REPORT f3 2019:04

WELL-TO-WHEEL LCI DATA FOR HVO FUELS ON THE SWEDISH MARKET

Report from an f3 project

April 2019

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report is the result of a collaborative project within the Swedish Knowledge Centre for Renewable Transportation Fuels (f3). f3 is a networking organization, which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities,
- Carries through system oriented research related to the entire renewable fuels value chain,
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. f3 also finances the collaborative research program Renewable transportation fuels and systems (Förnybara drivmedel och system) together with the Swedish Energy Agency. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

This project is an addition to a previous project within f3: Well-to-wheel LCI data for fossil and renewable fuels on the Swedish market (Hallberg *et. al*. 2013). Hallberg et al. should preferably be read together with the report from this project, including the datasheets from the study. The datasheets presenting the LCI repository are the main delivery from this project.

As a part of the project, a number of relevant industry representatives were consulted regarding the modelling and the results. However, the LCI-data do not represent the production processes of any specific brand or fuel producer.

The project has received additional funding from the Network for Transport Measures (NTM) and Stiftelsen IVL (SIVL).

From IVL Swedish Environmental Research Institute the following persons were involved in the study; Albin Pettersson (Project manager, LCI-data gathering), Simon Andersson (LCI-data gathering, modelling), Tomas Rydberg (Senior project supervisor), Felipe Oliverira (LCI-data gathering, modelling), and Mia Romare (internal review).

This report should be cited as:

Källmén, A., *et. al*., (2019) *Well-to-wheel LCI data for HVO fuels on the Swedish market.* Report No 2019:04, f3 The Swedish Knowledge Centre for Renewable Transportation Fuels, Sweden. Available at www.f3centre.se.

EXECUTIVE SUMMARY

The aim of this project has been to supplement the Life Cycle Inventory (LCI) repository made within f3 by Hallberg et al (2013) with new data on Hydrotreated Vegetable Oil (HVO) in order to better reflect the prevailing conditions on the Swedish fuel market. The actual figures are presented in separate excel sheets and not in this report. However, illustrations of the results for the fuel data sets for a number of selected parameters are presented here.

The study only includes well-to-tank data (WTT) while the emissions for tank-to-wheel (TTW) can be found in Hallberg et al (2013). For the feedstock production two different approaches have been used. Firstly, a cut-off approach to reflect the conditions of the EU Renewable energy directive for feedstocks currently considered as a waste or a residue. Secondly, an approach with economic allocation selected to exemplify a potential scenario where the feedstocks are not considered as a waste or a residue. For the HVO production process, energy allocation has been applied for all types of HVO.

The global warming potential (GWP) results show a large difference between the uses of a cut-off approach versus the economic allocation. With the cut-off approach the emissions are lower as the emissions from the feedstock production are not included. In the economic allocation the upstream emissions from feedstock production are included and the emissions from the life cycle thereby become higher. We can also see that regardless of approach all types of HVO give a decrease in GWP compared to fossil diesel.

As concluding remarks, we would like to highlight the importance of the method used in calculations for life cycle analysis. As this makes the results differ largely the selection needs to be made with caution based on the conditions of the case studied. Besides the methodology the result potentially can vary significantly depending on factors such as location of feedstock production and the properties of the production facility (technology and age etcetera). Also, the amounts of open literature data available on HVO are relatively small. The results presented here should therefore be seen as indicative for the different fuels, to be used predominantly for brief comparisons with fossil alternatives. For more detailed comparisons, for example between different HVOs in a specific context, we recommend that data should be requested from each fuel supplier.

SAMMANFATTNING

Syftet med detta projekt har varit att komplettera de livscykelinventeringsdata (LCI-data) som presenterades i Hallberg et al. (2013) med nya data för hydrerad vegetabilisk olja (HVO). Detta för att bättre återspegla rådande förhållanden på den svenska bränslemarknaden. Data presenteras främst i tillhörande Excel blad men ett urval illustreras även i denna rapport.

Denna studie inkluderar enbart data för well-to-tank (WTT) medan vi för data för utsläpp från tank-to-wheel (TTW) hänvisar till Hallberg et al (2013). För produktion av råvaror har två olika metoder använts, dels en cut-off metod och dels en metod som bygger på ekonomisk allokering. Alternativet med cut-off är tänkt att spegla förhållandena i EU:s Förnybarhetsdirektiv för sådana råvaror som ses som ett avfall eller restprodukt. Alternativet med ekonomisk allokering har beräknats för att exemplifiera ett tänkbart scenario där dessa råvaror inte ses som ett avfall eller restprodukt. För produktionen används en allokering baserat på energiinnehåll för samtliga fall.

När vi studerar klimatpåverkan (GWP) från beräkningarna ser vi stora skillnader beroende på om cut-off eller ekonomisk allokering har använts. Med en cut-off metodik blir utsläppen lägre i och med att utsläppen från produktion av råvaran inte är inkluderad då den i det fallet anses vara en restprodukt. I fallet med ekonomisk allokering är dock utsläppen från produktionen inkluderad och utsläppen WTT blir således högre. Vi kan även se att oavsett metodik så medför användandet av HVO en minskning i GWP jämfört med fossil diesel.

Som avslutande kommentarer vill vi belysa vikten av metodval i livscykelanalysberäkningar. Då dessa val får stor påverkan på resultatet bör det göras omsorgsfullt och baseras på förhållandena i studien. Vid sidan av metodval påverkas även resultaten av faktorer så som vart odling av råvaror sker och produktionsanläggningens ålder och teknologi. Tillgången på datakällor för produktion av HVO är också begränsad. Resultaten ska därför ses som indikativa värden och kommer främst till användning i övergripande analyser, såsom översiktliga jämförelser med fossila alternativ. Om mer detaljerade jämförelser eftersträvas, till exempel mellan olika HVO-typer är vår rekommendation att data efterfrågas från specifika leverantörer.

ABBREVIATIONS

GWP	Global warming potential, expressed as kg carbon dioxide (CO_2) equivalents.
HVO	Hydrotreated vegetable oil
iLUC	Indirect land use change
LCA	Life cycle assessment
LCI	Life cycle inventory
LUC	Land use change
MK1	Diesel according to Miljöklass 1
PFAD	Palm Fatty Acid Distillate
TTW	Tank-to-wheel, the combustion of the fuel in a vehicle
UCO	Used Cooking Oil
WTT	Well-to-tank, the production of the fuel cradle-to-gate
WTW	Well-to-wheel = WTT+TTW, i.e. the whole perspective from cradle-to-combustion in an engine

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1 INTRODUCTION OF THE PROJECT AND THE STUDIED FUEL

The project “Well-to-wheel LCI data for fossil and renewable fuels on the Swedish market” carried out by Hallberg, *et. al.* (2013) aimed to *“gather and compile the best available environmental data for vehicle fuels on the Swedish market, for use in environmental assessments (such as LCA etc.) within the transport sector as well as other sectors”*. Since the publication of Hallberg *et. al.* (2013) the fuel market has evolved, and new types of fuels have entered the market, such as various raw materials and production routes for Hydrotreated Vegetable Oil (HVO). Some efforts have been made in for example Martin et al (2016) and Hjort et al (2017) to model missing or insufficiently represented fuels. However, the complete life cycle inventories (LCI) were not presented in these studies.

Improved LCI data is a key stone in the development of more precise environmental assessment. The use of different types of fuels is included in most product systems and public availability of fuel LCI data is there of high importance. One initiative to improve the availability of LCI data is the Global Life cycle access data network, GLAD (UNEP). This report strives to support such developments.

1.1 AIM OF THE PROJECT

The aim of this project is to supplement the Life Cycle Inventory (LCI) data from Hallberg et al. (2013) with new data in order to better reflect the prevailing conditions on the Swedish fuel market.

1.2 STUDIED FUEL: HYDROTREATED VEGETABLE OIL (HVO)

The prioritization of which fuels to include in the study was based on a comparison of the current market conditions combined with the information on which fuels that were included in Hallberg *et. al*. (2013). According to the statistics from Energimyndigheten (2017) the market for hydrotreated vegetable oil (HVO) has developed rapidly during recent years. Together with the fact that Hallberg *et. al* (2013) only includes two types of HVO feedstocks, HVO was given the highest priority among the fuels on the Swedish market. Due to limitations in project budget no further fuels were in the end updated or included.

Table 1 presents the fuels included in Hallberg et.al (2013) and the added fuel and the fuels calculated with new approaches in this study. Where possible, the data for the fuels reflect the Swedish market.

Table 1. Fuel types included in Hallberg et.al. (2013) and this study. No updates of the fuel data in Hallberg et. al has been made. However, for HVO based on Rapeseed oil a new allocation alternative has been added.

Fuels included in Hallberg et.al. (2013)
ED95 - Sugar cane
ED95 - Wheat
Fossil diesel – Miljöklass 1 (MK1)
Fossil diesel – EN590
Rapeseed methyl ester (RME)
Hydrotreated Vegetable Oil - Rapeseed oil
Hydrotreated Vegetable Oil - Palm oil
Natural gas
Ethanol from sugar cane
Ethanol from wheat
Ethanol from sugar beets
Fuel types added in this study
Hydrotreated Vegetable Oil – Used cooking oil (UCO)
Hydrotreated Vegetable Oil – Slaughterhouse waste
Hydrotreated Vegetable Oil - PFAD
Hydrotreated Vegetable Oil – Tall oil
Hydrotreated Vegetable Oil - Rapeseed oil (New allocation alternative)

1.2.1 Hydrotreated Vegetable Oil - Use, production and market

Hydrotreated Vegetable Oil (HVO) can be used as a blend-in component in fossil diesel or as a standalone fuel (HVO100).

HVO can be produced from several different feedstocks such as used cooking oil (UCO), animal fats or vegetable oils from rapeseed, palm, tall, camelina, corn, jatropha, soybean or other origin. According to the Swedish Energy Agency the Swedish HVO market, consists mainly of HVO made of used cooking oil (UCO), palm fatty acid distillate (PFAD), and animal fat (Energimyndigheten, 2017), see figure 1. HVO from corn, tall oil, rapeseed oil and soy and barley also have minor shares.

The market for HVO has been developing rapidly in Sweden during recent years both in absolute volume but also regarding the composition of different types of HVO. The market for HVO was grown from 320 GWh in 2011 (Energimyndigheten, 2012) into 11 529 GWh in 2016 (Energimyndigheten, 2017). When making assessments based on LCI results in this report it is important to keep the rapid developments of the HVO market in mind, as it might lead to changes in value chains, production technologies, and feedstock production, potentially affecting the LCI results.

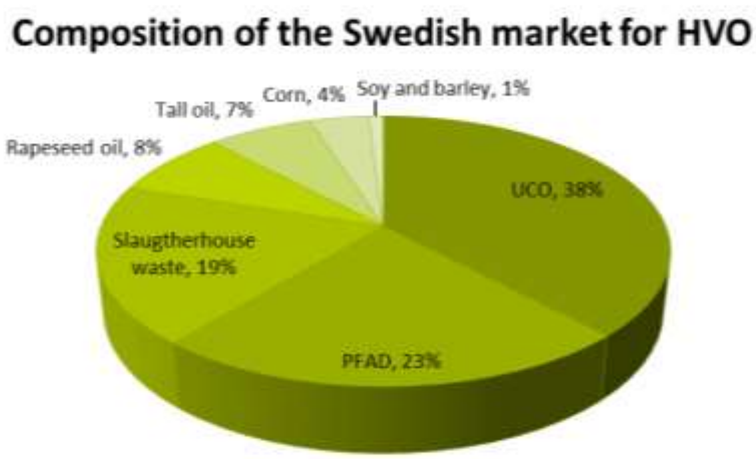

Figure 1. Composition of the Swedish market for HVO 2016 (Energimyndigheten, 2017).

The physical properties of HVO can show small variances. The properties in Table 2 have been used in this study.

Table 2. Physical properties of HVO compared with fossil diesel (MK1).

Data set in database	Heat value [MJ/kg]	Density [kg/m³]	Source
Hydrotreated Vegetable Oil (HVO)	44.1	780	Mikkonen et. al. (2012)
Fossil diesel - MK1	43.3	815	SPBI (2010)

2 METHOD AND LIFE CYCLE INVENTORY

Life cycle inventory data (LCI data) for well-to-tank (WTT) has been calculated in the project. Well-to-tank represents the production and distribution of the fuel. The data is published in excel sheets with files for each HVO type. These excel sheets are available at www.f3centre.se. The name of each file is presented in appendix A. Tank-to-wheel (TTW) data are available in Hallberg et.al (2013).

2.1 CALCULATIONS AND DATA SELECTION

The data presented from this study is based on adaptations and developments of the life cycle assessment (LCA) modelling made in Martin et.al (2017). Details for each fuel type are available in the excel sheets. Before starting this modelling, several potential data sources were reviewed for full LCI results, such as Edwards, R *et al* (2014), Energimyndigheten (2017) and Gode *et al* (2011). However, the LCAs reviewed did not include any full LCI for the studied fuels and as the purpose of this study was to investigate full LCI these sources were excluded. However, if a more limited scope is of interest, such as only energy use and greenhouse gas emissions, other sources excluded from this study may be referred to.

Due to the use of generic data, the models represent HVO production processes in general and the LCI data from this study do not directly represent any specific fuel producer or market brand. It should also be noticed that the environmental performance of feedstock production differs significantly between different geographical regions and even from field to field within a region. This is also the case for HVO production as such where different production facilities can differ significantly depending on factors such as production technology, age etc.

The LCI data are calculated with an attributional perspective with focus on existing production. Therefore, emissions from Land use change (LUC) and indirect land use change (iLUC) have not been included. An inclusion of LUC and iLUC would probably imply a significant increase in greenhouse gas emissions for crops and substrates expanding into non-abandoned land areas. The detailed documentation of the data including system boundaries, assumptions, allocations and underlying data sources can be found in each excel sheet. This report serves to complement the excel sheet with a brief description of the studied fuels. The excel sheets should be considered as the main deliverable from the project.

The reference unit for the reported LCI-data is 1 MJ fuel.

2.2 REPORTED PARAMETERS

Well-to-tank

In the well-to-tank (WTT) data, the parameters in Table 3 have been reported. The parameters were selected in order to align with Hallberg et.al (2013).

Table 3. Parameters reported in the well-to-tank (WTT) analysis.

Non-renewable resources WTT	Emissions from WTT	
	To air	**To water**
Crude oil	Carbon dioxide (CO_2)	Nitrate
Hard coal	Methane (CH_4)	Ammonium/ammonia
Lignite	Nitrous oxide (N_2O)	Phosphate
Natural gas	Carbon monoxide (CO)	
Uranium	Nitrogen oxides (NO_x)	
	Sulphur dioxide (SO_2)	
	Non-methane volatile organic compounds (NMVOC)	
	Particles (PM) (>PM10, PM2.5-PM10, PM2.5)	

Tank-to-wheel

This project has not made any additions or updates of data for combustion of fuels used for propulsion of vehicles (TTW) compared to Hallberg et. al. (2013).

2.3 SCENARIOS WELL-TO-TANK

In this project, different types of allocation have been applied for the different life cycle stages. This is presented in Table 4. For the feedstock production two different approaches have been applied, Cut-off and economic allocation.

The Cut-off allocation was chosen to reflect the conditions in the EU Renewable Energy Directive (RED) for feedstocks considered as a waste or a residue. According to the RED directive PFAD, tall oil, slaughterhouse waste and used cocking oil (UCO) are considered as a waste or a residue, meaning that none of the impact from upstream processes is allocated to the feedstock.

The economic allocation differs from the Cut-off approach and was chosen to reflect a potential scenario where the feedstocks mentioned above is not considered as a waste or a residue, in this case an allocation of environmental impacts is made. In processes with multiple outputs the environmental impacts are divided based on the market value of a product flow set in relation to the total market value of all outputs from the process. For these scenarios it should be noted that market prices are volatile and might change over time. The market price and other references used in this study is stated in the excel sheets. It should also be noted that it is possible to use other alternatives for allocation besides economic allocation.

For the HVO production process, the impact is allocated between produced HVO and co-products based on energy content. For more details regarding allocation, see the specific fuel sheets in the database. After the pre-treatment of the crude bio oil, it has been assumed that all types of HVO have the same properties when processed in the HVO production process.

Table 4. In the table below the approach for each HVO type is presented. Divided into feedstock production and HVO production.

Data set in database	Feedstock production	HVO production process
Hydrotreated Vegetable Oil - Rapeseed oil	Economic allocation	Energy
Hydrotreated Vegetable Oil - PFAD	Cut-off	Energy
Hydrotreated Vegetable Oil - Tall oil	Economic allocation	Energy
Hydrotreated Vegetable Oil - Tall oil	Cut-off	Energy
Hydrotreated Vegetable Oil - Slaughterhouse waste	Cut-off	Energy
Hydrotreated Vegetable Oil - Used cooking oil	Cut-off	Energy

2.3.1 Differences between the allocation alternatives versus system expansion as used in Hallberg et.al

As mentioned above, this study uses different types of allocation or a cut-off approach in the calculations. These approaches complement the HVO data in Hallberg et.al (2013) where the calculations were based on system expansion.

When using system expansion, co-products, wastes and residues are considered as replacements to the production of other products. The environmental impact from avoided production of other products is therefore subtracted from the studied system. In contrast to the allocations approach system expansion can result in negative values in total or for some parts of the life cycle. One example in Hallberg et.al is biogas produces from manure. In the system expansion alternative, the digestate remaining after the biogas is produced is assumed to replace other types of fertilizers. It is therefore given a large negative credit in the calculations.

Whether a cut-off scenario, economic allocation or system expansion should be used depends on the aim and scope of the LCA study using the data. The selection between the different approaches does in many cases have high influence on the results of an LCA. The data presented in this study must therefore be used with some caution, and in the right context.

Finally, it is also important to highlight that there are other types of approaches and types of allocation that can be applied in certain cases, such as allocation based on mass. However, due to limitations of the size of this project these were excluded.

3 RESULTS – GLOBAL WARMING POTENTIAL (GWP)

This section presents the global warming potential (GWP) for the different types of HVO studied. GWP was selected as an illustrative example from the LCI, while graphs for other types of emissions can be seen in appendix B. Notice that the relative ranking of environmental impacts of one type of HVO compared to another can vary drastically depending on which type of emission that is studied. The full LCI data is presented in the excel sheets.

In figure 2 the global warming potential (CO_2-eq./MJ) for the full life cycle of the different types of HVO is presented. The bars are divided into well-to-tank (WTT) with the data from this study and the tank-to-wheel perspective (TTW) with data from Hallberg et.al (2013). For HVO based on tall oil there are two scenarios; cut-off and economic allocation. For HVO based on PFAD, rapeseed oil, UCO and slaughterhouse waste one scenario per type of HVO is presented. For further description of the allocation used, see section 2.3.

By looking at the results a large difference between use of the cut-off approach and economic allocation can be seen. For the cut-off approach the emissions are lower than for the approach with economic allocation as the emissions from the feedstock production are not included. In the economic allocation the upstream emissions from feedstock production are included and the emissions from the life cycle thereby become higher.

HVO from rapeseed oil based on the economic allocation shows a reduction of 25% compared to fossil diesel MK 1. Compared to the results from Hallberg *et.al* (2013) the emission is higher in this report, 58 g CO_2-eq./MJ versus 48 g CO_2-eq./MJ. The main reason for this difference lies in the applied methodology. As described in section 2.3.1 Hallberg et. al (2013) uses system expansion to account for multi-output processes. This led to a large credit for the usage of rapeseed meal for application outside of the fuel life cycle.

In the tank to wheel data from Hallberg et al (2013) there is no emissions of fossil CO_2 from combustion of HVO. However, the global warming potential (GWP) is not zero since there are small emissions of the greenhouse gases CH_4 and N_2O. For the different types of HVO these emissions are visible as small additions on top of the bars in figure 2.

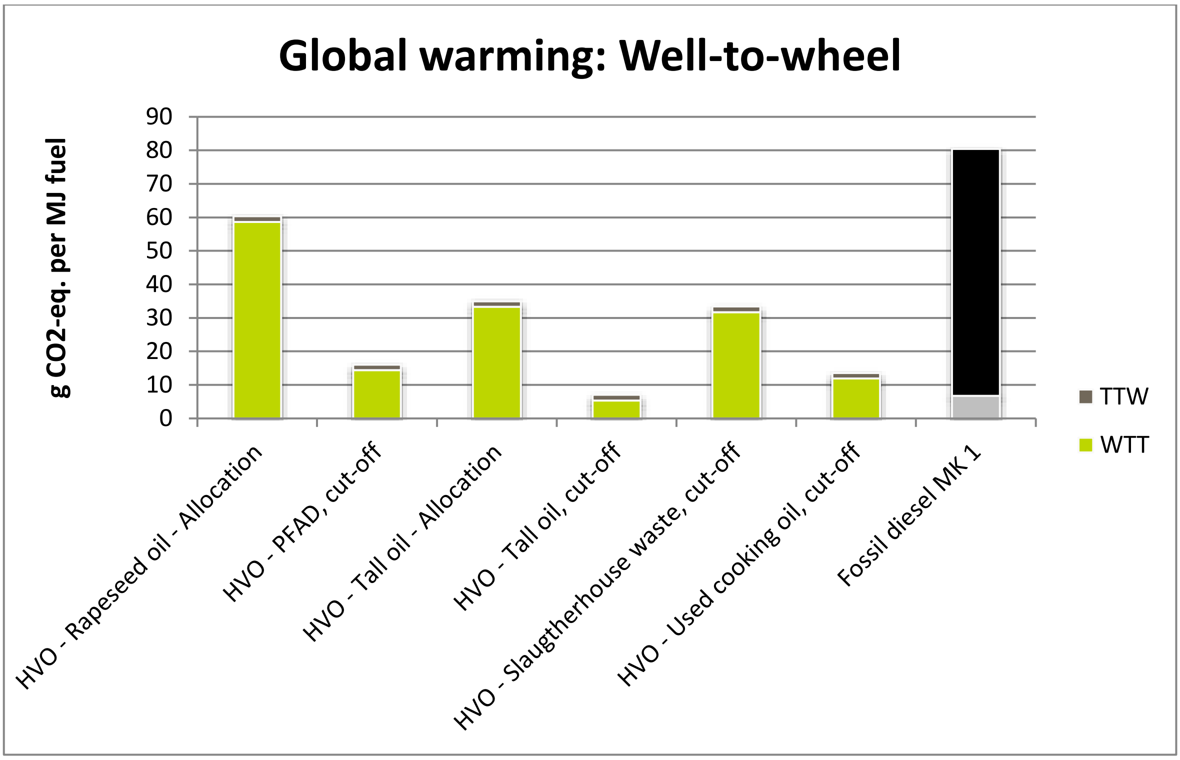

Figure 2. Global Warming Potential: Well-to-wheel with fossil diesel MK1 as a reference. After the name of each HVO type the approach for the feedstock production is stated. The cut-off approach selected to reflect RED and the economic allocation as a potential alternative. For more details regarding see section 2.3 or the each excel sheets.

4 CONCLUDING REMARKS

The main deliverable from this study is the Life cycle inventory (LCI) in associated excel sheets. When using the data, the following remarks are important to consider.

- In accordance with the project scope, we have only compiled information from literature sources and not directly from production sites. Furthermore, the aim was to provide a full LCI. Many of the studied sources did inly report a limited set of indicators, for example only greenhouse gases as GWP. The amount of studies with full LCI data for HVO is very limited which makes the possibilities to compare the results from this study limited.

- We would like to highlight the importance of the method used in calculations for life cycle analysis. As this makes the results differ largely the selection needs to be made with caution based on the conditions of the case studied. This can for example be seen in the results for HVO based on rapeseed. The results differ significantly depending on the use of economic allocation as in this study or system expansion as used in Hallberg et. al. (2013).

- Whether the HVO feedstock is considered as a residue or not have high impacts on the results. When reflecting the RED and thereby using a cut-off approach for the feedstock production, the emissions get substantially lower compared to the case with an economic allocation. Hence, when calculating the environmental performance of fuels the selection needs to be made with caution.

- Besides the methodology the result potentially can vary significantly depending on factors such as location of feedstock production and the properties of the production facility (technology and age etcetera).

- With previous points in mind the results presented here should be seen as indicative for the different fuels, to be used predominantly for brief comparisons with fossil alternatives. For more detailed comparisons, for example between different HVOs supplied to a specific user in a specific time frame, we recommend that data should be requested from each fuel supplier.

Recommendations for future research:

- Carry out sensitivity analyses for the market value of the HVO feedstock to get a better understanding of how potential changes in market value effects the results. The market has been developing rapidly which makes the validity of the data based on economic allocation uncertain for the future.

- Further validate the results against more current and potentially new data sources to reduce the uncertainties in the data.

- Ideally, develop LCI data sets based on specific production processes in cooperation with fuel producers.

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APPENDIX A: LCI DATABASE CONTENT

		f3: Fuel LCI Database content		
Project		*f3: WELL-TO-WHEEL LCI DATA FOR HVO FUELS ON THE SWEDISH MARKET*		
Comment		Available life cycle inventory data (LCI-data) for well to tank (production of the fuel) as well as tank to wheel (combustion of the fuel in a vehicle) have been gathered in the project. The data are published in a database delivered to f3, distributed as Excel files.		
No	**Fuels/fuel components**	**Well to tank**		**Tank to wheel**
		Allocation scenario **Excel file name**	**System expansion scenario** **Excel file name**	**Euro X (X = V and VI)** **Excel file name**
"Diesel fuels"				
D6	**Hydrotreated Vegetable Oil - Rapeseed oil**	D6.2 Hydrotreated Vegetable Oil (HVO) - Rapeseed oil - f3 fuels		Hallberg et.al. (2013) D6&7_HVO combustion in heavy duty truck or bus, Euro X, tank-to-wheel - f3 fuels
D8	**Hydrotreated Vegetable Oil - PFAD**	D8.1 Hydrotreated Vegetable Oil (HVO) - PFAD as residue - f3 fuels		
D9	**Hydrotreated Vegetable Oil - Tall oil**	D9.1 Hydrotreated Vegetable Oil (HVO) - Tall oil - f3 fuels		
		D9.2 Hydrotreated Vegetable Oil (HVO) - Tall oil as residue - f3 fuels		
D10	**Hydrotreated Vegetable Oil - Slaughterhouse waste**	D10 Hydrotreated Vegetable Oil (HVO) - Slaughterhouse waste as residue - f3 fuels		
D11	**Hydrotreated Vegetable Oil - Used cooking oil**	D11 - Hydrotreated Vegetable Oil (HVO) - Used cooking oil as residue - f3 fuels		

APPENDIX B: SELECTED CHARTS WELL-TO-TANK

In the appendix below selected graphs based on figures from the LCI database are presented.

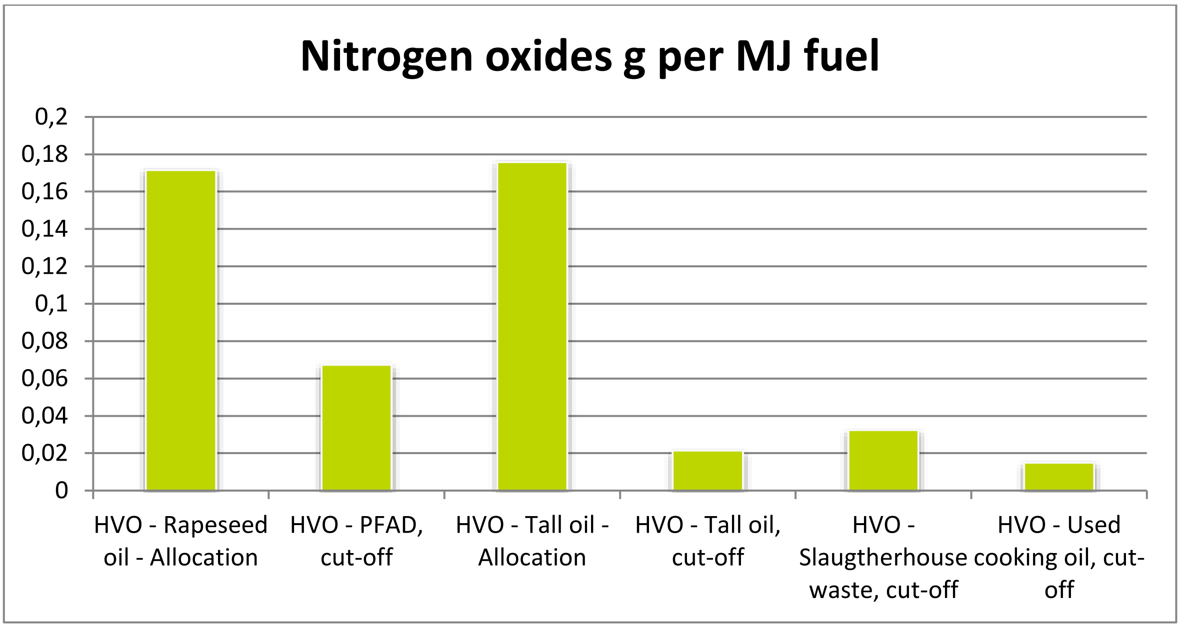

Figure A1. Nitrogen oxides Well-to-tank, g per MJ fuel. After the name of each HVO type the approach for the feedstock production is stated. The cut-off approach selected to reflect RED and the economic allocation as a potential alternative. For more details regarding see section 2.3 or the each excel sheets.

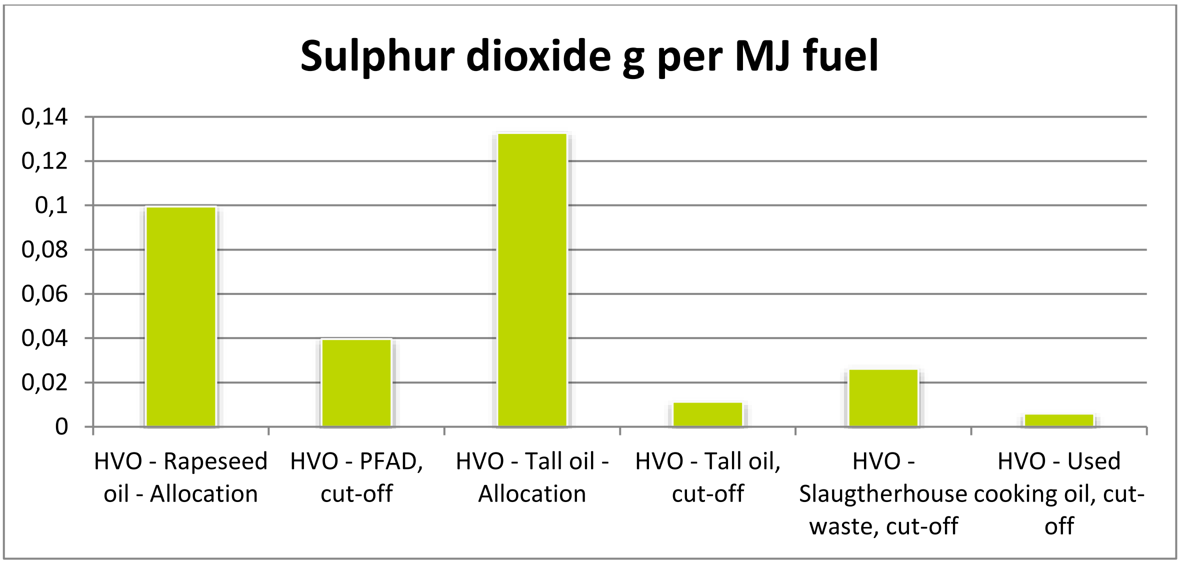

Figure A2. Sulphur dioxide Well-to-tank, g per MJ fuel. After the name of each HVO type the approach for the feedstock production is stated. The cut-off approach selected to reflect RED and the economic allocation as a potential alternative. For more details regarding see section 2.3 or the each excel sheets.

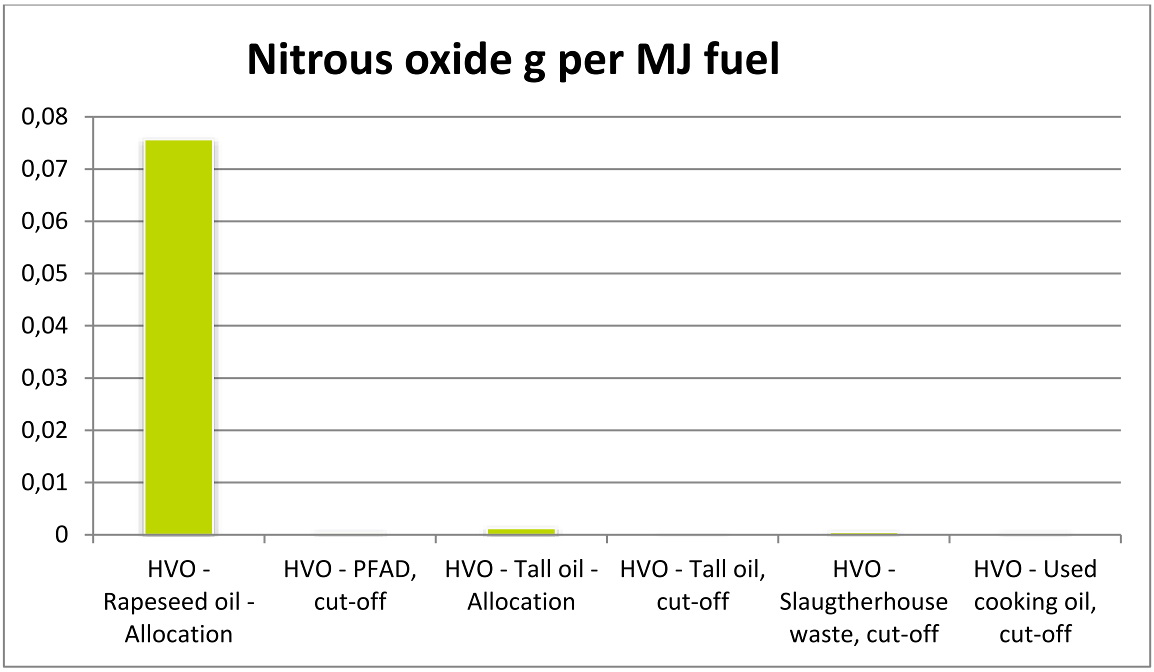

Figure A3. Nitrous oxide Well-to-tank, g per MJ fuel. After the name of each HVO type the approach for the feedstock production is stated. The cut-off approach selected to reflect RED and the economic allocation as a potential alternative. For more details regarding see section 2.3 or the each excel sheets.

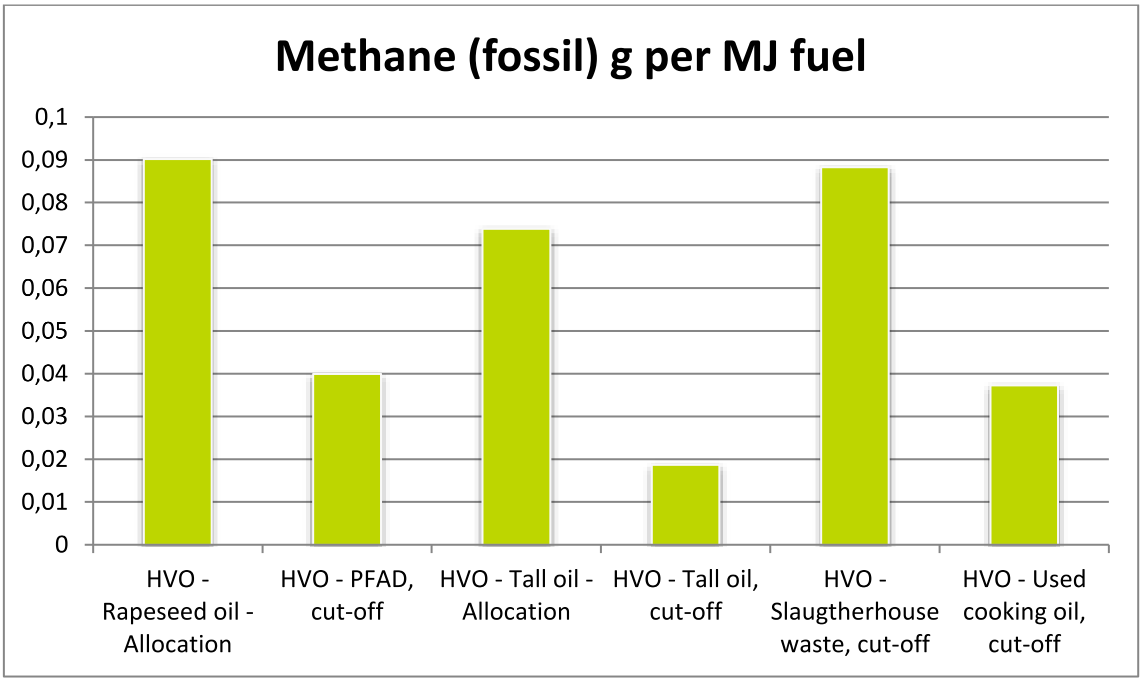

Figure A4. Methane (fossil) Well-to-tank, g per MJ fuel. After the name of each HVO type the approach for the feedstock production is stated. The cut-off approach selected to reflect RED and the economic allocation as a potential alternative. For more details regarding see section 2.3 or the each excel sheets.

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