Biodiesel Supply Chain Dynamics

System Boundaries

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As an effort to reduce dependency on imported fossil fuels and tackle global warming, the European Commission has recognised the need to promote renewable energy exploitation, sustainable development and security of supply. As part of the Renewable Energy road Map [COM(2006) 848] EU has established a binding target of 20% for renewable energy's share of energy consumption by 2020 and a target of 10% share of renewable energy in the transport sector [1]. Under this picture, biodiesel fuel comes into the market as one of the possible actors to achieve this goal. This paper aims to analyse the market opportunity for future investors on biodiesel in Sweden based on a system approach towards a biodiesel system optimization.

Keywords: Biodiesel, Supply Chain, Transport Sector, Feedstock, Distribution, Renewable Energy Directive, Sweden

CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

LIST OF ABBREVIATIONS

EU	European Union
FAME	Fatty Acids Methyl Ester
FQD	Fuel Quality Directive
GHG	Greenhouse gas
HHV	High Heating Value
LEAP	Long-range Energy Alternatives Planning
RED	Renewable Energy Directive
RME	Rapeseed Methyl Ester

1. INTRODUCTION

1.1 Background

Biodiesel production in Sweden started around the years 2005 and 2006 by small to medium sized private companies together with farming business, using rapeseed oil as the main feedstock [2]. Biodiesel consumed in Sweden comes from domestic production as well as from imports from foreign countries, due to the insufficient local production [3]. One of the advantages of biodiesel, or chemically referred to as FAME, is that it can be used in almost all unmodified diesel engines. Currently, the two types of biodiesel that can be found on the market are [4]:

- B20 (20% FAME blend in fossil diesel) and lower percentage of blended FAME that can be used in almost all of the existing heavy duty vehicles without any modification of the engine.
- B100 or pure FAME that can only be used in vehicles with modified engines.

The trend in biodiesel consumption in Sweden since 2006 is given in Figure 1, in which the values in million litres were converted to TWh using the following information: rapeseed oil density = 912 g/L and HHV = 39.52 [5]. The initial observed increase was due to the blending directive applied to EU Member States; i.e. biodiesel had to be incorporated in diesel, as well as due to the higher price of existing fossil fuel prevailing at that time [6]. High rapeseed oil price caused a decrease in biodiesel production, and hence consumption, in the year 2007/2008 [7]. As rapeseed oil price slowly decreased after 2008, production and consumption started increasing again [7]. Then, the Swedish government announced a new measure to add more 7% biodiesel with the conventional diesel by 1st July 2010 [8]. Moreover, in 2012 there was a possibility of increasing the biodiesel market share to 5% more than the previous year, by hydro-treated vegetable oil feedstock [6]. From 2011 the consumption rate of biodiesel is in a steady position because the domestic level biodiesel production is not increasing alike to the prior time and also is affected by the decrement of the import from other countries.

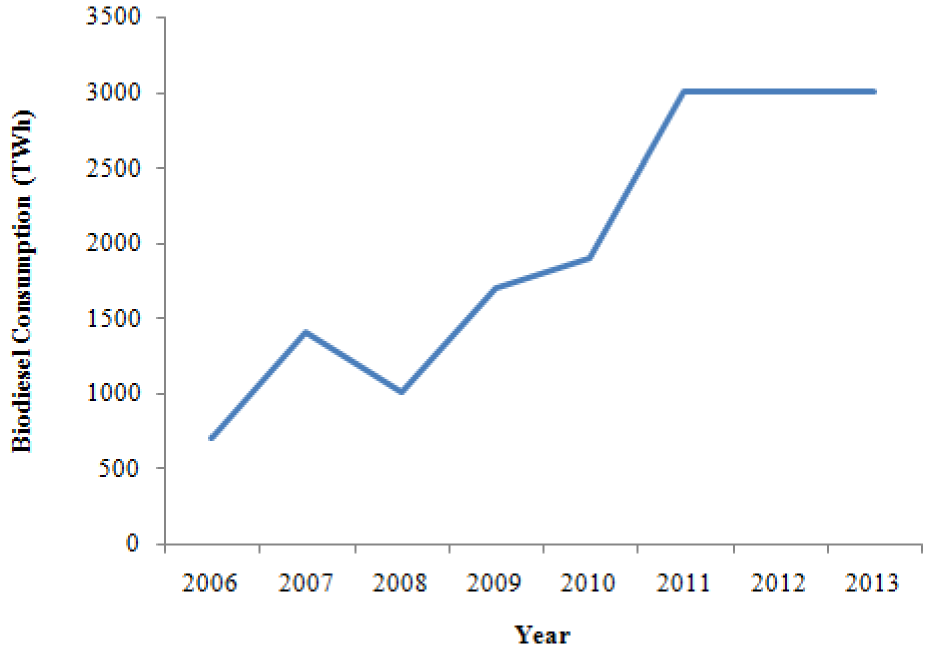

Figure 1: Biodiesel consumption in Sweden

Although biodiesel has been used both for transportation and residential district heating, its relatively late introduction in the Swedish market implies that it is currently still in the "introduction" phase, as can be seen from Figure 2, with a slight movement to the "growth" phase motivated by national policy instruments supporting production of biodiesel feedstock in Sweden [9].

Besides promoting biodiesel feedstock production, the Swedish government has been aiming to introduce biodiesel in the market since 2006 when it decided to promote full availability of biofuels in all major fuel stations in Sweden. Furthermore, other measures have been taken to consolidate this "introduction" towards a steady "growth" in the national market [9]:

- Energy and carbon taxes
- Since 2006, possibility to include 5% FAME in environmental class 1 diesel (7% 2010, 10% 2014)
- Since 2007, tax exemption for biofuel-based motors
- Since 2007, a minimum of 85% of all cars purchased by government authorities, as well as 25% of emergency services, have to be environmental friendly
- Subsidy of 10.000 SEK/vehicle for vehicles that use renewable fuels and for energy efficient vehicles
- Implementation of local policy instruments

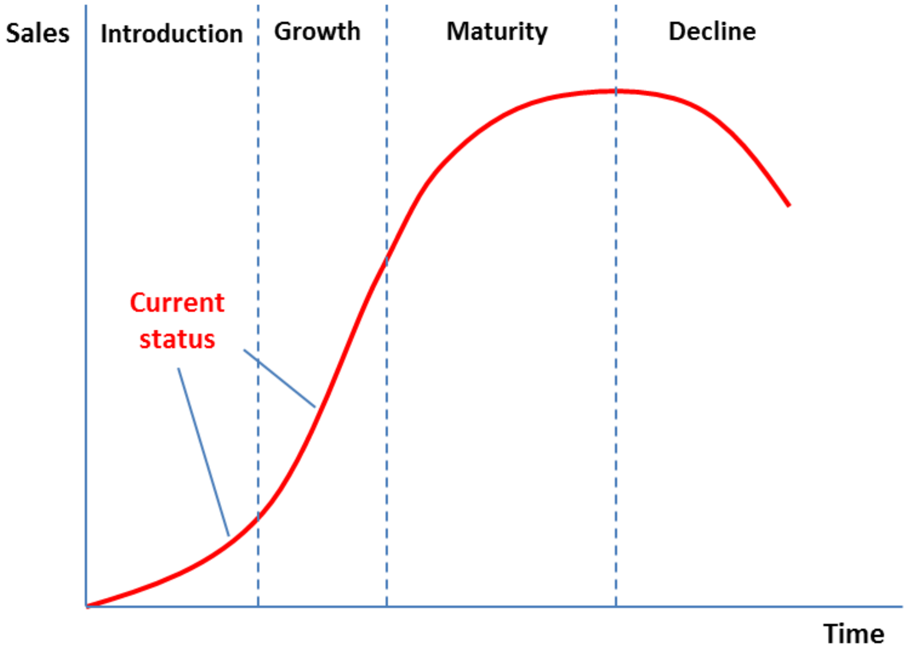

Figure 2: Estimation of the stage of biodiesel in Sweden

Stockholm has already introduced itself as the largest city in Europe with clean vehicles based on the number of vehicles that are driven by biodiesel, bioethanol and biogas. The process of introducing clean vehicles and clean fuels started early in 1994. In addition, there are over 1400 clean taxis and approximately 100 clean police vehicles [10]. Nevertheless, huge amount of biofuels are still required to replace the 42533.6889 TWh of petroleum diesel that are used annually in the Swedish transport sector [2].

1.2. Rationale

As a member of the European Union, Sweden has to comply with the European Commission's Directive 2009/28/EC on renewable energy which sets a target of 10% share of renewable energy in the transportation sector by 2020, among other goals.

Using available figures from 1970 to 2010 [11] and assuming no new policies by the Government, the "business-as-usual" scenario was generated by a polynomial increase for both the final energy use in the transportation sector and for the final energy provided by renewable motor fuels, as given in Figure 3. A polynomial trend line of order 3 was selected for final energy use because it has the highest R^2 value, indicating highest reliability. Although trend lines of polynomial orders 4, 5 and 6 had slightly higher R^2 values, their gradients tend to become zero or even negative after 2010, which is unrealistic. The same argument justifies choosing a polynomial trend line of order 2 instead of polynomial trend lines of higher orders. By extrapolating, the final energy use in the transportation sector and the final energy provided by renewable motor fuels were forecasted to be 169.33 TWh and 15.24 TWh respectively in 2020; which is equivalent to a share of 9.0% of renewables in the transportation sector. This implies that the targeted 10% share is highly achievable, provided biofuels production is sufficiently increased to supply the 1.0% missing from the "business-as-usual" scenario, which is equal to 1.693 TWh.

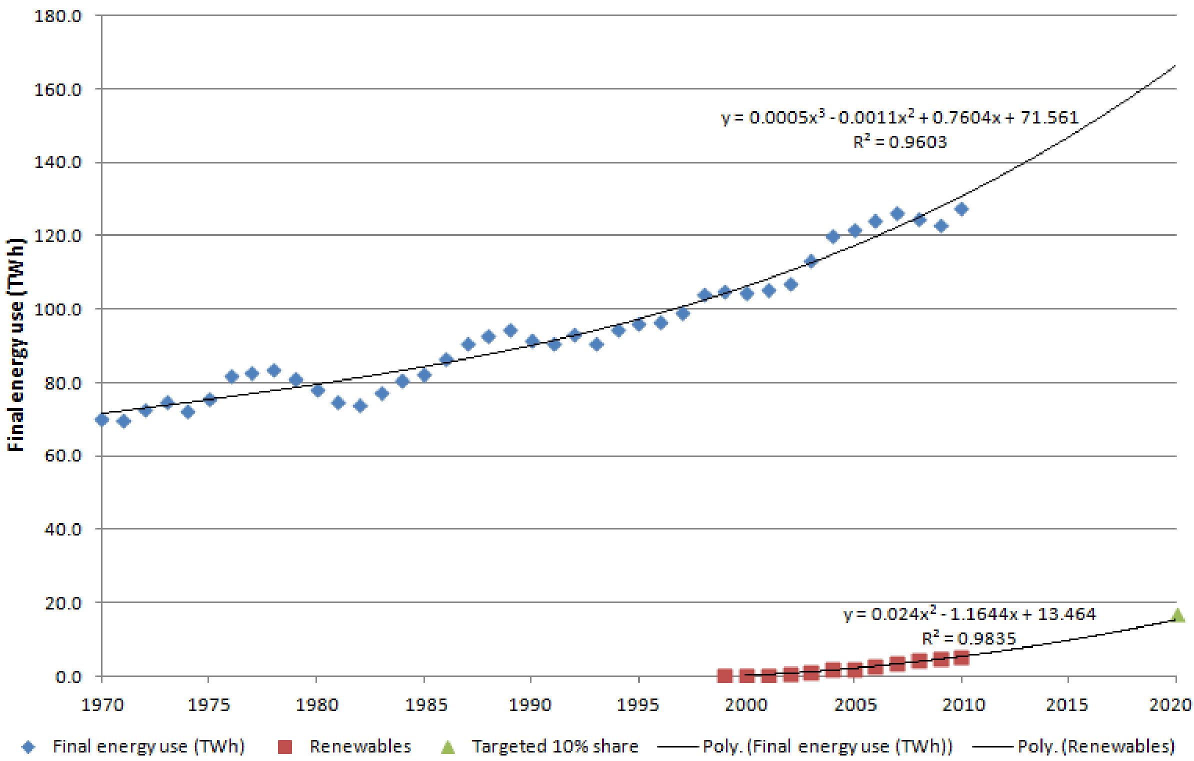

Figure 3: Forecasted final energy use in the transportation sector

An increase in diesel use was observed from 2000 to 2009 due to an increase in new diesel car sales and in heavy good transports [9]. Diesel use has actually increased by 51% whereas that of gasoline has decreased by 15% during the same time period [11]. Biodiesel is therefore the biofuel which can contribute most significantly in reaching the targeted 10% share in 2020 due to the need to satisfy the growing demand for diesel.

1.3. Aim and Objectives

The aim of the project was to assess the potential contribution of biodiesel in Sweden in meeting the target of 10% share of renewable energy in the transportation sector by 2020 as defined by European Commission's Directive 2009/28/EC on renewable energy. Therefore, biodiesel considered in this project deals exclusively with its use as a transportation fuel.

The specific objectives were:

- To review the current status of biodiesel as transportation fuel in Sweden
- To map the existing biodiesel supply chain in Sweden
- To define the system boundaries of the biodiesel supply chain to be analysed
- To model the biodiesel supply chain defined by the system boundaries using LEAP and BioGrace modelling software

1.4. Methodology

An exhaustive literature search was conducted in order to obtain all information related to biodiesel use as transportation fuel in Sweden. Reliable statistics were obtained from the Swedish Energy Agency whereas other information were collected from published papers, reports, dissertations, websites, books, journals and newspapers.

All the stakeholders involved in the supply of feedstock for biodiesel, in the production and the distribution and consumption of biodiesel were identified and collected information of them. Based on all this material, the biodiesel supply chain was mapped to give an overview of the biodiesel flow in Sweden and the boundaries of the biodiesel supply chain system to be modelled were subsequently defined.

To define biodiesel supply chain system, both LEAP and BioGrace modelling software were used. The results generated were then presented, interpreted and discussed in terms of the extent of biodiesel to contribute in attaining the 10% share of renewable energy in the transportation sector by 2020.

2. MAPPING OF BIODIESEL SUPPLY CHAIN

2.1. Biodiesel Supply Chain

2.1.1. Feedstock

Rapeseed oil and used cooking oil are respectively the most widely and second most widely used raw feedstock for producing biodiesel in Sweden. The used cooking oil was reported to be a mixture of sunflower seed oil and palm oil, possibly with other oils and animal fats as well [2]. On the other hand, methanol was obtained from fossil sources.

Regarding biodiesel produced from forest sector feedstock in Sweden, although synthetic diesel from Fischer-Tropsch process and synthetic gas for subsequent biodiesel production were found in literature [2], their supply chains were not considered in this study because none or insufficient updated information could be gathered about them, suggesting that they were not yet being produced on commercial scale. On the other hand, tall oil is currently being used by one company to produce biodiesel. Tall oil is obtained from black liquor, a by-product of pulp mills.

2.1.2. Feedstock Logistics

Around half of the biodiesel producers only bought the rapeseed oil from external vendors or large extractors; whereas the remaining half extracted the oil from rapeseed. Rapeseed oil was partly supplied by neighbouring farms, with their own presses and bought the missing required amount of rapeseed oil from external sellers. However, almost all of the biodiesel producers mention that it is not easy to get decent contracts for both rapeseed and rapeseed oil from external sellers [2] while there is no problem in finding sufficient used cooking oil.

A few of the biodiesel producers also import all or part of their feedstock, mainly rapeseed and rapeseed oil, from some of the nearest European countries south of Sweden. Around 70% of the feedstock is obtained locally while the remaining 30% have to be imported [3]; although biodiesel producers claim that rapeseed from Nordic countries has better properties for biodiesel to be used in cold weather climate areas.

All the crude tall oil required for biodiesel production is bought mainly from pulp mills, but also from trade agents [2]. However, contracts on crude tall oil are generally hard to obtain because other chemical industries consume a significant amount of crude tall oil for other purposes [2].

2.1.3. Biodiesel Production

All the producers using agricultural feedstock use methanol for the trans-esterification process. To generate process heat, production residues and by-products were internally burnt. Producers involved in other businesses also use materials originating from these too [2]. One to two workers are generally required to run the biodiesel production, but the number of shifts depends on the scale of the facilities.

Raw materials account for almost all of the biodiesel production cost. Glycerol is the main by-product and is used in producing animal feed, chemical compounds, fertilisers and biogas. Due to their geographical location, biodiesel producers do not perceive any competition among themselves for raw materials and market shares; but their main worry is that biodiesel does not receive as much media attention as bioethanol or biogas, which might negatively influence customer acceptance and awareness in general [2].

Biodiesel production from tall oil has started since April 2010 in a plant just outside Piteå where approximately 20 employees work [12]. The biodiesel production process consists of first separating crude tall oil from black liquor of the pulp mill process and then subjecting it to esterification with an alcohol [2]. Once separated from the other compounds, the crude tall diesel is hydro-processed at Preem’s refinery in Gothenburg into biodiesel with almost identical properties as petroleum diesel [12].

There are around 10 biodiesel producers in Sweden and they are mostly located in the Southern part of the country, as shown in Figure 4. Since existing competitors are very important for a new company, competitors’ data such as raw material consumptions, final productions, capacity per year and costumer information are provided in Table 1. This information identifies the opportunities but also the challenges that a new biodiesel producer can face at present and also in the near future.

Biodiesel Producer	Product	Feedstock	Capacity/ year *	Customers *
PerstorpBioProducts AB [13]	Biodiesel (B100, BXN, BXE) & Glycrin	Rapeseed oil	160000 MT	90% to fuel companies; Rest to redistributors, private companies
Ecobränsle [14]	Biodiesel (RME 100, RME Fuel Oil) & Glycerol – Alkaline	Rapeseed oil	50000 m^3/year	Own filling stations, private companies
SunPine AB [15]	Biodiesel (A300, OX450, P2000, X2000)	Pine oil (by-product from pulp & paper mill)	50000 MT /from 100000 m^3 of raw tall oil)	Fuel companies
Lantmännen, cobränsle AB [16]	Biodiesel	Rapeseed oil	50000 MT	Transport companies, and industrial companies
Swedish Biofuel [17]	Biodiesel (BioJet, B100)	Grain crops or cellulosic raw material, including wood	----	Aviation mark et, Aircraft
Ageratec [18]	Biodiesel (PE3000, PE8000, PE24000)	vegetable oils, animal fats and fish oils	1070 MT	----
Prosbio [19]	Biodiesel (B100)	Rapseed oil	1800 MT	----
Sveprol Bio Production AB [20]	Biodiesel	Used fat and oils, used cooking oil (UCO)	----	Diesel trucks
Svensk Biobränsle, Norrköping AB [8]	Biodiesel	Rapeseed	330000 MT	----

Table 1: Biodiesel producers in Sweden

* The information that is not provided in this table will be completed with further research and interviews.

Figure 4: Biodiesel producers in Sweden

2.1.4. Biodiesel Distribution

Biodiesel is distributed to final consumers, individuals or companies, via gas stations all over Sweden. Depending on the market-based decisions of the company, some prefer to sell the major part of the biodiesel produced to fuels companies in order for them to blend it with their fuels and sell it in normal filling stations all over Sweden to be used in trucks, buses or construction machinery. On the other hand, other biodiesel companies own their private filling stations where they do not sell blends but pure B100, used by haulers and transport companies. The filling stations are open for customers with granted access [2].

The locations of B100 filling stations of the two main biodiesel producers are given in Figure 5. It can be seen that the distribution of these filling stations is located in the highly populated region of the country. FAME biodiesel filling stations have to fulfil the same legal requirements than petroleum-based fuel stations. Only small modifications in FAME biodiesel stations are needed in order to prevent blockage in the pumps' filter system [4] but the petrol pump has to be substituted for one especially made to resist FAME as it is aggressive to the elastomers that are typically used in meters and pumps. Customers generally have to bring their own pumps or tanks when purchasing biodiesel from smaller producers that do not own filling stations [2].

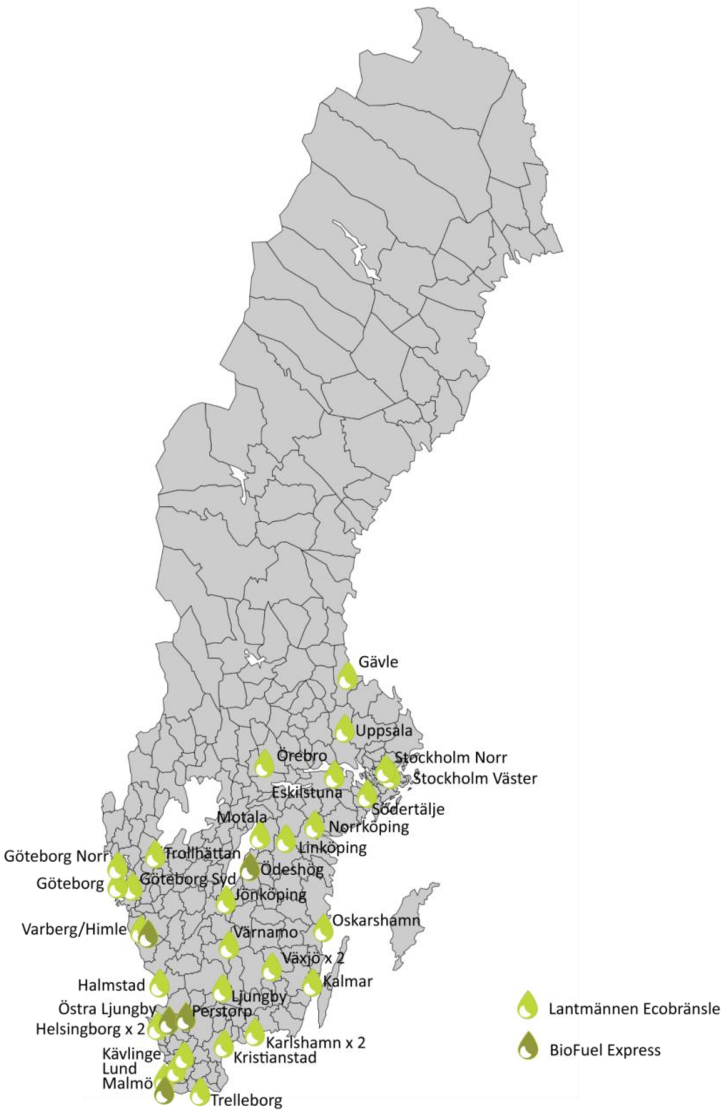

Figure 5: B100 filling stations of two biodiesel producers

2.2. Biodiesel Supply Chain Mapping

As Figure 6 illustrates, biodiesel can essentially be produced from 6 different feedstocks. In Swedish biodiesel industries, rapeseed is the most used feedstock which is currently being utilized by 5 producers. SunPine AB uses tall oil from black liquor as feedstock for biodiesel production. However, black liquor is also used as raw material in the chemical industry and also for producing heat in Sweden. Since black liquor is a by-product of pulp in paper industries, there is a limitation for using it as a raw material to produce heat and also biodiesel in Sweden [21].

Currently, three producers (Ageratec, Svensk Biobränsle Norrköping and Sveprol Bio Production AB) use waste oil, such as used cooking oil and animal fats from fast foods and restaurants, to produce biodiesel. For instance, Sveprol Bio Production AB is collecting used cooking oil from all over Sweden. Fish oil is also being used by Ageratec Company but it is not on a large scale.

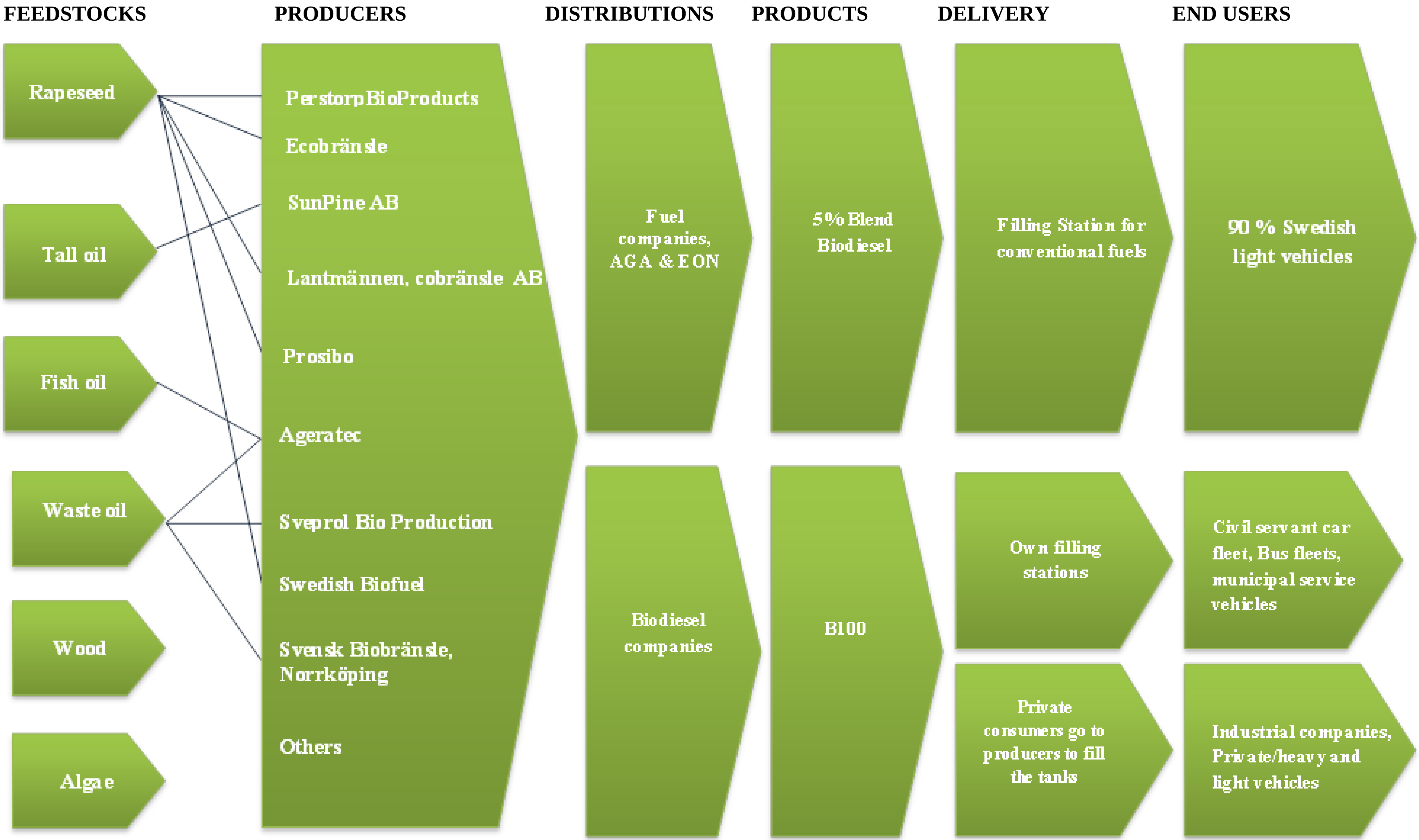

Figure 6: Mapping of biodiesel supply chain

None of the mentioned producers uses algae for making biodiesel currently in Sweden. There are some restrictions to cultivate and grow algae in Sweden. Some of these restrictions are mentioned in the following paragraphs.

There are some studies about producing biodiesel from algae that state that for cultivating algae, sufficient solar radiation and also proper temperature are needed. The range of temperatures in Sweden in summer (June) is around -2°C to 16°C and in winter (December) is approximately -16°C to 4°C [22]. According to this, winter time is not suitable to cultivate algae in Sweden and also, in summer the temperature is not sufficient to have high productivity of algae for producing biodiesel [22]. On the other hand, the range of sunlight availability hours in June is around 160 to 340 hours but considerably less in December which is only 0 to 60 hours [22]. The corresponding average sun intensity are respectively 140 to 200 kWh/m^2 in June and around 0 to 20 kWh/m^2 in December [22]. The climatic conditions in Sweden are hence unsuitable for cultivating algae. However, Sweden might potentially invest in a facility for biodiesel production from algae in one of the closest countries where the conditions are favourable for algae cultivation and the resulting biodiesel exported back to Sweden.

2.3. Biodiesel Supply Chain Model Boundary

As the number of stakeholders in the biodiesel supply chain is not significantly high and essential information about them has been found in literature to enable mapping the flow for the whole country, the boundaries of the system to study are set to national, i.e. considering the whole of Sweden. Moreover, national data was more readily available than regional or local information.

3. MODELLING OF BIODIESEL SUPPLY CHAIN

3.1. Modelling Tools

The study was carried out by using system modelling. Presenting the Swedish transportation sector and biodiesel supply chain simplifies the analysis and enables communicating the final results in an easily understandable way.

3.1.1. LEAP

The software tool LEAP was used due to its modelling capabilities appropriately suited for this study. Its built-in calculations have managed all the “non-controversial” energy, emissions and cost-benefit accounting calculations, that were used to determine how far it is beneficial to invest in biodiesel in Sweden; and it enables users to enter spread sheet-like expressions which can be used to specify time-varying data or to develop sophisticated multi-variable models [23], which is especially relevant for the transportation sector.

Moreover, LEAP is a medium to long-term modelling tool which enables developing and comparing alternative scenarios. This is particularly important because it has recently been said that the European Union will very soon introduce a limitation on the use of biofuels produced from food crops such as rapeseed and wheat, such that these biofuels should account for a maximum of 5% share of energy in the transport sector in 2020 [24] However this information has not yet been confirmed, hence the need of creating one scenario considering this limitation and another scenario excluding this limitation.

One of the greatest advantages of LEAP is its low initial data requirement [23]. The fact that up-to-date detailed information about the stakeholders in the biodiesel supply chain is scarce for confidential reasons or unavailability of relevant studies makes LEAP optimally suited for this study. It is also a powerful and complete decision to support a system which depicts how a sector might evolve scenario-wise based on historical data and which can "backcast" how to reach a set target [23].

3.1.2. BioGrace

To calculate the amount of GHG emissions from biodiesel, the software BioGrace was used instead of LEAP. The main purpose of BioGrace is to evaluate the amount of GHG emissions from all biofuels according to the RED and the FQD. This is performed by reproducing the calculation of the GHG emission default values of 22 biofuel production pathways listed by the RED Annex V part A which is done according to the methodology set out in the same Annex part C [25]. Moreover, the BioGrace Excel calculation is very convenient as it enables the user to input individual values, to define the standard values, to modify the process steps of an existing biofuel production chain and to develop entirely new biofuel production chains [25].

BioGrace is hence an all-in-one reference software tool to determine the GHG savings and emissions associated with biofuels production because it has been developed based on the RED and FQD, thereby generating results which are in accordance with the guidelines and rules set out in these two directives. It has thus been found to be optimally suited in calculating GHG emissions from biodiesel production in this project.

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