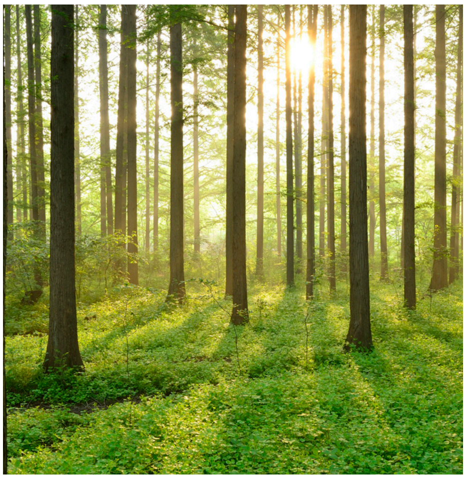
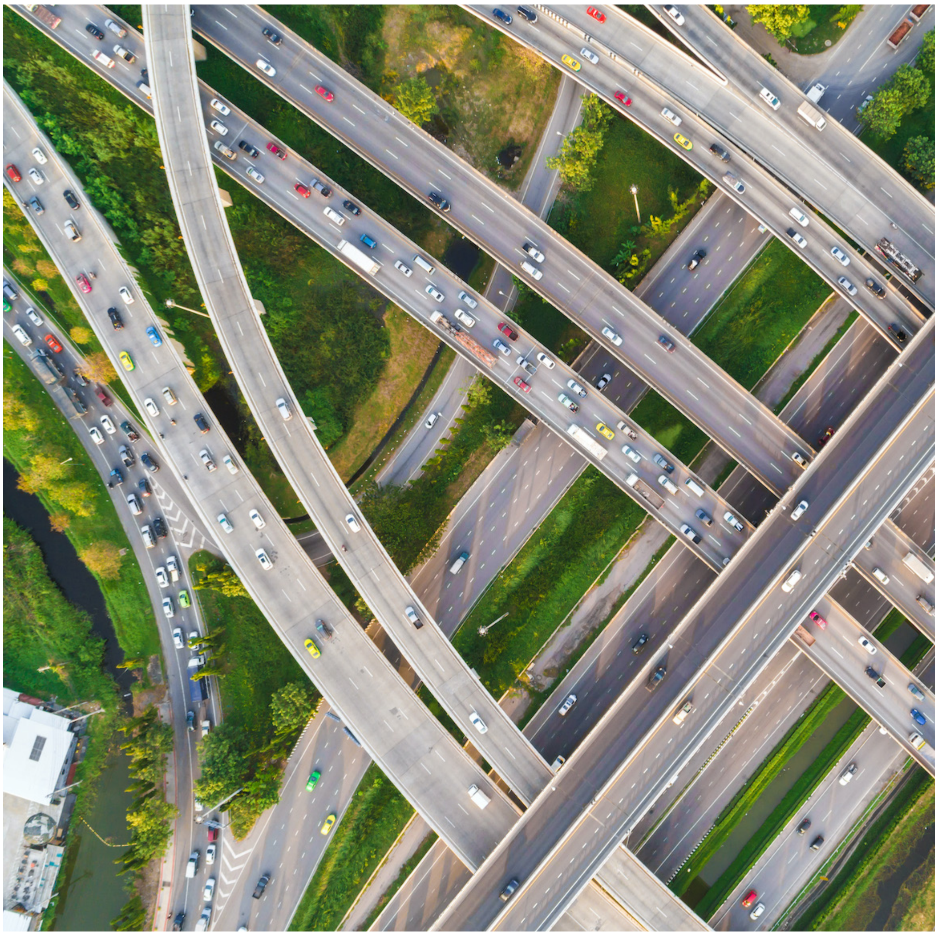
CLIMATE IMPACT OF A PASSENGER CAR IN SWEDEN

REPORT 2021:724



Energiforsk

Climate impact of a passenger car in Sweden

Total CO_2 equivalent emissions of a passenger car in Sweden from a life cycle perspective

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ISBN 978-91-7673-724-8 | © Energiforsk March 2021

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Foreword

Understanding of the environmental impact of different fuels and drive lines is important to reach the climate target for the transport sector. This report analyses the total CO_2 equivalent emissions of a passenger car in Sweden from a life cycle perspective. The results could be used for more well informed decisions.

The results and conclusions of this project *Climate impact of a passenger car in Sweden* has been conducted by Roger Gottleben, Adriana Tellez, Karina Puurunen and Henna Poikolainen at AFRY Management Consulting Oy. The model used in the analysis is developed by AFRY using only open-source data.

These are the results and conclusions of a project conducted by AFRY Management Consulting OY on commission by Energiforsk, financed by Neste AB. The authors are not responsible for the content towards any third parties.

Summary

This report analyses the total CO_2 equivalent emissions of a passenger car in Sweden from a life cycle perspective, using a model developed by AFRY from open-source data. The goal of the study was to indicate quantitatively how selected fuel types in the current Swedish market compare with each other in terms of greenhouse gas (GHG) emissions, accounting all stages in the vehicle and fuel life cycle, i.e. production of vehicles, use phase of 200 000 km and the vehicle end-of-life. In addition to conventional fuels and electricity, biofuels and hydrogen were included.

In Sweden, the climate footprint of a passenger vehicle ranges from 9 ton to 37 ton of CO_2-eq (47 gram CO_2-eq/km to 182 gram CO_2-eq/km) during its lifetime. Biofuel, biogas and electricity powered vehicles can have three times lower climate impact than the cars using conventional fuels. Electric cars have the lowest climate impact of 9 ton of CO_2-eq (47 gram CO_2-eq/km), closely followed by biofuel and biogas. The highest climate impact results from using conventional gasoline as a fuel, i.e. 37 ton of CO_2-eq (182 gram CO_2-eq/km).

In the use phase, electric cars fueled with Swedish electricity mix have the lowest emissions of 0.6 ton of CO_2-eq. However, the production phase of electric cars contributes more significantly to the total GHG emissions than that of internal combustion engine vehicles, due to the emissions related to battery production.

The diesel blend of reduction quota 2019 results in 27.6 ton of CO_2-eq emissions during the vehicle life cycle, which is 16% lower than that of 100% diesel. For the reduction quota 2030, the diesel blend results in roughly half of the CO_2 emissions compared to those of 100% diesel. The plug-in-hybrid with 50 km of electric range results in roughly half of the GHG emissions during its life cycle compared to the conventional gasoline.

The climate impact of hydrogen vehicles is higher compared to other alternatives for conventional fuels due to the chosen hydrogen production pathway, which utilizes natural gas as raw material, currently the most common technique. With advanced production methods, e.g. electrolysis using low carbon electricity, hydrogen could fall in the same range of GHG emissions as electricity or neat biofuels.

The sensitivity analyses showed large variations of GHG emissions among the same fuel type produced from different sources, which can be further strengthened by assumptions on the production stage, e.g. the total CO_2 emissions of a car fuelled with HVO ranges from 11 ton of CO_2-eq (HVO from animal fats) to 21 ton of CO_2-eq (HVO from rape seed).

The assumptions and limitations of publicly available sources used in the model directly affect the results. Thus, when interpreting the results, getting acquainted with the assumptions on the main sources is encouraged. Due to data scarcity, sources with heterogeneous assumptions were accepted. Therefore, the results should be interpreted as indicative.

Utökad sammanfattning

Denna utökade sammanfattning beskriver resultaten i föreliggande rapport där klimatpåverkan från olika bränslen över ett passagerarfordons hela livscykel jämförs. Den inhemska transportsektorn i Sverige, ej medräknat inhemskt flyg, behöver reducera sina utsläpp med 70 % till 2030 jämfört med 2010 års nivåer. För att uppnå detta är en förståelse för den totala klimatpåverkan som olika bränslen och drivmedel har viktigt för både konsumenter och beslutsfattare för att skapa förståelse och största möjliga utsläppsreduktion.

Energiförbrukningen i den svenska transportsektorn var 2017 88 TWh, varav petroleumbränslen stod för 75 % och biobränslen för 22 % av totalen.[1] För att visa vilken utsläppsreduktion som är möjlig, jämför denna studie klimatpåverkan från en rad olika bränslen över en passagerarbils hela livslängd.[2] De bränslen som ingick i studien valdes på grundval av att de är de vanligast förekommande bränslena på den svenska marknaden.

Öppet tillgängliga källor har legat till grund för det modellerade resultatet.[3] Bristande tillgång till data ledde därmed till att källor med heterogena antaganden och avgränsningar inkluderades. De resultat som presenteras bör därmed tolkas som indikativa.

Flertalet känslighetsanalyser genomfördes därför för att illustrera betydelsen av vissa antaganden och i vilken omfattning de påverkar slutresultatet. Till exempel har råvara för produktion och utformning av produktionsled en betydande påverkan på alla typer av bränsle, från HVO till elektricitet. Genomgående belyser känslighetsanalysen variationer i utsläppsnivåer inom samma bränsletyper producerade från olika råvaror, vilka ytterligare kan förstärkas genom antaganden rörande produktionsledet.

STUDIENS RESULTAT

De modellerade utsläppen av växthusgaser, under ett fordons hela livscykel, resulterar i mellan 9 ton till 37 ton CO_2-ekv antaget svenska förhållanden och energimix.[4] Lägst klimatpåverkan har elektriska fordon tätt följt av biobränslen och biogas. För en översikt av ingående bränslen och resultaten av klimatpåverkan

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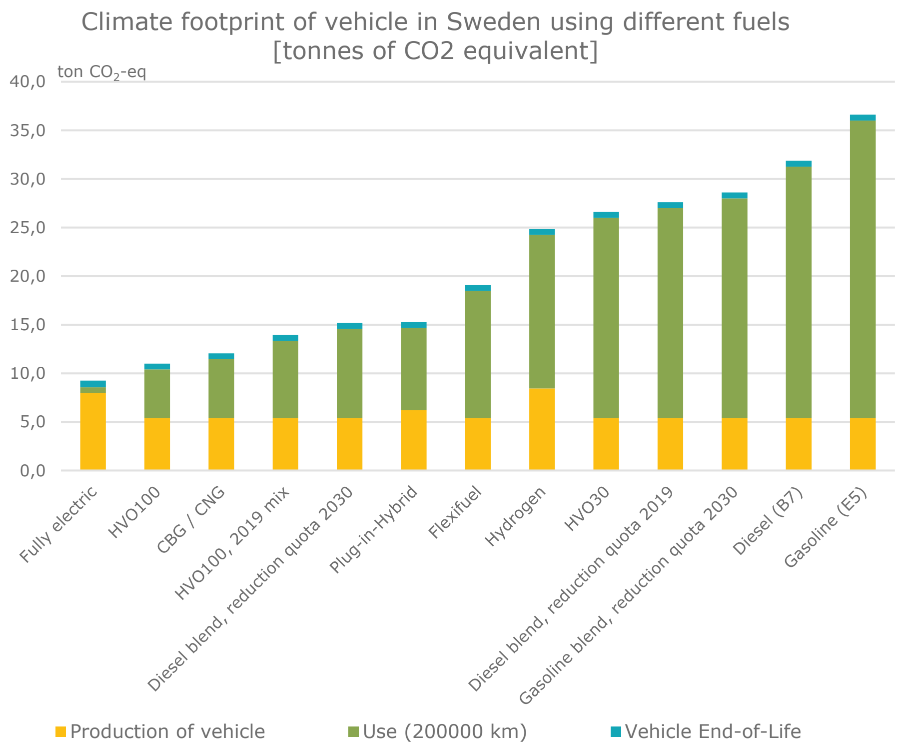
[1] Energy in Sweden, 2019

[2] I denna studie antas en bils livslängd vara i 200 000 km. Livscykeln delas upp i fyra segment: fordonsproduktion, användning (vilket inkluderar förbränningsavgaser samt produktion av drivmedel), batteribyte för elbilar, och hantering vid livscykelns slut. Den bil som använts för modelleringen är en standard sedan, C Segment, vilket är den vanligast förekommande passagerarbilen i Europa.

[3] I huvudsak användes främst tre källor för datainsamling: JRC, EUCAR, CONCAWE, JEC, 2020; Ellingsen et al. 2016; Emilsson & Dahllöf, 2019.

[4] Enligt en rapport från Energimyndigheten 2019 består den Svenska elmixen av 40 % vattenkraft, 39 % kärnkraft, 11 % vind and 10 % kraftvärme.

över livscykeln se Figur 1. För en översikt av utsläpp uppdelat över livscykeln var god se Tabell 3 på sidan 14.



ANTAGANDEN OCH DESS PÅVERKAN PÅ RESULTATEN

Under användningsfasen resulterar elbilen i absolut lägsta utsläppsnivåer, 0,6 ton CO_2-ekv, med en svensk el-mix som bränsle. Då batteritillverkning resulterar i höga utsläpp i relation till tillverkning av fordon med förbränningsmotor blir slutresultatet över livscykeln 9,3 ton CO_2-ekv eller 47 gram CO_2-ekv/km, vilket är något lägre än motsvarande värden för HVO 100 baserat på animaliska fetter (11 resp. 55)

Utsläppens storlek för dessa två alternativ är beroende av hur bränslet produceras. I denna studie har HVO modellerats med antagandet att animaliska fetter används som råvara vid framställning av bränslet. Rapsolja som råvara ger nästan dubbelt så höga utsläpp, 21 ton CO_2-ekv, och leder till att HVO baserad på rapsolja placeras på en åttondeplats bland ingående bränslen.[5] Om elbilen istället laddas med en europeisk energimix resulterar elbilen i nästan 17 ton CO_2-ekv och hamnar på en sjundeplats.

CBG/CNG (Compressed Bio Gas / Compressed Natural Gas) resulterar i den svenska kontexten i hög emissionsreduktion som ett resultat av den stora mängd

[5] Bränsletypen i modelleringen är baserad på uppskattade svenska medelvärden.

biogas som används. I Sverige bestod 2017 CBG/CNG av 90% biogas (CBG), men med 100 % naturgas (CNG) hade klimatpåverkan istället varit nära den av bensin och högre än konventionell diesel över livscykeln.

JÄMFÖRELSE MED TRADITIONELLA BRÄNSLEN

Även med annan energimix än den svenska och HVO producerat av raps resulterar elbilen och 100% HVO i betydande utsläppsreduktion i jämförelse med traditionella fossila bränslen. Jämfört med en bensindriven bil resulterar till och med en hybrid, med 50 km räckvidd vid batteriframdrift, i nästan hälften så stor klimatpåverkan över livscykeln.

Utblandning av diesel med biobränsle enligt reduktionskvoten för 2019 resulterar i 16% lägre utsläpp i jämförelse med 100% diesel. När reduktionskvoten för 2030 uppnås resulterar detta i ungefär hälften så stora utsläpp som 100% diesel. För bensin resulterar 2030 års kvot i 23% lägre utsläpp än 100% bensin.

VÄTGASENS ROLL

På den svenska marknaden har vätgasfordon relativt hög påverkan i jämförelse med andra bränslealternativ som ingick i studien, vilket beror på de antaganden som gjorts för produktion. I dagsläget är det vanligast att naturgas (CNG) används som råvara för vätgasproduktionen. I framtiden förväntas däremot påverkan bli lägre och snarlik den för fullt batterielektriska fordon. Detta om teknologiska framsteg uppnås och möjliggör effektiv vätgasproduktion med förnybar el genom elektrolys. Däremot kunde inga primärdata för vätgasfordon återfinnas i dagens utvecklingsläge inom vätgas.

List of content

1 Introduction

This report analyses the total CO_2 equivalent emissions of a passenger car in Sweden from a life cycle perspective.

Environmental issues, climate change in particular, pose a significant pressure on the ability of societies to meet human ends. The transport industry is trying to develop more climate-friendly solutions with new vehicles and fuels entering the market. In this changing environment, it is important for both consumers and decision makers to understand the environmental impact of different fuels and vehicles available to be able to make well-informed choices.

The goal of this study is to indicate quantitatively how selected fuel types in the current Swedish market compare with each other in terms of greenhouse gas (GHG) emissions, accounting all stages in the vehicle and fuel life cycle, i.e. production of vehicles, use phase of 200 000 km and the vehicle end-of-life. In addition to conventional fuels and electricity, biofuels and hydrogen are included in this study. The emphasis has been to use only one main source per life cycle phase, thus minimizing the inconsistency in the underlying assumptions. However, as data available for the purposes of this analysis are limited, some unavoidable variation between the assumptions of the studies exists. The evaluation is limited to publicly available reports, thus the full transparency on the background data used was not possible.

Based on the results, the climate footprint of a passenger vehicle ranges from 9 ton to 37 ton of CO_2-eq in Swedish conditions during the vehicle lifetime from production to end-of-life treatment of the vehicle. Cars fueled with either neat liquid biofuels, biogas or electricity are the most competitive in terms of the CO_2 equivalent emissions during the vehicle lifetime, electric cars marking the lowest climate impact with 9 ton of CO_2-eq during the vehicle lifetime (47 gram of CO_2-eq per km). The highest climate impact results from using conventional gasoline as a fuel. The total lifetime emissions of a passenger vehicle fueled with conventional gasoline are 37 ton of CO_2-eq (182 gram of CO_2-eq per km).

Total energy use in the Swedish transport sector in 2017 was 88 TWh, of which petroleum products accounted for 75% and biofuels for 22%[6]. To reduce greenhouse gas emissions, Sweden implemented a GHG reduction regulation in 2018, which mandates biofuels in diesel and gasoline[7]. The domestic transport sector (excluding aviation) is required to reduce GHG emissions by 70% by 2030 compared to 2010 levels. Other actions supporting the GHG reduction is for example the bonus-malus system, which favors cars with CO_2 emissions below a certain level with a premium (bonus) and punishes cars above a certain CO_2 emission threshold with an increased vehicle tax (malus)[8].

[6] Energy in Sweden 2019

[7] Regulation (2018:195) on the Reduction of Greenhouse Gas Emissions

[8] Transportsektorns klimatmål, 2019

2 Scope and method

This study compares the climate impact of various fuel types during the life cycle of a passenger vehicle in the current Swedish market. The life cycle of a vehicle is assumed to be 200 000 km. The used vehicle is a standard sedan, "C segment" car, e.g. Volkswagen Golf, as it is the most widespread European segment of passenger vehicles.[9]

2.1 METHODOLOGY

The climate impact of a passenger car in Sweden is calculated by combining GHG emission sources from various stages of the vehicle life cycle. The life cycle emissions of a passenger vehicle are divided into three main segments: vehicle production, use phase and end-of-life treatment. The use phase comprises exhaust emissions and the production of fuels.

In selecting the literature sources, emphasis was put on minimising methodological variation between fuel or car types (e.g. HVO vs. electricity) to allow for comparison. However, some unavoidable variation in calculation methodology between lifecycle stages (e.g. car production vs. vehicle use) occur due to differences in the underlying assumption between sources.

The data used in the modelling are derived mainly from three sources:

- The emissions of the fuel production and vehicle use phases are based on the JEC Well-To-Wheels Report v5 [9]
- The vehicle production and end-of-life (excluding battery) emissions are based on the Ellingsen study [10]
- The battery production emissions are based on the IVL study [11]

The data in these three studies include a number of countries and a wide range of various fuels. Thus, a selection criteria for relevant fuels in Sweden had to be established. The selection of the fuels for the analysis was based on the "Komplettering till Kontrollstation 2019 för reduktionsplikten" report [12], which estimates the average GHG emissions per fuel type in the Swedish market in 2019 based on the Swedish GHG reduction mandate. The selected fuels used in the model is presented in Table 1. As the GHG emission range within each fuel segment is wide, the results of other relevant fuels within each category are compared in the sensitivity analysis part of this report.

[9] JRC, EUCAR, CONCAWE, JEC Well-to-Wheels Report Version 5 (2020)

[10] Ellingsen, The size and range effect: Lifecycle greenhouse gas emissions of electric vehicles" (2016)

[11] IVL, Lithium-Ion Vehicle Battery Production (2019)

[12] Komplettering till Kontrollstation 2019 för reduktionsplikten, (2019)

Table 1. Fuel selection. The chosen JEC values applied were selected to represent the Swedish averages for GHG emissions

Total GHG emissions including combustion closest to Swedish average [gram CO_2-eq / MJ]			
Category	Expected Swedish average[12]	Value of the fuel chosen to represent Swedish market	Range of relevant fuels in JEC study[13]
FAME	28.5	31.8	12 - 60
HVO	12.0	17	11 - 60
Ethanol	26.0	23.5	17 - 82

What type of raw material is used in the production of HVO100 is important for the GHG-value. Using only waste and residues, such as animal fats, gives a high GHG reduction potential and is used for modelling purposes. In addition to HVO based on the table 1 selection criteria, HVO mix of 2019 was added to the results. That's the latest official statistics from the Swedish Energy Agency regarding the share of different raw materials for production of HVO sold on the Swedish market[14].

Swedish market fuels are blends and therefore an approach for converting the volume basis to energy basis had to be established. The conversion was based on the fuel properties described in the JEC study[15].

For the production phase emissions of the batteries, a 2019 IVL study was chosen to battery production. In the earlier studies, the production and end-of-life emissions of the battery production per capacity unit were multiple times higher than in the most recent estimates. On the other hand, battery capacities have increased in the modern electric vehicles, thus offsetting the benefits of the lowered CO_2 emissions per kWh of a battery produced. The battery sizes used in the model are based on the 2015 vehicle specifications in the JEC report: 21 kWh for fully electric and 10.5 kWh for plug-in hybrid. JEC defines only two alternatives for electric vehicles, either 2015 or 2025+ specification. After comparing these two alternatives, the 2015 was a better representative for the electric vehicle fleet in Sweden. The battery production is assumed to use virgin materials, and the batteries are not expected to have a second life in the presented results. The estimated effect of a battery's second life is presented in the sensitivity analysis part of this study. The chosen GHG emission value for produced capacity of battery in the model, 77 kg CO_2-eq per kWh battery capacity, is in line with the IVL report as well as the PEFCR (2018) report[16].

As the geographical scope of the JEC report is Europe, a method to evaluate the Swedish electricity mix in the model was established. According to Swedish

[13] JRC, EUCAR, CONCAWE, JEC Well-to-Tank report v5 (2020)

[14] ER 2020:26, Drivmedel 2019 (2020)

[15] JRC, EUCAR, CONCAWE, JEC Well-to-Wheels report v5 (2020)

[16] PEFCR – Product Environmental Footprint Category Rules for High Specific Energy Rechargeable Batteries for Mobile Applications (2018)

Energy Agency's report[17] The Swedish electricity mix consists of 40% hydropower, 39% nuclear, 11% wind and 10% CHP. Based on Biograce[18], Swedish electricity produces 6.1 gram of CO_2-eq emissions per MJ. This figure was used to determine the emissions of electric vehicles.

The production stage emissions of hydrogen vehicles are not included in the main sources used. Thus, the production emissions of hydrogen vehicles are estimated based on the LCA comparison study of BEV and PHEV[19] (2013). This study was selected as it also contains production phase emissions of BEV and those results are in agreement with the Ellingsen study that is used as one of the main sources for the model. In addition, the end-of-life (EoL) emissions of hydrogen vehicles are estimated based on the Ellingsen study[20], (2016). However, as hydrogen fuel cell vehicles are not commercially produced, the results rely heavily on simulation and estimations. Based on these sources, the production and EoL emissions of hydrogen vehicles are approximately 4% higher than that of the production of an electric vehicle. In the model, all ICE vehicles are assumed to have similar production and EoL emissions as the C-segment vehicle described in the Ellingsen study.

2.2 ASSUMPTIONS AND LIMITATIONS

Multiple sources were used to cover all the inputs needed in the model for this study. Due to limited data availability, some methodological variances between the sources had to be accepted. Differences include varying functional units, temporal scopes and different allocation methods. However, as the project's purpose was to give indicative qualitative results to serve rather as a pre-study, data selection criteria were established as relatively low.

Table 2 highlights some of the most critical differences in assumptions between the studies used as data sources in the model. The original studies refer to the underlying assumptions in further detail.

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[17] Energy in Sweden 2019

[18] Biograce, www.biograce.net

[19] Comparison between hydrogen and electric vehicles by life cycle assessment: A case study in Tuscany, Italy (2013)

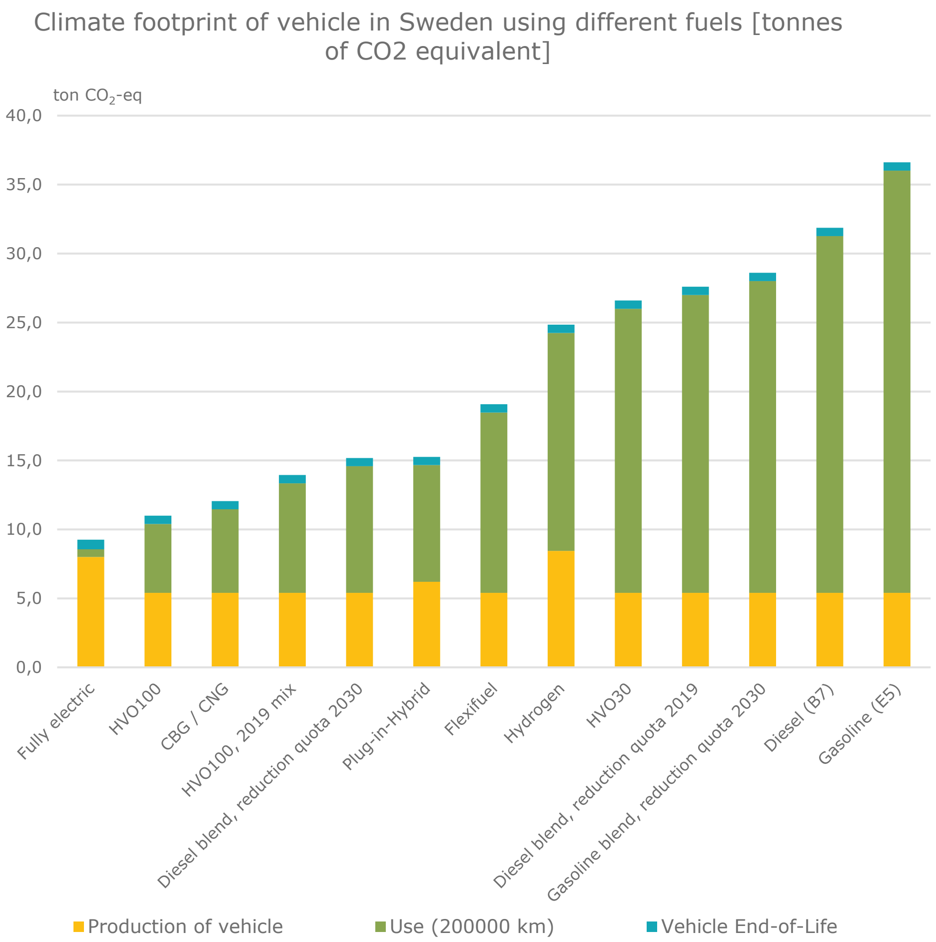
[20] Ellingsen, The size and range effect: Lifecycle greenhouse gas emissions of electric vehicles" (2016)

Table 2. Overview of differences in assumptions between the main studies used as data sources in the model.

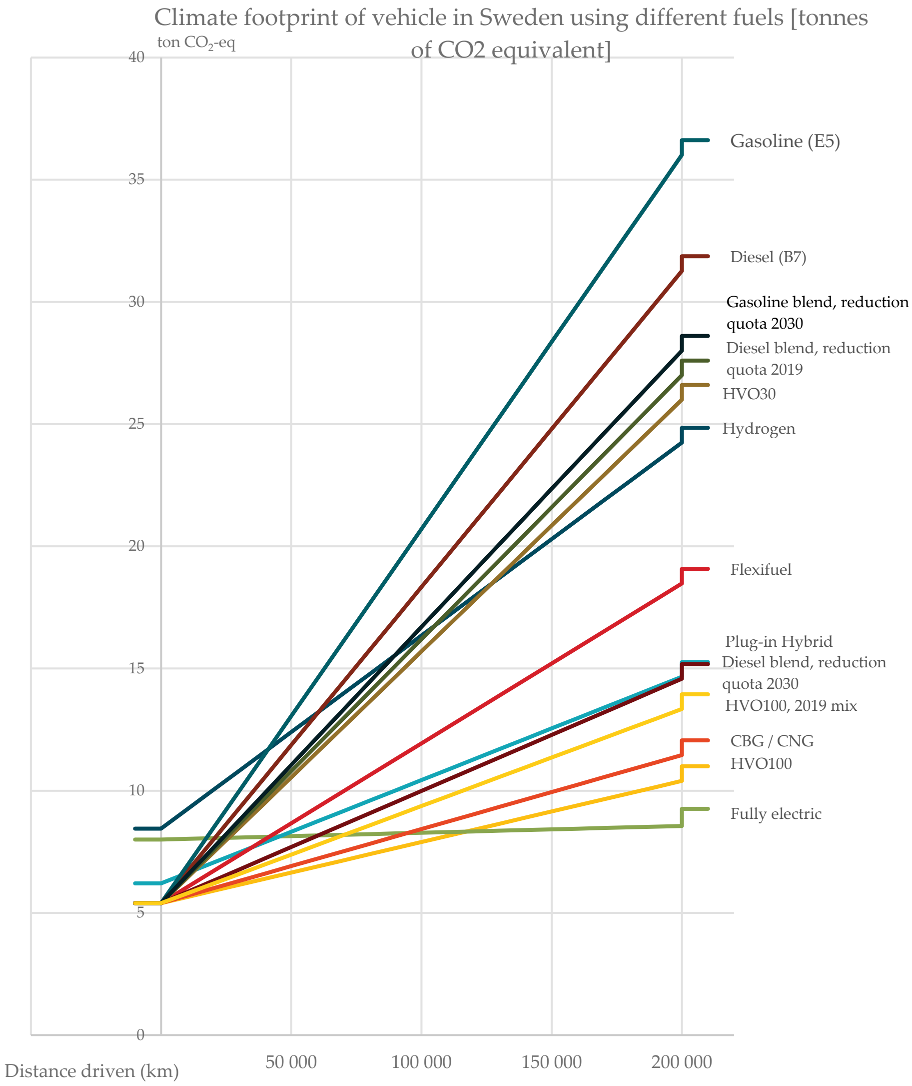
	JEC 2020	Ellingsen 2016	IVL 2019
Use in the model (Lifecycle stage)	Use phase impacts; fuel combustion and fuel production	Production and end-of-life of vehicles (excluding battery)	Production and end-of-life of Li-ion batteries
Technological scope	C-Class 5 seater compact EU sedan	Multiple vehicle types; small, medium, large, luxury	Several different battery packs
Functional unit	1 km of motion on the NEDC cycle	ton of CO_2-eq	kWh of battery capacity
Conversion of functional unit in the model	Lifetime is 200 000 km NEDC cycles	Functional unit used directly	Electric car battery sizes based on JEC study
Geography	Europe	Germany	Europe
Temporal scope	2015	Best available technology	Best available technology
Allocation method	System expansion	No system expansion	Economic & mass allocation
Other assumptions	LULUC and ILUC excluded		

3 Results

The results for the climate footprint of a passenger vehicle in Sweden are presented in Figure 1 and Figure 2. The fuels chosen are representative of the current Swedish market. The units are ton of CO_2 equivalent during the whole life cycle of a passenger vehicle, which is assumed to be driven for 200 000 km. Results are also shown in Table 3, which includes the units in gram CO_2-eq/km.



In terms of GHG emissions, the best available option is fully electric car, resulting in total emissions of 9 ton of CO_2-eq during the vehicle life cycle, followed closely by 100% HVO fuelled car with 11 ton and CBG/CNG with 12 ton of CO_2-eq. The CBG/CNG fuel benefits from the high biogas (CBG) content of 90% in Sweden.



For electric cars, the use stage emissions are the lowest due to the Swedish electricity mix, which relies 90% on fossil free. However, based on the results, the production phase emissions are higher than those of the internal combustion engine vehicles, thus slightly offsetting the benefits of the lower carbon footprint during the use phase of electric vehicles.

The diesel blend of reduction quota 2019 results in 27.6 ton of CO_2-eq emissions, which is 16% lower than that of 100% diesel. For the reduction quota to 2030, the diesel blend results in 15.2 of CO_2 emissions, which is 54% lower than fossil diesel on a well-to-wheels basis. When comparing the results of conventional gasoline to plug-in-hybrids, the plug-in-hybrid with 50 km of electric range results in almost 60% less GHG emissions during the vehicle life cycle. Gasoline blend reduction quota 2030 results in 24% lower emissions than 100% gasoline.

Table 3. Climate footprint of passenger vehicles in Sweden per lifecycle phase using different fuels.

	(ton CO_2-eq)					(gram CO_2-eq/km)
Description	Productio n	Use		End-of-life	Total lifetime emissions ton CO_2-eq	Total emissions gCO_2-eq/km
Electric vehicle, Swedish electricity mix	8.0	0.6		0.7	9.3	47
HVO 100, 100 % HVO, animal fats	5.4	5.0		0.6	11.0	55
CBG/CNG, 90 % biogas, 10 % natural gas	5.4	6.1		0.6	12.1	60
HVO 100, 100% HVO, 2019 mix	5.4	7.9		0.6	13.9	70
Diesel blend, reduction quota 2030	5.4	9.2		0.6	15.2	76
Plug-in-hybrid, Swedish electricity mix + convl gasoline (E5)	6.2	8.5		0.6	15.3	77
Flexifuel, 85 % ethanol, 15 % gasoline	5.4	13.1		0.6	19.1	80
Hydrogen, natural gas on-site reforming	8.4	15.8		0.6	24.8	124
HVO30, 70 % diesel, 30 % HVO	5.4	20.1		0.6	26.6	133
Diesel blend, reduction quota 2019	5.4	21.6		0.6	27.6	138
Gasoline blend, reduction quota 2030	5.4	22.6		0.6	28.6	141
Diesel (B7), 7 % FAME, 93 % diesel	5.4	25.9		0.6	31.9	159
Diesel (B0)	5.4	27.0		0.6	33.0	165
Gasoline (E5), 95 % gasoline, 5 % ethanol	5.4	30.6		0.6	36.6	182
Gasoline (E0)	5.4	31.4		0.6	37.4	187

Owing to the selected hydrogen production method based on natural gas (CNG/LNG), the climate impact of hydrogen vehicles is higher compared to the other alternatives for conventional fuels. With other production methods, such as electrolysis using only low carbon footprint electricity, hydrogen has potential to be one of the best fuels in terms of climate impact. This is described in further detail in the sensitivity analysis.

3.1 SENSITIVITY ANALYSIS

The goal of the sensitivity analysis is to test different fuel types in the vehicle's use phase and provide further understanding about the differences in GHG emissions within each fuel blend and the feedstock's impact. Different possible fuels within each fuel type were modelled to indicate quantitatively the range of variation in GHG emissions within the fuel type, due to the blend and the fuel source.

The fuel sources or feedstocks and the production pathway of the feedstock and the fuel have a large impact on the GHG emission savings of any type of fuel. The CO_2 emissions data during the use phase are taken from JEC Well-to-Wheel Analysis [21].

Figure 3 illustrates the effect of fuel feedstocks on CO_2 emissions. Reduction in CO_2 equivalent emissions per feedstock type for HVO and gas are compared against 100% conventional diesel. CO_2 reduction of HVOs range from 43% to 81% when compared to conventional fossil diesel. Biogas CO_2 reduction is 86%. Some studied fuels, i.e. HVO100 rape seed, do not reach the minimum GHG savings, 60%, required by RED II [22]. Thus, carbon intensity of a fuel is highly impacted by the feedstock type.

[21] JRC, EUCAR, CONCAWE, Well-to-Wheels Report Version 5 (2020)

[22] Renewable Energy Directive II (2018)

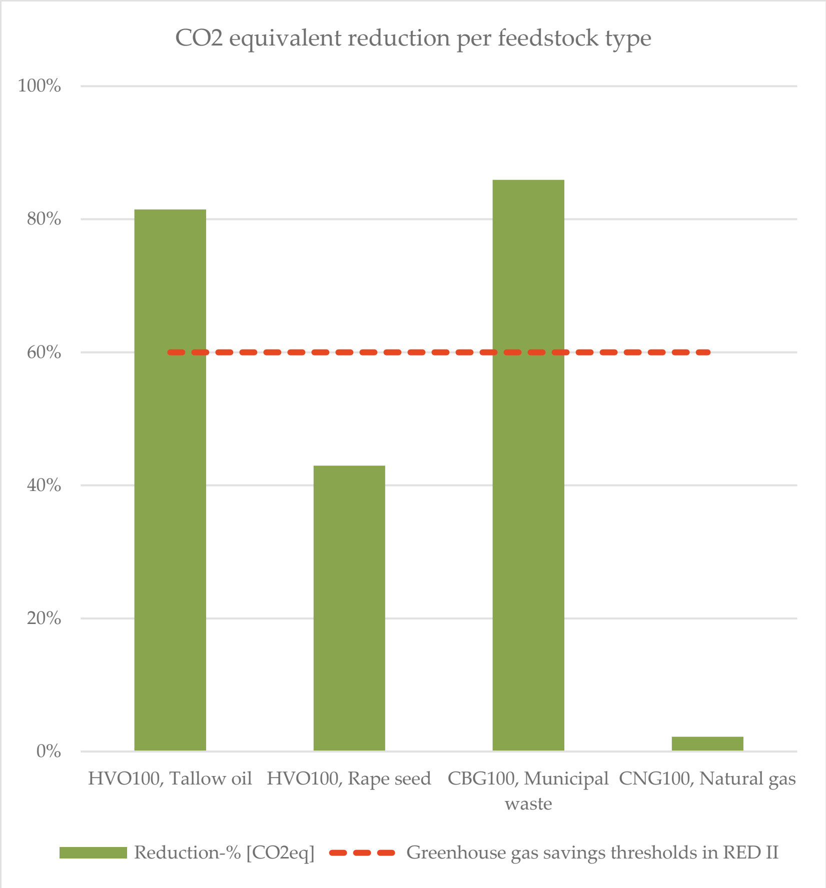
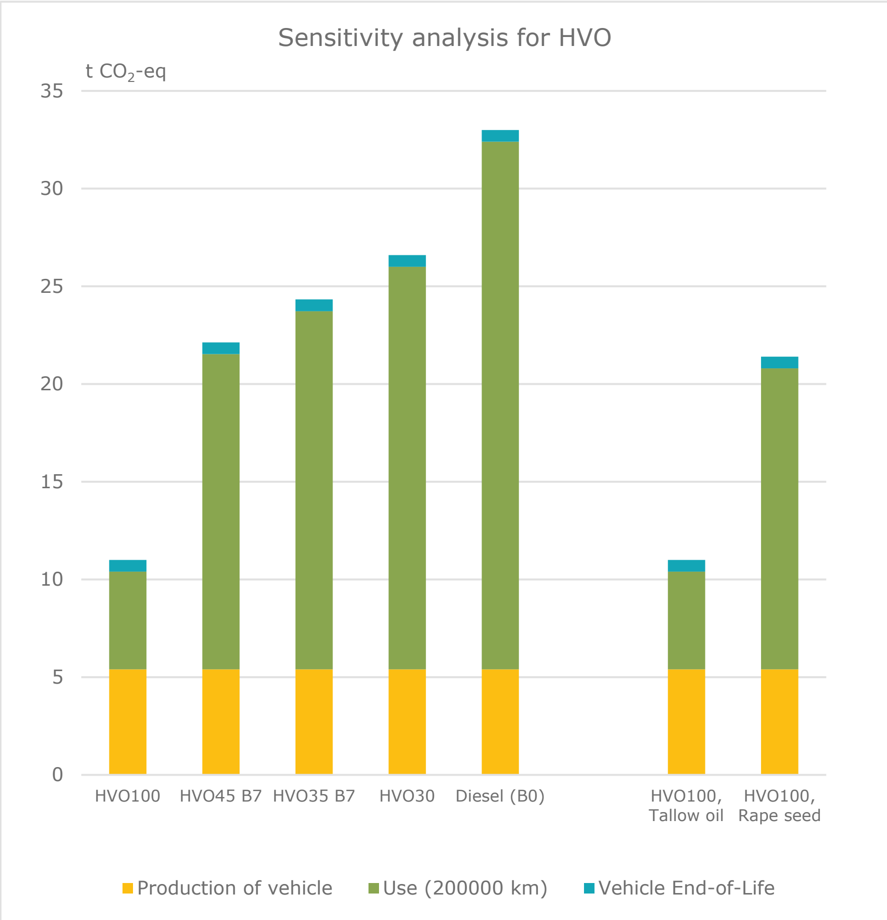


Figure 4 shows the range of variation in GHG emissions between different types of HVO. On the left, impact on GHG emissions of blending HVO to diesel is visualized from 30% HVO to 100% HVO. On the right, HVOs from different raw materials are compared.

The difference between the best and worst case for 100% HVO is rather substantial, the animal fats HVO resulting in 11 t of CO_2-eq and the HVO based in rape seed causing 21 t of CO_2-eq during the vehicle life cycle (Figure 4).



In Sweden during 2017, biogas had a share of 90% within the CBG/CNG based on Energigas report [23], resulting in low GHG emissions for CBG/CNG. 100% CNG would cause a climate impact very close to that of conventional gasoline and higher than that of conventional diesel during the vehicle life cycle (Figure 5).

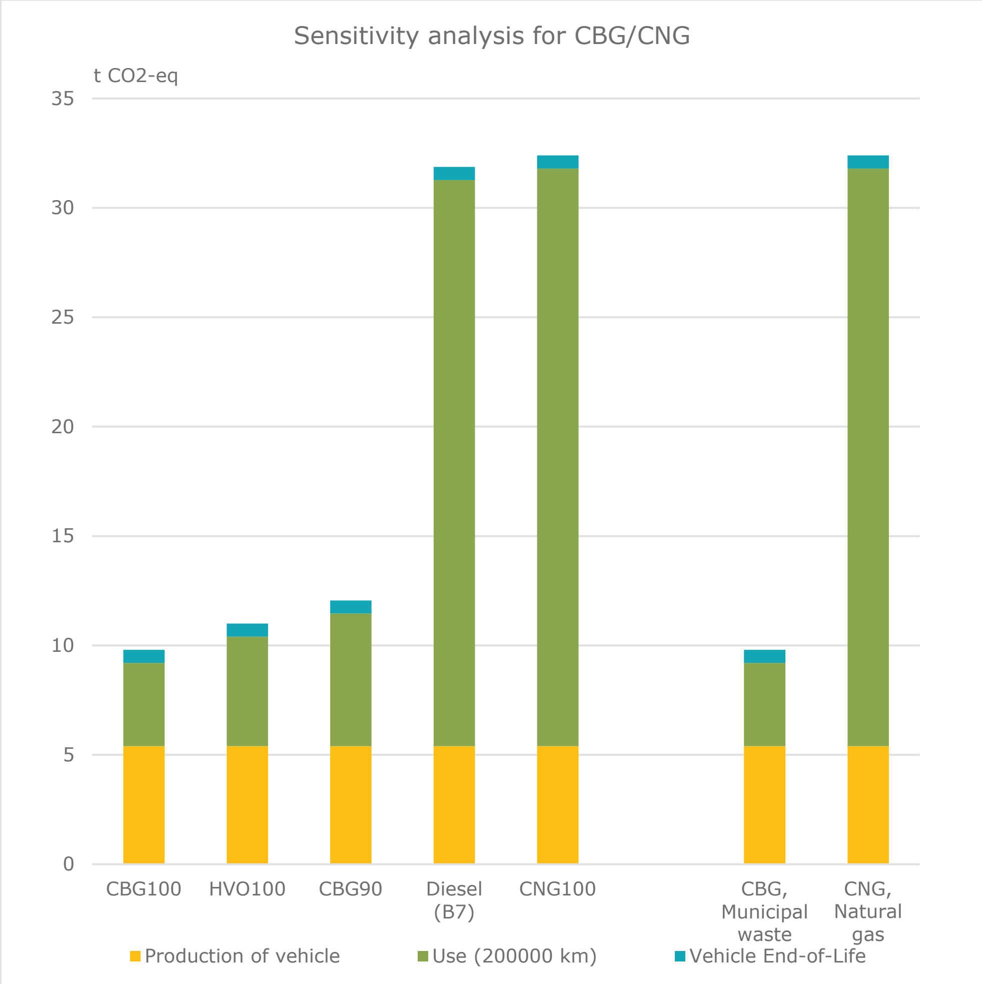
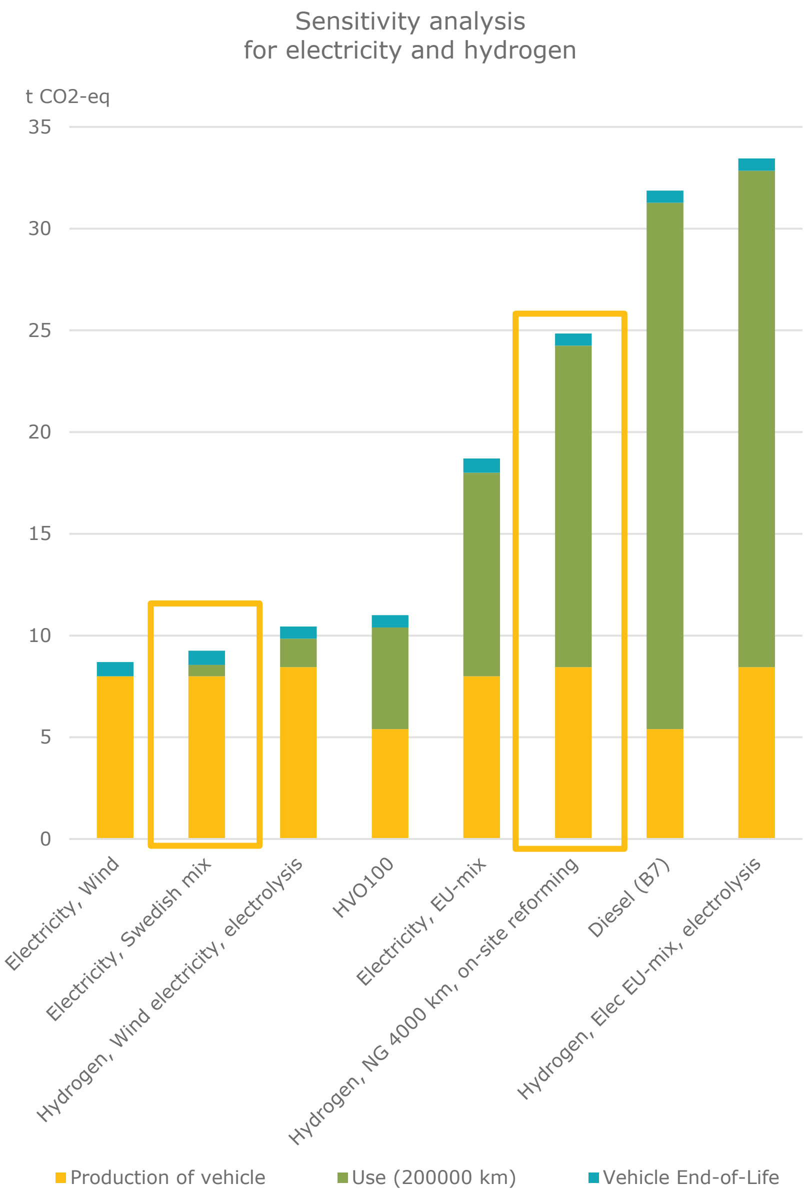


Figure 5. Sensitivity analysis for biogas (CBG) and natural gas (CNG). In Swedish market, CBG90 (90% of biogas and 10% natural gas) is available. Yellow box indicates the results used in the main fuel comparison in Figure 1.

The use phase emissions of electric vehicles are very dependent on the electricity generation method (Figure 6). CO_2 equivalent emissions from wind electricity are so low that they are assumed to be negligible in the model, while the carbon heavy EU electricity mix produces almost 17 t of CO_2-eq. When comparing all scenarios of electric and hydrogen vehicles, hydrogen as an energy carrier has potential to be equally positioned in terms of GHG emissions compared to electricity. This would require that the energy demand of hydrogen fuel production would be covered with electricity generated with close to zero GHG emissions, e.g. electrolysis using wind power.

[23] Energigas, National Biogas Strategy 2.0 (2018)



When comparing E5 gasoline to E0 gasoline and B7 diesel to B0 diesel, the impact of adding 5% ethanol to gasoline or 7% fame to diesel is rather marginal in terms of GHG emissions during the vehicle lifetime (Figure 7.)

The main results do not take into account possible second life of batteries. Figure 8 illustrates the climate impact if the original electric car battery uses a recycled car battery, assuming zero losses in regeneration of the battery. In this case, the emissions of an electric vehicle would decrease by 1 ton of CO_2-eq. Furthermore, the main results assume the emissions related to battery production to be 77 kg CO_2/kWh. In IVL study, the range for battery production is 61-106 CO_2-eq/kWh.

Applying this range to the model would result in 8.9 – 9.9 tonnes of total CO_2-eq emissions..

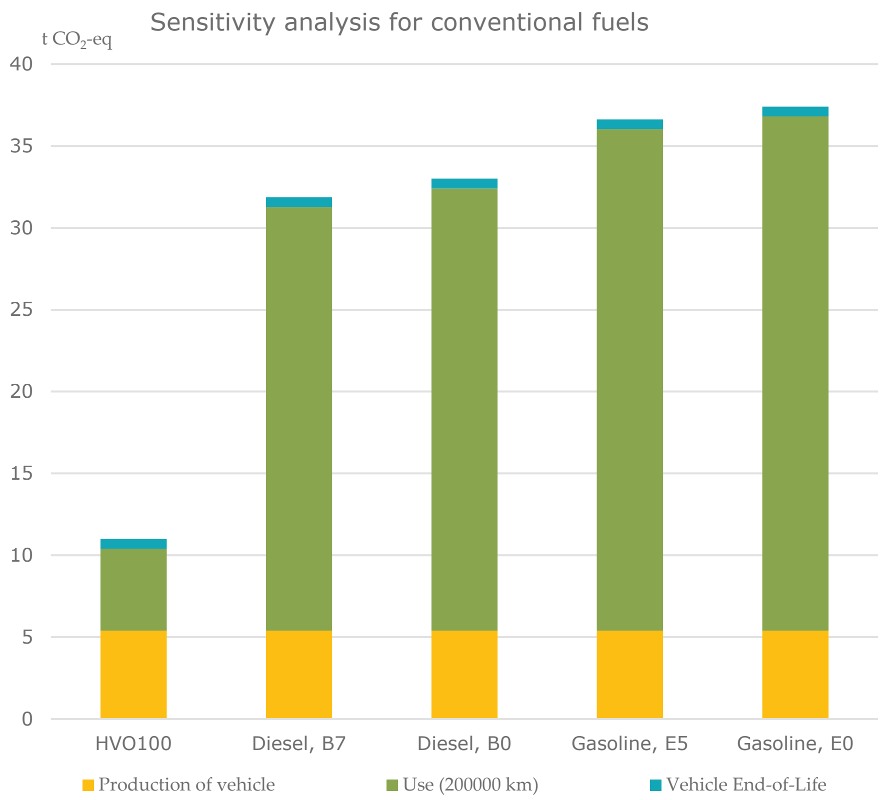
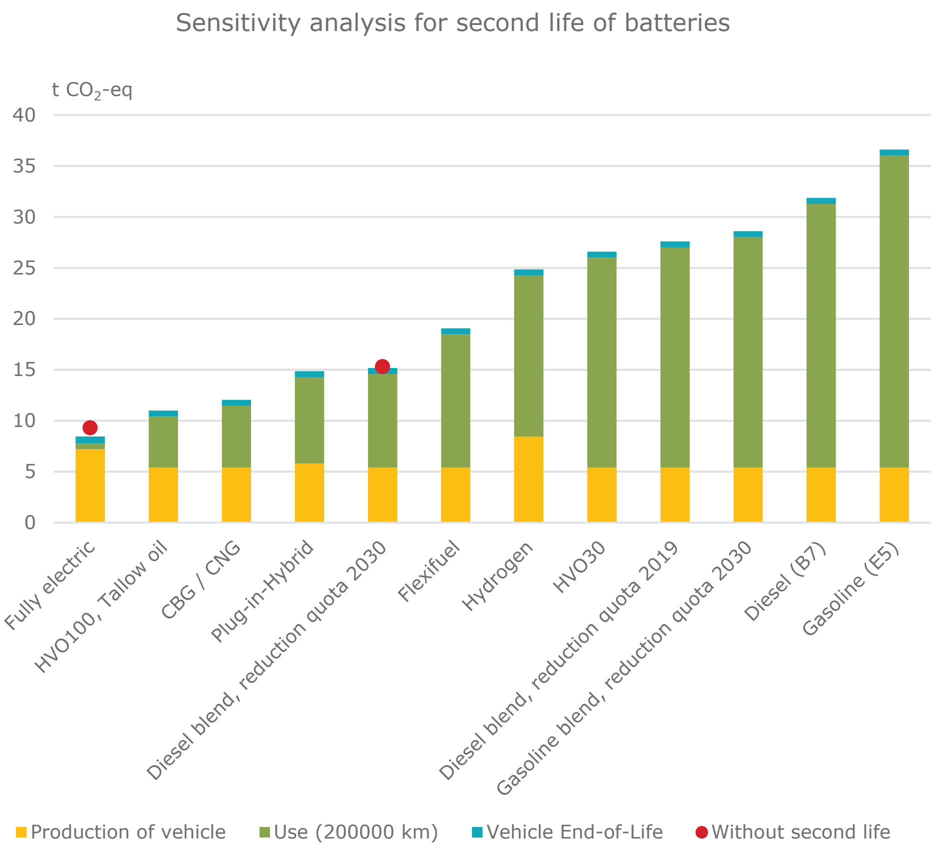


Figure 7. Sensitivity analysis for conventional fuels. Yellow box indicates the results used in the main fuel comparison in Figure 1.


Sensitivity analysis for second life of batteries
t CO2-eq
40
35
30
25
20
15
10
5
0
Fully electric
HVO100, Tallow oil
CBG / CNG
Plug-in-Hybrid
Diesel blend, reduction quota 2030
Flexifuel
Hydrogen
HVO30
Diesel blend, reduction quota 2019
Gasoline blend, reduction quota 2030
Diesel (B7)
Gasoline (E5)
Production of vehicle
Use (200000 km)
Vehicle End-of-Life
Without second life

4 Discussion and conclusions

The goal of this work was to indicatively compare the greenhouse gas (GHG) emissions of each fuel type in Sweden. Based on the results, biofuel, biogas and electricity powered vehicles can have three times lower climate impact than the cars using conventional fuels. If further recycling of materials and renewable electricity mix in the vehicle production stages were assumed, the climate impact could potentially be even lower.

The modelled results of GHG emissions during a vehicle's full life cycle from the production and use phases to the end-of-life treatment in the Swedish market range from 9 to 37 ton of CO_2-eq, or 47 to 182 gCO_2-eq/km, where electric and 100% HVO mark the lowest climate footprints. In use phase emissions, electricity using Swedish electricity mix results in the lowest emissions with 0.6 t of CO_2-eq. With electric vehicles, the production phase emissions have more significant contribution to the total GHG emissions than with internal combustion engine vehicles, due to emissions related to battery production.

The diesel blend of reduction quota 2019 results in 27.6 ton of CO_2-eq emissions during the vehicle life cycle, which is 16% lower than that of 100% diesel. For the reduction quota to 2030, the diesel blend results in roughly half of the CO_2 emissions compared to those of 100% diesel. The plug-in-hybrid with 50 km of electric range results in roughly half of the GHG emissions during its life cycle compared to the conventional gasoline.

The climate impact of hydrogen vehicles in the Swedish market is higher compared to other alternatives for conventional fuels. The results derive from the hydrogen production pathway selected for the model, which utilizes natural gas as raw material, since it is the most commonly used production pathway for hydrogen currently. With advanced production methods, e.g. electrolysis using low carbon electricity, hydrogen has potential to be positioned in the same range of GHG emissions with electricity or neat biofuels such as HVO100.

Fuel feedstocks and production pathways are found to have a major impact on the GHG emissions of any type of fuel, from HVO to electricity. Throughout the sensitivity analyses, large variations of GHG emissions are found among the same type of fuel produced from different sources, and even these variations can be enlarged by different production pathways. For example, in the modelled results, the total CO_2 emissions of a car fueled with HVO ranges from approx. 11 ton of CO_2-eq (HVO made from animal fats) to 21 ton of CO_2-eq (HVO made from rape seed).

The results are an outcome of a model based on publicly available data sources and other studies show similar results[24] The assumptions and limitations of sources used in the model directly affect the modelled results and therefore, for interpreting the results, getting acquainted with the assumptions behind the model's main sources is encouraged. Due to data scarcity, sources with

[24] From the well to the wheel (2019)

heterogeneous assumptions were accepted and therefore, the modelled results should be interpreted as indicative.

5 Bibliography

Bartolozzi et al, 2013. – Comparison between hydrogen and electric vehicles by life cycle assessment: A case study in Tuscany, Italy.

Directive (EU), 2018. – Renewable Energy Directive II

Ellingsen et al, 2016. – The size and range effect: Lifecycle greenhouse gas emissions of electric vehicles.

Emilsson & Dahllöf, 2019. – Lithium-Ion Vehicle Battery Production.

Energigas, 2018. – National biogas strategy 2.0.

Energimyndigheten, 2019. – Komplettering till Kontrollstation 2019 för reduktionsplikten

Konkunkturinstitutet, 2019. – Transportsektorns klimatmål, Årlig rapport 2019

Prussi, M., Yugo, M., De Prada, L., Padella, M., Edwards, 2020. – JEC Well-to-Wheels Report v5. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-wheels-report-v5

RECHARGE, 2018. – PEFCR - Product Environmental Footprint Category Rules for High Specific Energy Rechargeable Batteries for Mobile Applications

Swedish Energy Agency, 2019. – Energy in Sweden 2019.Volkswagen, 2019. – From the well to the wheel. https://www.volkswagen-newsroom.com/en/stories/from-the-well-to-the-wheel-4888

6 Appendix

The HVO sensitivity analysis is shown in table format below, in which further details are provided about the assumptions on the production pathway of each HVO type.

Table 4 describes different HVOs used in the sensitivity analysis. The production routes are described in further detail in JEC Well-to-Tank report.

Table 4. Sensitivity analysis for HVO [t of CO2-eq]

Description	Production of vehicle	Use (200000 km)	Vehicle End-of-Life	Total
HVO100	5.4	5.0	0.6	11.0
HVO45 B7	5.4	16.1	0.6	22.1
HVO35 B7	5.4	18.3	0.6	24.3
HVO30	5.4	20.6	0.6	26.6
HVO, animal fats	5.4	5.0	0.6	11.0
HVO, Rape seed	5.4	15.4	0.6	21.4

Table 5 describes the modelled fuels in further detail. The modelled CBG is municipal waste from closed digestate and the CNG is remote LNG, vaporised at the import terminal.

Table 5. Sensitivity analysis CBG/CNG t of CO2-eq.

Description	Production of vehicle	Use (200 000 km)	Vehicle End-of-Life	Total
CBG100	5.4	3.8	0.6	9.8
CBG90	5.4	6.1	0.6	12.1
CNG100	5.4	26.4	0.6	32.4
CBG, Municipal waste	5.4	3.8	0.6	9.8
CNG, Natural gas	5.4	26.4	0.6	32.4

Table 6. Sensitivity analysis for electricity and hydrogen (t of CO2-eq).

Source of electricity in use phase	Production of vehicle	Use (200000 km)	Vehicle End-of-Life	Total
Hydrogen, Wind electricity, central electrolysis	8.4	1.4	0.6	10.4
Electricity, Wind	8.0	0.0	0.7	8.7
Electricity, Swedish mix	8.0	0.6	0.7	9.3
Electricity, EU-mix	8.0	10.0	0.7	18.7
Hydrogen, NG 4000 km, on-site reforming	8.4	15.8	0.6	24.8
Hydrogen, Elec EU-mix (MV), on-site electrolysis	8.4	24.4	0.6	33.4

Table 7. Sensitivity analysis for conventional fuels (t of CO2-eq).

Description	Production of vehicle	Use (200000 km)	Vehicle End-of-Life	Total
Diesel, B7	5.4	25.9	0.6	31.9
Diesel, B0	5.4	27.0	0.6	33.0
Gasoline, E5	5.4	30.6	0.6	36.6
Gasoline, E0	5.4	31.4	0.6	37.4

CLIMATE IMPACT OF A PASSENGER CAR IN SWEDEN

This is a review of the total carbon dioxide equivalent emissions of a passenger car in Sweden from a life cycle perspective, a so called Well-To-Wheel approach, WtW including production and scrapping of the car.

The greenhouse gas emissions of each fuel type have been indicatively compared. The goal was to indicate quantitatively how selected fuel types in the current Swedish market compare with each other in terms of greenhouse gas, GHG emissions, accounting all stages in the vehicle and fuel life cycle, i.e. production of vehicles, use phase of 200 000 km and the vehicle end-of-life. In addition to conventional fuels and electricity, biofuels and hydrogen were included.

The study shows that HVO100, biogas and battery electricity powered vehicles can have three times lower climate impact than cars using conventional fuels.

The modelled results based on open source data of GHG emissions range from 9 to 37 tons of carbon dioxide equivalent during a vehicle's full life cycle from production and use to the end-of-life treatment in the Swedish market. The sensitivity analyses show large variations of GHG emissions among the same fuel type produced from different in-feed sources, which can be further strengthened by assumptions on the production stage.

The results are an outcome of a model based on publicly available open data sources. The assumptions and limitations of sources used in the model directly affect the modelled results and therefore, for interpreting the results, getting acquainted with the assumptions behind the model's main sources is encouraged. Due to data scarcity, sources with heterogeneous assumptions were accepted, and thus, the results should be interpreted as indicative.

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