations in Finland, Sweden, and Norway. According to the values, overfilling is valued the most in Norway. After that, the valuation is highest for high blend biofuels in Sweden. The lowest valuation for overfilling is in Sweden for low blend biofuels and for Finland. Tables 7 and 8 reveal that the biofuel obligation will be filled first in Finland and last in Norway, but overfilling is done first in Norway and last in Finland. This might soften the incentive for biofuel trade between the three countries.

Table 8 WTP of renewable diesel in Finland, Sweden, and Norway when overfilling the biofuel obligation

	WTP (€/GJ)
Finland	16.41
Sweden, high blends	24.08
Sweden, low blends	11.59
Norway	26.37

The WTP in Finland is higher than all the fuel prices in 2020 (shown in Table 5), so any of the biofuels could be supplied in Finland. In Sweden the WTP for biofuel with 50 % emission reduction is below the price of all the biofuels except FAME and UCOME. This means, that any other biofuel than FAME and UCOME supplied to Sweden must have a higher emission reduction in order to be economically viable to supply. Equation 9 can be used to find out the minimum GHG emission reduction level of biofuel with the highest price. By setting the WTP to 32.14 €/GJ, which is the price of advanced ethanol, the emission reduction value of 68% is acquired. Therefore, for advanced ethanol, which has the highest price in €/GJ, the GHG emission reduction level must be at least 68 %.

To conclude, all the WTP's calculated here would probably be higher because of other costs related to not filling the biofuel obligations (such as bad reputation). However, these calculations provide some indication on the differences in the WTP's of Finland, Sweden, and Norway, and what fuel suppliers take into consideration regarding the maximum cost of fulfilling the biofuel obligations.

7.2 Renewable diesel sustainability characteristics valuation

In this subsection the valuation of different biofuel sustainability characteristics in Finland, Sweden, and Norway is evaluated. The evaluation is done by choosing three example types of biofuels with different sustainability characteristics. The valuation of these three biofuel types in each country is assessed, after which the differences in the order of valuation between countries is assessed. The valuation of the three example biofuel types is done by estimating the WTP and the cost of the biofuel types in each country. WTP of the fuel will tell how much the fuel is valued in the country. The cost will tell how much the fuel supplier faces expenses when supplying the fuel type. The cost includes the price and the excise duty of the biofuel. If the biofuel type is highly valued in the country, it should have some benefits such as tax exemption of double counting. These benefits should be reflected in the cost.

However, different biofuel types have different prices, so the level of tax exemption must be high enough to show in the cost if the biofuel price is very high. In the conclusion of this subsection the reflection of the biofuel type valuation in its cost is also evaluated.

The evaluation is done for three types of renewable diesels. Renewable diesel was chosen because it will most probably be supplied the most in Finland, Sweden, and Norway due to the high levels of biofuel obligations and blend wall restrictions of other biofuels.

The following three renewable diesel example types are viewed:

1. renewable diesel from sunflower oil with GHG emission reduction of 60%

2. renewable diesel from tall oil with GHG emission reduction of 80 %

3. renewable diesel from PFAD with GHG emission reduction of 50 % when classified as a by-product (SWE&NOR), and 90 % reduction when classified as a process residue (FIN).

The renewable diesel types are chosen by picking different kinds of sustainability characteristics for each fuel type, but still using realistic values. For example, biofuels based on waste feedstocks generally have higher GHG emission reduction, because the emissions from feedstock production are not calculated. The GHG emission reduction values are chosen based on RED II annex IV default values and average values published on biofuel producer's websites.

As tall oil is listed in RES-directive annex IX part A, Type 2 renewable diesel is double countable in Finland and Norway. Type 3 biofuel is made from PFAD, which refers to Palm Fatty Acid Distillate produced in palm oil production process. PFAD is classified as a process residue in Finland (Finnish Energy Authority 2014a), but as a by-product in Norway (Norwegian Environmental Agency 2019a) and Sweden (Naturskyddsföreningen 2018). Therefore, in Finland, only emissions generated after collection of PFAD are taken into account. In Sweden and Norway, also the emissions related to the oil palm, for example cultivation emissions, must be taken into account.

In the following sections the WTP and cost of fulfilling biofuel obligation with 1 GJ (Finland and Norway) or 1 kgCO_2 (Sweden) of the example fuels is assessed. Even though the Norwegian fuel obligation is volume based, the assessment is done based on energy amounts, to be able to compare the results with Finland. As all the example fuels are renewable diesel, they have the same energy content and thus they are comparable in the Norwegian system when using the energy based values. If the example fuels would have different energy contents (like ethanol and renewable diesel), looking only at the energy based values would not show the valuation of energy content of the fuel in Norway. The energy content of ethanol is 21 MJ/l and renewable diesel 34 MJ/l, so in Norway 1 GJ of ethanol would fill the biofuel obligation more than 1 GJ of renewable diesel.

The prices in Table 5 and the fuel properties listed in Annex 1 have been used in the calculations.

7.2.1 Finland

The biofuel suppliers' willingness to pay for the example fuels in Finland is calculated using equation 1 for single countable biofuel and equation 2 for double countable biofuel. The only variable in the equations is the biofuel tax level, which is lower for waste and residue based biofuels.

The cost of supplying the biofuels is calculated by adding the biofuel tax to the price.

1. Renewable diesel from sunflower oil with GHG emission reduction of 60%

Sunflower oil biofuel is considered as a single counting biofuel, belonging under the 7 % food and feed crop cap.

For the Type 1 biofuel the price of HVO can be used (27.99 €/GJ). The tax for non-waste or -residue paraffinic biobased diesel is used (10.50 €/GJ).

2. Renewable diesel from tall oil with GHG emission reduction of 80 %

Tall oil is double countable as it is mentioned in the RES directive Annex IX A list. Therefore, it can be also used to fill the sub mandate of 0.5 % for advanced biofuels. Tall oil is also considered as process residue (Finnish Energy Authority 2014b).

The benefit of supplying double countable biofuel instead of single countable biofuel is that more fossil fuels can be supplied. 1 GJ biofuel demand can be fulfilled with only 0.5 GJ of double countable biofuel, which allows 0.5 GJ more of fossil fuel to be supplied. The cost of filling 1 GJ of the biofuel obligation with double countable biofuel can be calculated by calculating the cost of supplying 0.5 GJ biofuel and 0.5 GJ fossil fuel:

$$C_D = 0.5P_b + 0.5T_b + 0.5P_f + 0.5T_f \tag{11}$$

Where C_D = cost of filling biofuel obligation with double countable biofuel (€/GJ)
P_b = Price of biofuel (€/GJ)
T_b = Tax for biofuel (€/GJ)
P_f = Price of fossil fuel (€/GJ)
T_f = Tax for fossil fuel (€/GJ)

The price for advanced diesel (30.05 €/GJ) and the tax for waste and residue based paraffinic biobased diesel (7.74 €/GJ) are used for the type 2 biofuel.

3. Renewable diesel from PFAD with GHG emission reduction of 90 % when classified as a process residue

PFAD is considered as a process waste in Finland and therefore it is grandfathered to the RES directive annex IX A list. This means, that even though PFAD is not double countable in Finland, it can be used to fill the 0.5 % sub mandate for advanced biofuels at least in 2020.

For the type 3 biofuel the price of HVO and the tax for waste and residue based biofuel are used.

Results

Results for the WTP and cost of supplying the example biofuel types are listed in Table 9. The prices have been included in the table for reference.

Table 9 Price, WTP, and cost of the example fuels in Finland

	Price (€/GJ)	WTP (€/GJ)	Cost (€/GJ)
Type 1 Sunflower oil, 60 % GHG reduction	27.99	53.65	38.49
Type 2 Tall oil, 80 % GHG reduction	30.05	96.41	30.97
Type 3 PFAD, 50 % or 90 % GHG reduction	27.99	56.41	35.72

According to the calculated values, the WTP and costs are in line with the legislation, so what is valued more, is also causing less expenses. This can be seen when comparing the cost and price of type 2 biofuel with type 1 and 3 biofuels. Even though type 2 biofuel has a higher price in the market, the costs of supplying it are lower than for type 1 and 3, because it is valued the most.

7.2.2 Norway

Norway has set a tax of 11.52 €/GJ for biobased diesel filling the biofuel obligation. The tax level is the same for all types of biobased diesels, so the WTP in Norway does not change for different types of biobased diesels.

1. Renewable diesel from sunflower oil with GHG emission reduction of 60%

For a single countable food based renewable diesel the tax for biobased diesel and the price for HVO is used.

2. Renewable diesel from tall oil with GHG emission reduction of 80 %

As tall oil is mentioned in the RES directive Annex IX list, it can be used to fill the 4 % sub mandate for advance biofuels. It is also double countable.

For a double countable process waste the tax for biobased diesel and the price for advanced diesel is used. The cost of double countable biofuel is calculated in the same way as in Finland (equation 11).

3. Renewable diesel from PFAD with GHG emission reduction of 50 % when classified as a by-product

For a single countable by-product the tax for biobased diesel and the price for HVO is used.

Results

The price, WTP, and cost of the example fuels in Norway have been listed in Table 10. Even though the WTP is equal for all the example fuels, it has to be noted that Type 2 is double countable so the value of the biofuel can be experienced in the next supplied GJ, which does not need to be biofuel. The biofuel valuation is better seen in the cost of supplying the biofuel type. Type 2 biofuel has the lowest cost because of the double countability. As the Type 2 biofuel price is the highest, the cost would be also highest without the double countability.

Table 10 Price, WTP, and cost of the example fuels in Norway

	Price (€/GJ)	WTP (€/GJ)	Cost (€/GJ)
Type 1 Sunflower oil, 60 % GHG reduction	27.99	14.85	39.51
Type 2 Tall oil, 80 % GHG reduction	30.05	14.85	33.97
Type 3 PFAD, 50 % or 90 % GHG reduction	27.99	14.85	39.51

7.2.3 Sweden

In Sweden only the biofuel emission reduction value affects the WTP of the fuel. The WTP's for the example fuels have been obtained by placing the emission reduction values in equation 9.

The cost of filling the emission obligation has been calculated for filling 1 $kgCO_2$ of the obligation. Here also the prices for biofuels in Table 5 have been used. The different emission reduction levels are not taken into account in the biofuel prices. In reality, the emission reduction also affects the price, and therefore the price for e.g. ethanol with 50 % and 100 % emission reduction would be different. However, sources for biofuel prices showing the emission reduction impact on price were not available. Therefore, it has been assumed here that emission reduction does not have an impact on the price.

The amount of biofuel required to fulfil 1 $kgCO_2$ reduction obligation can be calculated with equation 12. The emission of fossil diesel used in the Swedish biofuel obligation calculations is 95.1 $kgCO_2/GJ$.

$$Q_b = \frac{1}{E_{b_{red}} * E_f} \tag{12}$$

Where Q_b = amount of biofuel needed (GJ)
E_f = emission intensity of diesel = 95.1 $kgCO_2/GJ$
E_{b_red} = emission reduction of biofuel (%)

The acquired amount of each type of biofuel needed is listed in Table 11. The cost of supplying the calculated amount of biofuel is calculated also in the table. The cost is formed from the price of biofuel and the tax. The price of HVO has been used for Type 1 and 3 biofuels and the price of advanced diesel for Type 2 biofuel. In Sweden the tax for biofuels filling the biofuel obligation is equal to the tax of fossil fuel.

Table 11 Amount needed of the example fuels and the cost of the amounts in Sweden

	Amount (GJ)	Cost (€/kgCO_2)
Type 1 Sunflower oil, 60 % GHG reduction	0.018	0.71
Type 2 Tall oil, 80 % GHG reduction	0.013	0.56
Type 3 PFAD, 50 % or 90 % GHG reduction	0.021	0.85

Table 12 lists the price, WTP, and cost of the example fuels in Sweden. The cost of the biofuel is not in the same unit as the price and WTP, so the absolute values cannot be compared. However, by comparing the relative values the differences in biofuel sustainability characteristic can be evaluated. The order of biofuel valuation is equal when looking at the costs and WTP values: the greater the valuation (WTP), the smaller is the cost. That means that the purpose of the Swedish biofuel legislation can be well seen in the biofuel market valuation. The purpose of the Swedish emission reduction obligation is to reduce emissions and therefore give more benefits for biofuels with lower emission reduction. This can be seen in the cost of supplying biofuels, as the lower the biofuel emissions are, the lower the costs are even though the price of the biofuel would depend on other characteristics such as feedstock of the fuel.

Table 12 Example fuel prices and WTPs in €/GJ and cost in €/kgCO2

	Price (€/GJ)	WTP (€/GJ)	Cost (€/kgCO_2)
Type 1 Sunflower oil, 60 % GHG reduction	27.99	28.91	0.71
Type 2 Tall oil, 80 % GHG reduction	30.05	38.26	0.56
Type 3 PFAD, 50 % or 90 % GHG reduction	27.99	23.91	0.85

7.2.4 Conclusion of sustainability characteristics' valuation

The WTP's calculated for the example fuels in each country are listed in Table 13. The table also shows the price of the fuel. By comparing the order of biofuel valuation in each country, it is possible to see if the legislative environment creates favourable conditions for intra-industrial trade.

According to Table 13 Norway values each fuel equally. However, Type 2 fuel is double countable and therefore will fill up the biofuel obligation fastest. Finland and Sweden both value Type 2 biofuel the most. The least valued biofuel in Finland is Type 1 biofuel and in Sweden Type 3 biofuel. That means, that a biofuel supplier could potentially save money by supplying Type 1 biofuel in Sweden and Type 3 biofuel in Finland instead of the other way around. This might incentivize fuel suppliers to transport Type 1 biofuel from Finland to Sweden and Type 3 biofuel from Sweden to Finland.

Table 13 WTP and price of the example fuels in Finland, Norway, and Sweden in 2020 in €/GJ

	Finland	**Norway**	**Sweden**	**Price**
Type 1 Sunflower oil, 60 % GHG reduction	53.65	14.85	28.91	27.99
Type 2 Tall oil, 80 % GHG reduction	96.41	14.85	38.26	32.14
Type 3 PFAD, 50 % or 90 % GHG reduction	56.41	14.85	23.91	27.99

By comparing the WTP's with fuel prices in Table 13, it can be noticed that Type 3 biofuel is at the moment too expensive to be supplied in Sweden and all the example biofuel types are too expensive to be supplied in Norway.

The cost of fulfilling 1 GJ or 1 $kgCO_2$ of biofuel obligation with the example biofuels in Finland, Norway, and Sweden has been listed in Table 14. As the units are not unified it is not possible to compare the absolute costs on the basis of the table. However, the order of cost can be compared. The order of the fuel valuation is equal to the assessment of WTP's in Finland and Sweden. In Norway, the valuation of double countability of biofuel type 2 can be seen in the cost.

Table 14 Cost of the example fuels in Finland, Norway, and Sweden in 2020

	Finland	**Norway**	**Sweden**
Type 1 Sunflower oil, 60 % GHG reduction	38.49 €/GJ	39.51 €/GJ	0.71 €/$kgCO_2$
Type 2 Tall oil, 80 % GHG reduction	30.97 €/GJ	33.97 €/GJ	0.56 €/$kgCO_2$
Type 3 PFAD, 50 % or 90 % GHG reduction	35.72 €/GJ	39.51 €/GJ	0.85 €/$kgCO_2$

As seen from Table 13 and Table 14, the different order in biofuel valuation in Finland and Sweden reveals that there is a spot for biofuel traders to make profit with intra-industrial trade. If Type 1 biofuel is supplied in Sweden instead of Type 3 biofuel, a fuel supplier will save 0.14 €/$kgCO_2$ when filling its emission reduction obligation. If Type 3 biofuel is supplied in Finland instead of Type 1, a fuel supplier will save 2.77 €/GJ when filling its biofuel obligation.

Some of the example fuel types can fill only part of the biofuel obligations. For example, Sweden and Norway have separate obligations for biocomponents blended in petrol, and renewable diesel cannot be used to fill these obligations. The Finnish 7 % cap for food and feed crops and Finnish and Norwegian sub mandates for advanced biofuels create further limitations for filling the biofuel mandates with the example fuel types. The Finnish 7 % cap for food and feed crops creates a cap for Type 1 biofuel. The sub mandates for advanced biofuels in Finland and Norway create demand for Type 2 and 3 biofuels in Finland and Type 2 biofuel in Norway. This might give an extra incentive for fuel traders for intra-industrial trade. After the 7 % cap has been filled in Finland, more Type 1 biofuel cannot be supplied in Finland anymore. As Sweden appreciates Type 1 biofuel more than Type 3 biofuel, it will create an incentive to transport all the rest of Type 1 biofuels to Sweden. The sub mandate for advanced biofuels in Finland creates a demand for Type 2 and 3 biofuels, which again acts as an incentive to transport at least Type 3 biofuel from Sweden and Norway.

8 Discussion

The calculations executed in section 7 show that the biofuel policies are creating arbitrage in the biofuel markets in Finland, Sweden, and Norway. First of all, in a situation that there is not enough biofuels available to fulfil all the three biofuel obligations in Finland, Sweden, and Norway, the differences in biofuel valuation creates arbitrage. As Finland has the highest penalty fee for not fulfilling the biofuel obligation, it can be expected that all the available biofuel would go to Finland in order to avoid paying the penalty fee.

Secondly, arbitrage situation is created when there is enough biofuel to fulfil all the three biofuel obligations because Finland, Sweden, and Norway value different sustainability characteristics of biofuels. This can be seen especially when comparing the example fuel Types' 1 and 3 valuation in Finland and Sweden. According to the calculations, a biofuel supplier will save 0.14 €/kgCO_2 when filling its emission reduction obligation in Sweden with Type 1 biofuel instead of Type 3 biofuel. Similarly, a biofuel supplier will save 2.77 €/GJ when filling its biofuel obligation in Finland with Type 3 biofuel instead of Type 1 biofuel. Furthermore, the caps and sub mandates create a further incentive for intra-industrial trade of biofuels in Finland, Sweden, and Norway.

To get a view of how much money can be potentially saved by using Type 1 biofuel to fulfil the Swedish obligation and Type 3 biofuel to fulfil the Finnish obligation instead of doing the other way around, the maximum amount saved is calculated. To fulfil the biofuel obligation in 2020, 35 936 600 GJ of biofuel is needed in Finland (see Appendix 2 for sources and assumptions). The cost difference on filling the entire biofuel obligation with example biofuel Type 1 or 3 is 99 M€, Type 3 being the cheaper option. To fulfil the Swedish obligation for diesel based biofuels entirely with Type 1 or 3 biofuel, 55 430 900 GJ or 66 517 080 GJ biofuel is needed, respectively. The cost savings when using only Type 1 biofuel instead of Type 3 biofuel is 182 M€. This calculation implicates that there is an incentive with significant economical value to transport biofuel with different sustainability characteristics from Finland to Sweden and from Sweden to Finland.

The rules applied in the chain of custody method influence on the flexibility of using proofs of sustainability in fulfilling biofuel obligations. The following section assesses whether biofuel actually needs to be physically transported between Finland, Sweden, and Norway to be able to transfer biofuel sustainability characteristics between the countries.

8.1 Mass balance rules and fuel transport

In this subsection the mass balance rules of Finland, Sweden and Norway are evaluated, and their impact on biofuel trade is assessed.

In a situation, where a fuel trader supplying fuel to Finland, Sweden, and Norway, procures biofuel from outside these three countries, it will first decide to which country the biofuel batch is brought to. Depending on its storage facilities, it might bring the biofuel batch straight to the country it finds the most economically beneficial to supply in. As soon as the biofuel is despatched to a terminal, the mass balance rules of the country will apply. When, in turn, biofuel is procured from one of the three countries, the biofuel supplier will probably first evaluate in which country the biofuel type is valued most, and then ship it to that country.

In Finland and Norway, the mass balance borders encompass at largest the terminal area. Therefore, in Finland and Norway, the sustainability characteristics of a biofuel batch located in a certain tank in the terminal, can be switched with the sustainability characteristics of another biofuel batch located in the same terminal, but in a different tank. If the fuel supplier would like to move some of its renewable diesel from Norway or Finland to Sweden, it could physically take a batch of renewable diesel with a small GHG emission reduction, but switch the sustainability characteristics with a renewable diesel batch in the same terminal, but with higher GHG emission reduction.

In Sweden, the mass balance borders encompass at largest all the fuel supplier's terminals in Sweden. Therefore, sustainability characteristics of biofuels located in different terminals in Sweden can be switched. When transferring some renewable diesel from Sweden to Finland, the fuel supplier could physically move a biofuel batch from a terminal closest to the receiving terminal and attach the sustainability characteristics of a biofuel batch which is physically located in a terminal in the other side of the country. However, this would not be possible when transporting biofuel from Sweden to Norway, because Norway doesn't recognise the Swedish national sustainability scheme, and the ones its does recognise, must have mass balance borders which encompass at largest a terminal or other facility.

In summary, physical transfer of biofuels is required, when sustainability characteristics are relocated to another country. The larger mass balance borders in Sweden enable less physical movement of biofuels inside Sweden, even though some biofuel must be physically transferred to Finland with the sustainability characteristics.

In their article of intra-industrial biofuel trade, Meyer et al. (2013) argues that a book and claim system as a chain of custody method would remove the incentive for biofuel trade. This has been acknowledged in the EU when preparing the RES directive (SEC(2008)85). However, the European Commission chose the mass balance system in order to also create an incentive for investments in local biofuel production.

8.2 Emissions from fuel transport

Biofuel trade creates emissions due to the emissions formed from transporting the fuel. According to Meyer et al. (2013) the ethanol trade between the US and Brazil emits 3.2 gCO_2e/MJ, which is approximately 12 % of the total emissions from the biofuel consumption. Transporting biofuel naturally also increases the costs related to biofuel.

The way that transport emissions are calculated in the EU might lead to neglection of some of the emissions resulting from biofuel trade. According to the RES-directive, biofuel life-cycle emissions can be calculated either by using the default value given in the directive, calculating the actual emissions, or partly calculating the actual emissions and partly using disaggregated default values for certain emissions given in the directive. The overall default value and the disaggregated default value for transport emissions include the emissions of all the transport states during the life cycle of the biofuel, including emissions from delivery.

A biofuel producer can sell biofuel to traders who sell or supply the biofuel in a country where it is valued the most. If the biofuel producer uses in its emission calculations the overall default value or the disaggregated default value for transportation, the producer's calculations then include the trader's emissions, because all the emissions from transport and delivery are included in the default values. Some biofuel producers estimate a certain distance range for the transport occurring after selling biofuel forward. They calculate the emissions of transporting the biofuel batch for the amount of the estimated distance and add these beforehand calculated emissions to the life cycle emissions.

The biofuel producer must submit a proof of sustainability to the trader, stating the biofuel life cycle emissions. If all the biofuel life cycle transport emissions are included in the emission calculations, the trader can use the same proof of sustainability when selling the biofuel to another trader or when supplying it in another country. Therefore, the trader does not need to conduct its own calculations and provide new proofs of sustainability. However, if the default values or the beforehand estimated emissions cover only part of the distance what the biofuel in reality travels, then all the transport emissions are not taken into account. For example, it is unlikely that these emission values would take into account the possibility that biofuel is transported from the EU to the US and then back to the EU again. This, however, was economically viable during the “dash and splash” legislative period introduced in the literature review. It is therefore possible, that biofuel traders transport biofuels even long distances to benefit from differentiating biofuel laws and then legally neglect the emissions from transport.

It is, however, unclear if the above described neglection of emissions is legal. It highly depends on the interpretation of the RES-directive and national laws implementing the directive. Some countries may demand that traders calculate their transport emissions on top of the default values. This issue, however, is not clearly addressed in the Finnish, Swedish, or Norwegian legislation or guides, nor in the ISCC voluntary scheme guides, and all seem to approve, or at least not clearly deny, the use of default values when estimating the transport emissions of the entire life cycle of biofuels.

According to RED II a Union database shall be put in place for traceability of biofuels. The economic operators selling and supplying biofuels would enter sustainability data of all their sustainable biofuels into the database. This would probably allow the commission to also track the entire journey of each biofuel batch and how its transport emissions are calculated. Based on that information it could be possible to evaluate if the transport emissions are estimations and default values are accurate. However, it is still unclear how the database will function.

8.3 Future changes in legislation

As this thesis shows, differences in the Finnish, Swedish, and Norwegian biofuel legislation influence the biofuel markets. Therefore, changes in the biofuel legislation of any country might have a great impact also on other countries’ biofuel supply. In this section, the pending changes in the biofuel legislation in Finland, Sweden, and Norway are introduced.

The calculations in this thesis have been made based on the biofuel legislation based on the RES directive. The RES directive sets the rules and targets until 2020, after which the RED II is followed. The RED II must be implemented on the member states’ national legislations by the end of June 2021. Neither Finland, Sweden, nor Norway have yet implemented RED II in their national legislation, so it is still unclear how they will implement all the new rules and targets, and if something more is going to be proposed. Only Finland has set its targets for 2030 in its biofuel legislation before the RED II was written. However, some aspects coming from the RED II still need to be added.

At the moment it is known that the double counting of biofuels will be seized in Finland, and that the targets for biofuel share in transportation increases. In addition, the higher sub mandate for biofuel feedstocks mentioned in RED II annex IX has been implemented in Finland and must be still implemented in Sweden and Norway.

Norway has been changing its biofuel taxation in a very short time frame during the writing of this thesis. The Norwegian ministry of finance gave a new tax proposal to the parliament on September 27th 2019 proposing the removal of the tax exemption of overfilling the biofuel obligation starting from 2020. Furthermore, changes on the fuel tax levels were proposed. The changes in the fuel taxes included removing the tax exemption of overfilling the biofuel obligation, increasing the CO_2 tax and lowering the road tax. The change in the road tax for ethanol is more significant than for other fuels because of the lower energy content of ethanol. Earlier, the tax for ethanol was higher than for petrol when converting the tax levels to energy based levels. Now, due to the bigger change in the tax for ethanol, the ethanol tax is lower than the petrol tax. (Det Kongeliege Finansdepartement 2019.) The Norwegian government has proposed that the changes will be brought into effect in summer 2020 (Sørenes 2019).

This surprising and quickly implemented change in the Norwegian biofuel legislation shows that unexpected and fast changes in biofuel legislation are possible. These changes might have significant impact on the biofuel amounts and types supplied in the country, but also outside the country, by creating or removing demand for certain types of biofuels.

If the suggested changes will be implemented in the Norwegian biofuel taxes, the WTP for over blending biofuel in Norway will decrease significantly. This would practically remove the incentive for over blending in Norway. In that case, more biofuels would be available for over blending in Sweden and Finland. Then it would only depend on the biofuel price if it would be economically viable to over blend the Swedish and Finnish obligations.

8.4 Limitations of the study

In this thesis the valuation of biofuel in Finland, Sweden, and Norway was calculated. The valuation was calculated for biofuel overall and for different sustainability characteristics of renewable diesel. The valuation of renewable diesel's sustainability characteristics was calculated by choosing three different types of renewable diesels and estimating fuel suppliers' willingness to pay for them. Calculations were not made for other types of biofuels, as it has been estimated that renewable diesel will be used the most in Finland, Sweden, and Norway due to the high biofuel obligations. To get a broader view of biofuel markets and biofuel valuation in Finland, Sweden, and Norway, more different types of biofuels could be taken into the assessment.

As the fuel prices could not be estimated with more accuracy, it adds inaccuracy to the results. Also, the fuel prices used in the calculations do not take into account the influence of biofuel emission reduction on the price. The only way this is showing in the biofuel prices in this thesis is the different price category for advanced biofuels, which often may have lower life-cycle emissions than crop-based biofuels. Not having a clear price divisions for biofuels with different emission reduction values affects especially on the WTP values in Sweden. In reality, the cost of supplying biofuel with higher emission reduction value can be estimated to be higher than presented in this thesis. Therefore, it can be assumed that the difference in the cost of fulfilling the Swedish biofuel obligation with different example fuel types is not as big as calculated in this thesis.

The results of this thesis could be validated by comparing the prices and fuel suppliers' revenues to actual values and seeing if biofuels are traded between Finland, Sweden, and Norway. However, this is not possible as the biofuel legislations have changed recently, and therefore the impact on the current or future biofuel legislation on markets could not be seen by comparing the past numbers. The greatest recent change affecting the results is the Swedish biofuel obligation, which was considerably more similar to the Finnish and Norwegian obligation until July 2019, when Sweden implemented an emission reduction based obligation for biofuels. As the calculations in this thesis are made by using the legislation in place in 2020, the validity of the results could be estimated more precisely after 2020.

9 Conclusions

This master's thesis aimed to answer the following question:

- Can the differences in the Finnish, Swedish, and Norwegian biofuel legislation create arbitrage and thus intra-industrial trade of biofuels?

The question was divided into the following sub questions:

- How the valuation of biofuels differs in Finland, Sweden, and Norway?
- How much can a fuel trader profit by trading biofuels inside Finland, Sweden, and Norway?

Differences in the Finnish, Swedish, and Norwegian biofuel legislation were found. The valuation of biofuels was mainly affected by the different levels of tax exemptions and penalty fees. Also, the differences in the valuation of biofuel's emission reductions and feedstocks affected the biofuel valuation. The valuation of biofuels was calculated by estimating fuel suppliers' willingness to pay for biofuel supplied to the market.

Possible arbitrage situations were found by comparing the WTP's in Finland, Sweden, and Norway. In case there would not be enough biofuel available to cover all the biofuel obligations, biofuel would be traded to Finland, were not fulfilling the obligation would have the highest cost. Norway would be left without biofuels due to the lower valuation of biofuels fulfilling the obligation. If there would be surplus of biofuels after filling all the biofuel obligations, overfilling would start in Norway, while Finland would be the least attractive country to overfill the obligation.

One more arbitrage situation was found by comparing fuel suppliers' willingness to pay for different types of renewable diesels. Renewable diesel made from a food crop with 60 % emission reduction value was valued more in Sweden than renewable diesel made from PFAD, when Finland valued them in an opposite order. The cap for food and feed crop based biofuels in Finland further increases the difference in the valuation of these two fuels. This kind of opposite valuation could cause intra-industrial trade of renewable diesel between Finland and Sweden. Finally, the possible profit from trading biofuels between Finland and Sweden was calculated by using the fuel suppliers' willingness to pay for different types of biofuels.

This thesis aimed to find out if the differences in Finnish, Swedish, and Norwegian biofuel legislation can create arbitrage in the biofuel market. The emphasis was more on the policy environment created by national legislations, which is the reason that this thesis concentrated more on the legislative differences and biofuel valuation in Finland, Sweden, and Norway. The actual amounts of biofuels traded was not studied as it was out of the scope of this thesis. Furthermore, as biofuel legislation in Finland, Sweden, and Norway has changed recently and is on the verge of change, there is not yet trade numbers to be compared with the current or future legislation.

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List of appendices

Appendix 1. Conversion factors

This appendix lists the conversion factors used in calculations in this thesis. The values of emission factors, lower heating values, and densities are derived from the renewable energy directive, the directive for implementation of the fuel quality directive, and a report referred to in the latter directive. These sources have been chosen because they are also used in the Finnish, Swedish, and Norwegian regulation.

Table 15 Currency rates

	Value	**Source**
Currency rate of Swedish krona	1 € = 10.4991 SEK	European Central Bank 2019. (Average rate on 23.9.2018-24.9.2019)
Currency rate of Norwegian krone	1 € = 9.7271 NOK	European Central Bank 2019. (Average rate on 23.9.2018-24.9.2019)

Table 16 Emission factors

	Emission factor (gCO_{2ekv}/MJ)	**Source**
GHG emission intensity of diesel	95.1	(EU) 2015/652
GHG emission intensity of petrol	93.3	(EU) 2015/652

Table 17 Lower heating values

	LHV (MJ/l)	**Source**
Diesel	35.9	JRC 2013
Petrol	32.2	JRC 2013
Ethanol	21	2009/28/EC
Renewable diesel	34	2009/28/EC
Biodiesel	33	2009/28/EC
ETBE	27	2009/28/EC

Table 18 Densities

	Density (kg/m^3)	**Source**
Gasoline	745	JRC 2013
Diesel	832	JRC 2013
Renewable diesel	780	JRC 2013
Biodiesel	890	JRC 2013
Ethanol	794	JRC 2013

Appendix 2. Fuel demand

In this appendix the amount of fuel supplied to consumption in Finland, Sweden, and Norway is estimated. Values from 2017 are used, because they were available for all the three countries. This information is needed to calculate the amount of biofuel needed to fill the biofuel obligations. The fuel demand is expressed in energy (TJ), not volume (m^3), because the demand is energy based even though fuels are sold in litres.

The fuel demand in Sweden is derived from a table available in the Swedish Energy authority's (Swedish Energy Authority 2019b) database (see Table 19). As Sweden still had double counting in place on 2017, the amounts in Table 19 include double counting of certain biofuels. According to the Swedish progress report for the years 2015 and 2016, 80 % of biofuels consumed in Sweden in 2016 were double countable. However, some biofuels had a bigger share of double countable batches than others. 70 % of biobased diesel and less than 1 % of ethanol was double countable. Also, most of the biogas was double countable. (Government Offices of Sweden 2017.) By using the share of double countable biofuels, we can calculate the actual amount of biofuels in fuels. The amounts of high blend and low blend fuels are kept separately, as they are opposed to different excise duty levels. The double countability of ethanol is ignored, as the share is negligible.

Table 19 fuel sales in Sweden in 2017 (Swedish Energy Authority 2019b)

Fuel	**Amount in the source (TJ)**	**Share of double counted biofuels (%)**	**Physical amount (TJ)**
Petrol with ethanol blended	99 240		99 240
Petrol without ethanol blended	95 914		95 914
Low blend ethanol	3 326	< 1 %	3 326
High blend ethanol	1 036	< 1 %	1 036
Diesel with biocomponents blended	171 808		158 374
Diesel without biocomponents blended	133 424		133 424
Low blend FAME + HVO	38 384	70 %	24 950
High blend FAME + HVO	21 535	70 %	13 998

Table 20 shows the amount of petrol and diesel supplied in Finland, Sweden, and Norway. The amounts of fuels supplied in Norway are given in litres in SSB (2019). The exact share of biofuels in the supplied fuel is not known, so the values are converted to TJ's by using the lower heating values of petrol and diesel (listed in Appendix 1).

Table 20 Amount of diesel supplied to consumption to transport in 2017. The Norwegian value has been converted to TJ's using the diesel and petrol lower heating values listed in Table 17.

Country	**Amount of diesel with blended biocomponents**	**Amount of petrol with blended biocomponents**	**Total amount**	**Source**
Finland	119 608 TJ	60 075 TJ	179 683 TJ	Statistics Finland 2019
Sweden	158 374 TJ	99 240 TJ	257 614 TJ	Swedish Energy Authority 2019b and Government Offices of Sweden 2017
Norway	3 299 million l (= 115 921 TJ)	1 223 million l (= 39 381 TJ)	155 302 TJ	SSB 2019