REPORT f3 2017:20

COMPARISON OF DIESEL AND GAS DISTRIBUTION TRUCKS – A LIFE CYCLE ASSESSMENT CASE STUDY

Report from an f3 project

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report has been prepared by Volvo Group for f3 The Swedish Knowledge Centre for Renewable Transportation Fuels. 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.

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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 report uses the data from a life cycle assessment (LCA) performed for the research project "Utveckling av metodik att kommunicera miljöskadekostnadsdata". The project is financed by Energimyndigheten and project partners include IVL Swedish Environmental Research Institute, Chalmers University of Technology, AkzoNobel, SCA Hygiene and Volvo Group. In this report, an in depth analysis in the comparison of the fuel and powertrains is provided, interpreting the results of this assessment in terms of f3 focus.

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SUMMARY

This work presents a life cycle assessment (LCA) of a distribution truck for urban applications, with either a diesel or otto engine using different fossil and bio-based fuels. Impact of electrification is also briefly discussed. The impact assessment is done with both CO_2-eq emissions and environmental damage cost assessment (using the Environmental Priority Strategy methodology, EPS) to provide impact on different perspectives and times when it comes to sustainability evaluation. This somewhat broader perspective, compared to conventional well-to-wheel (WTW) analyses, can give better understanding of different environmental risks in technology development choices.

The results confirm previous studies when it comes to CO_2-eq emissions, where agricultural based biofuels show approximately 50 % CO_2-eq reduction compared to fossil alternatives and waste based fuels give approximately 80 % reduction.

In the EPS assessment, the production of the vehicle itself becomes important, and in particular the rare platinum group metals used in the after-treatment catalysts. “Design for recycling” and proper recycling schemes are necessary for long-term sustainability, something that is also a concern when electrified alternatives are to be considered.

In the use phase there are differences in EPS score for different fuels mainly due to the variations in CO_2 emissions and fossil resources use implying that the fuels with the highest impact in the CO_2-eq category also has a higher contribution from the use phase. There are, however, deviations from this pattern due to the emissions of dust particles in the processing of some of the biofuels. Dust has a high EPS score giving HVO (Hydrotreated Vegetable Oil) from palm oil and ethanol from sugar cane a higher long-term environmental cost than some of the alternatives.

SAMMANFATTNING

Projektet har utfört en livscykelanalys (LCA) av en distributionslastbil med diesel- eller otto-drivlina och olika bränslen, med fokus på både emissioner av CO_2-ekvivalenter (CO2-eq) och miljöskadekostnad (med metoden EPS – Environmental Priority Strategy). Även elektrifiering av drivlina behandlas kortfattat. Utvärderingen ger kort och långsiktigt perspektiv på olika hållbarhetsaspekter för transporter.

Resultaten gällande CO_2-eq-emissioner konfirmerar tidigare studier att grödbaserade biobränslen ger ca 50 % CO_2-eq-reduktion jämfört med fossila alternativ (skillnaderna kan dock förstås vara stora beroende på process och vilken energi som används i produktionen). Avfallsbaserade bränslen som HVO från slaktavfall och biogas ger ca 80 % CO_2-eq-reduktion.

I EPS-utvärderingen ger produktionen av lastbilen en stor påverkan, vilket till stor del beror på användningen av sällsynta platinagruppmetaller i efterbehandlingen av avgaser. Att på olika sätt i hela livscykeln underlätta för återvinning är viktigt för långsiktig hållbarhet, vilket är speciellt viktigt också när elektrifierade alternativ utvecklas.

I användarfasen beror skillnaderna i EPS-resultaten främst på variation vad gäller CO_2-emissioner och användningen av fossila resurser, vilket i sin tur innebär att de bränslen med höst inverkan på CO_2-eq också har högst EPS i användarfasen. Det finns dock avvikelser från detta mönster och för vissa av biobränslena, och det beror på utsläpp av partiklar i produktionen av bränslena. Partiklar har ett relativt högt EPS-värde och detta gör att HVO (Hydrotreated Vegatable Oil) från palmolja och etanol från sockerrör får högre miljöskadekostnad än några av alternativen.

CONTENTS

1 INTRODUCTION AND BACKGROUND

Distribution trucks are medium duty trucks used for daily distribution of goods in and around cities. A typical specification is 16 ton weight, 4x2 axle configuration (two axles, one driven) and a 300 hp (~220 kW) engine. Driving patterns include many start stops and the distances driven are shorter than for long haul highway trucks. In distribution applications, a range of different fuels can be used, for example diesel, ethanol, gas and electricity.

This report investigates the environmental impacts of mainly two different distribution truck powertrains; diesel and otto. These are in turn combined with both fossil (diesel and natural gas) and renewable fuels (HVO, ethanol and biogas). Impact on electrified powertrains is addressed briefly in the discussion, but here more background data is needed for a complete assessment.

For background on previous works on well-to-wheel (WTW) analyses and life cycle assessment of vehicles, we refer to for example the JEC study (JEC - Joint Research Centre, 2014), GREET (Argonne National Labs, u.d.) and research reports with focus on heavy duty vehicle WTW studies such as Ecotraffic 2008 (Ahlvik, 2008) and the MetDriv project (Börjesson, et al., 2017).

The LCA in this report is performed in accordance with ISO 14040:2006 (European Committee for Standardization, 2006) and ISO 14044:2006 standards (European Committee for Standardization, 2006). Impact assessment is performed in two categories in accordance with the goal and scope. The first is global warming potential (GWP), where the life cycle impact from the trucks is measured in CO2-equivalents. The second is EPS – Environmental Priority Strategy – a weighting method which estimates the cost our resource depletion and emission damage will have (Steen, 2015) (Steen, 2015). Using both these categories gives insight into environmental impacts on different time scales; global warming ~100 year and EPS 1000+ years.

In the comparison of fuels and powertrains for vehicles, there is normally a focus on CO_2 equivalent emissions in the well-to-wheel phase (WTW). By using LCA we want to extend the comparison between different fuels and powertrain combinations in two ways. Firstly, we want to include the long-term resource perspective when it comes to fuels, by including EPS assessment. Secondly, we want to include also the impact from the vehicle production itself, which is included in LCA but excluded in WTW assessments.

2 GOAL AND SCOPE

The goal of the LCA is to assess the environmental impact of two distribution trucks with either diesel or otto gas engine using different fuels; diesel, HVO, ethanol and gas. The assessment determines the impact in the global warming potential category, as well as in the EPS weighting method. The assessment covers impact of the different life cycle stages like raw material extraction, manufacturing, use and recycling.

Table 1 gives an overview of the studied powertrains and fuels. The assessment is an initial screening and aims to identify the most important risks and opportunities with each powertrain and fuel (regarding both long term material resource usage and shorter term global warming potential).

Table 1. The LCA consist of several cases with the goal of being able to identify the major environmental risks and opportunities with each driveline and fuel type.

Fuel	**Powertrain**	**Fuel consumption MJ/100km**
Diesel + 7%FAME	Diesel, 9l engine	890 (42,7 MJ/l)
HVO	Diesel, 9l engine	890 (44,1 MJ/l)
Ethanol	Diesel, 9l engine	890 (25,7 MJ/l)
Natural gas an biogas	Gas, 9l engine	1070 (20% more than for the diesel driveline) (Biogas: 45,2 MJ/kg) (Nat gas: 49 MJ/kg)

Functional unit

The desired function in this study is transport of goods during a defined period of time (lifetime of the truck). Therefore the functional unit for the LCA is:

- A distribution truck during its entire lifetime able to distribute according to demands on current diesel trucks.

The amount of material needed, thickness, weight and durability all relate to being able to perform this function.

Limitations and cut-off

Only the trucks and fuels are included, maintenance infrastructure or user facilities are not included.

In general, all processes not directly linked to the trucks are excluded, including transportation, maintenance, losses in assembly and quality testing etc.

3 RESULTS

3.1 LIFE CYCLE INVENTORY

The LCI data in this study are based on a typical medium duty diesel truck configuration. For the gas truck, changes to fuel tanks and aftertreatment system have been done, as these are seen as the main differences. Below is a summary of the input data used:

Table 2. The table presents an overview of the data collected for the LCA and the sources used.

Life cycle stage	Source
Materials	Typical material composition of a medium duty truck, 300 hp 9l engine, 16 ton weight, 4x2 axle configuration • Diesel Euro VI aftertreatment including SCR (Selective Catalyst Reduction) catalyst and particle filter • Gas Euro VI aftertreatment including three way catalyst Extraction and processing of raw material taken from data sets in the LCA software GaBi.
Manufacturing	Data from Volvo Group environmental report, vehicle and engine plant operations
Transports	Internal transports between Volvo Group manufacturing sites located in EU
Maintenance	Service and exchange of parts according to maintenance protocol.
Use phase	The total driving distance for the truck was assumed to be constant for the different cases; 600 000km. Fuel consumption according to table 1. Fuel production data from GaBi. Tail pipe emissions are taken from f3 report 2013:29 (Hallberg et al).
End of life	Three scenarios, see chapter 3.3.

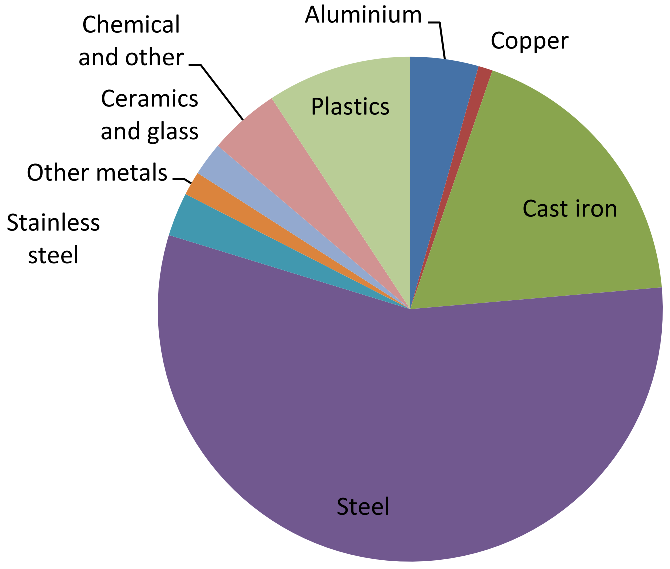

Figure 1. Material composition of the diesel and gas truck. On a mass basis it is steel and cast iron that dominate.

Figure 1 shows the result of the material composition assessment for the diesel and gas trucks. Steel and cast iron are a large part of any truck material composition. The change in powertrain does not impact overall material composition to a great extent, and therefore the chart in figure 1 is representative for both alternatives.

What the large scale overview of the material composition does not show, however, is the increased use of very rare and expensive materials like platinum group metals in the catalyst (or rare earth elements for electric motors in electrified powertrains). These materials are not present in the vehicles in any large volumes, but since they are scarce they come at a large cost and cause large environmental impact in the material depletion area (seen in the EPS results).

Fuel production data is taken from Gabi (thinkstep) and f3 report 2013:29 (Hallberg, 2013). Table 3 gives a summary of the fuel pathways used in this study. The pathways are chosen as representative for fuels from fossil source and biofuels from crops and wastes.

The tailpipe emissions are taken from f3 report 2013:29 (Hallberg, 2013).

Table 3. The fuel pathways that were used in this study are presented in the table together with the sources used for assessing the environmental impacts of the fuels.

Fuel	**Production data from GaBi**
Diesel+FAME	EU-27: Diesel mix at filling station (100 % fossil) EU-28: Biodiesel based on rape seed methyl ester (RME)
HVO	FI: Hydrotreated Vegetable oil (HVO) from palm oil FI: Hydrotreated Vegetable oil (HVO) from beef tallow
Ethanol	EU-27: Bioethanol from corn EU-27: Bioethanol from sugar beet EU-27: Bioethanol from wheat
Gas	Biogas: Only electricity allocated to gas production from sludge: SE: Electricity grid mix GLO: Compressed natural gas (CNG) RER: Natural gas PlasticsEurope EU-28: Electricity grid mix

3.2 LIFE CYCLE IMPACT ASSESSMENT

Figure 2 shows the global warming potential (GWP) of the fuel and powertrain cases that are investigated in the study. With a conventional fuel like diesel, the global warming emissions are almost entirely from the use phase, from both the production of the fuel itself and from the emission from driving. For the biogas produced from waste resources and HVO from beef tallow, the use phase and the production stages are in the same order of magnitude. The low impact from the production stage is due to the fact that no environmental impact from the upstream handling of the feedstock (sludge or tallow) is included in the fuel life cycle. Additionally, emissions resulting from land use change are not included. Energy allocation between the HVO and byproducts is used for the refining stage.

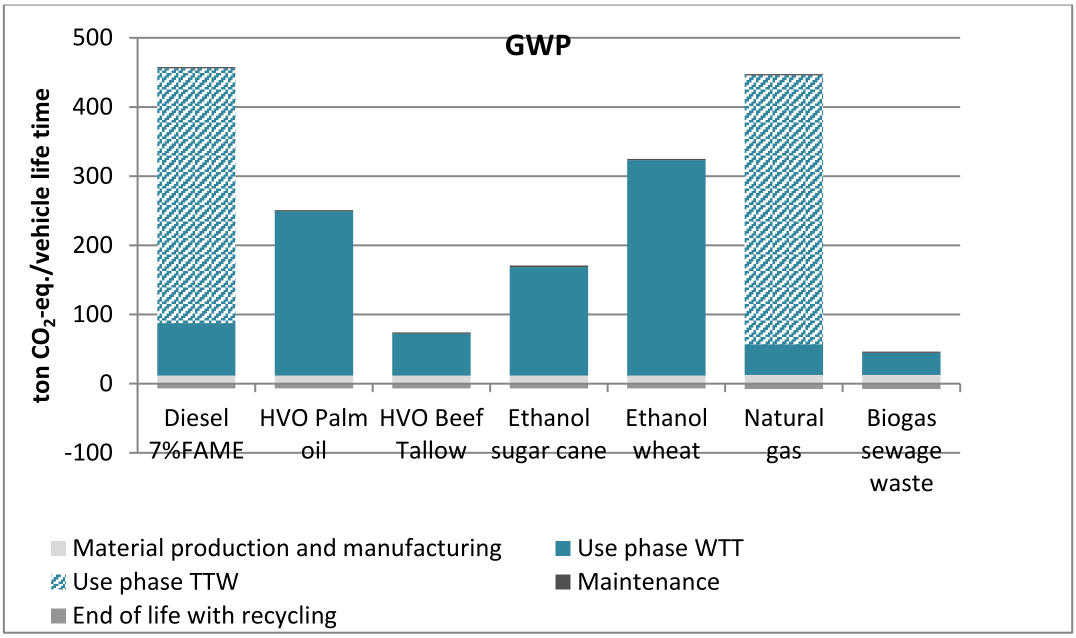

Figure 2. Global Warming Potential for the studied fuel/powertrain combinations: diesel engine - B7, HVO and ethanol (ED95) and Otto engine – natural gas and biogas from sewage sludge.

In comparison of the GWP data it can be noted that the fossil fuel based alternatives, diesel and natural gas have a similar result. We would like to emphasize here that we model distribution driving with one typical duty cycle. In real situations there is a range of different driving patterns that could influence the result, and a more in depth analysis should be done in each specific case. For example, the diesel engine has a benefit when it comes to fuel efficiency, while the otto gas engine may have emissions benefits in urban driving.

HVO from palm oil and ethanol from sugarcane/wheat are selected as examples for crop-based biofuels. Ethanol from wheat (in this case process driven by natural gas), has a relatively high GWP. It should be noted, however, that using a bioenergy heating and CO_2 capture can significantly improve the result for wheat-based ethanol. HVO from palm oil and ethanol from sugarcane have similar GWP result.

With the allocation chosen in this study, HVO from beef tallow and biogas from sewage sludge are examples of waste based biofuels. They have similar GWP, although slightly in favor for biogas.

The EPS results of the different powertrain and fuel combinations are shown in figure 3. A first observation is the large impact from the materials used in the gas truck. The difference comes from the platinum group metals catalysts material in the exhaust after treatment system, used to reduce NO_x emissions. The catalyst in the gas truck requires considerably larger amounts of platinum group metals compared to the diesel catalyst.

In order to understand why this makes a difference in the EPS score we must understand that platinum group metals are very uncommon in earth’s crust. This implies that our depletion of reserves will cause the need for future generations to extract platinum group metals from a source with very low concentration – at a very high cost. Other metals may have a much lower environmental cost as they are more abundant in the crust.

In the diesel case 87 % of the EPS score from production and material comes from the platinum group metals. For the gas otto case it is 97 %. This also implies that there are significant benefits when properly recycling these materials, and the difference between different drivelines when including recycling is much smaller.

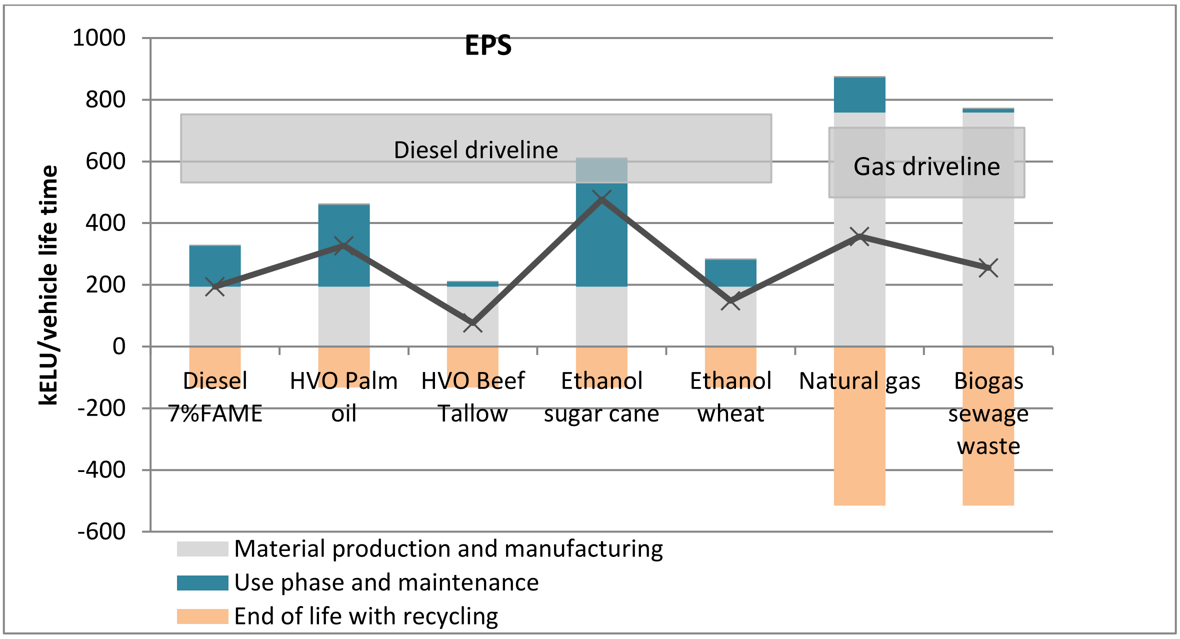

Figure 3. The figure shows the contribution to the EPS score of the vehicles from different life cycle stages. The total impact is given by the line. It is clear that the difference in scarce metal use is important, as well as the recycling of these materials. Additionally, particle emissions and carbon dioxide emissions are important in the use phase.

The use phase gives a relatively low contribution to the EPS score especially in light of its long duration. The contribution of the use phase to the EPS score is mainly from the depletion of fossil resources (oil) or from CO2 emissions when producing and using the fossil fuels. For the HVO from palm oil and the ethanol from sugar cane there is an additional impact from the emission of dust particles in the production of the fuel.

The emission of dust is what allows the EPS of the use phase to deviate from the use phase results in the global warming potential category, clearly exemplified in the case of ethanol from sugar cane. The conclusion of this observation is that dust is an important emission to consider when evaluating environmental damage cost with the EPS method.

3.3 SCARCE MATERIAL AND THE IMPORTANCE OF RECYCLING

Three recycling cases are included in this LCA. The first represents a current best-case scenario. In this scenario, it is assumed that the collection follows the best possible collection rates for the materials in the automotive sector, according to estimates of industry data, and that the materials are recycled to a high quality. High quality implies there is a detailed sorting allowing high value steels to be recycled to the same grade.

The second case represents a more modest estimate of the current situation where the collection rate is set below best case based on the size distribution of parts. The quality factor is changed to represent the change in value from primary material to average scrap, implying that we assume a less quality oriented sorting.

The third case, no recycling, assumed that we do not perform any end of life recycling, and the life cycle is cut off after the use phase.

Table 4. The chosen end of life cases are a rough first estimate of different recycling cases. The best case is represented by industry figures for collection and high level sorting of metals fractions. The moderate case assumes only larger parts to by sorted, as well as a lowered quality due to downcycling, especially of high-alloyed steels. The cases are EU focused.

	Current best case		**Current moderate case**	
Material	Collection rate	Quality factor*	Collection rate	Quality factor
Aluminium (European Aluminium Association (EAA), 2006)	0,9	0,9	0,9	0,9
Copper **	0,6	1	0,6	1
Steel	1	1	1	0,5
Stainless steel (Reck & Graedel, 2009)	0,87	1	0,82	0,6
Platinum group metals (Hagelüken, et al., 2005)	0,9	1	0,7	1
Lead in battery	1	1	1	1
Tires	1	0,25	1	0,25

*Quality factor based on relation between primary and secondary material pricing.

** Estimation, cables recovered

The value (or credit) of what is recovered in end of life depends both on how much of the material that is recovered, and also on the state in which it is recovered. The recovered material is seen as a negative impact in the life cycle, and the size of this negative impact (or credit) depends on the quality and amount recovered. If the material is in a worse state than the pure material, the value for future generations has decreased, and the difference is visible in the life cycle of the product. The impact of this difference can be seen in Figure 4.

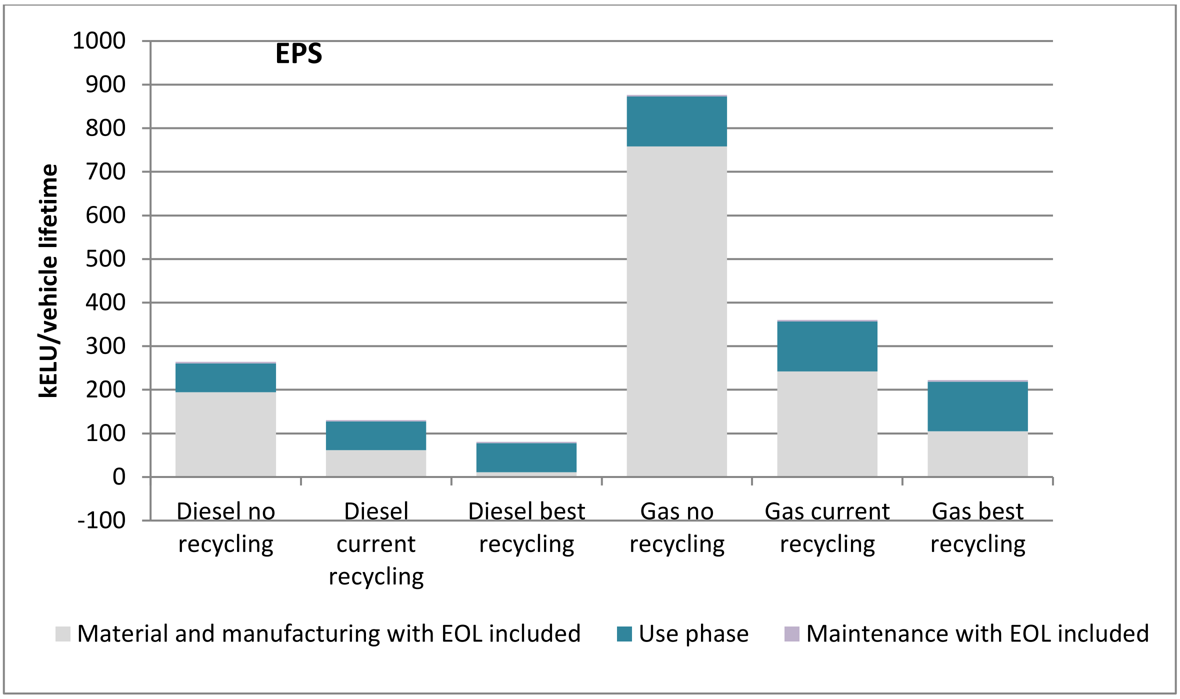

Figure 4. EPS score depending on the three recycling scenarios, for diesel driveline (fossil diesel) and otto gas driveline (natural gas).

A larger amount of valuable materials also implies larger benefits in the recycling stage, but for sustainability recycling is necessary for all materials. Recycling of platinum group metals from exhaust aftertreatment catalyst is one of few examples where scare materials are recycled to a high extent. This is mainly possible due to the good knowledge of its location in the truck and the relatively high amounts present. The effect of this can be seen in the results for the best case diesel recycling.

4 DISCUSSION AND CONCLUSIONS

For distribution trucks using conventional fuel, like diesel, the life cycle global warming impact is dominated by the use phase driving, while the impact from the vehicle itself is relatively small. The CO_2-eq emissions from the diesel truck and the spark-ignited truck fueled by natural gas are similar. For biofuels, the CO_2-eq emissions are highly dependent on the feedstock and the source of energy used in the production process. In this report, we show data for selected fuels from an agricultural feedstock. As shown here, and in many other studies these give a CO_2-eq reduction of approximately 50 % compared to their fossil counterparts. It should be noted that this is without indirect land use (iLUC) change effects taken into account. Fuels from waste based alternatives, HVO from beef tallow and biogas give significant CO_2-eq reduction, approximately 80 %.

In the EPS assessment, the impact from the fuel in the use phase is comparable to the impact from the vehicle itself. For the use phase, the impact is a combination of the depletion of the fossil resource, as well as the cost of the CO_2 emissions when driving. In the production phase, it is mainly due to the use of scarce material resources.

Platinum group metals and rare earth elements are two important groups of scarce materials, and they present both a sustainability issue as well as a short-term economic risk. The EPS assessment makes it clear that good recycling is crucial, to begin with when it comes to these critical material groups, but in the long term also on all materials. Proper recycling significantly lowers the impact of material depletion, and as a result, it evens out the results between different drivelines.

4.1 REFLECTIONS ON THE USE OF EPS FOR COMPARISON

LCAs of heavy-duty vehicles often show a large impact from the use phase. This is due to the long duration of this life cycle stage, the fact that often focus is only on CO_2 emissions, as well at the fact that large amounts of diesel are consumed in total. Here EPS assessment also is included which highlights that resource consumption also plays an important role when focusing on long term implications of environmental impacts.

The results from the EPS assessment do not imply that we can stop focusing on global warming, but it can help us understand the risks with incorporating too many rare materials without having strategies to ensure that they are returned to the loop after use in our products. Additionally, for biofuels we must have a more detailed assessment of particle emissions during production, since these also impact the environmental damage cost due to their costly impact on human health.

EPS can help us when, for example, looking at components to focus extra attention on in the work towards circularity and increased recyclability. EPS can support decisions for what is long term sustainable, but cannot serve as a sole guide to what it environmentally beneficial in a shorter time frame.

4.2 POTENTIAL IMPACT OF ELECTRIFICATION

Partly because of lack of complete data, hybrid and full electric trucks are excluded from this study. There is, however, considerable current technical development in this area, which makes it relevant to briefly discuss in light of the aim of this study: to include also environmental considerations for the vehicle itself in the assessment.

Battery production can give a high contribution to GWP, as has been shown in previous studies IVL report C243 (2017). The results are sensitive to electricity mix in the country/region of production and there is need for more research studies in this area to fully understand the impacts. There is also need for scenario work as current LCAs are for current small series production.

What is clear, however, is that there is a shift of materials when moving from conventional powertrains towards electrified. The amount of steel and cast iron is reduced, while more copper wiring is introduced, along with battery materials, chemicals and more stainless steel. Since currently cast iron and steel are the materials in the truck with the best recycling chains, this change implies a challenge for recycling and material management.

These effects on the production and recycling stages of the life cycle as less frequently discussed than the benefits of electrification in the use phase. An electrified truck has zero local emissions of NO_X and SO_X, which can be highly beneficial to human health. Additionally the reduced noise is important. Despite this, the production cannot be ignored.

Zero local emissions does not imply zero emissions in the use phase either, it is dependent on the production of the electricity. Electricity does, however, have an advantage over fossil-based fuels, as it is not inherently carbon based making it more open to improvements.

4.3 RECOMMENDATIONS

The results indicates that there can be more than one recommendation for changes in the driveline, and that the different powertrains and fuels can, and need to be, combined in different ways depending on local market, application, driving, customer etc.

We suggest that improving the environmental performance of distribution trucks is not a question of right or wrong, but of different perspectives that have to be weighed together. The different fuels provide different benefits and come with different risks, which can be long and short term. In the development of new technologies for trucks, it is important to take into account the relevant aspects and perspectives: e.g. climate, emissions and material aspects. Looking too much at only one environmental aspect may lead to creating other problems in the end.

Looking at the material consumption, the main recommendation based on this assessment is to focus on recyclability and recycled input to ensure long-term sustainability. Increased use of electronics, as well as the use of platinum group metals is connected with a long-term environmental risk. Maximizing the life cycle utilization of these parts in turn represents a large step towards a circular business, as well as sustainability. For electrified trucks, it is recommended to work further with the production and recycling.

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