CHALMERS

Investigation of released CO_2 and consumed energy for two different usages of electrified vehicles of various levels, operating in service situations

Master of Science Thesis

JONNA ROSÉN

Department of Energy and Environment
Division of Electric Power Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2013

Investigation of released CO_2 and consumed energy for two different usages of electrified vehicles of various levels, operating in service situations

JONNA ROSÉN

Department of Energy and Environment
Division of Electric Power Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2013

Investigation of released CO_2 and consumed energy for two different usages of electrified vehicles of various levels, operating in service situations
JONNA ROSÉN

Department of Energy and Environment
Division of Electric Power Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover: Exhaust pipe of a petrol operated car [1]

[see 2.3 - Regulations and Future goals; CO_2 emissions]

[Chalmers Reproservice]

Gothenburg, Sweden 2013

Investigation of released CO_2 and consumed energy for two different usages of electrified vehicles of various levels, operating in service situations

JONNA ROSÉN
Department of Energy and Environment
Division of Electric Power Engineering
Chalmers University of Technology

ABSTRACT

This report aims to study the possible implementation of electrified vehicles in two specific but differently demanding service situations; Hemtjänsten & Flexlinjen. The study included not only different petrol mixes with ethanol; 95% and 90% petrol, but also several electricity mixes where the denotation Worst symbolises Scandinavian Electricity mix and Ultimate is what could be produced in the future (100% hydro power). The study reveals that the more electricity used the less CO_2 emissions (g/km). If using a hybrid electric vehicle in Hemtjänsten instead of a fuel operated vehicle the reduction of CO_2 emissions is more than 41%, a remarkable save of more than 1000 kg of CO_2 per year. If Hemtjänsten instead would use a battery electric vehicle the reduction would be almost 50% even considering the, for Sweden, worst possible electricity mix with burning fossils. There is an almost 90% reduction in CO_2 emissions (more than 2000 kg/year) for the upper range of Sweden's electricity median. For Flexlinjen, the gains are similar, although proposed emission level regulations will be harder to lie under.

Keywords: electrified vehicles, CO_2 emissions, well-to-wheel, CO_2 regulations, service vehicles, drive cycles, vehicle efficiency, petrol, electricity

This page intentionally left blank

ACKNOWLEDGEMENTS

This work has been carried out at the Department of Energy and Environment at Chalmers University of Technology.

I would especially like to thank my thesis supervisor Emma Arfa Grunditz who has been very generous regarding input and sharing of knowledge and I am most grateful to my examiner Torbjörn Thiringer for allowing me to write this thesis.

I would also like to express gratitude to Nina Rantanen Larsson at Hemtjänsten Nödinge-Nol-Alafors and Pia Johansson at Hemtjänsten Kaverös for their contributions as well as Gordon Strömfelt for the loan of his Nissan Leaf.

Much appreciation to friends for their support: Maggan, Soffan & Puffen

and thank you dad!

Jonna Rosén

Gothenburg, Sweden, 2012

This page intentionally left blank

CONTENTS

LIST OF ACRONYMS

AER	All electric range
BEV	Battery electric vehicle
CD	Charge depletion
CO_2	Carbon dioxide
CS	Charge sustaining
EM	Electric motor
EU	European Union
FOV	Fuel operated vehicle
GPS	Global Positioning System
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
LHV	Lower heating value
NEDC	New European Driving cycle
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PTW	Production-to-wheel
SOC	State of charge
TTW	Tank-to-wheel
WTT	Well-to-tank
WTW	Well-to-wheel

This page intentionally left blank

1. INTRODUCTION

This report is written to examine the performance of electric cars and electric hybrid cars in order to investigate possibilities to implement more environmentally friendly alternatives than fuel operated vehicles (FOV) in service situations. The experiments in this study are applied to two different situations; Hemtjänsten and Flexlinjen, both situated in the public service sector.

The most common vehicles today have an internal combustion engine (ICE) fuelled by for example petrol or diesel. This report will review different electrical alternatives including hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) as well as pure battery electric vehicles (BEV).

Electrified vehicles are of interest due to the possibility to decrease emissions of greenhouse gases and especially, as focused on in this study, carbon dioxide (CO_2). To be considered are the negative effects on the environment that emissions of greenhouse gases have; large cities with widespread usage of ICE might have inhabitants with health problems due to the extensive exhaust and emissions produced. Another reason for continued research and further development is that pure electric or plug-in electrified vehicles can be run on electricity produced by renewable energy sources (RES).

In Sweden plug-in electric vehicles (PEVs) are cheaper to drive per mile than FOVs with an ICE due to the overall cheap electricity but expensive petrol. Estimation gives that a BEV is around 4 times cheaper to drive than a FOV[1]. The initial cost of purchasing a PEV is high, mostly due to today's' very expensive batteries which also have a limited lifetime and are precarious regarding manageability. A private person might not afford a PEV, or will possibly choose a cheaper alternative due to the high cost of purchase, but with electricity from renewable energy sources the fuel cost will be cheaper than for FOVs and electricity from RES is a better alternative for the environment. PEVs will also be viable alternatives for the future since RES will have a longer life span than today's ending resources of petrol. A good first step is for the local authority to invest in electrified cars in service situations in order to not only encourage further development of the powertrains and batteries for electrified vehicles, but to inspire private persons to purchase them.

[1] Estimating the fuel consumption of a FOV to be 0.05 l/km and the price of petrol ranging from 10-15 kr/l and the fuel economy for a BEV to be 0.20 kWh/km and the price of electricity ranging from 0.5-1 kr/kWh.
In the time of writing, electricity is cheap (~0.60 kr/kWh) and petrol expensive (~15 kr/l) giving that with today's rates it's 6.25 times cheaper to drive a BEV than a FOV.

1.1 PROBLEM BACKGROUND

By knowing the needs required for a car, i.e. if the car has a specific driving pattern, electrical adaption can be considered without the possible performance anxiety that BEVs can contribute with due to their limitations regarding long distance driving compared to FOVs[2]. It's easier to specify the needs of and specifications for vehicles in some service situations with expected utilization and driving pattern in comparison to privately driven cars which can vary a lot between city and highway driving as well as have unpredictable distances. This also makes service situation vehicles good to work with in virtual environments since simulated results and calculations can be established and accepted due to the regularity.

This study strives to investigate whether it's beneficial, emission-wise, to in two types of vehicles currently used in service situations, replace the ICE with an electric engine or a combination of both, as is the case with hybrids of different sorts. Electrified vehicles might be a better alternative for the environment regarding CO_2 released to the atmosphere and since electricity can be produced from different sources the technology can therefore have a longer lifetime thanks to RES in comparison to the limited source of petroleum. But can a BEV be a fully operational alternative to today's FOVs in both service situations?

1.2 PREVIOUS WORK

Several investigations exist regarding CO_2 emissions although many focus on all greenhouse gases. There are many WTW analyses and all differ depending on information accounted for and most of them are based on electricity accessed in the US. No comparisons have been found regarding several choices of electricity and petrol in combination with comparisons between ICE and electrified vehicles operating in service situations.

1.3 PURPOSE

The purpose of this report is to investigate and compare different electrified vehicles applied to two different service situations where the load, the vehicle body and the conditions regarding usage are very different. The different situations are chosen to explore if and where, with today's' technology, implementations of electrified vehicles can occur. The comparisons are made to an ICE and have a basis regarding released CO_2. Questions to be answered are for example: What reduction of CO_2 emissions is there if a BEV, PHEV or HEV is used instead of a FOV? What are the actual benefits of one electric choice compared to another and also compared to the petrol choices that can be made?

---

[2] Range anxiety (Swedish = räckviddsångest)

1.4 APPROACH TO PROBLEM

With models made in Matlab Simulink of the different vehicle types the simulations and experimental set-up are applied to two different situations. Hemtjänsten and Flexlinjen are both situated in the public service sector with different driving behaviour as well as prerequisites regarding vehicles size and weight, length of utilization and time between charging. Inquisitive interviews are made with Hemtjänsten regarding their usage of cars in order to estimate a drive cycle which is driven and measured with a global positioning system (GPS). Regarding Flexlinjen the drive cycle is found by going on a trip with an actual car and then elongating that trip to last as long as required. The most focus lies on the carbon dioxide released whilst utilizing the different models and comparisons will be made between the dedicated drive cycles and the New European driving cycle (NEDC).

1.4.1 PROBLEM DEFINITION

The scope of this thesis is to investigate the energy consumption/km as well as the CO_2 emissions released by the different types of vehicles in the two different situations where the strain on the electric drive and the battery will differ due to the length between charges as well as the differences in routes.

The analysis of the CO_2 released by the different cars is compared to the NEDC which is used by car companies in Europe when displaying the g CO_2/km as well as the l/100 km and the kWh/100 km usage. Furthermore investigations are made in order to make a full WTW analysis of both petrol and different power sources for electricity.

1.4.2 RESTRICTIONS AND DELIMITATIONS

The study is only focused on CO_2 due to difficulties estimating the amount of the other greenhouse gases released in the different situations; the importance of CO_2 equivalents, i.e. other greenhouse gases, are most clear regarding gas and ethanol vehicles. Since the information released by car companies are focused on g CO_2/km (measured with the NEDC) and there exists directives regarding reduction of the same (see 2.3), the delimitation feels valid. However, this study does not include the technique of CO_2 capture and storage.

The different alternatives of power sources for electricity depend on choices of power sources that can be made on the Swedish market; no consideration is taken to from which sources the actual electricity is produced nor to the generation capacity or export/import.

The choice of fuel for comparison is petrol. Tests and calculations were done in order to enable 5% and 10% ethanol in the petrol.

This report only covers a series-connected hybrid vehicle; however several variations exist.

No load is added to the vehicle weight due to uncertainty. Hemtjänsten's load would not be excessively more than the curb weight; however Flexlinjen's load would differ a lot depending on number of passengers and possible aids.

There won't be any consideration to extra appliances such as air cooling systems or radios even though they do contribute to the energy consumption. Nor will any consideration be taken to wind resistance or temperature, factors that also affect the energy consumption.

No attention has been paid to the decreasing range lithium-ion batteries will provide at cold temperatures.

It should be noted that even though consideration is taken to CO_2 emissions regarding the whole chain of fuel from well to the vehicle, no reflection about the life cycle of the car takes place and therefore nothing is said about the life cycle assessments of e.g. lithium-ion batteries vs. ICE.

1.5 METHODS AND MATERIALS

Further development and adjustments are made to pre-existing Matlab Simulink models[3]. System simulations with different calculations for comparison of the FOV, BEV, HEV and PHEV vehicles are made from the adjusted models.

Drive cycles for the different situations are practically acquired from test driving with a GPS and will be compared to the NEDC.

Comparisons are done between the different models regarding the amount of g CO_2/km in combination with WTW studies of petrol as well as for different power sources of electricity.

There are two types of vehicles in this study and specifications are made as accurate as possible with the car for Hemtjänsten modelled after a Volvo V50 and the car for Flexlinjen modelled after a vehicle in duty; a Renault Master minibus. Estimations are made regarding the weights of the powertrain components, e.g. the weight of lithium-ion battery, the ICE, electric drive etc.

[3] The preexisting models were initially made by the thesis supervisor Emma Arfa Grunditz for a course at Chalmers University of Technology.

2 THEORY

In this part of the report basic theory and concepts will be presented in order to give sufficient background information for the Case set-up and coming Analysis.

2.1 FORCES ACTING ON THE VEHICLE

The speed of a vehicle is dependent on several factors (denotations in Table 1) which make up forces that propel and forces that create resistance to the vehicle progression. First and foremost is the torque, or rather traction force, from the powertrain ($F_{powertrain}$) which acts on the wheels in order to move the vehicle forward and in contradiction there is the negative braking force (F_{brake}). There are also forces on the vehicle that aren't voluntary; forces that put a resistance to the forward motion

$$F_{acc} = ma = F_{powertrain} - F_{brake} - F_a - F_r - F_c \tag{1}$$

These forces are the air drag

$$F_a = \frac{1}{2}\rho_{air}C_dAv^2 \tag{2}$$

the resistance from the tires on the ground (rolling resistance)

$$F_r = C_r mgcos(\alpha) \tag{3}$$

and the gravitational force that occur when there is a climb [2]

$$F_c = mg\sin(\alpha) \tag{4}$$

Table 1: The denotations for the parameters regarding forces acting on a vehicle

Constants	g	m/s^2	Gravitational acceleration (9.82 m/s2 for Sweden)
	ρ_{air}	kg/m^3	Air mass density (1.205 kg/m3)
Vehicle propulsion	v	m/s	Vehicle longitudinal velocity
	a	m/s^2	Acceleration of vehicle
	α	rad	Angle of road inclination; the climb
Vehicle constants	m	kg	Mass of vehicle
	A	m^2	Effective frontal vehicle cross-sectional area
	C_r	-	Rolling resistance coefficient, depend on material, temperature, structure, pressure etc. of both tire and road
	C_d	Ns^2/kgm	Coefficient of aerodynamic resistance, depend on shape of vehicle

(1) reveals that the acceleration of the vehicle will be positive as long as the brake pedal isn't pressed and the restrictive forces are less than the power from the powertrain.

2.2 WELL-TO-WHEEL CONCEPT AND DESCRIPTION

The concept of WTW aims to regard the whole chain from the oil-well or power source to when the fuel has been used in the vehicle as can be seen in Figure 1. Electricity must be produced, transferred and then used to charge the PEV and petrol has to be refined and transported. This report has divided the concept of WTW into well-to-tank (WTT) and tank-to-wheel (TTW) regarding efficiency of energy source and powertrain. The same denotations are used when regarding CO_2 emissions for petrol, however for PEVs, there is no combustion in the powertrain and in order to account for some of the emissions caused by electricity, TTW figures are not considered but rather PTW figures which include emissions from fossils in production. The WTW figures for PEVs include emissions from the building of the power plants.

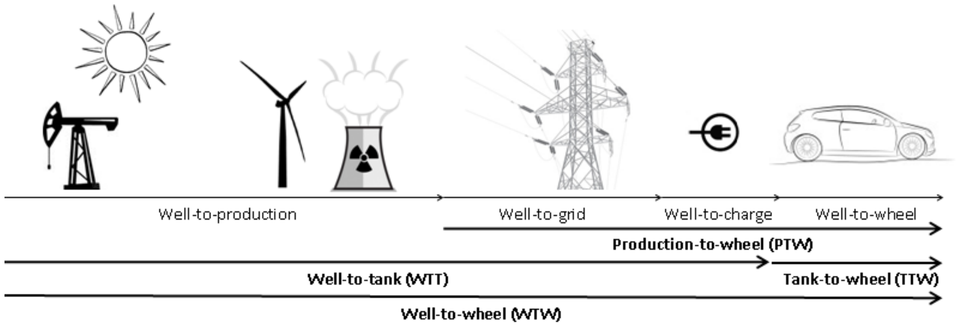


Figure 1: The chain of Well-to-Wheel

Since the WTW concept covers both efficiency and CO_2 emissions there are several units for measurement. In this report l/100 km will be used for FOVs and HEVs, kWh/100 km will be used for PEVs and there is a common measurement of g CO_2/km for emissions.

2.2.1 EFFICIENCY

The powertrains of the different vehicles consist of different components with uncertain efficiencies before simulation (TTW). However, the efficiency WTT can be calculated by applying information about the efficiency of the chain before the vehicle.

2.2.1.1 Electricity

The average losses in the Swedish grid are about 7% (6.6896%) [3] and the losses that occur whilst charging the vehicle are estimated to 8% [4]. Table 2 displays typical values of efficiencies of the different power sources presented in this report and also recalculation for grid and charging losses. The efficiency of hydropower is mostly dependant on the water turbines which have greater efficiency; the bigger the power plant the greater the fall, and 90% of all hydro power plants are very large with up to 95% efficiency. Regarding wind power it’s declared non-dependant on placement, e.g. off-shore, but rather on the efficiency of the wind turbines and the fact that the blades vs. wind strength will only allow generation of maximum 35%. [5]

When considering the efficiency of each vehicle model the round off losses in Table 2 will be calculated to match the electricity mixes in Figure 10 (see 3.3.2).

Table 2: The WTT efficiencies of different power sources for producing electricity [5]

Selection	Well-to-Grid	Well-to-Charge	WTT
Hard coal	33 %	31 %	28 %
Oil	41 %	38 %	35 %
Gas	39 %	36 %	33 %
Nuclear	35 %	33 %	30 %
Bio fuels	35 %	33 %	30 %
Hydro	95 %	88 %	81 %
Wind	35 %	33 %	30 %

2.2.1.2 Petrol

The chain for petrol from WTT goes from extracting crude oil (petroleum), to refining and later distributing it to petrol stations. The WTT theoretical efficiency of petrol is 81.7 % [6]. However, WTT figures regarding petrol are difficult to define due to the many different transportation possibilities and ethanol is even harder since it can be made from many different sources and also have different ways of transportation and transportation lengths. The CO_2 efficiency for pure petrol can be concluded to be (TTW emissions/WTW emissions) = 85.5% and for 95% petrol 84.9% (see Table 5).

Table 3: Usable energy and density information for petrol and ethanol

Type	**Energy [kWh/l]** [7]	**Density [g/l]** [7]
100% ethanol	5.90	790
100% petrol	9.10	750
95% petrol,5% ethanol	8.94	752
90% petrol 10% ethanol	8.78	754

2.2.2 POWER SUPPLY AND EMISSIONS

There are two scenarios to be considered; TTW and WTW emissions. The TTW emissions are what are regarded by regulations and car manufactures – the emissions that are directly produced by the vehicles powertrain. However, regarding PEVs there are no emissions produced by the powertrain but in order to give a somewhat fair comparison to FOVs (instead of reporting 0 g), this study uses PTW emissions instead. PTW emissions are what are released in the production of electricity and only include burning of fossils as well as the transmission and charging losses. The WTW emissions will be presented in the following sections and represent the chain of electricity; from well (building of plants, digging for oil) to the charging of the vehicle.

2.2.2.1 Electricity sources

In Sweden there are several electric supply companies with various combinations of energy sources provided in different mixes for customers to select from (see 3.3.2). Table 4 displays figures corresponding to CO_2 emission from extraction, distribution and production (Well-to-grid) until when entering the vehicle for the different energy sources [8]. Regarding BEVs, there are no added effects to the CO_2 emissions in the powertrain, no combustion, which is why the emission figures are recalculated to correspond to 1 kWh in to the vehicle and displayed as WTW figures.

Table 4: Round off figures in g CO_2/kWh WTW for different power sources of produced electricity giving 1 kWh to the vehicle.

Selection	Well-to-Grid	Well-to-Charge	WTW
Hard coal	993.0	1064.2	1156.7
Oil	825.8	885.0	961.9
Gas	885	948.4	1030.9
Nuclear	13.0	13.9	15.1
Bio fuels	32.3	34.6	37.6
Hydro	3.8	4.0	4.4
Wind	16.5	17.7	19.2

2.2.2.2 Petrol

In the case of gasoline, emissions are produced while extracting petroleum from the earth, refining it, distributing the fuel to stations, and burning it in vehicles. The CO_2 emissions for petrol are calculated and displayed in Table 5 with the notation that bioethanol doesn't contribute with TTW CO_2 emissions but with 368.7 g CO_2/l ethanol WTT [9].

Table 5: Emissions for pure petrol and petrol mixed with ethanol, per litre and per fuel energy content

		WTT	**TTW** [7]	**WTW** [9]
100 % petrol	*g CO_2/l*	400.0	2360.0	2760
	g CO_2/kWh	44.0	259.3	303.3
95 % petrol	*g CO_2/l*	398.4	2242.0	2640.4
	g CO_2/kWh	44.6	250.8	295.4
90 % petrol	*g CO_2/l*	396.9	2124.0	2520.9
	g CO_2/kWh	45.2	241.9	287.1

2.3 REGULATIONS AND FUTURE GOALS; CO_2 EMISSIONS

Both nationally in Sweden and internationally via the European Union (EU), regulations and goals are set in order to regulate CO_2 emissions from vehicles and are presented as g/km. It should be noted that all regulations and goals are based upon the manufacturers' usage of the NEDC. It is only the CO_2 created in the burning process of the ICE or in the production of electricity that is measured, no respect to the emissions created in the production of petrol or building of power plants. The standardized cycle does not take into consideration the effects driving behaviour, weather, road conditions or comfort devices (such as radios and heaters) have on the fuel consumption and thereby the emissions of a vehicle.

2.3.1 EUROPEAN UNION DIRECTIVES

The EU created a new regulation that was accepted April 23rd 2009, revised several times, that states that the goal for average CO_2 emissions from new cars should be below 95 g/km in the year 2020. The regulation also states that gradual reduction shall occur until 2020 and be valid up until 2016 with the goal being values below 120 g/km. The equation for determining the accepted emissions by a manufacturer is based on the curb weight (M_{curb}) of the average mass of sold vehicles (per year)

$$Emissions_{rated}\left[\frac{g}{km}\right] < (M_{curb} - 1372)0.0457 + 130 \quad (5)$$

The goal requires vehicle manufacturers to reach 130 g/km but that other actions such as viable fuels and higher demands on tires and air conditioning shall account for the latter 10 g/km. Vehicle manufacturers must account for their new cars and light-duty vehicles and show that CO_2 emissions are less than the goal limit. In 2012 vehicle manufacturers shall report the figures for 65% of their new cars and in 2015 for 100%. Also mentioned in the directive are “super credits” which are applied on vehicles with lower emissions than 50 g CO_2/km. Super credits would mean that vehicle manufacturers can count several super low fuel consuming vehicles as one traditional. [10]

2.3.2 SWEDEN’S TAX DIRECTIVES AND CLASSIFICATIONS

In Sweden there is a classification (“Miljöbil”) for cars and light duty vehicles meant to induce environmental awareness by offering tax reliefs if the vehicle emits less than 120 g CO_2/km (about 5 litre petrol/100 km) [11]. The corresponding classifications for PEVs have a limit of 37 kWh/100 km [11]. In Sweden as in the EU there is also a harder regulation with a cost reducing premium (around 12-26%[4]), with the limit of 50 g CO_2/km (“Supermiljöbil”) [12]. A common energy measurement for PEVs of 30 kWh/100 km was proposed to be used [13].

In 2012 the government proposed a change in the existing regulation regarding maximum emissions of 120 g CO_2/km, meant to come into force January 1st 2013 and to be revised in 2016 and 2019. The change would mean that respect is taken to the vehicle’s mass, thereby also including larger vehicles such as minibuses and lighter trucks (maximum 3500 kg). The proposal contains an equation similar to that of the EU but with a lower limit for emissions

$$Emissions_{rated}\left[\frac{g}{km}\right] < (M_{curb} - 1372)0.0457 + 95 \quad (6)$$

If the manufacturer’s rated emissions from the NEDC for a vehicle shows a smaller number than the calculated, the vehicle passes the limit. [14]

[4] In the spring of 2012 the preemie was 40kkr

2.3.3 STATISTICS (FOR VEHICLES REGISTERED 2011 IN SWEDEN)

Even though vehicle efficiency has improved and CO_2 emissions would be expected to have lowered, a 9% increase is noted from 1990 to 2010 instead of the expected 13% decrease [9]. This is due to increased road traffic and it is a valid reason for further improvements in vehicle efficiency but for a sustainable future, other fuels than fossils are demanded. Municipal initiatives regarding alternatives to petrol have already been taken considering that the overall percentage of newly registered cars in 2011 that runs on petrol was 31.4% for all of Sweden but amongst municipal-owned cars it was 10.5%. Figure 2 displays the distribution between all newly registered municipal-owned vehicles for 2011 and even though almost 60% are diesel fuelled there are 2.2% electrified vehicles (HEV & PHEV) and 0.4% BEVs [9]. Considering CO_2 levels the total average for all newly registered petrol and diesel vehicles in Sweden 2011 was 144 g/km in 2011; 20 % above the Swedish goal. For the municipal-owned it was 133 g/km, a figure relating to 70% of all the newly registered municipal-owned cars [9].

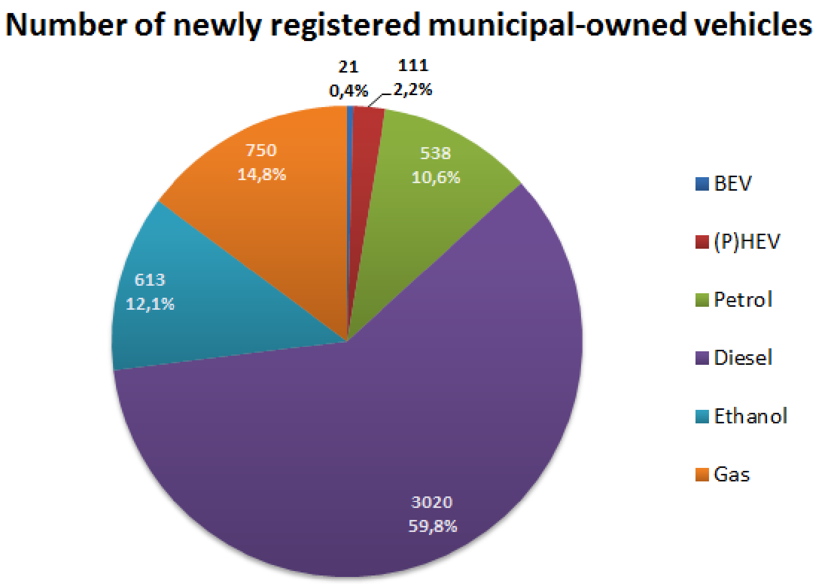


Figure 2: Fuel distribution regarding newly registered municipal-owned vehicles in Sweden 2011 [9]

2.4 FUEL OPERATED VEHICLE - INTERNAL COMBUSTION ENGINE

The efficiency of an ICE is easily displayed with the help of a brake-specific fuel consumption (BSFC) map; see Figure 3, together with the lower heating value[5] (LHV) of the fuel used. The map is convenient to view regarding at what torque and speed an engine gets the highest efficiency from the fuel consumed. BSFC is measured in g fuel/kWh (mechanical energy) and the LHV of petrol is

$$\frac{9.1\ (kWh/l)}{750\ (g/l)} = 0.0121\ \left[\frac{\text{kWh}}{\text{g}}\right] \tag{7}$$

which gives that the efficiency of 100% petrol in an engine is

$$\frac{1}{0.0121BSFC}\ [\%] \tag{8}$$

[7] [2].

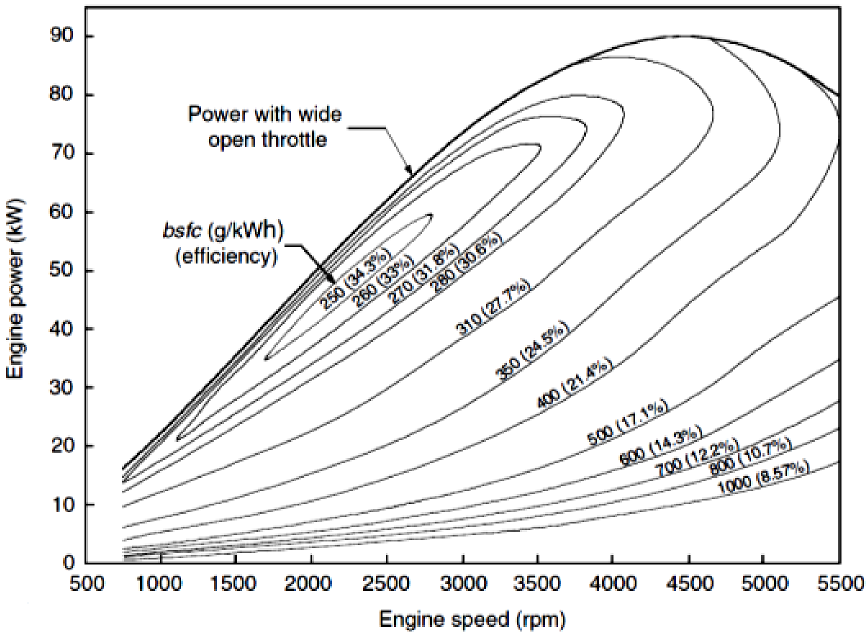


Figure 3: A BSFC map of an internal combustion engine [2]

[5] The LHV represents figures assuming that a heat or temperature below 150°C cannot be put to use i.e. LHV is the energy content value of petrol after the burning process in the ICE

2.5 BATTERY ELECTRIC VEHICLES

The major components of a BEV are the battery, which is the source of power refilled via electricity from the grid, and the electric machine, mainly acting as an electric motor (EM) (Figure 4). A big advantage with electrified vehicles is the regenerative braking, where the EM acts as a generator when braking and the energy that in a FOV is lost as heat due to friction between the brake pad and the rotor, will be recovered and used to charge the battery. In difference to FOVs with ICEs, a BEV doesn't have idling which means that electric motors are good for city driving with a lot of stops, the torque from the EM is directly applied to the wheels.

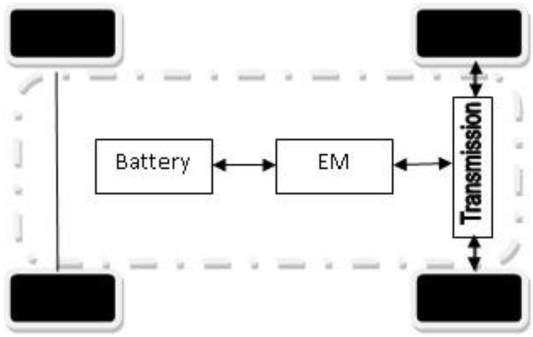


Figure 4: Schematic of a battery electric vehicle powertrain

2.6 HYBRID ELECTRIC VEHICLES

There are many configurations for hybrid vehicles and many degrees of hybridisation but the concept for all is to use regenerative braking in order to recapture some of the energy lost as heat. Another function commonly used is the start/stop function in which the ICE is shut off instead of idling and turned on when the clutch is used. The hybrid electric vehicle benefits from usage of an EM at low speeds because that's when the ICE is the least efficient. At higher speed the ICE is used in order to reduce the need of a larger battery however, the electric machine can still be used but as a generator recharging the battery but if not, a separate electric machine can be added to the configuration.

2.6.1 SERIES HYBRIDS

As can be seen in Figure 5 all the power to the wheels goes via the EM; the powertrain is electrically coupled. This implies that the EM must be dimensioned to handle all the power required for the vehicle. When the battery is depleted the ICE charges it via a generator but it's also charged via the EM when braking (regenerative braking). Since the EM is directly connected to the wheels, with the exception of a final drive, the series connected HEV has the same benefits as BEVs regarding no idling.

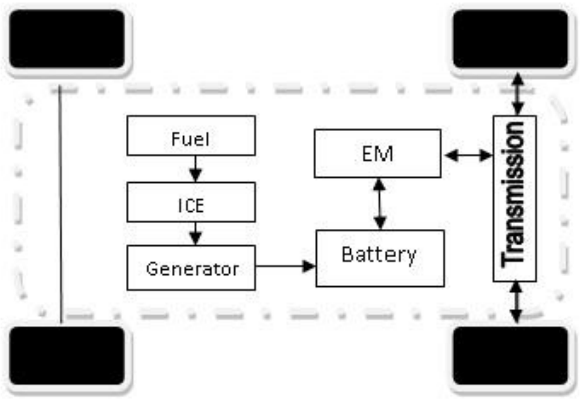


Figure 5: Schematic of a battery series hybrid powertrain

2.7 PLUG-IN HYBRID ELECTRIC VEHICLES

A PHEV can be configured in the same way as a HEV with the addition of being able to charge the battery via the electric grid as well as whilst driving. The PHEV can be considered to have characteristics of both a HEV and a BEV and the losses and fuel emission calculations are determined by two segments; one with all electric range (AER), meaning the battery is in charge depletion (CD) all electric mode (if series connected), and one driving with the ICE, meaning that the battery is in charge sustaining mode (CS). The CD segment will be run for as long a distance as possible until the ICE would turn on, i.e. until the lower limit of the CS, and the total fuel consumption and energy calculations are based on the length of the CD of the whole drive cycle. To this day, there exists no consensus approach for calculating the energy and fuel consumption for PHEVs. However, the usage of a utility factor (UF), ratio of total driven all-electric distance over the total distance driven per year is one way of translating PHEV consumption figures to correspond to those given by the other types of vehicles. This according to

$$UF = \frac{D_{ELEC}}{D_{ELEC} + D_{FUEL}} \tag{9}$$

$$F_{TOT} = F_{CD} * UF + F_{CS} * (1 - UF) \tag{10}$$

where D_{ELEC} and D_{FUEL} are the distances annually driven on each energy form and F_{CD} and F_{CS} are the fuel consumption during CD and CS respectively [15].

3 CASE SET-UP

In this part of the report vehicle parameters and model information as well as the drive cycles energy consumption and CO_2 emissions will be presented for the two different service situations: Hemtjänsten and Flexlinjen.

Hemtjänsten is a Swedish municipal-owned service which translates into home care for those who find it difficult to cope at home because of age, illness or disability. The service may include nursing help with eating, dressing and hygiene and can also be service activities such as cleaning and shopping. There are no typical vehicles designated for usage in this type of work and the only transportation of people required is of those who are in duty. However, the vehicles must be of such size that cleaning materials and groceries can fit in it. This report models a Volvo V50 since the size is quite small but still large enough to carry several different supplies and if needed, people.

Flexlinjen does require large vehicles and transportation of people is the main purpose of the publicly owned service which is a part of the municipal public transport. The Flexlinjen vehicles have room for aids such as walkers or wheelchairs and most importantly there are many more stops on the route in comparison to buses and the stops are also placed near residential entrances and other facilities. The driver of Flexlinjen is also required to assist when needed implying that the service factor is much higher than the larger public busses. The trips are booked in advance guaranteeing a seat but not time of arrival because that is dependent on the destinations of the other passengers in order to optimize the driving routes. The vehicles used are minivans or minibuses with extra space for aids and several seats. In this study a Renault Master minivan was chosen after having been spotted in the traffic on duty.

3.1 DRIVE CYCLES

For the two different scenarios and vehicles, two different drive cycles were created to be compared to the NEDC (see 5.1). The NEDC contain four segments of the urban drive cycle ECE (also known as UDC) together with one segment of the extra urban driving cycle (EUDC) which is more aggressive high speed driving [16]. Together they create the NEDC (see Figure 6) used for emissions certification of light duty vehicles [17].

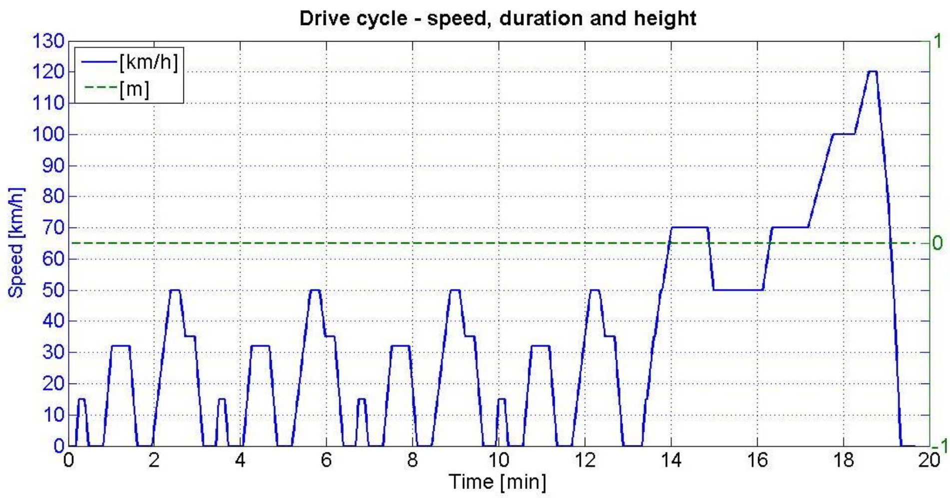


Figure 6: The NEDC

3.1.1 HEMTJÄNSTEN

Interviews were held with different departments of Hemtjänsten in Gothenburg. Hemtjänsten is divided into many sections and as it would turn out some do not use vehicles. In order to get information about usage that would be valid for this study a department of Hemtjänsten outside of Gothenburg was contacted [18]. The collected information revealed an average usage of 10 km approximately four times a day and could if necessary enable charging opportunities of about one hour between usages. A drive cycle was created by driving with GPS based on the given information, as seen in Figure 7 below. The drive cycle is repeated twice in order to fulfil a day's usage of a vehicle, giving a total duration of 72 min and a total distance of 42.7 km in this scenario.

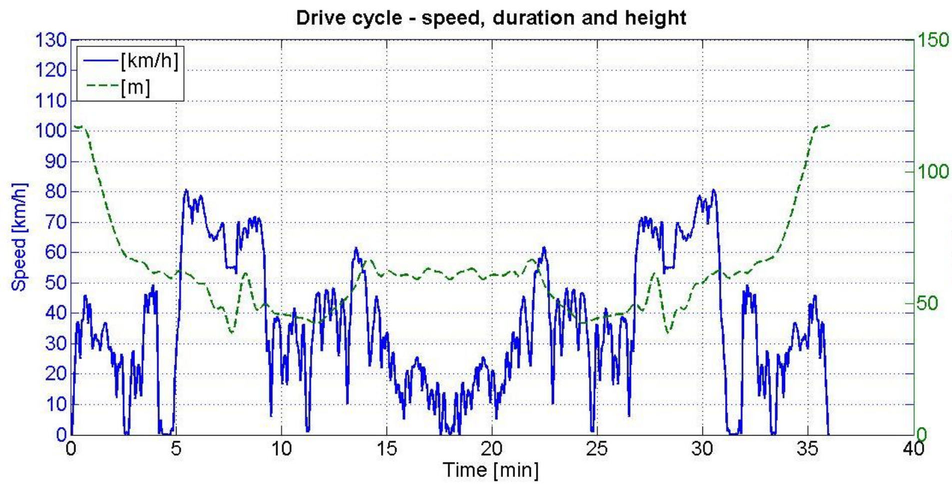


Figure 7: The drive cycle for Hemtjänsten

3.1.2 FLEXLINJEN

Flexlinjen’s usage-a-day has been estimated to about 8 hours with no in-between time to charge [19]. The drive cycle is characterized by urban driving and many stops. Below (Figure 8) is a run-through of one cycle segment of about 70 min that has been acquired via GPS by taking a 17.4 minute trip with a vehicle on duty. The trip has then been elongated with itself four times to achieve a drive cycle of about one hour. The part of Flexlinjen that was utilized for the information was Högsbo, one of Gothenburg’s many Hemtjänsten departments and also one of the hilliest areas, notice the rather frequent and large height differences. The drive cycle will be repeated seven times in order to fulfil a day’s usage of a vehicle, giving a total duration of 8 h and 7 min and a total distance of 185.2 km in this scenario.

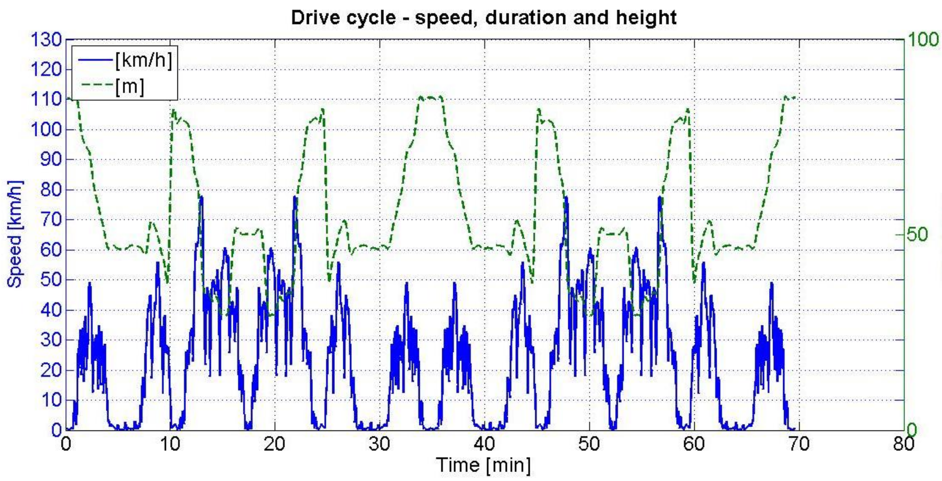


Figure 8: The drive cycle for Flexlinjen

3.1.3 DRIVE CYCLE COMPARISON

Both of the vehicle adjusted drive cycles are compared to the NEDC since it is used for the rated CO_2 emission factors given by vehicle manufacturers and also for the goals set by the EU (see Table 6).

Table 6: A comparison of different parameters for each of the drive cycles used in this report

	Hemtjänsten	NEDC	Flexlinjen
General information	City driving with incorporated higher speeds	Combination of: city driving and high speed driving	Slow city driving with many stops
Total duration [min]	36.0	19.7	69.7
Total distance [km]	21.3	10.9	26.5
Max speed [km/h]	80.8	120	77.8
Average speed [km/h]	33.1	31.9	21.8
Max acceleration [m/s^2]	2.7	0.9	1.7
Max negative acceleration [m/s^2]	2.7	1.5	1.7
Height difference [m]	79.2	0	56.1
Maximum instant inclination [°]	4.4	0	4.2
No of stops	5	12	11

3.2 VEHICLE AND MODEL PARAMETERS

There are a lot of different factors that have an impact on the performance of a vehicle. In this section the different parameters for the two vehicles are presented and Figure 9 reveals the different limitations the regulations that both the EU and the proposal of the Swedish government permit until 2016. This would put the accepted CO_2 emission for Hemtjänsten (M_{curb} = 1484 kg) to about 135 g/km according to the EU and about 100 g/km according to the proposed Swedish regulations. Flexlinjen (M_{curb} = 2770 kg) would have the EU limit of close to 194 g/km and the Swedish limit of almost 160 g/km.

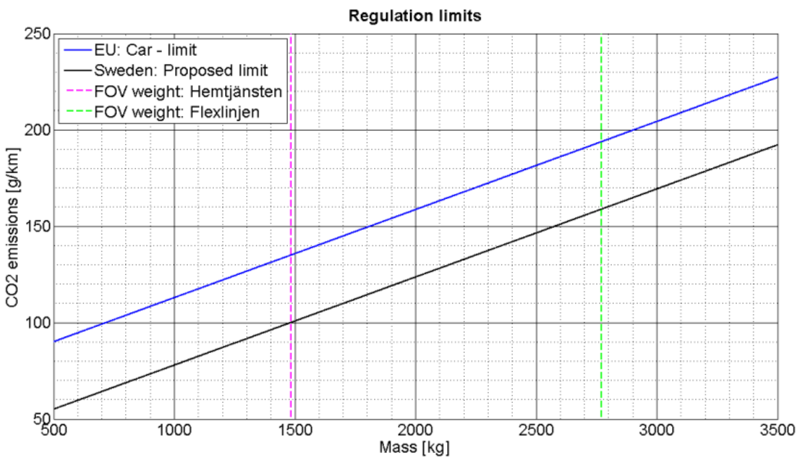


Figure 9: The g/km versus mass regulations of the EU and Sweden

3.2.1 VEHICLE PARAMETERS

The drag coefficient and frontal area for Hemtjänsten are based on a Volvo V50 [20], however the equivalent figures for Flexlinjen are based on estimations of a Renault Master Minibus [21] and the information about aerodynamic resistance is based on a similar body [2]. The rolling friction [2] and wheel radius are estimated based on tires equal to those fitting each car and the maximum torque and power are modelled and calculated after what has been required in simulations. The vehicle parameters in Table 7 are important, together with velocity (υ), road inclination (α) and mass, in order to calculate the forces on the vehicles (as displayed in section 2.1).

Table 7: Parameters for the vehicle body

	Hemtjänsten	Flexlinjen
Initial curb weight [kg]	1484	2770
Frontal area (A) [m^2]	2.2	4.8
Drag coefficient: C_d	0.31	0.50
Rolling friction: C_r	0.009	0.009
Wheel radius [m]	0.31725	0.34798

3.2.1.1 Power Calculations and restrictions; engines/motors

The component sizes and the power needed for the different models and scenarios are dependent on what the vehicle must manage. Fast acceleration can be discarded immediately since the vehicles are in service situations that aren't in direct need of fast acceleration. However there is a need for enough power to handle some road inclination, for at least some time, especially for the Flexlinjen vehicle which is positioned in a hilly area. The modelling process is mostly focused on balancing maximum power and average power needed. The dimensioning of the engine sizes is viewed from the extreme cases in order for the vehicles to handle all situations. The balance of cost and weight regarding the vehicle dimensioning requires consideration to the different needs of the different situations the vehicle can be put in. The cheaper and lighter components that are required for the average situations might prevail over the difficulties the vehicle could have due to weaker components than actually needed in other situations. Acceleration, speed and road inclination together with the vehicle mass are parameters included in calculations of vehicle propulsion and are estimated ahead in order to give a base for the upcoming simulations. The estimations for Hemtjänsten are based on the curb weight used throughout the report. ; 1484 kg. However, for Flexlinjen the weight is 3410 kg in order to dimension for potential passengers and therefore eight passengers à 80 kg is added to the curb weight. The following equations will conclude the need for the powertrain torque and power in order to handle the surrounding forces. By using **(**1**)** and eliminating the brakes, the traction need of the vehicle depends on air, roll and climbing as follows for Hemtjänsten

$$F_{trac\_Hem} = F_a + F_r + F_c = 0.411v^2 + 131.2\cos(a) + 14573\sin(\alpha) \quad (11)$$

and for Flexlinjen

$$F_{trac\_Flex} = F_a + F_r + F_c = 1.446v^2 + 301.4\cos(a) + 33486\sin(\alpha) \quad (12)$$

The needs of the powertrain, that is, the size of the engine

$$F_{Powertrain} = F_{acceleration} + F_{traction} = ma + F_{traction} \quad (13)$$

is crucial for the coming simulations.

By studying Table 6 the information about the drive cycles is given and the maximum speed for both Hemtjänsten and Flexlinjen is about 80 km/h (22 m/s) and the maximum acceleration is 2.7 m/s^2 and 1.7 m/s^2 respectively. However, if the NEDC shall be run, the maximum speed will increase to 120 km/h; this is not necessary to give perfect results since it's unlikely that the vehicles will travel at such high speeds; the average speed is 35.6 km/h (10 m/s) for Hemtjänsten and 22.8 km/h (6 m/s) for Flexlinjen (according to Table 6). The consequence of not dimensioning the vehicle for the NEDC implies that the results will not be perfect for the NEDC simulations. Regarding road inclination the maximum values are estimated based on what is considered a steep hill in Sweden (where signs are put up to warn) which is 5%; measured in risen meters per 100 meter which concludes that a high α is $\approx$ 0.05 radians. In viewing the drive cycles the maximum instant inclination is higher, however it's more viable to regard inclination for a longer period and therefore 0.05 radians is used.

For Hemtjänsten the maximum traction needed force is

$$F_{trac\_max} = 0.411 * 22^2 + 131.2\cos(0.05) + 14573\sin(0.05) = 1058\ \text{N} \quad (14)$$

at 22 m/s giving 336 Nm[6] and 23.3 kW[7]. (13) states the need for the powertrain and in combination with the maximum acceleration the need is calculated to be

$$F_{P\_max} = 1484 * 2.7 + 1058 \ = \ 5065\ \text{N} \quad (15)$$

at 22 m/s which translates to 1607 Nm for the wheels or 111.4 kW.

If considering the average speed, 10 m/s, the traction need is

$$F_{trac\_av} = 0.411 * 10^2 + 131.2\cos(0.05) + 14573\sin(0.05) = 901\ \text{N} \quad (16)$$

giving a powertrain need at an, approximated, average acceleration of

$$F_{P\_av} = 1484 * \frac{2.7}{2} + 901 \ = \ 2904\ \text{N} \quad (17)$$

or 921 Nm, 29.0 kW at the wheels. Although the calculations are done for the curb weight, the possibly added weight for Hemtjänsten is not much (for example cleaning supplies and groceries). Reasonable dimension for an ICE is 110 kW (maximum power) however the dimensioning of the ICE fuel map used in this report gives the possible power to be 108 kW, which is deemed reasonable. For an EM, the maximum power doesn't have to be reached to the same extent as for an ICE due to the direct torque and higher efficiency. Reasonable modelling for the EM should be near the maximum though and the estimation in this report deems that 80 kW is fit. Considering the series connected hybrid, the size of the EM should be scaled to be the maximum required for the vehicle needs, giving a maximum power of 80 kW. However, the maximum effect of the ICE doesn't necessary need to be as big as required for a FOV, but the more power for the ICE the less often it will have to run giving that the dimensions in the series configuration is decided to be 80 kW for the ICE.

---

[6] T=Fr

[7] P=Fv

For Flexlinjen the curb weight of 2770 kg is not used in the dimensioning calculations, due to the potential passengers and therefore eight passengers à 80 kg are added to the curb weight = 3410 kg. The maximum traction needed force is

$$F_{trac\_max} = 1.446 * 22^2 + 301.4\cos(0.05) + 33486\sin(0.05) = 2675\text{N} \qquad (18)$$

at 22 m/s giving 931 Nm and 58.9 kW. **(**13**)** gives the need for the powertrain and in combination with the maximum acceleration the need is calculated to be

$$F_{P\_max} = 3410 * 1.7 + 2675 = 8472\text{ N} \qquad (19)$$

at 22 m/s which translates to 2948 Nm for the wheels or 186.4 kW.

If considering the average speed, 10 m/s, the traction need is

$$F_{trac\_av} = 1.446 * 10^2 + 301.4\cos(0.05) + 33486\sin(0.05) = 2120\text{ N} \qquad (20)$$

giving a powertrain need at an, approximated, average acceleration of

$$F_{P\_av} = 3410 * \frac{1.7}{2} + 2120 = 5019\text{ N} \qquad (21)$$

or 1747 Nm at the wheels and 50.2 kW. The dimensioning of Flexlinjen is extra difficult due to the hilly roads and the heavy vehicle, not so much regarding the acceleration or speed. The final need is decided however on that the general area that Flexlinjen shall cover isn't very large and therefore the maximum acceleration does probably not have to be very high in order to get from one destination to another within one hour (which is the condition for Flexlinjen). The power needed for Flexlinjen is at least 50 kW but with harsh conditions closer to 190 kW. However, what is possible to dimension with the fuel map for the maximum power for the ICE in this study is 180 kW. 150 kW is decided as the maximum power for the EM.

Gearing is needed in order to shift the revolutions of the motor/engine to not be as frequent as for the wheels. The gearing for the ICE has several more steps than for the EM. The range is smaller for the ICE (~900-6000 rpm) in comparison to the EM (~0-12000) and also the ICE is more sensitive to poor gearing due to the emissions of CO_2 and although the EM is less effective in some areas the impact of less gears is deemed higher for the ICE. The gearing for the FOV is: 5.5217, 2.3665, 1.5059, 1.1043, 0.8283; final drive 3.61:1 and the gearing for the Hemtjänsten EM is a final drive of 7.6:1 and for Flexlinjen a final drive of 3.3:1, both scaled for P=80 kW, i.e. e.g. 3.3*1 for Hemtjänsten's BEV.

Table 8 displays the characteristics of the powertrain components in each situation and the different models. The other parameters of the powertrain are listed in chapter 4 - Simulator.

Table 8: The vehicle parameters for the two service situations

Hemtjänsten		**FOV**	**BEV**	**HEV**	**PHEV**
ICE	*P [kW]*	108	-	80	80
	T [Nm]	230	-	170	170
Electric motor	*P [kW]*	-	80	80	80
	T [Nm]	-	170	170	170
Flexlinjen		**FOV**	**BEV**	**HEV**	**PHEV**
ICE	*P [kW]*	180	-	150	150
	T [Nm]	383	-	319	319
Electric motor	*P [kW]*	-	150	150	150
	T [Nm]	-	319	319	319

3.2.2 FUEL & BATTERY PARAMETERS

This report covers two very different scenarios and therefore also two different vehicles regarding body and fuel tank size. The SOC window of the batteries in the BEV models has been decided to range between 20-90% of the battery capacity and the HEV batteries have a SOC window between 30-65% [22]. In order to get the most AER from the PHEV the SOC window in CD mode is decided to 90-35% leaving a CS window of 25-35%.

Battery capacity, as with many parameters regarding vehicle dimensioning, demands a balance between weight and performance. Hybrid vehicles does not have large batteries since the only purpose is to capture braking energy which won't generate a lot of Wh. BEVs run only on batteries which makes the vehicles unsuitable for long distances. Continuous high power load will quickly drain the energy storage. Estimations of the required average kWh/km consumption including regenerative braking and losses are presumed according to simulations.

Hemtjänsten drives about 45 km in a day for a total of a bit more than an hour with an average, drive cycle specific simulation including regeneration, energy consumption per km of 0.064 kWh when considering the curb weight (1484 kg) which gives that the required battery size is

$$E_{Hem} = 0.064 * 45/(0.9 - 0.2) = 4.1 \text{ kWh} \quad (22)$$

Flexlinjen drives about 186 km in a day for a total of about 8 hours with an average, drive cycle specific simulation including regeneration, energy consumption per km of 0.21 kWh when considering the curb weight with added passenger weight (3410 kg) which gives that the required battery size is

$$E_{Flex} = 0.21 * 186/(0.9 - 0.2) = 55.8 \text{ kWh} \quad (23)$$

Hemtjänsten's BEV battery size is rounded off to 5 kWh to enable a little leeway on the drive cycle and the HEV batteries are dimensioned very small (1 kWh for Hemtjänsten and 2 kWh for Flexlinjen). The dimensioning of the batteries for PHEVs is dependent on the desired AER. Considered in this report is an AER of about one fourth of the distance travelled in a day giving a battery size of 1.5 kWh for Hemtjänsten and 15 kWh for Flexlinjen. The battery dimensions together with fuel tank size and given SOC windows are presented in Table 9 below.

Table 9: The fuel and battery parameters for the two different vehicles (Hemtjänsten and Flexlinjen)

		FOV	BEV	HEV	PHEV
Initial fuel: [l]	*Hemtjänsten*	50	-	28	20
	Flexlinjen	100	-	50	30
Initial battery [kWh]	*Hemtjänsten*	-	5	1	1.5
	Flexlinjen	-	60	2	15
SOC: CD window [%]		-	90-20	-	90-35
SOC: CS window [%]		-	-	65-30	35-25

3.2.3 BODY AND CAR COMPONENT WEIGHTS

The differences in mass dependent on type of vehicle can differ quite a bit due to the different powertrain components. A BEV does for example not have a combustion pipe or a heavy ICE but it does have a heavy battery. The weight distribution of the different powertrain components have been estimated from the weight distribution of a FOV where the total mass was first divided into percentages and then concluded to constants: 11% for the ICE, 6% for the fuel and exhaust, 6% for the transmission, leaving 77% for the body including driver, heating and internal structure [23]. The weight of the different components were set for a FOV and it was concluded that the ICE had a constant weight parameter of 1.5 kg/kW, the exhaust system 50 kg (fuel deducted) and the transmission 89 kg [24] [25]. The weight of a driver is included in the curb weight and set to 80 kg and the weight of the fuel was added[8]. The battery for electrified vehicles is estimated to 8 kg/kWh based on the weight of the Nissan Leaf battery pack (200 kg for 24 kWh) and an electric machine is estimated to 1.34 kg/kW [26]. The charger is concluded to weigh 4 kg and the power electronics approximately 10 kg.

The weights of the powertrain components of the different models simulated for Hemtjänsten are listen in Table 10. Hemtjänsten's weight parameters are modelled after a Volvo V50 with a curb weight of 1484 kg and a maximum weight of 1890 kg [20].

Table 10: The weight components for the different models - Hemtjänsten [kg]

Hemtjänsten [kg]	**FOV**	**BEV**	**HEV**	**PHEV**
Body weight	1063	1063	1063	1063
Battery	-	40	8	12
Electric motor	-	67	67	67
Generator	-	-	33	33
Charger	-	4	-	4
Power electronics	-	10	10	10
Transmission	89	28	28	28
ICE	164	-	121	121
Fuel	38	-	21	15
Exhaust	50	-	50	50
Driver	80	80	80	80
TOT	**1484**	**1292**	**1483**	**1483**

[8] The weight difference between pure petrol and ethanol petrol is neglected in the weight estimations.

The weights of the powertrain components of the different models simulated for Flexlinjen are listen in Table 11. Flexlinjen's weight parameters are modelled after a Renault Masters Minibus[9] used in the service with a curb weight of 2770 kg and a maximum weight of 3590 kg [21].

Table 11: The weight components for the different models - Flexlinjen [kg]

Flexlinjen [kg]	**FOV**	**BEV**	**HEV**	**PHEV**
Body weight	2203	2203	2203	2203
Battery	-	480	16	120
Electric motor	-	126	126	126
Generator	-	-	33	33
Charger	-	4	-	4
Power electronics	-	10	10	10
Transmission	89	28	28	28
ICE	273	-	227	227
Fuel	75	-	38	23
Exhaust	50	-	50	50
Driver	80	80	80	80
TOT	**2770**	**2931**	**2803**	**2904**

3.3 POWER SUPPLY

The two situations, Hemtjänsten and Flexlinjen, will be simulated with different vehicle models (as displayed in 3.1): FOV, HEV, BEV and PHEV. The interesting figures to compare for the different models are the emissions figures as well as energy consumption; be it petrol, petrol mixed with ethanol, different power source mixes of electricity or both. The result will be displayed and compared in two ways; for petrol TTW as well as WTW figures are presented and for electricity PTW as well as WTW figures will be presented.

[9] The Renault Masters Minibus used in Flexlinjen is considered a more access friendly and large version of a seven to eight person minivan regarding CO_2 emissions.

3.3.1 PETROL

The amount of fuel used during the drive cycle is decided by the use of a predetermined BSFC map with values for each operating point (torque versus speed). In order to simulate not only pure petrol but 5% and 10% ethanol dilution, the BSFC map must be dimensioned depending on the different LHV. For 100% petrol the LHV is 0.0121 kWh/g according to (7). For comparison, simulations have been made with 5% ethanol in the petrol as well as 10% ethanol. The LHV for 5% is calculated to be

$$\frac{0.95 * 9.1 + 0.05 * 5.9\ (kWh/l)}{0.95 * 750 + 0.05 * 790\ (g/l)} = 0.0119 \left[\frac{\text{kWh}}{\text{g}}\right] \quad (24)$$

and the LHV value for 10% is concluded to

$$\frac{0.90 * 9.1 + 0.10 * 5.9\ (kWh/l)}{0.90 * 750 + 0.10 * 790\ (g/l)} = 0.0116 \left[\frac{\text{kWh}}{\text{g}}\right] \quad (25)$$

with figures from Table 3 [7].

The BSFC map used in this study is scaled to fit those values according to

$$\frac{kWh_{fuel}}{kWh_{mech}} = \text{BSFC}_{\text{original}} 0.0121 \quad (26)$$

3.3.2 ELECTRICITY

In order to give a varied view of the CO_2 contribution several combinations of energy sources have been made as seen in Figure 10. There are several combinations for the sake of displaying not only the most CO_2 inefficient combinations but also to view upon the future capabilities that exist with further developed RES. What will be used and displayed in the Analysis section are the following six: *100% fossils*, *Worst*, *Bad*, *Median*, *Good* and *Ultimate*; where "Median" to "Good" represent the average range of the electricity sold in Sweden, by three major electricity selling companies that together stand for around 80% of the electricity production in Sweden [27]. The alternative denoted as "Worst" is equivalent with the combined net electricity in the Nordic countries [28] which is PTW rated to 320 g/kWh (for 43.8% fossils). The choice denoted ”Good” is based on a combination of 95% hydro power and 5% wind power because the combination is consistent with the choices provided by the companies in order to promote environmentally friendly choices. The last alternative (”Ultimate”) represent 100% hydro power which is the best possible alternative considering CO_2 emissions and it is also offered by many electricity distributors in Sweden scrutinized in this paper. The electricity companies do not provide precise figures for each of the power sources, however estimations about the division of sources in the company category for fossils has been done according to statistics for Sweden from 2009 (with no consideration to export and import) [29]. Coal and peat are put in the same category and therefore this paper uses emission figures for hard coal with the purpose of not undervaluing the resulting CO_2 emissions, since coal has a higher emission value than peat. The alternative denoted “100% fossils” has the previous division regarding fossils redistributed to be only fossils. Regarding RES, waste burning which doesn’t hold a large percentage on its own, has been combined with bio fuels due to unclear figures for CO_2 emissions. The power from solar photovoltaic systems has not been included because the percentage, in Sweden, is considered minuscule.

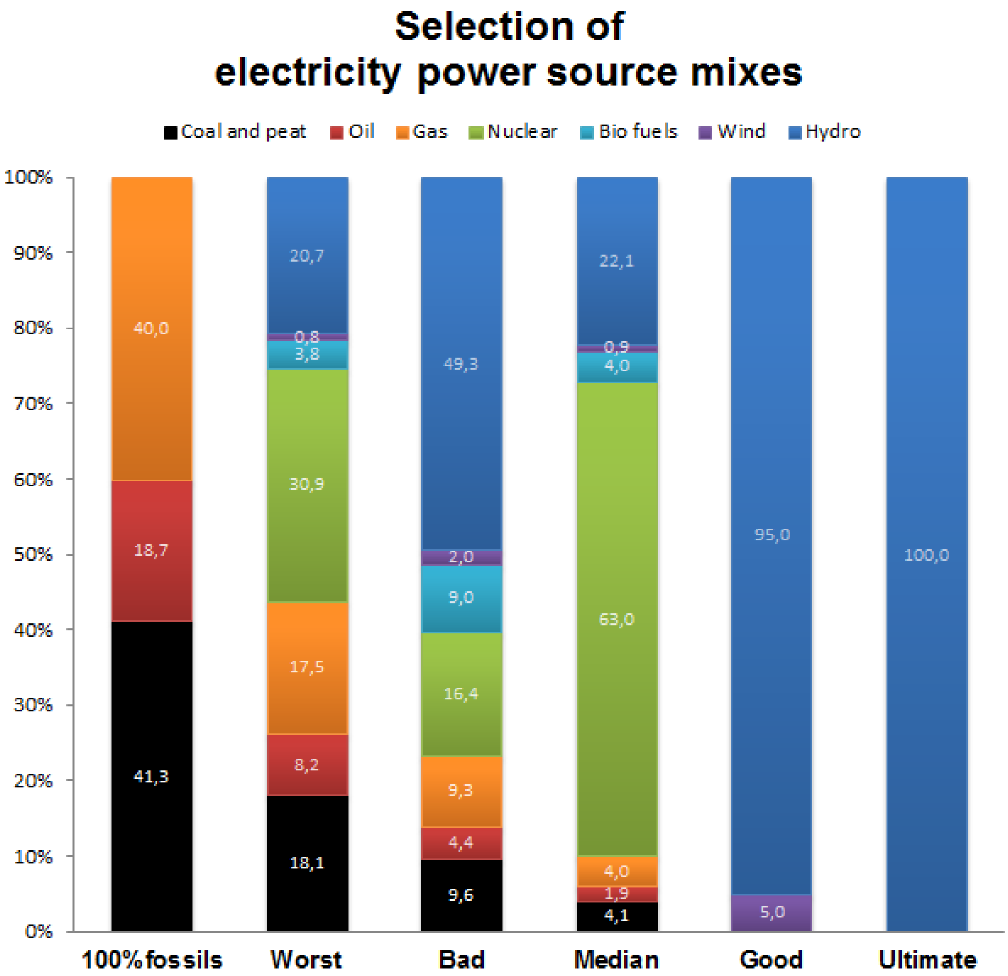


Figure 10: A summation of different power source mixes for electricity in Sweden 2012 as well as an example of 100% fossils [%]

The figures stated in international and national regulations correspond to TTW emissions regarding petrol which is why the test results in this study will include WTW figures as well as PTW emissions for electricity including production, transmission and charging in order to recognize the losses that occur before the electricity has reached the vehicle. Since the figures for PTW only include CO_2 emissions released when producing electricity, only fossils are considered. According to the combined net electricity in the Nordic countries for 2010, 43.8 % fossils[10] release 320 g/kWh which translates to a CO_2 total from fossils of about 731 g/kWh ("100% fossils") [28] rounding off to 851.5 g/kWh at the tank end of a vehicle, that is, including losses in the grid (6.6896%) [3] and whilst charging (8% [4]). Table 12 displays the PTW figures for a BEV, for the different electricity mixes (as displayed in Figure 10) with regards to the emissions for the vehicle in g/kWh, including losses in the grid and whilst charging.

Table 12: PTW emission figures for the different power sources and electricity mixes in g CO_2/kWh to the vehicle (i.e. including losses in the grid and whilst charging)

Selection	100% fossils	Worst	Bad	Median	Good	Ultimate
Fossils [g/kWh]	851.5	372.8	198.0	85.1	0.0	0.0

Table 13 however, shows the WTW calculated CO_2 emissions in g/kWh (from Table 4) for each of the electricity mixes in Figure 10.

Table 13: WTW figures for the different power sources and electricity mixes in g CO_2/kWh to the vehicle

Selection	100% fossils	Worst	Bad	Median	Good	Ultimate
Hard coal	477.7	209.4	111.0	47.4	0.0	0.0
Oil	179.9	78.9	42.3	18.3	0.0	0.0
Gas	412.4	180.4	95.9	41.2	0.0	0.0
Nuclear	0.0	4.7	2.5	9.5	0.0	0.0
Bio fuels	0.0	1.4	3.4	1.5	0.0	0.0
Hydro	0.0	0.9	2.2	1.0	4.3	4.5
Wind	0.0	0.2	0.4	0.2	1.0	0.0
TOT WTW [g/kWh]	**1070.0**	**475.8**	**257.7**	**119.1**	**5.2**	**4.5**

Table 14 displays WTT efficiencies for the different electricity mixes according to the efficiency of each power plant (see 2.2.1.1) and also including losses on the way to the vehicle.

Table 14: Calculated WTT efficiencies of the power source mix choices according to the electricity mixes, including losses until the vehicle

	100% fossils	Worst	Bad	Median	Good	Ultimate
WTT efficiency [%]	31.7	41.4	55.8	41.6	79.0	81.6

[10] Unfortunately no sectioning of the types of fossils have been found

4 SIMULATOR

The simulations for the models have been made in Matlab Simulink and the different components are described below.

Car body The propulsion of the vehicle is defined by the powertrain, the brake usage and the setting (see 2.1), it's clear that the weight of the vehicle is a major factor in the simulations.

The speed of the vehicle is calculated by integrating the accelerating force:

$$F = ma = m\left(\frac{dv}{dt}\right)$$

$$\Rightarrow\ v_{car} = \int \frac{F}{m}\,dt = \int \frac{\frac{T_{acc}}{r}}{m}\,dt$$

$$\omega = n\frac{\pi}{30}\left[\frac{\text{rad}}{\text{s}}\right] = \frac{v}{r} = 2\pi f,\ \{n\ [rpm]\}$$

Driver Controller: Comparison of reference speed and actual speed

$$v_{ref} - v_{car} = error$$

The pedal position (0-1) is defined by the error regulated by a PI controller

$$PedalPosition = error\ K_p + K_i\ \int error\ dt$$

Gear: The FOV is modelled to have five gears (five different limits for the speed) including a final drive and also an idling speed (minimum speed) of 900 rpm. The BEVs and HEVs have one gear (final drive) and no idling (direct torque).

ICE: BSFC map with brake specific fuel consumption (g/kWh) measures fuel efficiency. The map is scaled to fit different sizes of the engines as well as for different fuel mixes with ethanol that is, different LHV-values (kWh/g).

$$f(T,n)\left[\frac{g}{kWh}\right]$$

Fuel tank: The fuel tank has a weight varied depending on the amount of fuel left.

Battery: The battery is modelled with a constant voltage of 290 Volts and resistance of 0.1 or 0.2 ohms depending on the size of the battery.

0.2 Ω; HEV

0.1 Ω; PEV

The power from the converter is considered regenerative if positive and discharge power if negative into the power source.

The battery has limits for SOC and calculates the battery used as well as the losses [Wh]. This means that when the lower limit of the SOC is reached, the ICE is run and also that when the maximum is reached the ICE is shut off in order to utilize the energy stored in the battery.

EM: The losses in an EM are unpredictable and an efficiency map with torque and speed parameter is therefore used.

$f(T, n)$ [%]

Generator: Since a generator is an electric machine acting as a generator instead of an electric motor, the losses are as unpredictable as for the EM. The same efficiency map with torque and speed parameter is used as for the EM, but scaled.

$f(T, n)$ [%]

Converters: The losses in a converter are unpredictable and a map with torque and speed parameter is therefore used to predict the losses.

$f(T, n)\ [W]$

Energy Calculation: The used battery or fuel (or both if hybrids) is divided by the distance travelled to yield the energy consumption both TTW and WTW and also to calculate the emissions, total and per km (see tables Table 17 & Table 18 for petrol and Table 19 & Table 20 for electricity).

There is no consideration to possible differences in SOC comparing start and finish – the differences have been concluded to be small.

Losses: There are losses in the components.

Losses in: ICE - A function map depending on Torque and revolutions.

$$f(T, n) \left[\frac{g}{kWh}\right]$$

Losses in: EM & Generator - A function map depending on Torque and revolutions subtracted from the original/input power.

$$f(T, n)\ [\%]$$

Losses in: Converters - A function map depending on Torque and revolutions transformed from power to energy.

$$f(T, n)\ [W]$$

Losses in: Battery – Constant voltage and resistance.

$$P^2 \left(\frac{R}{U^2}\right)\ [W]$$

The powertrain efficiency is calculated by subtracting the losses from the used energy and then dividing it from the used energy (see figures in 5.2).

$$E_{out} = \frac{E_{in} - E_{loss}}{E_{in}}$$

5 ANALYSIS

The PTW and WTW figures for the different electricity mixes that will be used are (as seen in 3.3.2): 100% fossils, Worst, Median, Good and Ultimate to display a wide spread of possible CO_2 emissions from electricity.

5.1 SIMULATED: DRIVE CYCLES & TRACTION FORCES

The different drive cycles, both simulated and theoretical values, are displayed in the following figures (from FOV simulations since all simulations had similar results however slightly different weights). The simulated drive cycles are not perfect according to the optimal conditions in Table 6, however all the vehicles simulated have similar results. Regarding PHEVs, the decided size of the battery leads to a UF of about 20% (see Figure 29) for Hemtjänsten and 26% for Flexlinjen (see Figure 33) when all electric CD mode is run from 90% SOC to 25% SOC (according to the limits set for this study in Table 9). The NEDC-cycles have been adjusted to properly run full CD mode and the stabilize in the CS mode (5 cycles for Hemtjänsten and about 11 cycles for Flexlinjen). All cycles have been made to end up at 25% SOC for HEVs and PHEVs.

5.1.1.1 Hemtjänsten - Drive cycle

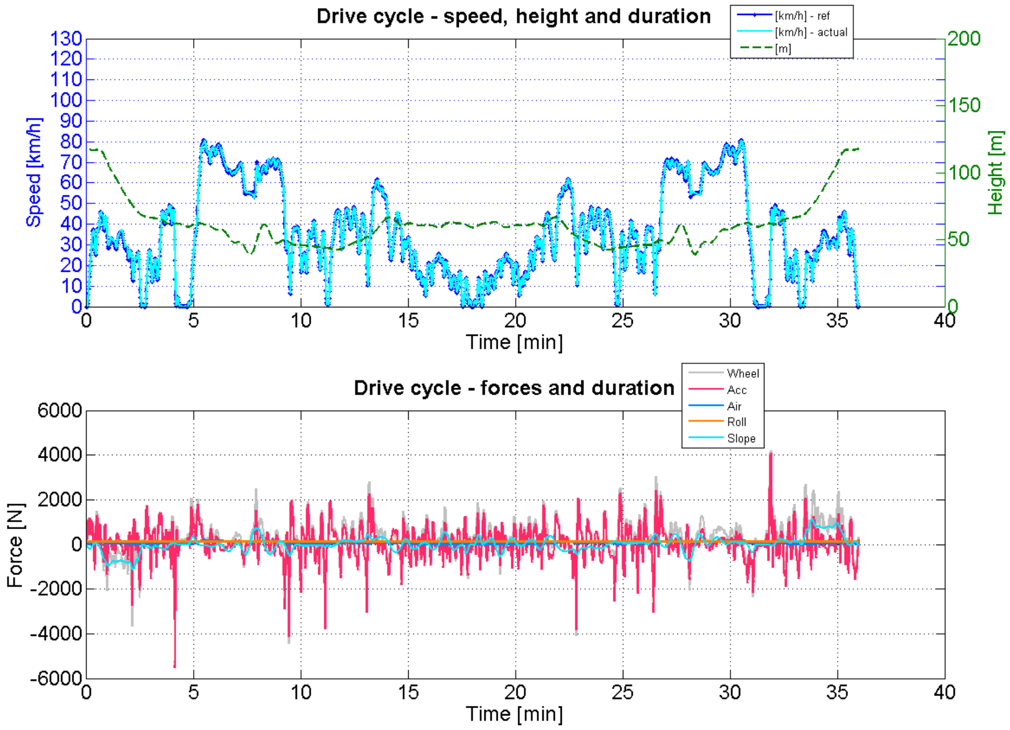


Figure 11: The driven cycle for Hemtjänsten

5.1.1.2 Hemtjänsten - NEDC

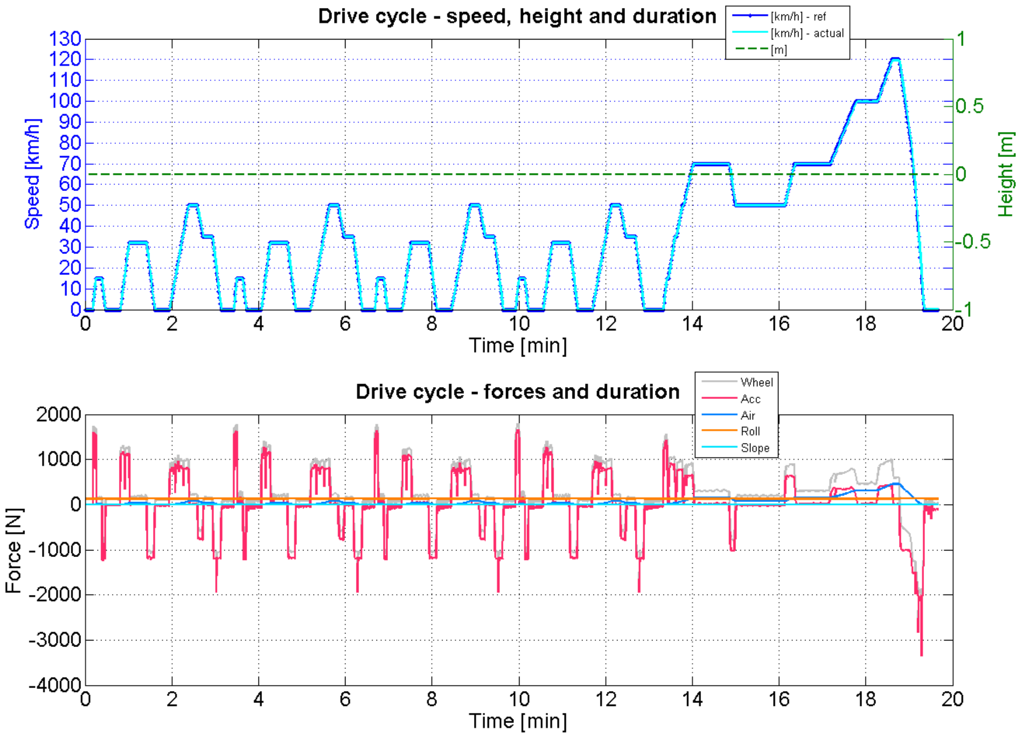


Figure 12: The driven NEDC for Hemtjänsten

5.1.1.3 Flexlinjen - Drive cycle

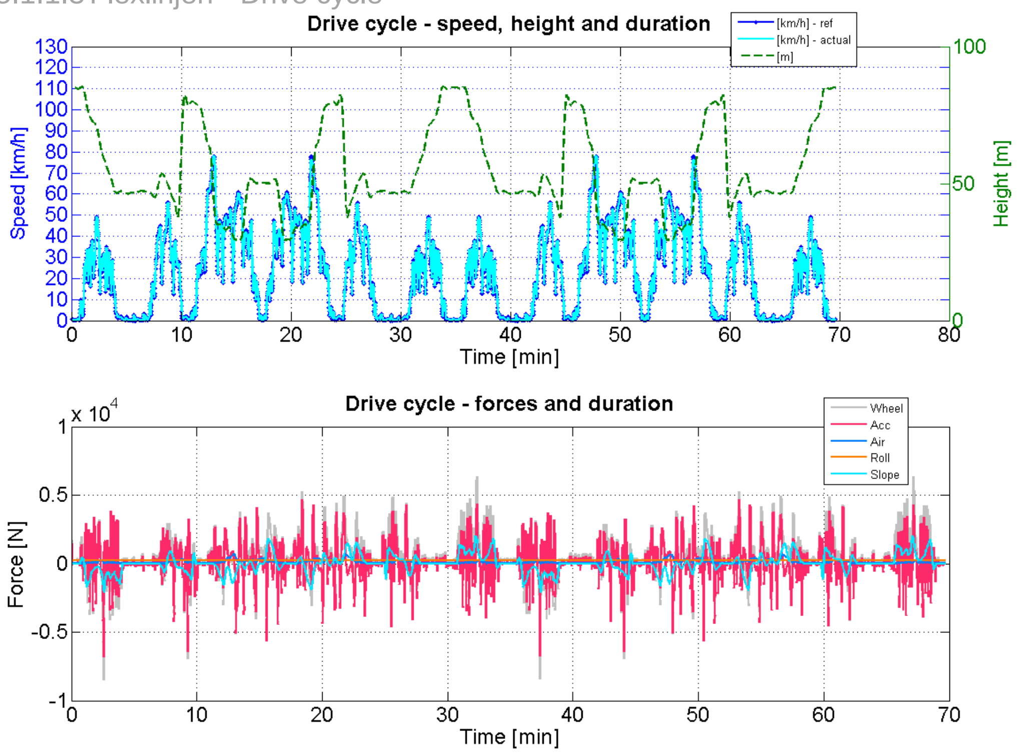


Figure 13: The driven cycle for Flexlinjen

5.1.1.4 Flexlinjen - NEDC

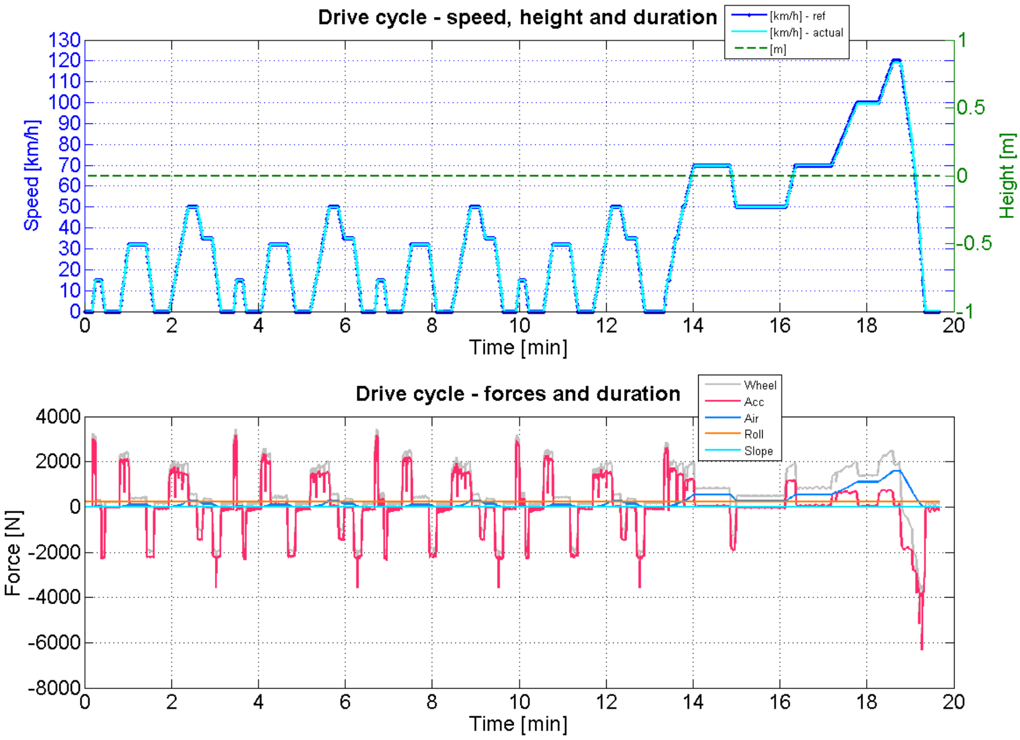


Figure 14: The driven NEDC for Flexlinjen

5.2 SIMULATED: EM & ICE EFFICIENCY

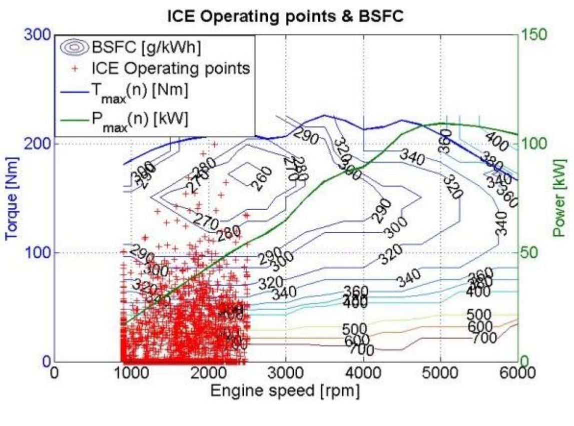
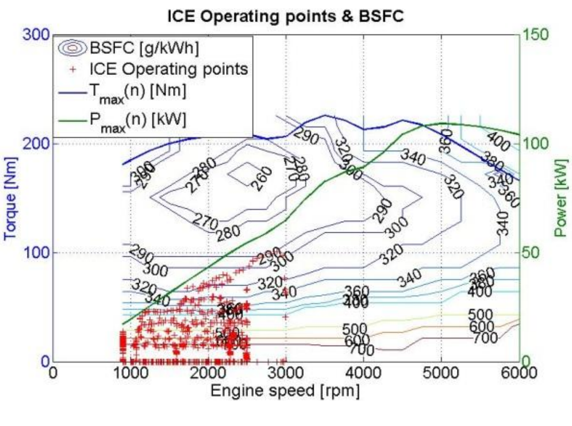
Model	**Hemtjänsten efficiency**	
FOV 100% petrol		

Figure 15: The efficiency of the ICE for Hemtjänsten 100%

Figure 16: The efficiency of the ICE for NEDC 100%

BEV

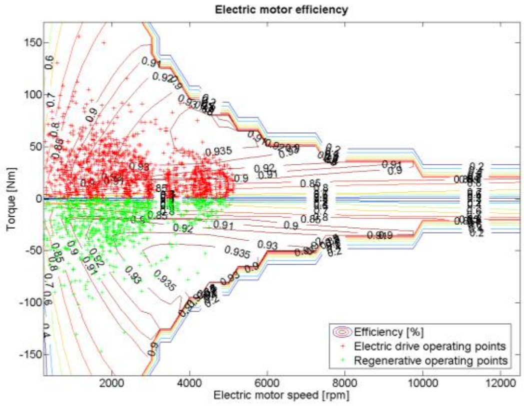


Figure 17: The efficiency of the EM for Hemtjänsten

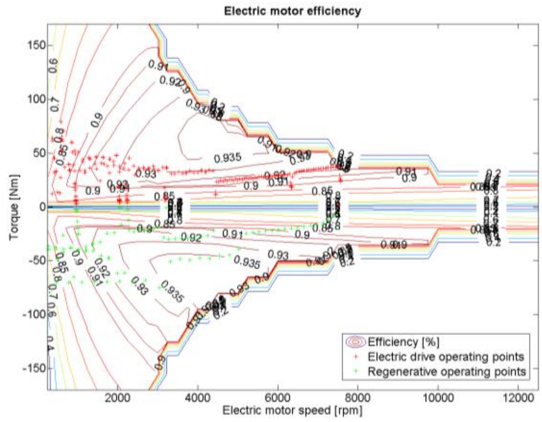


Figure 18: The efficiency of the ICE for NEDC

HEV

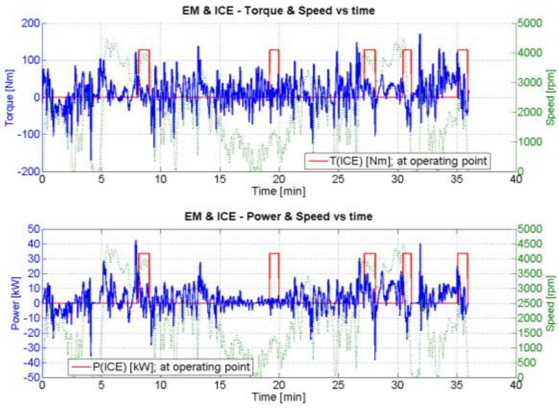


Figure 19: Torque & Power vs. speed (EM) and ICE operating point for Hemtjänsten

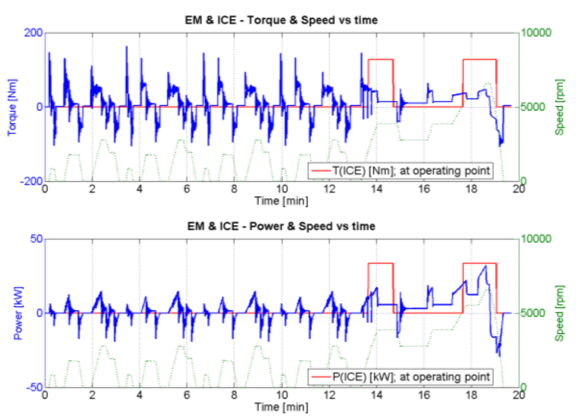


Figure 20: Torque & Power vs. speed (EM) and ICE operating point for NEDC-Hemtjänsten

Model **Flexlinjen efficiency**

FOV 100% petrol

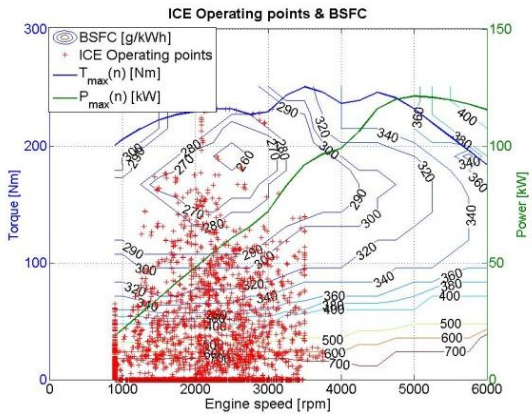


Figure 21: The efficiency of the ICE for Flexlinjen 100%

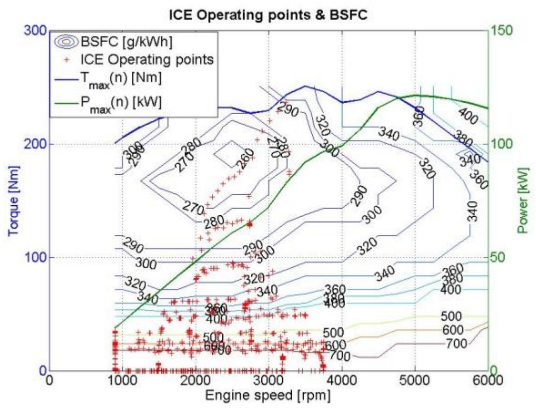


Figure 22: The efficiency of the ICE for NEDC 100%

BEV

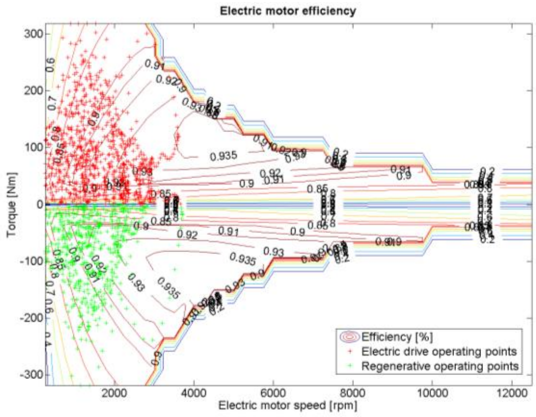


Figure 23: The efficiency of the EM for Flexlinjen

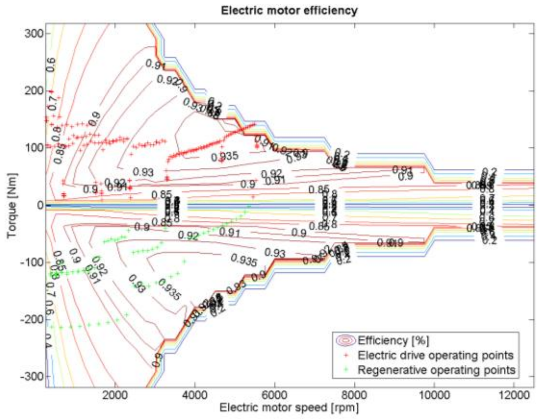


Figure 24: The efficiency of the EM for NEDC

HEV

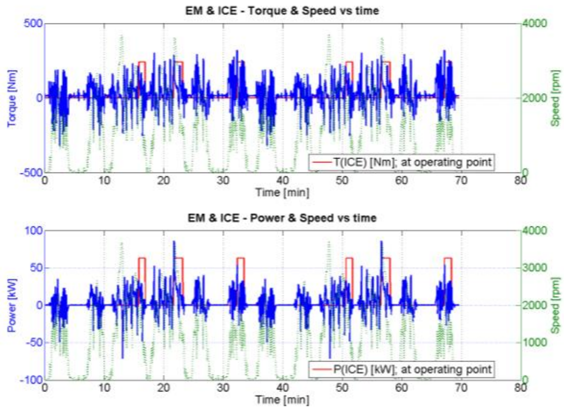


Figure 25: Torque & Power vs. speed (EM) and ICE operating point for Flexlinjen

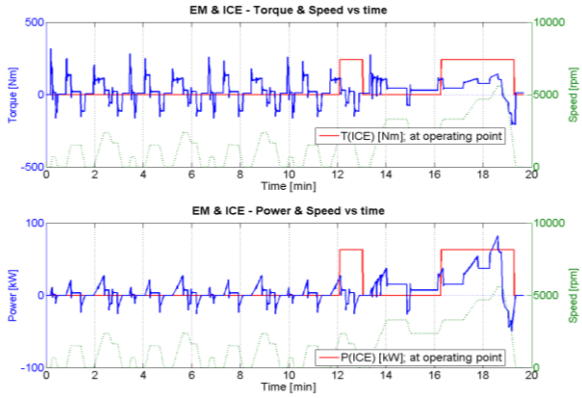


Figure 26: Torque & Power vs. speed (EM) and ICE operating point for NEDC- Flexlinjen

5.3 SIMULATED: SOC LEVELS

Model **Hemtjänsten SOC**

HEV 95% petrol

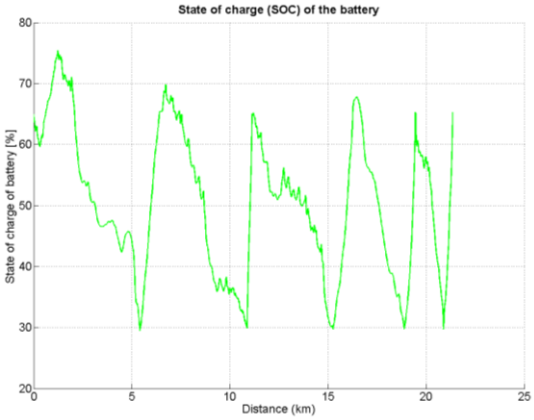


Figure 27: The HEV SOC for Hemtjänsten

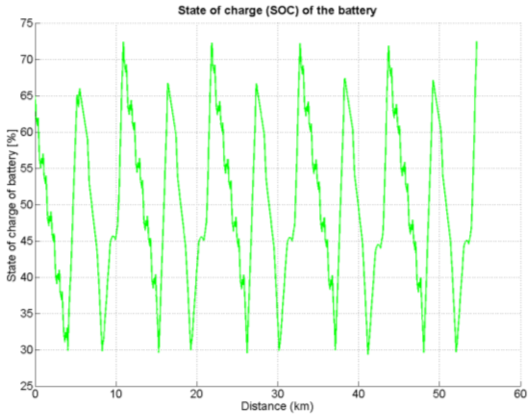


Figure 28: The HEV SOC for NEDC (5 cycles)

PHEV 95% petrol

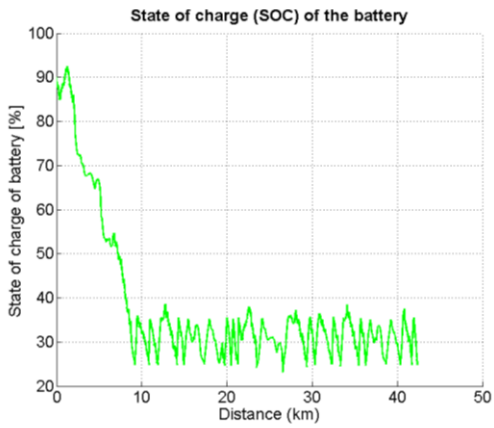


Figure 29: The PHEV SOC for Hemtjänsten

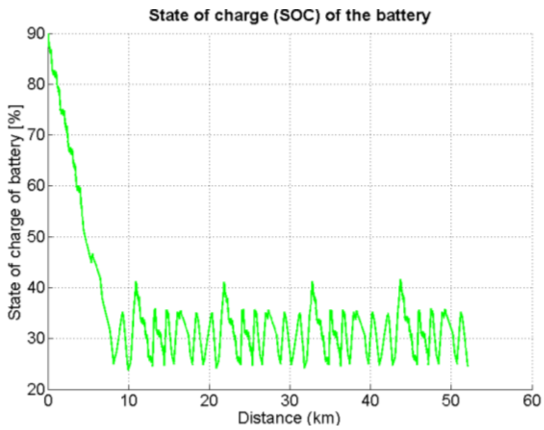


Figure 30: The PHEV SOC for NEDC (5 cycles)

Model **Flexlinjen SOC**

HEV 95% petrol

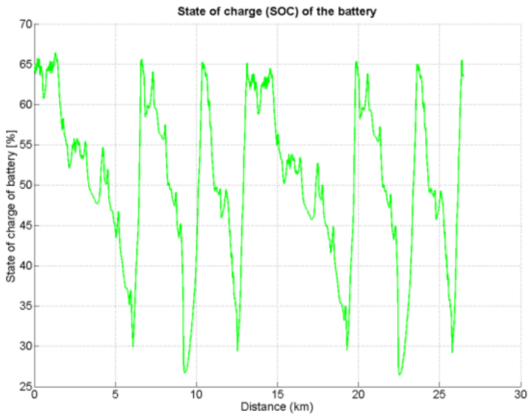


Figure 31: The HEV SOC for Flexlinjen

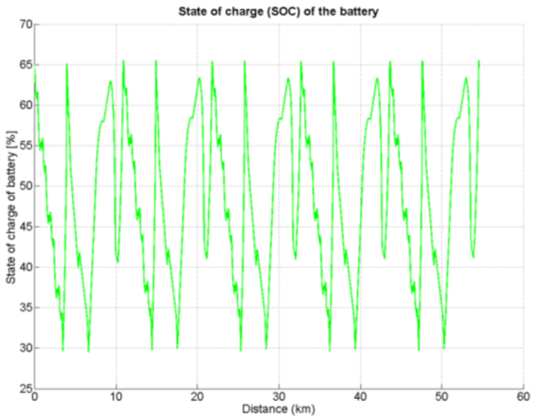


Figure 32: The HEV SOC for NEDC (5 cycles)

PHEV 95% petrol

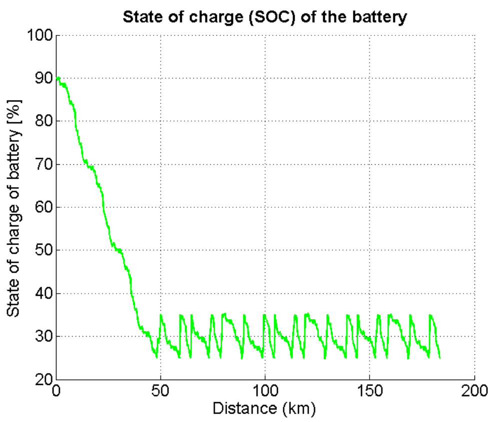


Figure 33: The PHEV SOC for Flexlinjen

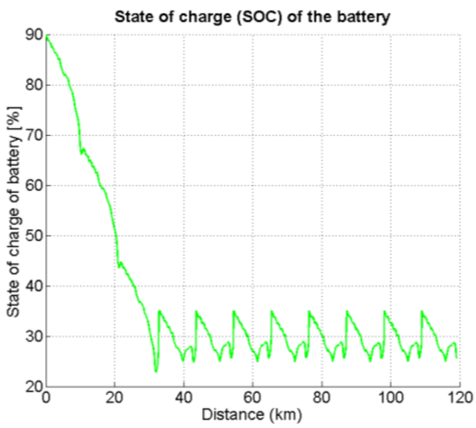


Figure 34: The PHEV SOC for NEDC (5 cycles)

5.4 EFFICIENCY: SIMULATED PER DRIVE CYCLE AND VEHICLE

If a comparison between efficiency is to be made, it is important to include the whole chain of supply of the energy used because even though the BEV has a more efficient powertrain the chain of supply is not as efficient for electricity as for petrol due to many steps each with losses. In Figure 35 and Figure 36 the efficiencies of Hemtjänsten and Flexlinjen are displayed with the simulated TTW for each drive cycle and WTT efficiency figures for 95% petrol (84.9%; see 2.2.2.2) and the total generation efficiency of each electricity mix.

The efficiency figures for PHEVs are based on the energy consumption calculated from a mean of the figures for CD (electricity) and CS (95% petrol) based on each drive cycle.

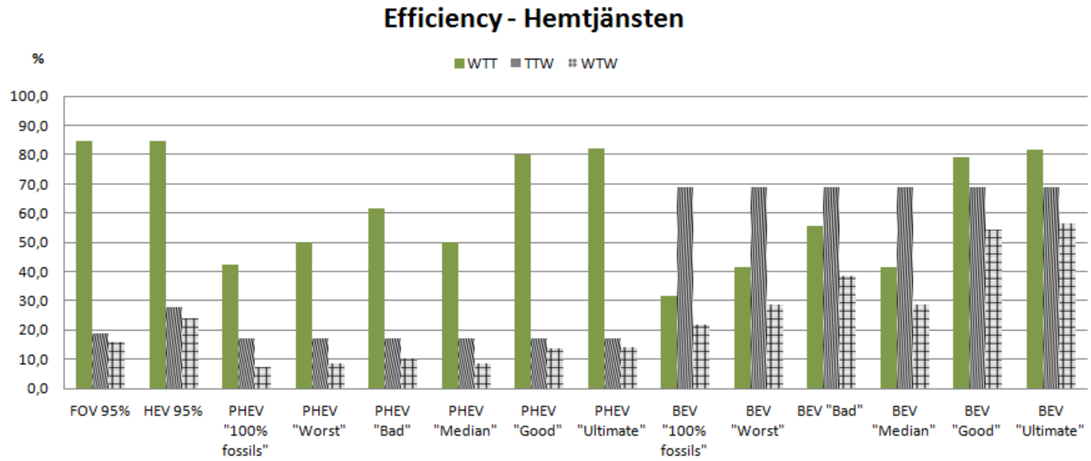


Figure 35: The efficiency figures for Hemtjänsten's drive cycle; 95% petrol and the efficiencies of the electricity mixes

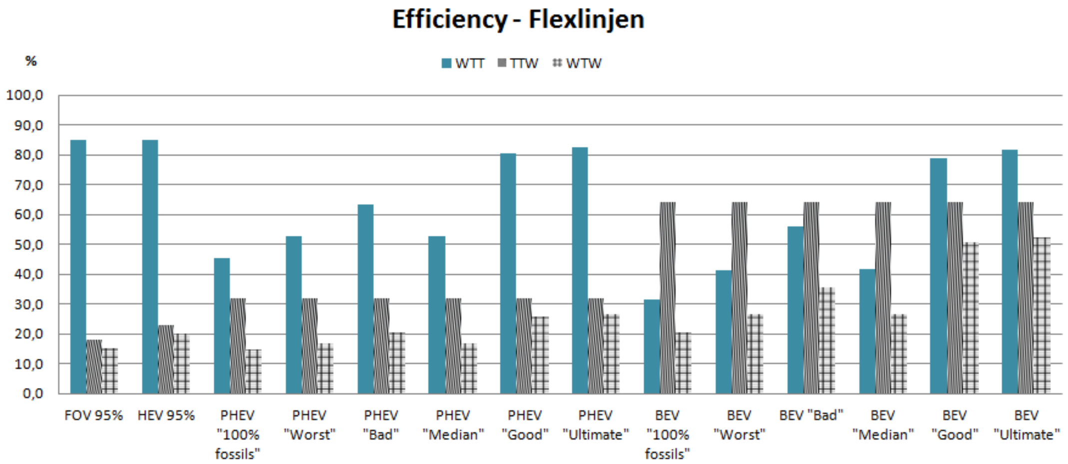


Figure 36: The efficiency figures for Flexlinjen's drive cycle; 95% petrol and the efficiencies of the electricity mixes

5.4.1 COMMENTS

When considering CO_2 emissions the efficiency of the different power sources, be it petrol or electricity, is not as important as the actual CO_2 released. The efficiency of e.g. a wind power plant is not 100% because it's dependant on the efficiency of the generators, also the outcome of produced electricity is much dependant on the presence of wind. However, if less electricity is generated due to less or no wind, there is no difference in the release of CO_2 since the only emissions concerning wind power come from the production of the power plants (WTW figures) and are thereby non-dependant on the generation of electricity. The problem at hand would rather be the possible shortage of electricity, something to be considered regarding all RES; is the demand lower or at least equal to the supply? Regarding petrol, the immediate losses occur whilst drilling and transporting and even though the general efficiency is high the, comparatively, inefficiency of ICEs are notable and important for a wider perspective than only CO_2 emissions since petrol is an ending source.

The results, especially regarding Flexlinjen, show TTW results of better efficiencies the more electricity that is used, i.e. the best TTW efficiency result is displayed for BEVs (64%) with a notably less percentage for PHEVs (32%). HEVs at 23% are not very far behind in the TTW efficiency results compared to PHEVs but FOVs have the least efficient drivetrain at 18%. Regarding the WTW figures, the high WTT efficiency of petrol changes the total results but BEVs are still the most efficient, no matter the production source. FOVs are still the least efficient if disregarding PHEVs "100% fossils", however PHEVs "Worst" and "Median" alternatives have similar figures. The WTW figures for Flexlinjen's PHEVs, depending on electricity mix, are better than the HEVs which have a WTW efficiency of about 20% (still higher than FOVs TTW figures). None of the PHEVs WTW figures for Hemtjänsten show better efficiency than for FOVs although the "Good" and "Ultimate" electricity mixes are not far behind. The poor efficiency for Hemtjänsten's PHEV compared to Flexlinjen's is most likely due to the proportionally larger weight of the conventional components; the ICE, power electronics, fuel tank, EM and generator. Also, the UF for Flexlinjen is higher (26% instead of 20%) giving that the Hemtjänsten drive cycle is proportionally more run with an ICE (which is less efficient than an EM).

The HEV for Hemtjänsten show a much higher WTW result than for Flexlinjen, this due to a more efficient powertrain (higher TTW figures). Regarding BEVs for Hemtjänsten, the "100% fossils" mix is not more efficient than 95% HEVs due to the poor WTT figures.

Interesting to note is the poor WTT figures for the "Median" alternative in comparison to the "Bad". The efficiency might be worse for "Median" but there is less release of CO_2, giving that the "Median" is at least a better alternative in that perspective.

5.5 DIRECTIVES: ELECTRICITY & PETROL

According to statistics (see 2.3.3) the levels for CO_2 emissions for all newly registered municipal-owned petrol and diesel cars in Sweden 2011 was 133 g/km. The reference number for Sweden in 2012 is however 120 g/km with the international goal of 95 g/km in 2020 (see 2.3.2). The corresponding number for vehicles powered by electricity, PEVs, is 37 kWh/100 km and for the harder regulations that provide a purchase bonus the number is 50 g CO_2/km. Since these numbers only refer to TTW emissions the test results in this study will provide the corresponding figures for electricity (i.e. PTW figures) as well as WTW figures. As mentioned in 2.3.2, the Swedish CO_2 emission limits until 2016 are for Flexlinjen about 160 g CO_2/km and for Hemtjänsten about 100 g/km; the EU regulations are 194 g/km and 135 g/km respectively.

5.5.1 PRESENT DIRECTIVES – 120 G CO_2/KM

Present Swedish directives (2.3.2) gives a limit for environmentally friendly electric vehicles at 37 kWh/100 km which, considering losses in the grid and whilst charging, translates to about 43 kWh/100 km produced electricity. Put in perspective to FOVs, the 43 kWh/100 km would translate to an electric production allowing

$$\frac{\frac{120\ gCO_2}{km}}{\frac{43\ kWh}{100\ km}} = \frac{120\ g\ \mathrm{CO_2}}{0.43\ kWh} = 279\ \left[\frac{g\ CO_2}{kWh}\right] \tag{27}$$

This value is lower than the ”Worst” electricity alternative (PTW=372.8 g/kWh, WTW=475.8 g/kWh) but higher than the “Bad” considering both PTW and WTW (PTW=198.0 g/kWh, WTW=257.7 g/kWh), therefore 279 g/kWh translates to an electricity mix higher than average in Sweden and is thereby not very difficult to stay below. This gives that the limit for PEVs doesn’t correspond to the equivalent limits for FOVs since 120 g/km is a low figure to achieve with a petrol fuelled vehicle today.

5.5.2 "SUPER" DIRECTIVES – 50 G CO_2/KM

Even though no comparison in kWh/100 km has been established for the super credit cars, a suggestion was 30 kWh/100 km (see 2.3.2) which considering losses in the grid and whilst charging translates to about 35 kWh/100 kWh. Put in perspective to FOVs the 35 kWh/100 km would imply an electric production allowing

$$\frac{\frac{50\ gCO_2}{km}}{\frac{35\ kWh}{100\ km}} = \frac{50\ g\ \mathrm{CO_2}}{0.35\ kWh} = 142.9\ \left[\frac{g\ CO_2}{kWh}\right] \tag{28}$$

This value is higher than the "Median" electricity alternative which represents one of the highest figures in the range that correspond to the average electricity sold in Sweden (PTW=85.1 g/kWh, WTW=119.1 g/kWh). In view of that 142.9 g/kWh correspond to the upper average of the electricity production in Sweden the limit of 30 kWh/100 km should be considered a high equivalent figure since 50 g/km would be difficult to achieve with a FOV today (about 2.2 l/100 km for 95% petrol).

5.5.3 THE FUTURE IN SWEDEN [G CO_2/KM]

The proposed future legislation from the Swedish government for environmentally friendly vehicles puts the limit for amount of CO_2 released in proportion to the weight of the vehicle (see 2.3.2).

In order to compare theoretical results with regulations, calculations for TTW and WTW conversions to l petrol/100 km will be performed as follows, with figures from Table 5:

$$\left(\frac{\frac{X\ g\ CO_2}{km}}{\frac{\mathrm{Y}\ g\ CO_2}{l}}\right)100 = \frac{l}{100\ km} \tag{29}$$

In order to translate the emissions figures to correspond to production, not only to l/100 km; TTW and WTW conversions to g/kWh will be performed as follows

$$\frac{\frac{g\ CO_2}{km}}{\frac{\frac{l}{100\ km}\frac{kWh}{l}}{'losses'}}100 = \frac{g\ CO_2}{kWh} \tag{30}$$

with figures from (29) and Table 5 as well as from Table 3.

The approximate curb weight of a typical vehicle for Hemtjänsten is 1484 kg which would allow 100 g CO_2/km and the electricity production results displayed in Table 15.

Table 15: Fuel & consumption figures in l/100 km and g/kWh equivalents (in production) of 100 g CO_2/km for different petrol mixes; TTW and WTW for Hemtjänsten

	TTW emission		WTW emissions
	[l/100 km]	**[g CO_2/kWh]**	**[g CO_2/kWh]**
100 % petrol	4.2	224.2	261.5
95 % petrol	4.5	213.2	245.6
90 % petrol	4.7	207.5	239.5

Typical weight for Flexlinjen is 2770 kg which would allow 160 g CO_2/km and the electricity production and petrol consumption displayed in Table 16.

Table 16: Fuel & consumption figures in l/100 km and g/kWh equivalents (in production) of 100 g CO_2/km for different petrol mixes; TTW and WTW for Flexlinjen

	TTW emission		WTW emissions
	[l/100 km]	**[g CO_2/kWh]**	**[g CO_2/kWh]**
100 % petrol	6.8	255.5	299.6
95 % petrol	7.1	249.1	289.9
90 % petrol	7.5	240.1	281.4

5.5.3.1 Comments

Since the weights are different, the allowed emissions in production differ for Hemtjänsten and Flexlinjen. Regarding Hemtjänsten, the corresponding emissions figures range from 240-261 g CO_2/kWh WTW equivalent to the electricity mix denoted “Bad” (257.7 g/kWh). For Flexlinjen the range WTW is 281-300 g/kWh which is higher than the “Bad” mix but lower than the ”Worst” alternative (475.8 g/kWh). The future emission regulations are fair in the sense that a vehicle independent on size can get under the limit, although with some difficulty (quite low limits). However, when comparing to the possibility of electrification the figures are very high since they all correspond to very poor electricity mixes (in Sweden). The rules for electrified vehicles should be made to correspond to the new regulations for FOVs, i.e. a similar rule should be made but custom made for electrified vehicles.

5.6 PETROL: CO_2 EMISSIONS & ENERGY EFFICIENCY

Represented ahead are tables with information from the simulations with results depending on type of vehicle (FOV or HEV) and the different petrol and ethanol mixes. The custom made drive cycles as well as comparisons are put in perspective to the parameterized vehicles for the NEDC, since the

NEDC measurements are what car manufacturers and vehicle specifications represent.

Table 17: TTW and WTW efficiency and CO_2 emissions for Hemtjänsten; Different petrol mixes – FOV & HEV

Selection		[g/km]		[l/100 km]		[kWh/100 km]	
		TTW	**WTW**	**TTW**	**WTW**	**TTW**	**WTW**
FOV	*100 % petrol*	144.2	168.6	6.1	7.1	55.6	65.0
	95 % petrol	139.5	164.3	6.2	7.3	55.6	65.5
	90 % petrol	134.9	160.1	6.4	7.5	55.8	66.2
FOV _NEDC	*100 % petrol*	161.9	189.3	6.9	8.0	62.4	73.0
	95 % petrol	156.8	184.7	7.0	8.2	62.5	73.7
	90 % petrol	151.3	179.5	7.1	8.5	62.5	74.2
HEV	*100 % petrol*	84.3	98.6	3.6	4.2	32.5	38.0
	95 % petrol	81.6	96.0	3.6	4.3	32.5	38.3
	90 % petrol	78.7	93.4	3.7	4.4	32.5	38.6
HEV _NEDC	*100 % petrol*	99.3	116.2	4.2	4.9	37.6	44.0
	95 % petrol	96.1	113.1	4.3	5.0	37.6	44.3
	90 % petrol	92.7	110.0	4.4	5.2	37.6	44.7

Table 18: TTW and WTW efficiency and CO_2 emissions for Flexlinjen; Different petrol mixes – FOV & HEV

Selection		[g/km]		[l/100 km]		[kWh/100 km]	
		TTW	**WTW**	**TTW**	**WTW**	**TTW**	**WTW**
FOV	*100 % petrol*	343.9	402.2	14.6	17.0	132.6	155.1
	95 % petrol	333.0	392.2	14.9	17.5	132.8	156.4
	90 % petrol	320.4	380.2	15.1	17.9	132.4	157.2
FOV _NEDC	*100 % petrol*	365.0	426.9	15.47	18.1	140.7	164.6
	95 % petrol	352.6	415.3	15.7	18.5	140.6	165.6
	90 % petrol	339.8	403.3	16.0	19.0	140.5	166.7
HEV	*100 % petrol*	229.4	268.3	9.7	11.4	88.6	103.6
	95 % petrol	221.8	261.3	9.9	11.7	88.6	104.3
	90 % petrol	214.0	254.0	10.1	12.0	88.6	105.1
HEV _NEDC	*100 % petrol*	300.8	351.8	12.8	14.9	115.9	135.4
	95 % petrol	290.9	342.6	13.0	15.3	115.9	136.5
	90 % petrol	280.6	333.0	13.2	15.7	115.9	137.6

5.6.1 COMMENTS

Very noticeable in the comparison tables with the NEDC are the difference in consumption and emissions and the higher values displayed for the NEDC. None of the vehicles are modelled to have the driving pattern fitting the NEDC but rather being dimensioned for lower speeds. Most noticeable is however that neither the emission figures in g CO_2/km for FOVs nor for HEVs passes the future Swedish limit at 160 g/km for Flexlinjen, not even the European limit of 194 g/km!

Today’s vehicles most likely use 95% petrol which compared to 100% petrol have already given a reduction of emissions of about 3% TTW (about 2.5% WTW); although the volume of the petrol mix is greater, the ethanol has a lower energy content and thereby less emissions. The same reduction occurs when going from 95% to 90% petrol and there is an equal reduction when changing petrol mixes in HEVs. However, when considering a change from FOVs to HEVs (with the same petrol mix) the reduction is 41.5% TTW and 41.6% WTW for Hemtjänsten and 33.3% TTW and 33.4 WTW for Flexlinjen. See Figure 37 and Figure 38 ahead for reduction in reference to 95% petrol in FOVs.

Considering the l/100 km values for Hemtjänsten in this study’s simulations, the actual/simulated WTW values are 7.1-7.5 l/100 km. The TTW figures are 6.1-6.4 l/100 km, far from the calculated regulations figures which span between 4.2-4.7 l/100 km which indicates that it will be very difficult for vehicle manufacturers to improve the engines to match the regulations. For Flexlinjen, the large differences are the same; WTW simulated: 17-17.9 l/100 km, TTW simulated: 14-15.5 l/100 km but environmental regulations allow 6.8-7.5 l/100 km.

5.7 ELECTRICITY: CO_2 EMISSIONS & ENERGY EFFICIENCY

To come are tables with information from the simulations with results depending on type of vehicle (BEV or PHEV) and the different electricity mixes as well as the alternative with 100% fossils. The PHEVs are running on 95% petrol since it’s the most common today and the different petrol mixes have proven (see Table 17 & Table 18) not to make a radical difference. The energy consumption for PHEVs is calculated by running in CD mode for as long a distance as is possible and then in CD mode, giving two consumptions figures. The total consumption is then calculated by adding the figures and dividing by the total distance of the drive cycle used.

Table 19: PTW and WTW efficiency & CO_2 emissions for Hemtjänsten; Different electricity mixes – BEV & PHEV

Selection		[g/km]		[l/100 km]		[kWh/100 km]	
		PTW	WTW	PTW	WTW	PTW	WTW
BEV	*100% fossils*	66.8	83.9	0.0	0.0	7.8	24.8
	Worst	29.3	37.3	0.0	0.0	7.8	18.9
	Bad	15.5	20.2	0.0	0.0	7.8	14.0
	Median	6.7	9.4	0.0	0.0	7.8	18.9
	Good	0.0	0.4	0.0	0.0	7.8	9.9
	Ultimate	0.0	0.3	0.0	0.0	7.8	9.6
BEV _NEDC	*100% fossils*	81.5	102.3	0.0	0.0	9.6	30.2
	Worst	35.6	45.5	0.0	0.0	9.6	23.1
	Bad	19.0	24.6	0.0	0.0	9.6	17.1
	Median	8.2	11.4	0.0	0.0	9.6	23.0
	Good	0.0	0.5	0.0	0.0	9.6	12.1
	Ultimate	0.0	0.4	0.0	0.0	9.6	11.7
PHEV (95%)	*100% fossils*	101.0	120.4	3.7	4.4	35.3	45.7
	Worst	91.2	108.1	3.7	4.4	35.3	44.2
	Bad	87.6	103.6	3.7	4.4	35.3	42.9
	Median	85.2	100.8	3.7	4.4	35.3	44.2
	Good	83.5	98.4	3.7	4.4	35.3	41.8
	Ultimate	83.5	98.4	3.7	4.4	35.3	41.7
PHEV _NEDC (95%)	*100% fossils*	102.0	121.6	3.7	4.4	35.4	46.1
	Worst	91.6	108.7	3.7	4.4	35.4	44.4
	Bad	87.7	104.	3.7	4.4	35.5	43.1
	Median	85.3	101.1	3.7	4.4	35.5	44.4
	Good	83.4	98.7	3.7	4.4	35.5	42.0
	Ultimate	83.4	98.7	3.7	4.4	35.5	41.9

Table 20: PTW and WTW efficiency and CO_2 emissions for Flexlinjen; Different electricity mixes – BEV & PHEV

Selection		[g/km]		[l/100 km]		[kWh/100 km]	
		PTW	WTW	PTW	WTW	PTW	WTW
BEV	*100% fossils*	171.4	215.5	0.0	0.0	20.1	63.6
	Worst	75.1	95.8	0.0	0.0	20.1	48.6
	Bad	39.9	51.8	0.0	0.0	20.1	36.1
	Median	17.2	24.0	0.0	0.0	20.1	48.4
	Good	0.0	1.0	0.0	0.0	20.1	25.5
	Ultimate	0.0	0.9	0.0	0.0	20.1	24.7
BEV _NEDC	*100% fossils*	250.5	314.7	0.0	0.0	29.4	92.9
	Worst	109.7	139.9	0.0	0.0	29.4	71.0
	Bad	58.3	75.8	0.0	0.0	29.4	52.7
	Median	25.1	35.0	0.0	0.0	29.4	70.7
	Good	0.0	1.5	0.0	0.0	29.4	37.3
	Ultimate	0.0	1.3	0.0	0.0	29.4	36.1
PHEV (95%)	*100% fossils*	197.2	235.8	6.8	8.0	66.0	88.2
	Worst	172.0	204.5	6.8	8.0	66.0	84.3
	Bad	162.7	182.9	6.8	8.0	66.0	81.0
	Median	156.8	185.6	6.8	8.0	66.0	84.2
	Good	152.3	179.6	6.8	8.0	66.0	78.2
	Ultimate	152.3	179.6	6.8	8.0	66.0	78.0
PHEV _NEDC (95%)	*100% fossils*	281.6	337.6	9.2	10.8	91.0	124.7
	Worst	239.2	284.9	9.2	10.8	91.0	118.1
	Bad	223.7	265.6	9.2	10.8	91.0	112.6
	Median	213.7	253.3	9.2	10.8	91.0	118.1
	Good	206.1	243.2	9.2	10.8	91.0	108.0
	Ultimate	206.1	243.2	9.2	10.8	91.0	107.6

5.7.1 COMMENTS

As with the FOV and HEV models, there are higher figures for consumption and emissions for the NEDC in comparison to the dedicated drive cycles for Hemtjänsten and Flexlinjen. None of the vehicles are modelled to have the driving pattern fitting the NEDC but rather being dimensioned for lower speeds. However, regarding the PHEV for Hemtjänsten the differences aren't as big as for the other models or for PHEV Flexlinjen, this is undoubtedly due to the small UF factor for Hemtjänsten: 20% (26% for Flexlinjen). The extra distance driven on petrol in the Hemtjänsten PHEV vehicle could be corrected by adding a larger battery and thereby shortening the total distance driven with the ICE. The initial calculations were aiming to have a UF of about 25% for both vehicle types however the proportionally larger weight of the constant fixtures, such as the ICE, power electronics, fuel tank, EM and the generator is most likely what made the need of a greater battery for Hemtjänsten than the theoretically calculated 25% of the BEV battery. As noticed for Flexlinjen, the PHEV weighs more, but has proportionally gained more when it comes to reduction in emissions and in used petrol than the corresponding vehicle for Hemtjänsten. Consequently, the PHEV for Hemtjänsten doesn't show as big a gain in emission reduction as for Flexlinjen. In fact the results show that the HEV for Hemtjänsten has both less emissions as well as higher efficiency figures.

In order to get palpable results for comparison, a base of 95% petrol is used. The reduction figures for Hemtjänsten can be viewed in Figure 37 and the reduction figures for Flexlinjen can be viewed in Figure 38 but will be briefly described hereon. The WTW emission figures for Hemtjänsten display a reduction of 48.9% (52.1% PTW) when choosing 100% fossils as the alternative for electricity in a BEV instead of the different petrol mixes in a FOV; a distinct reduction with an electricity alternative that is considered extremely bad. For Flexlinjen the reduction is almost as great with 48.5% WTW (45.1% PTW). Viewing the "Worst" alternative, the reduction in CO_2 is 77.3% WTW (79.0% PTW) for Hemtjänsten and slightly less for Flexlinjen. The figure for the "Bad" alternative is around 88% PTW; 88.9% WTW for Hemtjänsten and 88% PTW for Flexlinjen. Regarding the electricity mixes that are available in Sweden today, from "Median" to "Good", the reduction of CO_2 emissions WTW compared to 95% petrol in a FOV, displays figures from 94% WTW (similar PTW) to almost 100% WTW.

For the PHEV models, the reduction for Hemtjänsten is 26.7% WTW for “100% fossils” (27.6% PTW) and 34.2% WTW for “Worst” (34.6% PTW). For the “Median” alternative the reduction in CO_2 emissions is 38.6% WTW (38.9% PTW) and for the “Good” and “Ultimate alternatives the reduction is 40.1% both WTW and PTW, due to that the petrol usage is a larger percentage (UF≈20%). For Flexlinjen the reduction is 40.8% WTW for “100% fossils” (39.9% PTW) and 48.3% WTW for “Worst” (47.9% PTW). For the “Median” alternative the reduction in CO_2 emissions is 50.7% WTW (52.9% PTW) and for the “Good” and “Ultimate alternatives the reduction is about 54% both WTW and PTW.

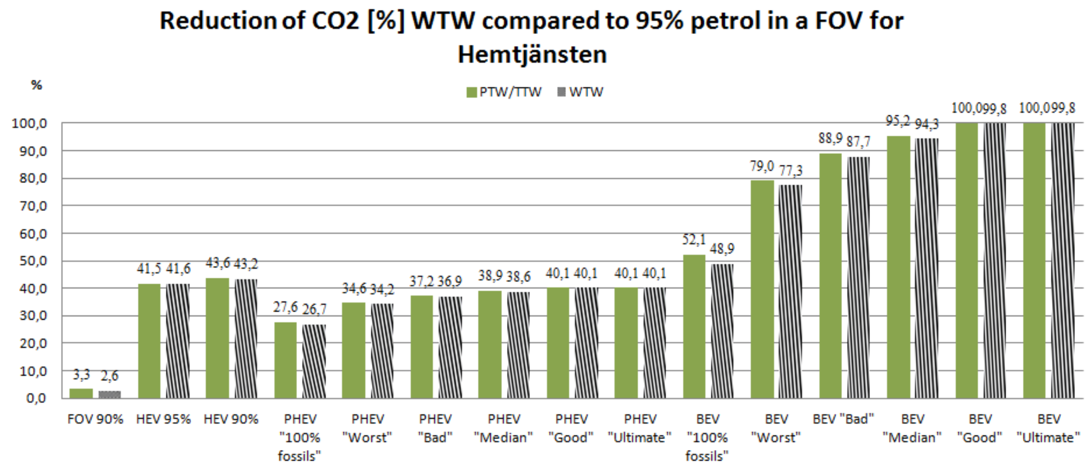


Figure 37: Reduction [%] in emissions [g/km] for Hemtjänsten compared to 95% petrol

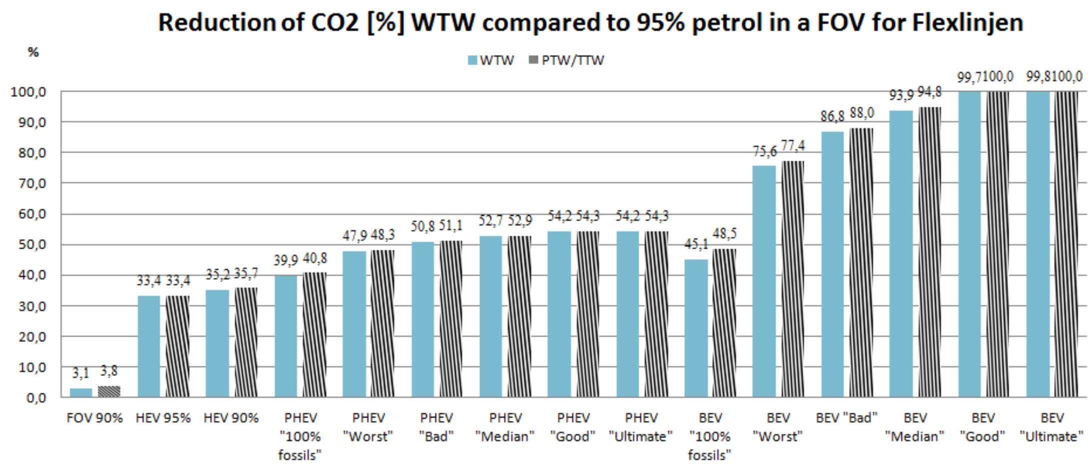


Figure 38: Reduction [%] in emissions [g/km] for Flexlinjen compared to 95% petrol

5.8 COMPARISON: LONGTERM CONSEQUENCES

For easier visualization of the TTW/PTW & WTW results in g/km for Hemtjänsten, see Figure 39, in which the PHEV results are displayed only in the electricity mixes (and not in petrol) for easier viewing[11].

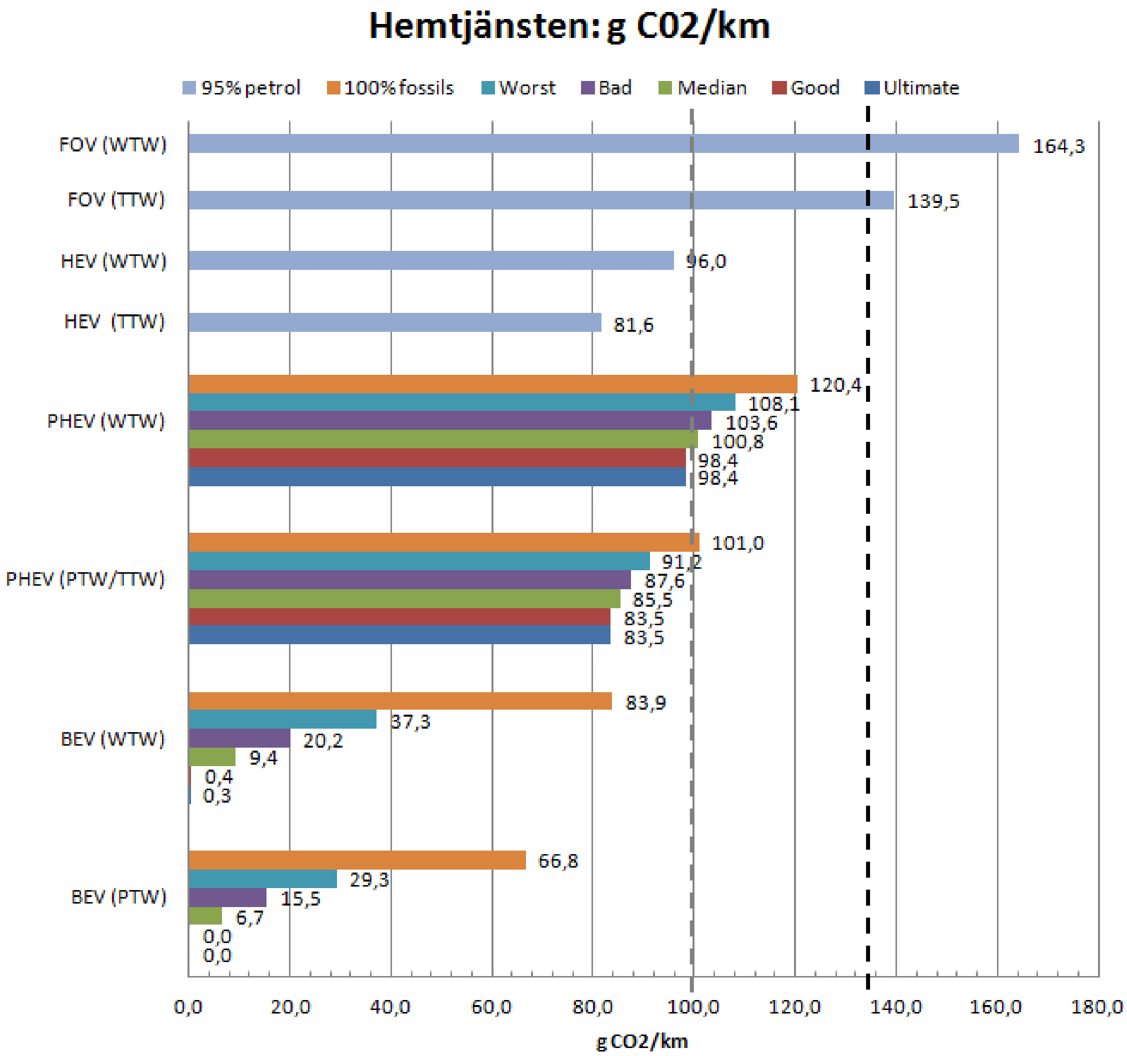


Figure 39: g CO_2/km for Hemtjänsten with a vertical line for the new Swedish regulation limits (100 g/km) and for the new European regulations (135 g/km) respectively

[11] The UF factor for Hemtjänsten is 0.2, meaning that 80% of the results shown in each electricity mix should be displayed as petrol, however the figure would become more unclear that way which is why the g/km results are only displayed in the corresponding electricity mix.

For easier visualization of the TTW/PTW & WTW results in g/km for Flexlinjen, see Figure 40, in which the PHEV results are displayed only in the electricity mixes (and not in petrol) for easier viewing [12].

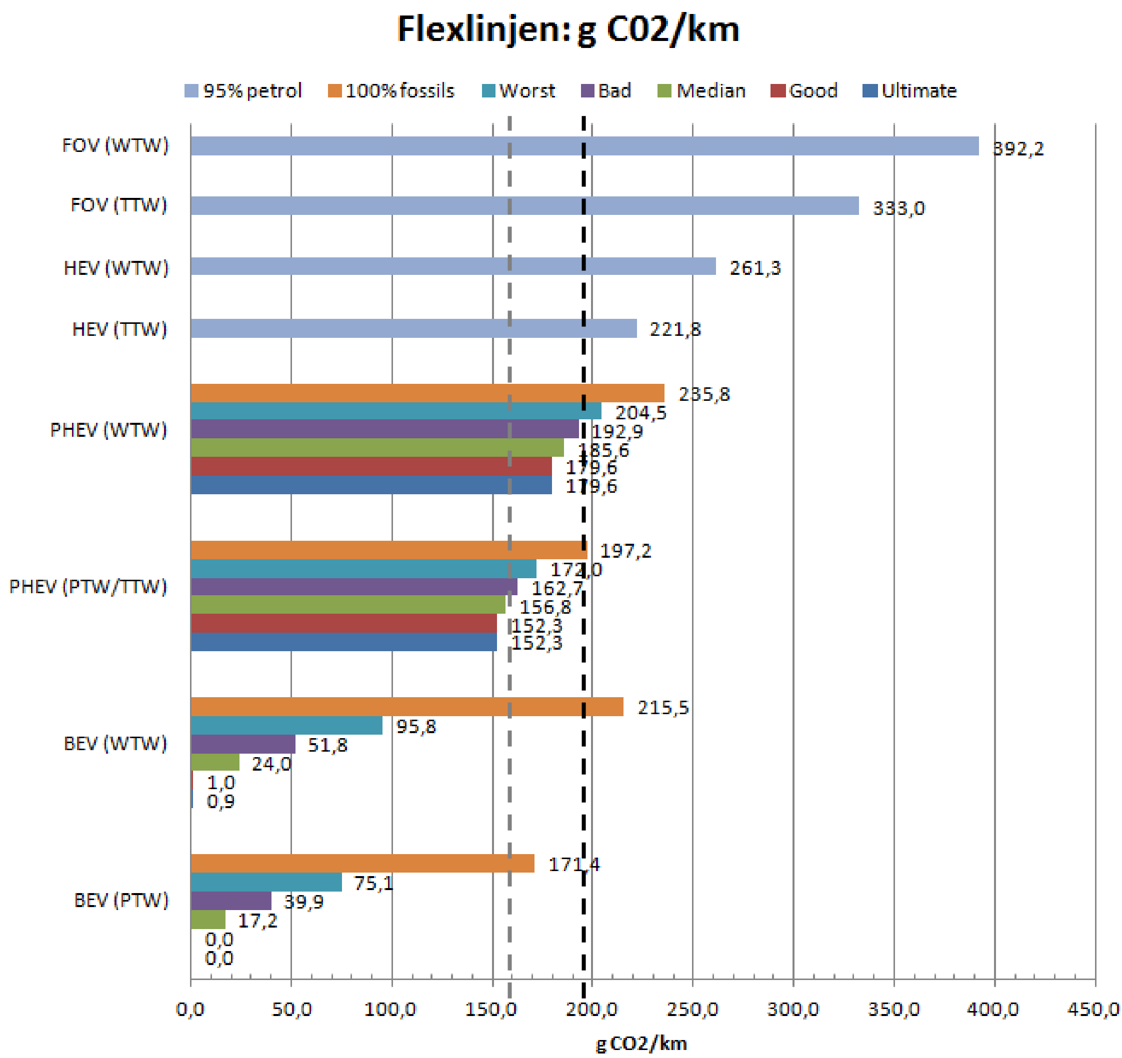


Figure 40: g CO_2/km for Flexlinjen with a vertical line for the new Swedish regulation limit (160 g/km) and for the new European regulations (194 g/km) respectively

[12] The UF factor for Flexlinjen is 0.26, meaning that 74% of the results shown in each electricity mix should be displayed as petrol, however the figure would become more unclear that way which is why the g/km results are only displayed in the corresponding electricity mix.

The choice of vehicle is important when taking the emissions into a yearly perspective. Hemtjänsten uses the same car for 21.3*2= 42.6 km/day, an estimated 360 days/year leading to a total usage of 15,336 km/year. Flexlinjen uses the same car for 26.5*7=185.5 km/day leading to an estimated total of 66,780 km/year. When considering the theoretically calculated total emissions of CO_2 per day and year, the weight of the vehicles is the previously determined weight from Table 10 & Table 11, i.e. without the added weight for Flexlinjen which implies that even more would be released if the weight of passengers and aids were included (3410 kg instead of 2770 kg as curb weight).

Considering a FOV with 95% petrol for Hemtjänsten, the emissions in kg CO_2/day would be about 7.0 WTW. By utilizing a HEV with the corresponding petrol mix instead, the emissions would be around 4.1 kg/day WTW, a reduction with more than 41% and more than a tonne of CO_2 per year. Viewing BEVs, the reduction could be more than 99%. For Flexlinjen a FOV with 95% petrol would release 72.8 kg CO_2/day WTW but a HEV with 95% petrol would instead release 48.5 kg/day WTW, a reduction with more than 33% and almost nine tonnes per year WTW. Regarding PHEVs, the electricity mix denoted 100% fossils would be even better than a HEV and with the “Median” mix the emissions would be 34.4 kg/day or a reduction with almost 53% (more than 13 tonnes of CO_2 per year). Viewing BEVs, the reduction could be up to 99%; the reduction from a FOV with 95% petrol to a BEV with “Ultimate” mix is more than 26 tonnes of CO_2 per year and 22.7 tonnes for the “Median” alternative.

If viewing the reduction in the use of petrol there is a 42% reduction TTW (41% WTW) from FOVs to HEVs regarding Hemtjänsten and a 33% reduction TTW (about 32% WTW) for Flexlinjen. The savings regarding the ending sources of petrol could lead up to 460 liters per year (WTW) for Hemtjänsten and 3,873 liters per year (WTW) for Flexlinjen if using HEVs with 95% petrol instead of FOVs with the same petrol mix. The result for the BEV models is 100% reduction in petrol usage since BEVs don’t use petrol in the powertrain. If regarding the electricity production however, there is oil burnt in Sweden which would mean that the save in petrol/oil usage would not be as high. Viewing the “Median” alternative only 1.9% is from oil and since the “Median” alternative is in the upper range of the average electricity production in Sweden, and it would be easier to eliminate oil usage in electricity generation than in vehicles, these facts are disregarded in this study. For PHEVs the displayed figures in Table 19 and Table 20 are the actual theoretically simulated figures for the used petrol, the figures doesn’t include oil burned whilst generating electricity (for those alternatives that have that option). The tables show a reduction of around 40% TTW and WTW for Hemtjänsten and around 54% PTW and WTW for Flexlinjen in comparison to 95% petrol in a FOV. The PHEV for Hemtjänsten does actually use more liters of petrol/km than the corresponding HEV, which is most likely due to that the UF for Hemtjänsten is low, about 20% (26% for Flexlinjen). The extra distance driven on petrol in the Hemtjänsten PHEV vehicle could be corrected by adding a larger battery and thereby shortening the total distance driven with the ICE. As noticed for Flexlinjen, the PHEV weighs more, but has more gained when it comes to reduction in emissions and in used petrol than the corresponding vehicle for Hemtjänsten.

If the electricity is not generated from burning oil, the savings regarding the ending sources of petrol by using BEVs instead of 95% petrol in FOVs could lead up to 1120 liters per year (WTW) for Hemtjänsten and 11,687 liters per year (WTW) for Flexlinjen, however no passengers are included so the figures are slightly misrepresenting.

6 CONCLUSIONS

What reduction of CO_2 emissions is there if a BEV, PHEV or HEV is used instead of a FOV? What are the actual benefits of one electric choice compared to another and also compared to the petrol choice of today?

6.1 WEIGHT

The estimations in this report give that the weight of the FOV, HEV and PHEV for Hemtjänsten have similar weights (around 1483 kg). This is due to that even though the HEV and PHEV have lighter transmission (single gear) and a smaller ICE, the power electronics, the EMs and the battery contribute to the weight. Although the HEV has a smaller battery, the fuel storing capacity is higher than for the PHEV. The BEV is the lightest model (1292 kg) and although it has power electronics and a big battery there is neither an exhaust system nor an ICE nor a fuel tank. Regarding Flexlinjen, the FOV is the lightest of the models (2770 kg) and the BEV is the heaviest (2931 kg) solely due to the very large battery needed to cope with the drive cycle. The HEV is in the middle with 2803 kg, having a small battery but still coping with the weight of all EV components as well as with the exhaust system. The PHEV weighs about 100 kg more than the HEV at 2904 kg, almost at the same weight as the BEV, naturally due to the rather large battery.

6.2 NEDC

When comparing the emissions and consumption results of the drive cycles to the NEDC it's apparent that since the drive cycles of Hemtjänsten and Flexlinjen don't have as high speeds as the NEDC, and even though the rather large inclinations are apparent, the NEDC consumption is higher. A better comparison for this study would have been to not use the full NEDC but rather only the segments of the urban drive cycle, the ECE/UDC since the vehicles in this study don't have velocities comparable to highway driving. Such comparison would most likely lead to better results for the virtual drive cycle (ECE) due to the more linear driving.

6.3 EFFICIENCY

The efficiency results (see Figure 35 and Figure 36) especially regarding Flexlinjen, show TTW results of better efficiencies the more electricity that is used. The best TTW efficiency result is displayed for BEVs (64%) with a notably less percentage for PHEVs (32%) and HEVs at 23% but FOVs have the least efficient powertrain at 18%. Regarding the WTW figures, focused on Flexlinjen, the high WTT efficiency of petrol promotes changes but BEVs are still the most efficient; up to 53% for the "Ultimate" mix (efficiency=81.6%) but only 20% with "100% fossils" (which have an efficiency WTW of 31.3%). However, giving that the "Median" mix has an WTT efficiency of 41.6% and the "Good" alternative 79%, the results of the Swedish WTT efficiency figures is concluded to lay around 60% and the WTW efficiency of just below 40%.

FOVs are still the least efficient at 15% WTW and PHEVs display results of up to 26% (“Ultimate”) but only 17% WTW for “100% fossils”. HEVs have a WTW efficiency of about 20% (still higher than FOVs TTW figures).

6.4 REGULATIONS AND CO2 EMISSION LIMITS

Today’s emission limit for “supermilljöbilar” lie at 50 g/km and for vehicles classified as environmentally friendly the limit is 120 g/km today with a goal at 95 g/km for 2020. Until 2020 both EU and Sweden have formulas for determining whether a vehicle is environmentally friendly. In Sweden for a vehicle the size of Hemtjänsten, the allowed CO_2 emissions lie under 100 g/km and in EU the limit is 135 g/km. As can be seen in Figure 39, none of the petrol combinations for FOV lie under the limit of present directives (120 g/km), however when using 90% petrol the limit for the EU is just passed at 135 g/km. Both the TTW and the WTW petrol combination figures for HEVs are below the limit for future Swedish directives (100 g/km), with the TTW figures and WTW 90% figures even below the 2020 goal of 95g/km. Regarding PHEVs for Hemtjänsten, “100% fossils” and 95% petrol would actually lead to PTW/TTW figures higher than the Swedish limit, i.e. ~101 g/km and WTW figures higher than the present limit at ~120.4 g/km. With the “Worst” alternative the PTW/TTW figures are just below the 2020 goal at 91.2 g/km and the “Good” and “Ultimate” electricity mixes WTW figures just miss the limit for 2020 at ~98 g/km. When regarding BEVs it’s interesting to see that even the figures for NEDC, higher due to higher speed, show results for “100% fossils” with PTW figures below the 2020 goal (95 g/km) at 81.5 g/km and WTW result just above the future regulation (100 g/km) at 102.3 g/km. The figures for the Hemtjänsten drive cycle reveal that “100% fossils” WTW lie at ~84 g/km and all other figures much below.

According to the new Swedish regulations a vehicle the size of Flexlinjen is allowed to release a maximum of 160 g CO_2/km and the corresponding figure for the EU regulations is 194 g/km. As with Hemtjänsten, none of the petrol mixes passes any limit but emits ~333 g/km TTW and 392 g/km WTW for 95% petrol. Not even the petrol figures for HEVs are below the regulations but shows theoretical values of ~222 g/km TTW and 268 g/km WTW. For PHEVs “100% fossils” end up at a theoretical value of ~197.2 PTW g/km which is just higher than the EU limit of 194 g/km. The span of electricity mixes “Bad” → “Median” has TTW figures ranging around 160 g/km; 162.7 for “Bad” and ~157 g/km for “Median”. The WTW figures for the “Median” mix and PHEVs ends up just below the future EU-limit (160 g/km) at ~156.8 g/km. Not even the WTW “Ultimate” selection passes the Swedish limit with ~180 g/km WTW (~152 g/km PTW). Regarding BEVs the theoretical WTW emission results for “100% fossils” is just above 200 g/km at 215.5 g/km and

171.4 g/km TTW. The “Worst” alternative shows figures of around 75 g/km PTW and almost 96 g/km WTW giving that even the “Worst” alternative passes the future Swedish limit with great margin (160 g/km) and viewing TTW even passes the 2020 level of 95 g/km. If considering the NEDC, the WTW figures for the “Worst” alternative are very low in comparison to the Swedish regulation at ~140 g/km (with PTW figures at around 110 g/km. The “Bad” alternative has PTW figures around 60 g/km (WTW ~76 g/km) for NEDC.

6.5 REDUCTION IN CO2 AND IN PETROL USAGE

If assuming that today’s vehicle in use for Hemtjänsten, as modelled in this study, consumes 95% petrol the corresponding emission figures per day would theoretically be 6.0 kg TTW and 7.0 kg WTW. By utilizing a HEV with 95% petrol instead of a FOV there would be a reduction in CO_2 emissions of more than 41%. A BEV with “100% fossils” would contribute with 49% reduction WTW and almost 95% reduction with the “Median” electricity mix. Assuming, as with Hemtjänsten, a 95% petrol mix in today’s FOVs for Flexlinjen, corresponding emissions figures for this study would be 61.7 kg/day TTW and 72.7 kg/day WTW. By utilizing a HEV with 95% petrol there would be a 33% reduction WTW compared to the CO_2 emissions for a FOV. A PHEV with “100% fossils” would give a 40% reduction WTW, the “Bad” alternative a reduction of more than 51% WTW. For BEVs the reduction compared to 95% petrol is almost 87% WTW for “Bad” and almost 94% WTW with the “Median” alternative.

If viewing the reduction in the use of petrol there is a 42% reduction TTW (41% WTW) from FOVs to HEVs regarding Hemtjänsten and a 33% reduction TTW (about 32% WTW) for Flexlinjen. The savings regarding the ending sources of petrol could lead up to 460 liters per year (WTW) for Hemtjänsten and 3,873 liters per year (WTW) for Flexlinjen if using HEVs with 95% petrol instead of FOVs with the same petrol mix The results for the BEV models are 100% reduction in petrol usage since BEVs don’t use petrol in the power train. For PHEVs the reduction in petrol usage is around 54% PTW and WTW for Flexlinjen in comparison to 95% petrol in a FOV.

It has been shown in this report that both Hemtjänsten and Flexlinjen can be provided as and benefit emission-wise from being built as BEVs, but even a small change from 95% petrol in a FOV to the same in a HEV would result in reduction of CO_2 emissions of more than 41% TTW and WTW for Hemtjänsten and a 33% reduction of CO_2 emissions TTW and WTW for Flexlinjen.

This page intentionally left blank

BIBLIOGRAPHY

[1] Electric Car News, "Green Motoring," Electric Car News, 14 June 2012. [Online]. Available: http://www.electriccarnews.co.uk/eu-to-propose-tighter-co2-regulations/.

[2] M. Ehsani, Y. Gao, S. E. Gay och A. Emadi, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentalsm Theory, and Design, 2nd red., CRC Press, 2005.

[3] Svenska Kraftnät, ”Statistikrapport; Sveriges Produktion, Förbrukning och Import/Export,” Svenska Kraftnät, 2012-04-30.

[4] Aker Wade, ”http://akerwade.indigofiles.com/,” Aker Wade, 8 November 2010. [Online]. Available: http://akerwade.indigofiles.com/AkerWade_DC_Fast_Charge_stations_nov_8_10r.pdf.

[5] Eurelectric; VGB Powertech, ”Efficiency In Electricity Generation,” EURELECTRIC “Preservation of Resources” Working Group’s “Upstream” Sub-Group in collaboration with VGB, 2003.

[6] General Motors Corporation, Argonne National Library, BP, ExxonMobil, Shell, ”Well-to-Tank Energy Use and Greenhouse Gas Emissions of Transportation Fuels – North American Analysis – VOLUME 3,” 2001.

[7] SPBI - Svenska Petroleum & Biodrtivmedel Institutet, ”Energiinnehåll, densitet och koldioixidemission,” 24 05 2012. [Online]. Available: http://spbi.se/faktadatabas/artiklar/berakningsmodeller.

[8] H. Baumann och A.-M. Tillmann, The Hitch Hiker's Guide to LCA; An orientation in life cycle assessment methodology and application, Studentlitteratur, 2004, pp. 485-497.

[9] Trafikverket & Konsumentverket, ”Index över nya bilars klimatpåverkan 2011 - i riket, länen och kommunerna inkl. nyregistrerade, kommunägda fordon och dess klimatpåverkan,” Trafikverket, 2012.

[10] European Union, ”Europaparlamentets och rådets förordning (EG) nr 443/2009 av den 23 april 2009 om utsläppsnormer för nya personbilar som del av gemenskapens samordnade strategi för att minska koldioxidutsläppen från lätta fordon (Text av betydelse för EES),” Europeiska unionens officiella tidning, 2009.

[11] Finansdepartementet, ”Vägtrafikskattelag (2006:227),” Regeringnskansliet, Stockholm, 2006-03-30; ändring 2012-07-19.

[12] L. Ek, Förordning om supermiljöbilspremie: SFS 2011:1590, Sveeriges Regering, 2011.

[13] L. Norberg, ”Uppdrag att utarbeta förslag till en supermiljöbilspremie,” Transportstyrelsen, 2011.

[14] Stockholms Stad & Malmö Stad, ”Miljöfordon - Regeringens förslag miljöbil 2013,” Stockholms Stad & Malmö Stad, 30 May 2012. [Online]. Available: http://www.miljofordon.se/aktuellt/106-regeringens-forslag-miljobil-2013.

[15] Françoise Nemry, Guillaume Leduc, Almudena Muñoz, ”Plug-in Hybrid and Battery-Electric Vehicles: State of the research and development and comparative analysis of energy and cost efficiency,” European Commission Joint Research Centre, Institute for Prospective Technological Studies , Luxembourg, 2009.

[16] ECOpoint Inc., ”DieselNet,” 2012. [Online]. Available: http://www.dieselnet.com/standards/cycles/ece_eudc.php. [Använd 3 May 2012].

[17] European Union, ”EEC Directive 90/C81/01,” European Union, 1990.

[18] N. R. Larsson, Interviewee, *Arbetsledare Hemtjänst mitt.* [Intervju]. 3 May 2012.

[19] Göteborg Stad, ”Flexlinjen (Högsbo),” Västtrafik, 2012. [Online]. Available: http://www.goteborg.se/wps/portal/!ut/p/c0/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gjU-9AJyMvYwMDSycXA6MQFxNDPwtTI3cvM_2CbEdFAAMxP0M!/.

[20] Volvo Cars, ”Volvo V50 technical information,” Volvo Cars, [Online]. Available: http://www.volvocars.com/se/all-cars/volvo-v50/details/pages/technical-spec.aspx. [Använd 2012].

[21] Transportstyrelsen, ”Fråga på annat fordon,” [Online]. Available: https://www21.vv.se/fordonsfraga/FragaPaAnnatFordon.aspx. [Använd 2012].

[22] A. Pesaran och T. Markel, ”The 24Th International Battery Seminar & Exhibit,” i *Battery Requirements and Cost-Benefit Analysis for Plug-in Hybrid vehicles*, Fort Lauderdale, Florida, 2007.

[23] O. O. Ajayi, C. Lorenzo-Martin, A. C. Greco och G. R. Fenske, ”Development of High Power Density Driveline for Vehicles,” Argonne National Laboratory, 2012.

[24] Tractive, ”Produkter,” Tractive, [Online]. Available: http://www.tractive.se/produkter/sekv-vaxellada-framhjulsdrivna-bilar__52. [Använd 2012].

[25] Fujikura Diesel Co., Ltd., ”WeiKu,” 2011. [Online]. Available: http://www.weiku.com/products/11861323/Isuzu_FTR_18t_Final_Drive_Gear_OEM47210_2750.html.

[26] Electro Vehicles Europe S.r.l., ”EVE - The electro vehicles Europe,” 2010. [Online]. Available: http://www.electro-vehicles.eu/default.asp?content=1,67,56,0,0,Electric_Motors,00.html.

[27] Svensk Energi, ”Elåret & Verksamheten 2011,” april 2012. [Online]. Available: http://www.svenskenergi.se/upload/Statistik/El%C3%A5ret/El%C3%A5ret2011.pdf.

[28] Svensk Energi, ”Vägledning angående ursprungsmärkning av el,” Svensk Energi, 2011.

[29] International Energy Agency, ”Electricity/Heat in Sweden in 2009,” 2009. [Online]. Available: http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=SE.

[30] I. Husain, Electric and hybrid vehicles - design fundamentals, 2nd red., Taylor and Francis group, LLC, 2011.

[31] A. Elgowainy, J. Han, L. Poch, M. Wang, A. Vyas, M. Mahalik och A. Rousseau, ”Well-to-wheels analysis of energy use and greenhouse gas emissions of plug-in hybrid electric vehicles,” U.S. Departement of Energy, 2010.

[32] S. Uppenberg, M. Almemark, M. Brandel, L.-G. Lindfors, H.-O. Marcus, H. Stripple, A. Wachtmeister och L. Zetterberg, ”Miljöfaktabok för bränslen - Del 1. Huvudrapport Resusrförbrukning och emissioner för hela livscykeln,” Svenska Petroleum Institutet, Stockholm, 2001.

[33] Naturvårdsverket, ”Index över nya bilars klimatpåverkan 2008; I riket, länen och kommunerna,” 2009.

FIN