Energianalys av Swedavia Fordons fordonsflotta – en förstudie

Energy analysis of Swedavia Fordon's vehicle fleet – a prestudy

Teknisk Rapport, Version 2.2 (final)

Document Number:

Datum: June 20, 2017

Författare/Utförare: Anne Piegsa, Feng Liu, Semcon

Beställare: Swedavia

Finansiär: Trafikverket

Contents

VEHICLE CATEGORIES ABBREVIATIONS

Abbreviation	Description (in Swedish)
AVB	Avisarbil
BAL	Bandlastare (inkl. Power Stow)
MBU	Minibuss (7,8 eller 9 passagerare)
BRB	Brandbil (Räddningsfordon, även utryckningsreg. personbilar)
CAT	Cateringfordon
DRD	Dragdumper
DRT	Dragtruck
FGK	Fältgräsklippare
FLA	Fläktblåsaggregat (trailerdragen TJS)
FMF	Friktionsmätfordon
FPB	FlygPlatsBuss, totalvikt över 3,5 ton. D-kort.
FPT	Flygplanstrappa, självgående
GAT	Gaffeltruck
GSP	Grusspridare, se även KES, KOS.
HIL	Main-deck-loader, high-loader
HYV	Hyvel (väghyvel)
KES	Kemikaliespridare, se även KOS, GSP.
KOS	Kombispridare (OBS! redskap, flakväxlare) (sand, urea, tallrik) se även KES, GSP.
LAB	Lastbil, tung, över 3,5 ton. C-kort
LAM	Lastmaskin (över 8 ton)
LLB	Lätt lastbil, under 3,5 ton
MÅM	Målningsfordon (B- eller C-kort)
OLF	Omlastningsfordon
PBI	Personbil, B-kort, under 3,5 ton (ej minibuss, se SKB)
PBT	Push back-traktor
PSB	Plog-sop-blåsmaskin
RSB	Redskapsbärare (under 8 ton)
SNS	Snöslungor (kast-, last- och självgående)
SOA	Sop, lätt, typ Swingo
SOB	Sug och sop, tung, glykolsug
SKB	Skåpbil, under 3.5 ton, B-kort, bil med lastutrymme där kaross är integrerad med förarhytt (inkl. minibuss)
SSB	Slamsugbil
TOB	Toalettservicebil
TRA	Traktor
VAB	Vattenservicebil
VIP	VIP-service
ÖVF	Övriga fordon(t.ex. bandvagn, åkgräsklippare, ATV, motorcykel, golfbil, magnetvagn)

1. INTRODUCTION

The European Union's targets call for 10 per cent of all transport fuel derived from renewable sources by 2020. Sweden sets a more challenging goal to have a totally fossil-free vehicle fleet by 2030 [1]. Swedavia's own vision is to achieve zero fossil-based CO_2 emissions by 2020 [2]. The main function of the airport facilities is providing access to aircrafts for both passengers and cargo. An airport operator's vehicle fleet is commonly the second largest energy user next to building/facilities. A major part, up to 95%, of an airport operator's CO_2 emissions can be caused by the operational vehicle fleet. To specify the CO_2 emission reduction strategy of an airport's vehicle fleet a specific energy analysis shows necessary. Moreover, a clear roadmap of improvements and upgrades of the vehicle fleet configuration is needed to secure a goal of zero fossil-based CO_2 emissions.

With regard to the vehicle fleet electrification aspect, many airports are ahead of Swedish airports. Since June 2015, 35 electric buses at Amsterdam Airport Schiphol have been transporting passengers to and from aircraft to gate [3]. London Heathrow Airport has one of the largest fleets of electric, airside vehicles in Europe; 850 of 8000 vehicles are electric motor powered [4]. The first electric bus fleet started operating on-airport by late 2016 in Sydney Airport, Australia [5]. However, no airports have yet even got close to zero CO_2 emission vehicle fleet.

This pre-study investigates, on the example of Swedavia's vehicle fleet, a typical airport operator vehicle fleet configuration and its CO_2 emission levels. Based on this use case study, an emission reduction strategy and a roadmap for realization of a zero fossil CO_2 emission goal is proposed. This strategy also addresses energy efficiency targets after 2020.

2. METHOD OF EVALUATION

Since the aim of this study is to define a strategy towards zero fossil-based CO_2 emissions in 2020, emission reduction methods with existing technology is the main focus in this report.

Alternative fuels and vehicle propulsion technologies for reducing CO_2 emission were reviewed and compared based on airport operation usage. All categories of vehicles in Swedavia's fleet were studied. To give realistic suggestions, a number of persons from Swedavia across different departments, responsibilities, and airports were interviewed. Some of the airports operated by Swedavia were visited for better understanding of the use cases of the vehicles and better understanding of their particular situations. Available products as well as technology trends of each category of the vehicle fleet were carefully evaluated to form roadmap suggestions. Regarding CO_2 and greenhouse gas emission calculations the following definitions and methods are used.

The Joint Research Center (JRC) of European Commission published a well-to-wheels (WTW) greenhouse gas (GHG) emission analysis for vehicles in Europe by 2020. Using standard driving cycle and simulation tools, WTW CO_2 emission of different alternative fuels were compared [6]. Well-to-wheels (WTW) CO_2 emission analysis, as illustrated in Figure 1, covers both production of the fuel and burning the fuel in vehicles [6]. In another study the electrification cost of cars and buses at a Turkish airport were calculated as Net Present Value (NPV) [7] based on assumed driving cycle.

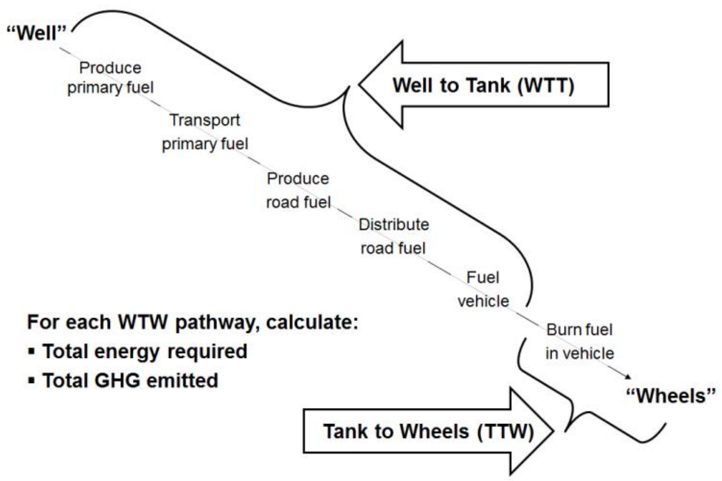

Figure 1: Concept of well-to wheels analysis

In Table 1 below, the calculated tank-to-wheel (TTW) carbon emissions factor of petrol, diesel, HVO (Hydrotreated Vegetable Oil), biogas, and CNG (Compressed Natural Gas) are listed. During combustion the carbon and hydrogen of the fossil fuels are converted mainly into carbon dioxide (CO_2) and water (H_2O), releasing the chemical energy in the fuel as heat. This heat is generally either used directly or used to produce mechanical energy. In energy statistics, consumption of liquid and gaseous fuels is specified in physical units, e.g. in tons or cubic meters. To convert these data to common energy units, e.g. joules, requires calorific values [8]. Net Calorific Value, NCV, is defined as the number of heat units measured as being liberated when a mass unit of fuel is burned in oxygen under standardized conditions [9]. In [8] the default carbon content and net calorific value is listed, calculated as carbon emission factor in [TJ], which can be converted to per unit volume fuel using the following formula:

Carbon emission factor (kg CO_2/unit) = {Default carbon content * Oxidation factor*Default Net calorific value* Carbon molecule mass ratio (44/12)*Fuel Density}.

Table 1: Carbon content of example fuels

Fuel	Default carbon content (Kg/GJ)	Oxidation factor	Net calorific value (TJ/Gg)	Carbon molecule mass ratio	Fuel density (Kg/Liter)	Carbon emission factor (Kg/Liter)
Diesel	20.2	1	43	44/12	0.845	2.691
Petrol	18.9	1	44.3	44/12	0.775	2.379
HVO	19.3	1	27	44/12	0.780	1.490
Biogas	14.9	1	50.4	44/12	0.168 ~0.199	0.463 ~ 0.548
CNG	15.3	1	48	44/12	0.180 ~0.212	0.485 ~0.571

Table 1above shows that diesel gives the highest CO_2 per liter, and biogas gives the lowest. If we calculate WTW CO_2 emission including carbon storage, biogas has even negative CO_2 emission factor. HVO gives 0.34 kg per liter, also close to zero CO_2 emission.

3. REVIEW OF VEHICLE TECHNOLOGIES

3.1 Alternative Fuels

Alternative fuels include biofuels, electricity, hydrogen, natural gas, and propane (also known as liquefied petroleum gas, LPG). Natural gas and propane are fossil based fuels, thus they are excluded in this report.

3.1.1 Biofuels

Biofuels have been around as long as cars have. Henry Ford designed Model T to run on ethanol. Rudolf Diesel, the inventor of diesel engine, was interesting in using vegetable oil as fuel and in fact his engine was shown to run on peanut oil. Nowadays, biofuels mainly include biodiesel from different renewable sources, ethanol, and biogas.

Biodiesel is a renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant grease for use in diesel vehicles. Biodiesel’s physical properties are similar to those of petroleum diesel, but it is a cleaner-burning alternative, like FAME, RME. HVO, also referred as second generation biodiesel, must be distinguished from ester-type first generation biodiesel. Many light-, medium-, and heavy-duty diesel vehicles are capable of running on biodiesel. From September 2016, PSA group (including Citroën, DS and Peugeot) confirmed that HVO-diesel can be used in all cars and transporters from PSA group equipped with new Euro5 or Euro6 engines. Two thirds of Sweden’s buses run on renewable fuels and biodiesel is the most popular choice.

FAME and RME have detrimental effects, like increased NOx emission, deposit formation, storage stability problems, more rapid aging of engine oil or poor cold weather properties [10]. HVO has the identical chemical structure as conventional diesel, thus it is free of the detrimental effects mentioned above.

Ethanol is a renewable fuel made from corn and other plant materials. Many countries blend 5% or 10% to petrol to reduce CO_2 emission. E85 (85% ethanol and 15% petrol) is an established alternative to petrol. Ethanol helps reduce petroleum use in transportation and GHG emissions; moreover, it reduces the dependence on imported oil. In Sweden, the ethanol is mainly imported from Brazil and made from sugar cane. It achieves proven high climate impacts and reduces carbon dioxide emissions by up to 95 percent compared to petrol [11]. Swedish researchers are pursuing the production of ethanol from cellulose, which is called a second-generation biofuel, since it is more effective than grain-based production and does not affect food crops [1].

Besides E85, which is widely used in Sweden as an alternative fuel for passenger cars, ED95 is an ethanol based fuel for adapted diesel engines. It consists of 95 percent pure ethanol with the addition of ignition improver, lubricant and corrosion protection. ED95 provides both good energy effect and reduces climate change – carbon dioxide emissions can be reduced by 70 percent. The latest generation of diesel ethanol engines (ED95-engines) from Scania is certified according to Euro5 and EEV [12].

Safety aspects of using E85 were highlighted in several research projects in Sweden about a decade ago [13] [14]. The chemical and physical properties of neat ethanol cause higher propensity of ignition than diesel and petrol in closed situation. Thus E85 and ED95 may not be suitable as fuel for firefighting vehicles. With a careful design of the engine and the fuel system, ethanol fuel vehicles have been used widely and safely for decades.

Biogas is a renewable gas produced by decomposing organic material. Biogas includes mainly methane (CH_4), the same as natural gas, but 100% fossil free. In Sweden, biogas is normally mixed with natural gas as “fordonsgas” for cars (at least 50% biogas). Green100 (Grön100) is also available for a little higher price.

The WTW report [6] compares conventional petrol, conventional diesel, and alternative non-hydrogen fuels with prediction of 2020 vehicle fuel consumption based on a standard drive cycle. As shown in Figure 2 almost all different types of biofuels in the study give lower CO_2 emission, but also higher energy consumption. Biogases have negative WTW CO_2 emission, and much higher energy consumption compared to conventional fuels.

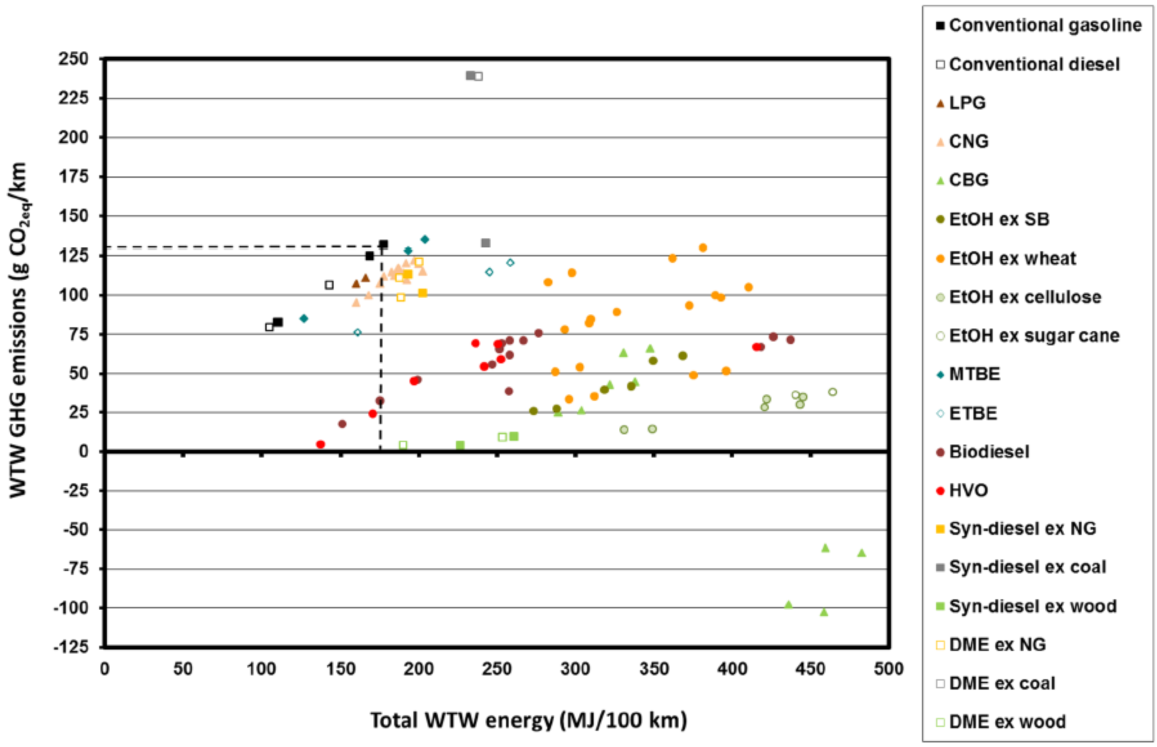

Figure 2: Well to Wheel GHG emission for non-hydrogen fuels (2020+ vehicles)

3.1.2 Electricity

Electricity can be used to power all-electric vehicles and plug-in hybrid electric vehicles. These vehicles draw electricity directly from the grid or other off-board electrical power sources and store it in batteries. Using electricity to power vehicles has significant benefits for local emissions. However, the use of electricity is limited by battery capacity and battery charging time which is discussed later in this report. Another issue to consider is the source of electricity. Using electric vehicles is only transferring the emission from one place to another place if the energy source for electricity generation is fossil based.

Västtrafik operates route 55 in Göteborg with electric buses which runs exclusively on renewable electricity obtained from wind power and hydro power from June 2016. An electric bus and a hybrid bus joined Västtrafik's route 60 from February 2017 to test the benefit on the drive cycle with a lot of uphill roads.

The Swedish Energy Agency's yearly report on Energy Supply in Sweden shows that around one third of the energy came from burning fossil fuels, see Figure 3. This means replacing fossil fuel vehicles with electric vehicles is not only resulting in zero fossil-based CO_2 emission locally, it will also reduce the overall CO_2 emission significantly. However, replacing biofuel vehicles with electric vehicles may cause higher overall CO_2 emission depending on electricity source.

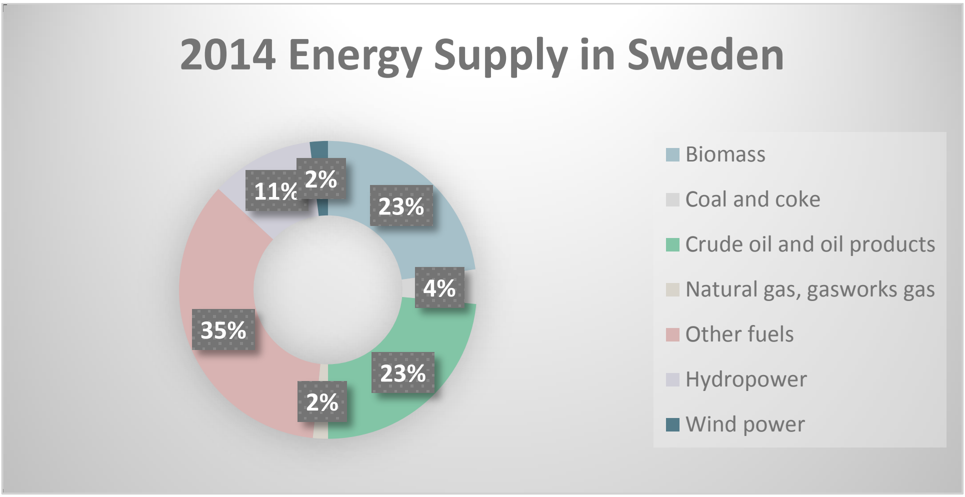

Figure 3: 2014 Energy supply in Sweden

3.1.3 Hydrogen

Hydrogen can be used to generate electricity through a fuel cell. The fuel cell works like a small power plant by combining hydrogen and oxygen to produce energy with the only exhaust being water [15]. Research and commercial efforts are under way to build the hydrogen fueling infrastructure and produce hydrogen fuel cell electric vehicles that are practical for widespread use. Hydrogen can also be used in internal combustion engines directly with small modifications of the engine.

Common ways to store hydrogen is either compressed at 200-700 bar or as a liquid at below –253 ºC. Its energy density is high per unit mass [16], about an order of magnitude better than the specific energy and energy density of a Li-ion energy storage system, but still considerably less than gasoline.

Hydrogen gas is explosive under certain conditions, but is not more difficult to handle than other fuels and energy carriers. Hydrogen is transient and disappears quickly in open air, if a leak should occur during fueling or at a car accident. Hydrogen is non-toxic and burns rapidly. This does not mean that hydrogen is totally safe. An explosion can occur if oxygen and hydrogen is blended in a confined space under specific conditions. As with other fuels and energy carriers, hydrogen must be handled with special requirements. Since hydrogen has been used in the industries for over a century, the knowledge minimizing the risk of incidents is very well established.

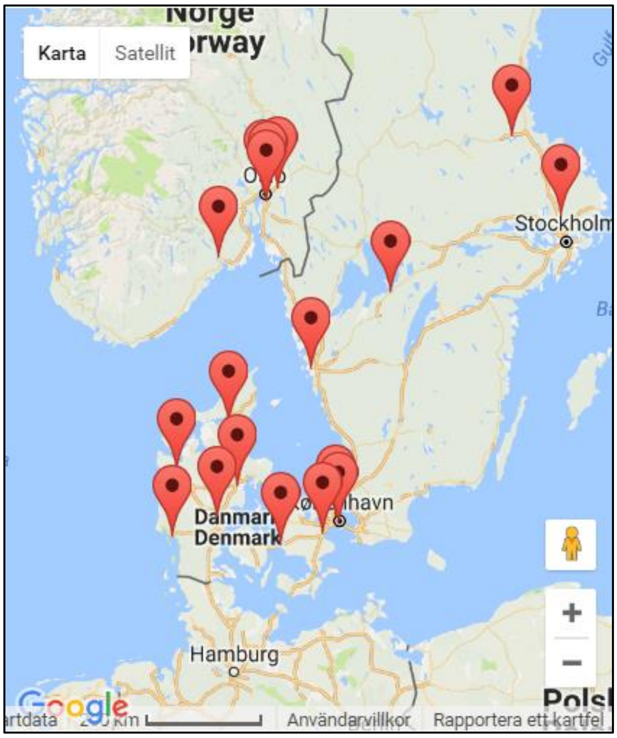

Figure 4: Hydrogen refueling station in Scandinavia

There are four (4) hydrogen refueling stations in Sweden, located at Sandviken, Arlanda Airport, Mariestad and Göteborg. There are five fuel cell buses running in Oslo, two vans are used in Denmark, and two Hyundai ix35 Fuel Cell Electric Vehicles (FCEV) are working in Sweden (also three of the same model cars in Norway, 17 in Denmark). The detailed review of FCEV is covered in section 3.2.1.

3.2 Comparison electric and conventional vehicles

Previous and existing Internal Combustion Engine (ICE) powered vehicles producing a lot of carbon emissions have left us exposed to greenhouse gases which has had a strong impact on the environment and climate. Electric vehicles are a great step forward to overcome this effect and contribute to a healthy and more stable environment. Electric vehicles can carry the energy in form of hydrogen in tanks (FCEV), or stored as electric energy in a high-voltage battery (BEV).

The following table gives the general and most common advantages and disadvantages of electric vehicles against ICE vehicle. If the driving cycle and charging infrastructure allows, electric vehicles are a feasible zero CO_2 emission option to replace conventional vehicles.

Table 2: Comparing electric and conventional vehicles

Area	Description	Pro / Con
Initial investment	Electric cars and buses are more expensive to buy or to lease. Building charging station is another initial investment that has to be done before the purchasing of the electric vehicles.	-
Range	The common range of electric cars is 160 km, up to 480 km in some cases.	-
Maintenance	Low maintenance since lubrication and engine related works are not present.	+
Environment	Using fossil free electricity only, no greenhouse gases and toxic gases emissions. Very low noise.	+
Financial Benefits	The cost of using electricity is very cheap. The total life time cost can be cheaper than diesel cars in long mileage cases.	+

3.2.1 Fuel cell electric vehicle (FCEV)

Fuel cell technology has the advantage of range due to higher energy density and specific energy of hydrogen, and the refueling time is much shorter than recharging time of comparable battery electric vehicles. The electrochemical reaction in batteries is more efficient than the reaction in a fuel cell, leading to lower efficiency and higher energy consumption in a FCEV. Fuel cell vehicles coming to market can actually be classified as fuel cell hybrid electric vehicles, FCHEV, as an on-board battery is necessary to enable regenerative braking and to increase responsiveness at acceleration [17]. The fuel cell technology is relatively expensive and in a hybrid configuration increased costs and complexity is added. STILL demonstrated two fuel cell powered baggage tow tractors at Hamburg airport, fuel cell buses have been tested in several European cities, and fuel cell cars have been commercialized. Apart from the high cost, the very limited model selection and extra requirements for the refueling data make it a less feasible option for airport operation.

3.2.2 Battery electric vehicle (BEV)

An electric battery is a device consisting of electrochemical cells with external connections provided to power the electric motor of the vehicles. The electricity to charge the battery comes from the grid. When charging only fossil free electricity the CO_2 the WTW emissions are zero. Major drawbacks of BEV are the limited driving range due to low energy density in the energy storage system and the recharge duration. Vehicles particularly suited to full electric propulsion are vehicles with a fixed, predefined, and relatively short route and duty cycle, with possibility to frequent stops at defined positions (for supportive charging); e.g. transit or frequently repeated tasks, i.e. airport busses or public transport. As a result of the development of battery technology, lithium-ion battery has shown to be the preferred choice for new vehicles. The type of available batteries in the market and the reason for going for lithium-ion batteries is explained in Appendix section 1.2**.**

3.2.3 Battery charging

The charging location, charging need, and charging period are three factors that drive the electric vehicle usage and utilization profile [18]. Electric vehicle's conductive charging interface has been standardized by International Electronical Commission in Europe. IEC 62196 [19] defines both AC and DC charging station requirements and technical specification. Additionally, there are different standards for low and high power charging, i.e. standard or fast-charging.

For heavy vehicles, including electric busses, there are different charging solutions as it is not similarly standardized as for light vehicles. For example Siemens presents an off-board top-down pantograph, an on-board bottom-up system and charging via connector [20]. This variation provides flexibility to an electric bus fleet but brings a potential compatibility issue for the selection of charging solution.

3.3 Other emission reduction methods

The engine start/stop functionality automatically shuts down and restarts the engine to reduce the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. It however keeps the engine running e.g. at low ambient temperatures, as well as when the air conditioning system needs to work.

The parking (engine) heater, as used at cold weather, uses external electricity or the fuel from the vehicle itself to warm up the engine and the compartment. Hence the engine will reach preferred working temperature in much shorter time and the compartment is preheated before use. When the system runs on fuel, it still has lower fuel consumption compared to running the engine to warm up the car, and the amount of NOx emission is also reduced compared to a normal cold start. Most electric vehicles warms up the compartment using electricity stored in the battery. However, since a couple of years also ethanol based heaters for electric vehicles [21] have appeared on the market and may be applied as standard in future models.

4. AIRPORT VEHICLE FLEET ENERGY CONSUMPTION ANALYSIS

This section presents and summarizes the current situation for a typical airport vehicle fleet, on the example of Swedavia vehicle fleet, with respect to energy consumption and CO_2 emissions. The performed analyses and calculations are described and their results have served as foundation to the proposed roadmap for reducing the fossil CO_2 emission to zero by

2020. The analyses and results presented are selected based on the available fuel consumption data, partly on complete mid-size airport operator level, partly for separate small to mid-size airports.

4.1 Method of analysis

The logical approach for fuel consumption and emission analysis is to investigate which vehicle categories use the most fuel/energy per km or hour. Due to the too low level of detail of the available fuel consumption data, in this analysis, comparisons between winter and summer months as well as between airports have been performed. These results can, in a further step, be scaled as approximations and assumptions on complete vehicle fleet level. As a next step an assessment of possible and feasible measures to decrease or remove these emissions was performed. For further specifications of e.g. electrification feasibility more detailed data from drive cycles and load cases on individual vehicle level is needed.

4.2 Current Fleet Configuration

The investigated vehicle fleet corresponds to typical setup of small to mid-size airport operation as per status 20/02/2017, including 10 small to mid-size airports. To simplify the vehicle fleet configuration for analysis purposes, all vehicles were classified into 7 groups: Ground Handling Vehicles, Runway Maintenance Vehicles, Buses, Rescue Vehicles, Light Vehicles, Heavy Vehicles, and Special Vehicles, as shown in Table 3 below. In this example, the Ground Handling is outsourced in 30% of the cases, hence lowering the amount of such vehicles. Buses are only used in the three mid-size airports. Some of the vehicles are electric or biofuel vehicles, which have zero or nearly zero fossil based CO_2 emission. The number of conventional powertrain (PT) vehicles in each group is indicated in Table 3 and charted per vehicle type as comparison in Figure 5. Light Vehicles has the largest share of the whole fleet, followed by Runway Maintenance and Heavy Vehicles. To carry out tasks like snow cleaning, several types of vehicles may be involved; PSB, SNS, FMF, LAM, and LAB.

Table 3: Classification of the investigated vehicle fleet into 7 vehicle categories.

Category	Vehicle Type	Amount
Ground Handling	AVB, BAL, CAT, FPT, HIL, PBT, TOB, VAB	8,3%
Runway	FLA, FMF, PSB, MÅM, SNS, SOA, SOB	24,0%
Bus	FPB	2,5%
Rescue Vehicle	BRB	6,5%
Light Vehicle	MBU, LLB, PBI, SKB, VIP	28,5%
Heavy Vehicle	DRD, LAB, LAM, OLF, TRA	21,2%
Special Vehicle	DRT, FGK, GAT, HYV, GSP, KES, KOS, RSB, SSB, ÖVF	8,9%

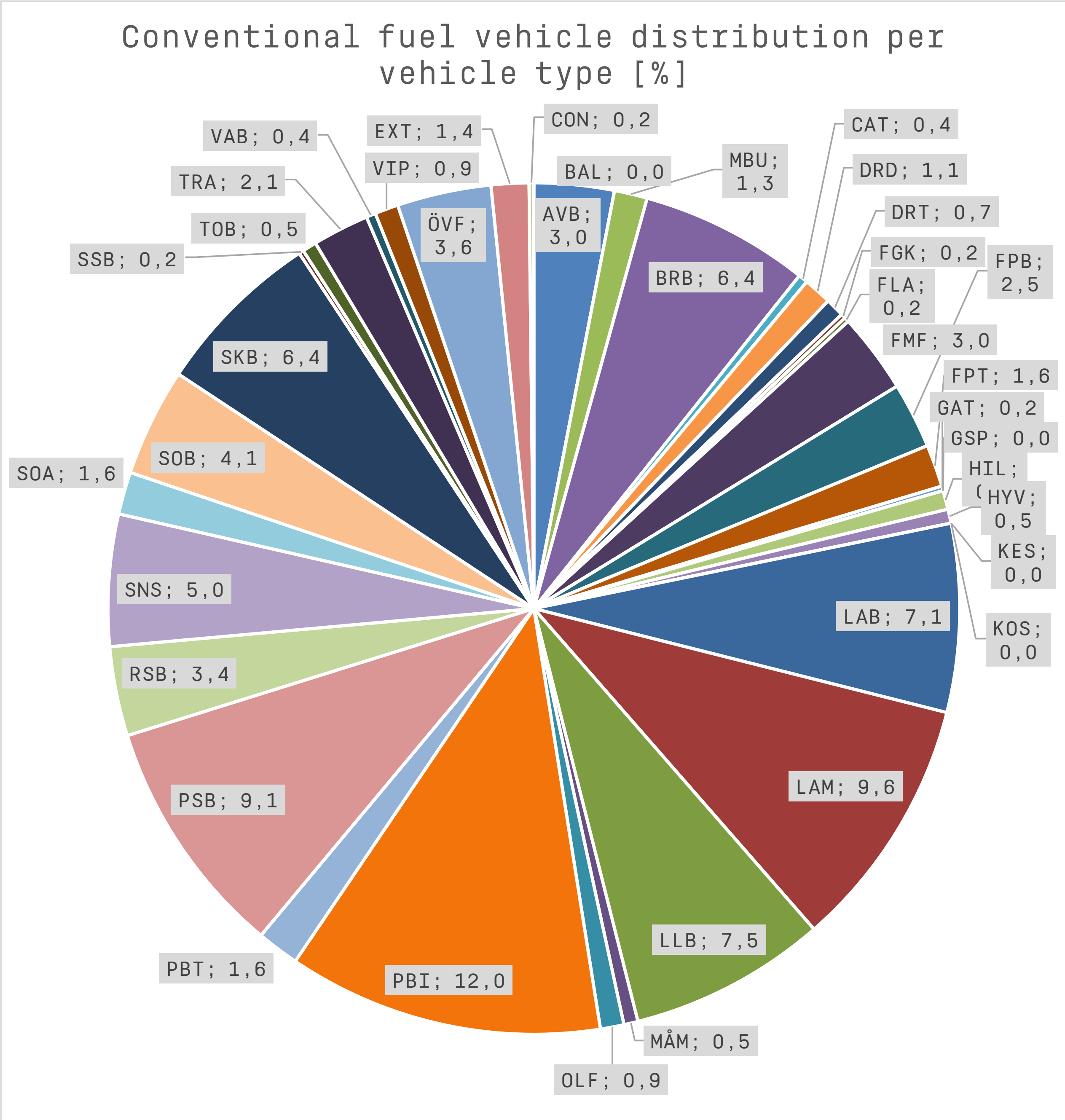

Figure 5: Percentage of conventional powertrain (PT) vehicles per vehicle type in standard airport operator vehicle fleet

4.3 Overall Fuel consumption and CO_2 emission

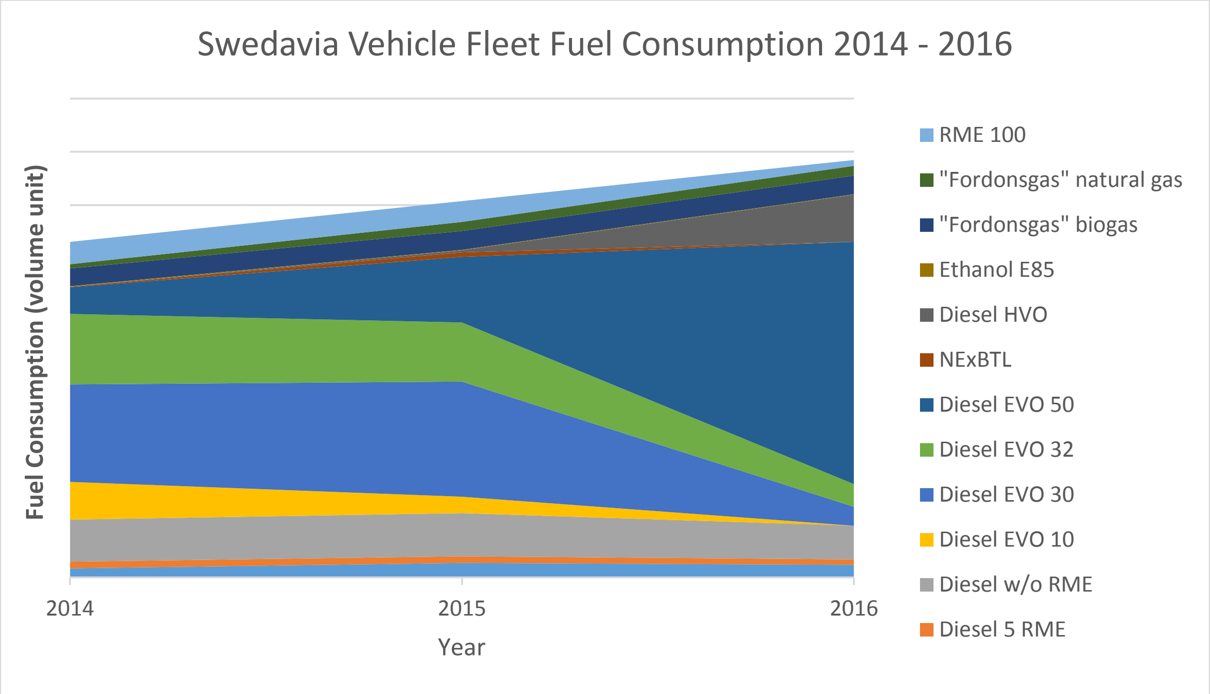

Figure 6: Progress of typical airport operator's vehicle fleet fuel consumption distribution

Figure 6 shows the fuel consumption trend of the investigated vehicle fleet from 2014 to 2016. Diesel takes the largest share among all 13 types of fossil and non-fossil based fuels. However, the main type of diesel consumed has changed from low blend diesel (EVO 30) to high blend diesel (EVO 50), and the usage of 100% HVO has increased significantly in 2016. As biofuels normally have lower calorific value (energy density), the fuel consumption in volume unit (cubic meter), or in mass unit (ton), increased over the past years. However, still the actual CO_2 emission decreased in 2016 because of increased use of biodiesel (see section 3.1.1), as shown in Figure 7. Note that Ethanol amount is much smaller

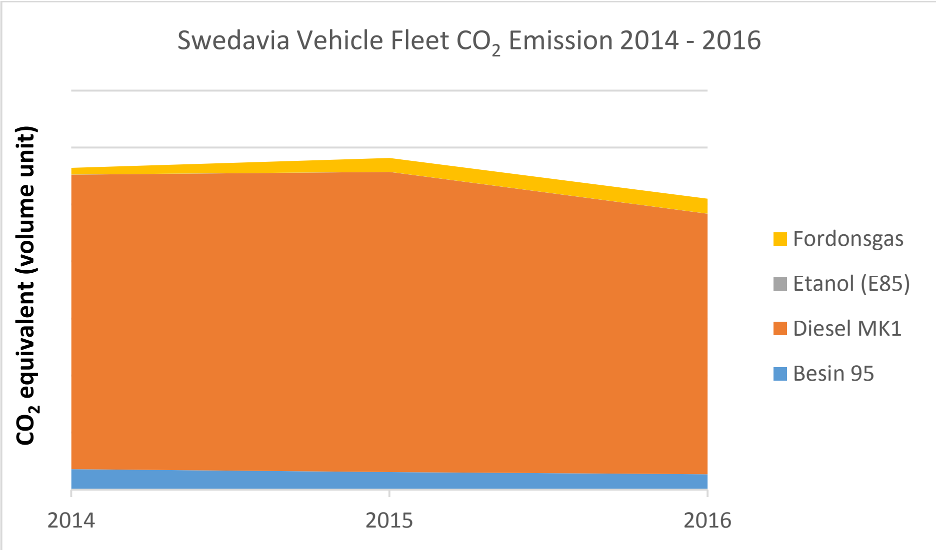

Figure 7: Corresponding CO_2 emission equivalent change for investigated vehicle fleet. Note: Etanol << Other.

4.4 Winter vs summer emissions

As pointed out above in section 4.2, Light Vehicle, Runway Maintenance, and Heavy Vehicle are the three largest vehicle categories. To identify the vehicle categories and types with the major part of CO_2 emissions, the monthly fuel consumption data was categorized into summer usage and winter usage; June, July, August and December, January, February, respectively. Assuming that there are no snow-cleaning tasks in the summer months, the major fuel consumption difference between summer months and winter months is due to the snow-cleaning tasks, here called winter operation. Winter operation includes using PSBs to open the runway and taxiway, using SNS to blow the snow away or transfer the snow to trucks (LAB), using LAMs to transfer the snow to trucks (LAB), using FMFs to measure the friction of the runway, and deice the airplanes with AVBs.

Based on the assumptions made, it can be noticed that at a mid-size airport in mid-Sweden, approximately 92 m^3 diesel (Diesel EVO 50) was consumed for winter operation in 2016, involving 5 AVBs, 9 PSBs, 3 SNSs, 2 FMFs, 1 LAM, and 1 LAB. That means the average diesel consumption is 34 m^3 per month, more than 10 times of summer months (3 m^3 per month). Similarly at a small airport in north Sweden, winter operation consumed approximately 13 m^3 diesel (Diesel 5 RME) in 2016, involving 3 AVBs and 1 FMF. That corresponds to 5.5 m^3 diesel per month, almost 5 times of the summer months (1.2 m^3 per month). Thus, the conclusion is that even though winter operation vehicles run mainly in snowy conditions, they consume more fuel and generate more CO_2 than light vehicles on a yearly basis.

	Summer			Winter		
	Jun	Jul	Aug	Dec	Jan	Feb
Diesel EVO 50%	1,8%	1,5%	1,1%	10,7%	27,8%	12,9%
Average	1,5%			17,5%		
Std Dev	0,003			0,076		

Table 4: Amount of total vehicle fleet diesel consumption at selected periods at typical mid-Sweden mid-sized airport

	Summer			Winter		
	Jun	Jul	Aug	Dec	Jan	Feb
Diesel (5% RME)	2,8%	2,7%	4,5%	12,2%	15,1%	18,7%
Average	3,3%			15,3%		
Std Dev	0,008			0,027		

Table 5: Amount of total vehicle fleet diesel consumption at selected periods at typical north-Sweden small airport

4.5 Fuel consumption at typical mid-size airport in south Sweden

Following the argumentation of the previous section, the heavy vehicles shall be further investigated. The reported driving distance and fuel consumption data of 48 FOVs was analyzed and summarized in Table 6 below. The data represents a period of 5 months from September 2016 to January 2017. Figure 8 shows the percentage per vehicle type of km-based fuel consumption. The corresponding tank-to-wheel CO_2 emission is plotted in Figure 9. The diagrams reveal that SOBs consumed 25% of the fuel and emitted 18% of CO_2. Firefighting trucks (BRB_H in the table and figures) emitted 16% of the emissions consuming only 13% of the fuel. This is because SOBs use HVO fuel and hence, the CO_2 emissions are lower; all according to the argumentation in section 2 specifically Table 1, stating that CO_2 emission per unit burnt fuel is different for different fuels.

From Figure 8 it can also be seen that FMF vehicles, although normal passenger cars, are largely contributing to the overall CO_2 emissions due to their high yearly mileage. Hence also this vehicle category should be addressed and evaluated for emission reduction measures.

Table 6: Field operation vehicles' fuel consumption logged with driving distance, over selected five months period.

Vehicle Abbr.	Vehicle type	Fuel type	Fuel consumption [L/100Km]	Average vehicle usage [Km]	Number of vehicles	Total usage [Km]	Fuel consump -tion [%]	*CO_2 emission [%] (calculation)*
BRB_H	Heavy	Diesel	167	1045	3	3135	21,2	26,9
BRB_L	Light	Diesel	15	4127	1	4127	2,5	3,2
OLF	Light	Diesel	32	921	1	921	1,2	1,5
PBI_D	Light	Diesel	85	1056	1	1056	3,6	4,6
PBI_HVO	Light	Diesel/HVO	58	1560	1	1560	3,7	2,6
FMF	Light	Bensin 95	23	7700	2	15400	14,4	16,1
LAB	Heavy	Diesel/HVO	53	2600	2	5200	11,2	7,9
LLB_B	Light	Bensin 95	30	1180	2	2360	2,9	3,2
LLB_D	Light	Diesel	41	1316	2	2631	4,4	5,6
SOA	Light	Diesel	90	1207	1	1207	4,4	5,6
SOB	Heavy	Diesel/HVO	160	2150	2	4300	27,9	19,6
SKB	Light	Diesel	114	338	1	338	1,6	2,0
MBU	Light	Bensin 95	6	4543	1	4543	1,1	1,2

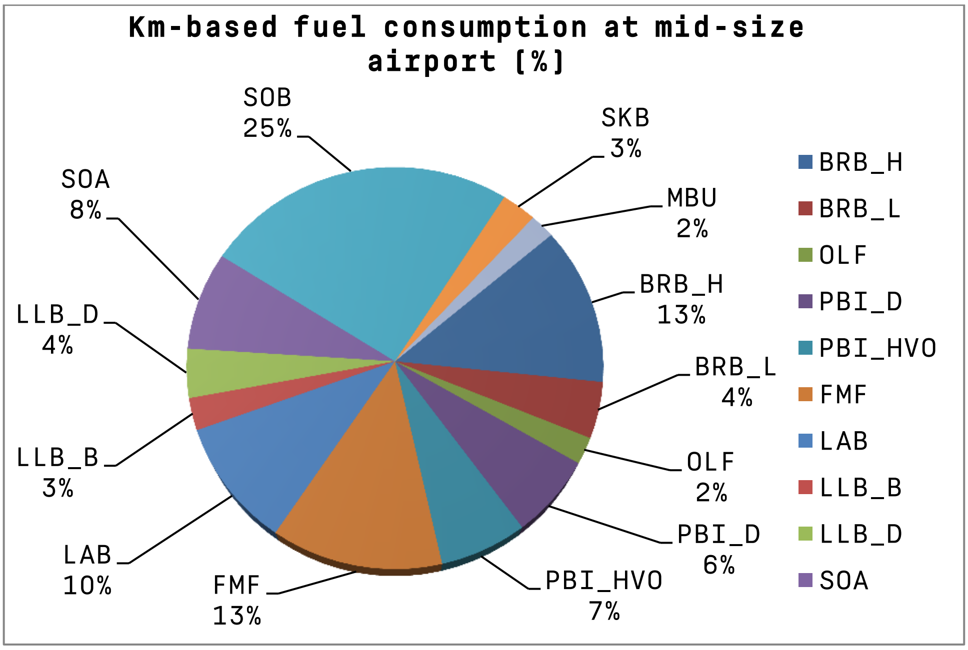

Figure 8: Percentage of km based fuel consumption for field vehicles per vehicle (tank-to-wheel)

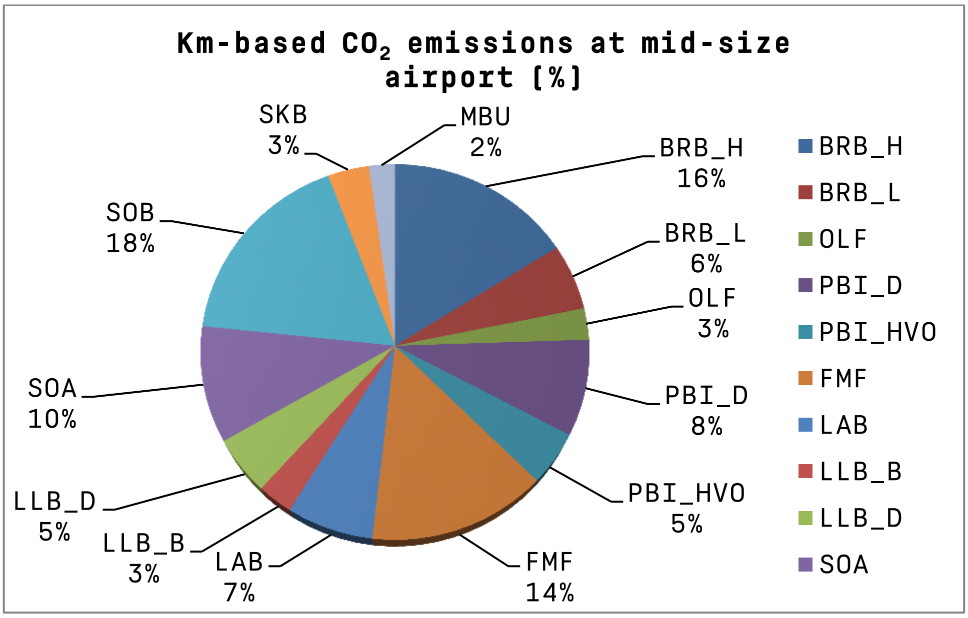

Figure 9: Percentage of km based CO_2 emissions at south Swedish airport for field vehicles per vehicle (tank-to-wheel)

As a second perspective for the data analysis, Table 7 provides detailed fuel consumption per working hour for snow-cleaning vehicles. Especially the heavier vehicle categories perform a lot of the work during standstill or low speeds, and the distance travelled is not a suitable normalization factor for fuel consumption comparison. In such cases the fuel consumption per hour (L/hr) is a more suitable unit, rather than the more common expression L/km. Figure 10 visualizes the percentage of hourly-based fuel consumption per vehicle type for the mentioned vehicle category. The available data shows that LAM, SNS and PSB have similar hourly fuel consumption, but the difference in operating time results in that PSBs emitted 60% of the CO_2 emissions caused by snow-cleaning vehicles.

Table 7: Hourly based fuel consumption of field vehicles at airport in south Sweden, Sep -16 to Jan -17

Vehicle	Vehicle type	Fuel type	Fuel consumption [L/Hr]	Average vehicle usage [Hours]	Number of vehicles	Total usage [Hours]	Fuel consumption [%]	*CO_2 emissions [%] (calculated)*
LAM	Heavy	Diesel/HVO	29	170	6	1020	19,2	19,2
PSB	Heavy	Diesel/HVO	32	320	12	3840	79,6	79,6
RSB	Heavy	Diesel/HVO	4	215	1	215	0,6	0,6
SNS	Heavy	Diesel/HVO	25	41	1	41	0,7	0,7

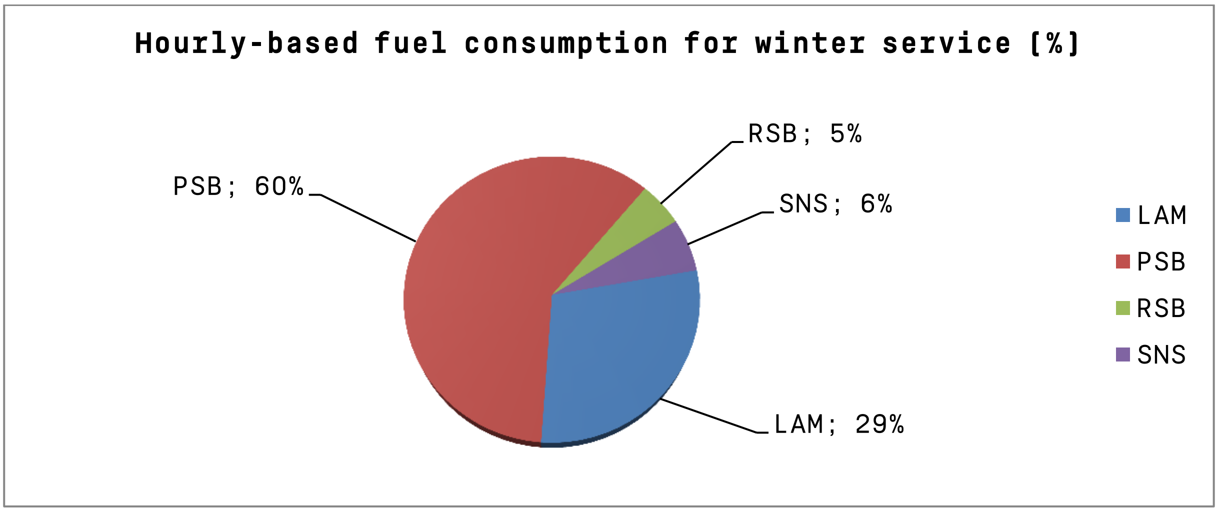

Figure 10: Percentage of hourly based fuel consumption at south Swedish airport for winter service vehicles per vehicle type (tank-to-wheel)

Another vehicle category responsible for large CO_2 emissions is the bus category, due to their great yearly mileage. At one of the investigated airports, eight of the buses are CNG powered, and their equivalent CNG-based CO_2 emission is presented in Table 8 in comparison with respective emissions from two other usage areas. CNG has a good carbon footprint, but due to low calorific value (see Table 1), the total fuel consumption increases.

Table 8: Comparison of CO_2 emissions per usage area at mid-size airport (based on 5 months period)

Vehicle usage	Vehicle type	Fuel type	Vehicle categories	CO_2 emissions [%] (calculated)
Fire/Rescue	Heavy/Light	Diesel	BRB, PBI (D/HVO)	6,3
Snow clearance	Heavy	Diesel/HVO	FMF, LAB, LAM, PSB, RSB, SNS	75,5
Passenger bus (airside)	Heavy/Light	CNG	FPB, SKB, MBU	18,2

4.6 Summary worst case vehicle categories

According to the previous sections analyzing fuel consumption and CO_2 emissions, the vehicles listed in Table 9 have been identified as being responsible for the largest amount of CO_2 emissions. The presented numbers represents a particular airport, but as an example of, and classified as a typical mid-size airport it can be assumed to be valid also for other airports. Hence the major effort for emission reduction measures should be directed to these vehicles types.

Table 9: Vehicles identified as responsible for the major part of CO_2 emissions over an entire airport operator vehicle fleet (data representing a selected 5 months period, mid-size airport)

Vehicle type	Description	Appr. CO_2 emission [%]
FPB	Airport bus (airside), heavy	18,0
LAM	Truck, > 8 ton	13,9
PSB	Plow-Sweep-Blow-machine, heavy	57,8
BRB_H	Fire/Rescue truck, heavy	4,4
SOB	Glycol suction, heavy	3,2
FMF	Friction measurement vehicle, light	2,7

4.7 Vehicle fleet use case analysis

This section contains the discussion regarding vehicle use cases and other requirements on the vehicle fleet. Beside the vision of reducing energy consumption and CO_2 emissions, the operative task of the vehicle fleet must be fulfilled. The results from the previous section identified the worst vehicle categories with regard to CO_2 emissions, as well as indicated probable candidates for part- or full electrification. This section further elaborates the additional requirements to be considered for recommending an improved vehicle fleet configuration with respect to propulsion system and fuel type.

4.7.1 Driving cycle

A driving cycle is normally defined as a series of data points with vehicle speed over time. The driving cycle is used for evaluating road vehicle fuel consumption and emissions, and usually tested using a power-absorbing chassis dynamometer or test bed. When the transmission system is unknown, engine speed is preferred to estimate the fuel consumption. In real world, other parameters like the elevation of the road, friction of the road, and load of the vehicle, and aerodynamic forces should be added into the evaluation.

The driving cycle variance of the airport fleet depends on the duty task. Some of the vehicles run on fixed schedules like land side buses at Stockholm Arlanda airport; other vehicles have to be available 24-7 but are not in very frequent use, like fire fighting vehicles. Thus the driving cycle analysis should be carried out with respect to each particular vehicle type for a specific airport. Table 6 gives an example of driving cycle data fields suitable for vehicle use case analysis. Additionally, vehicle speed, engine/motor/equipment load and geographical properties are relevant parameters. The energy analysis described in section 4.6 has identified the worst vehicle categories with respect to CO_2 emissions and energy consumption. To further conclude how to achieve a more environmentally friendly but still useful vehicle fleet, a more detailed investigation of the particular use cases and duty cycles is necessary. However, this data is not available detailed enough from the investigated airport use case. Such an investigation would answer the questions of which vehicle types are suitable to be fully electric, hybrid electric or remain as conventional vehicles, how many of each type as well as which vehicles would be target for sub-system electrification. With sub-system electrification energy optimizing equipment electrification is meant.

Zisimopoulos analyzed in [22] the landside bus routes of Stockholm Arlanda airport with expert judged fuel consumption and simulated electricity consumption. This method is only possible for Arlanda airport bus routes as the bus fleet used consists of buses with different powertrain systems and the driving routes are fixed.

4.7.2 Working conditions

Comparing many airports all over the world, Swedavia's airports have lower average temperature, longer winter, and more days with rain and snow. They are challenged by and hence design to make deicing vehicles and snow-plowing vehicles work at some extreme conditions. The same is valid also for light vehicles, both with regard to working conditions as well as working environment for the airport personnel. One feature shown to have great importance is the vehicle climate system. The cold and wet environment set extra requirements for electric cars and buses regarding climate system performance.

4.7.3 Availability requirement

The data analysis showed that rescue vehicles have lower mileage compared to other airport maintenance vehicles. However, all rescue vehicles must be available at all times, for all possible terrains, in adverse weathers, and must be able to be refueled or recharged instantly. This requirement needs to be considered when evaluating fuel types and driveline configurations.

4.8 Further findings

Additional to the results from the energy and use case analysis based on the available data and information from Swedavia, a number of other relevant findings are summarized in this section. To further specify future steps regarding the vehicle fleet, some of these findings should be addressed and investigated. In previous sections, the worst vehicle categories as well as probable candidates for part- or full electrification were identified. This section further elaborates the additional requirements to be considered for recommending an improved vehicle fleet configuration with respect to propulsion system and fuel type.

4.8.1 Improved vehicle usage logging

To carry out detailed analyses on individual vehicles, it is important to have the drive cycle data as discussed in section 4.7.1. Beside the vision of reducing energy consumption and CO_2 emissions, the operative task of the vehicle fleet must be fulfilled. With access to this data, running simulations becomes possible, and the fuel consumption and emissions can be calculated for other fuels and other powertrains for comparison. Other uses of load case data are to optimize the driving route for e.g. snow-cleaning tasks, to schedule the usage of electric vehicles depending on the charging status, or scheduling bus traffic optimizing number of vehicles, drivers, and utilization rate. Also the analysis of which vehicles could be replaced with pure electric or hybrid electric versions based on work load and driving cycles should be possible.

4.8.2 Refueling and charging infrastructure

The infrastructure arrangement needs to follow the emission reduction roadmap. This means enabling close and convenient stations for refueling or recharging without disturbance of the duty cycles or work processes. For example biogas, HVO, charging stations, and/or hydrogen refueling station (in case needed). However, the planning of the infrastructure must consider long-term goals in the road map, to avoid major investments in temporary or interim fuel solutions; i.e. biogas for busses versus probable full electrification later on.

4.8.3 Standardization and variance limitation

Apart from fulfilling transportation tasks, it is important to create a comfortable work environment in-and-around the vehicle. Experience shows that a climate control system in duty vehicles is required to handle the often cold and moisture weather in Sweden. This requirement also needs to be considered when evaluating the usability of electric vehicles (due to limited energy storage) for certain tasks. The same is valid for other types of alternative combustion fuels, as some of them are less suitable in cold climate, e.g. ethanol. A limitation in variance of vehicle models and makes within the fleet would reduce training and maintenance time and cost.

5. ROADMAP AND RECOMMENDATIONS

The previous sections contain the argumentation and proofs supporting the conclusions made regarding a strategy towards a more environmentally friendly vehicle fleet for an airport operator as well as some further recommendations in a broader perspective. The investigation has shown that the goal of zero fossil CO_2 emissions is achievable solely by using biofuels for current vehicles in a typical airport operative fleet, and by replacing biofuel incompatible vehicles to biofuel vehicles or electric vehicles.

5.1 Roadmap conclusions

Biofuels, especially HVO and biogas, are the most feasible alternatives to achieve the zero fossil CO_2 emissions. The technology of using HVO and biogas is mature to apply on all vehicle categories except firefighting trucks. In theory, HVO is safe and stable also for firefighting; however further studies are needed together with fuel producer. Due to lower energy efficiency of biofuel compared to fossil based fuel, and much lower than using an electric motor, it is worth to electrify the fleet if the drive cycle allows. For light vehicles and buses there are mature electric vehicles on the market now and hybrid and electric trucks will be available on the market in the near future. Heavy vehicles still need to be powered by HVO diesel. Hydrogen fuel cell technology is not matured today, thus it shall be evaluated again in 5 years.

To achieve zero fossil-based CO_2 emission for an average airport operative vehicle fleet the following steps are suggested:

1. Use HVO to replace conventional diesel. Continue using biogas and ethanol vehicle when electrification is not feasible.
2. Log driving cycles and workload for detailed electrification analysis.
3. Choose electric vehicle and HVO-electric hybrid vehicle if possible.
4. To improve energy efficiency, avoiding use biogas vehicles, and choose vehicles from the manufacturers approved for using HVO.
5. Investigate subsystem electrification possibility
6. Hydrogen fuel cell technology needs to be evaluated again in 5 years.

5.2 Further recommendations

However, as pointed out in section 3.1, compared with conventional petrol and diesel, biofuels have lower energy efficiency for mobile combustion, hence increasing overall fuel consumption. Furthermore, the investigation has shown that the (bio-) fuel usage in the fleet can be optimized for airport operation driving cycles, load cycles, and fuel availability. The vehicles' driving routes and load cycles can be refined to limit unnecessary driving. Beside the pure CO_2 emission reduction, other environmental and work related impacts caused by the vehicle fleet should also be addressed while making CO_2 emission reduction and fleet electrification plans. The following recommendations that can be addressed in parallel with a goal of zero fossil-based CO_2 emissions summarize this.

1. Use fleet management system for
    a. Data collection
    b. Vehicle coordination
    c. Economical driving encouragement
    d. Route optimization
2. Adaption of infrastructure with regard to fuel/energy type, e.g. charging or biofuel infrastructure
3. Consider further aspects of selected fuels, such as energy density, particulate emissions, other health and climate damaging emissions from burning fuel.
4. For electric vehicles/machines
    a. Use lithium-ion batteries (cleaner technology, safer for the environment along with benefits of weight, efficiency, performance, etc.)
    b. Comfort heating through ethanol (passenger cars and buses)
    c. Investigate subsystem electrification of heavy duty vehicles

6. DISCUSSION

6.1 Energy efficiency

As biogas has low tank-to-wheel CO_2 emission, and even negative well-to-wheel CO_2 emission, this makes biogas an ideal alternative fuel. However biogas has low energy efficiency for powering vehicles. It is worth to consider fuel usage strategy in line with energy efficiency strategy, as there is a point of brake-even between the consumption and emissions. Conventional diesel can simply be stored in a big tank, however gaseous fuels are more complex to store; biogas typically stores at 200 or 250 bars. An electric motor on the other hand has very high energy efficiency for powering vehicles. As the development of battery and charging technologies continues, electric vehicle could replace biogas vehicles in near future. Hence, investing on biogas vehicles and biogas refueling stations need to undergo a deeper economical assessment including other social factors.

6.2 Other emissions

Additional to monitoring CO_2 emissions and energy efficiency of a particular fuel, also other health and climate damaging pollutants need to be considered while deciding on the most suitable energy source. The emissions of primary concern include the regulated emissions of hydrocarbons (HC), nitrogen oxides (NOx), carbon monoxide (CO) and particulate matter (PM). Table 10 shows as an example a comparison between petrol, diesel, and CNG powered cars and their relative emissions of different pollutants.

CNG powered vehicles show CO emissions in the same order as those emitted from diesel vehicles. But total HC are relatively high because of the high content of methane (a very potent greenhouse gas) in natural gas. Emissions of NOx and PM from equivalent CNG vehicles are significantly lower than those from diesel vehicles, and NOx about half of those from petrol powered vehicles [23]. Biogas is the renewable version of natural gas, mainly a mix of methane and carbon dioxide, with basically neutral well-to-wheel CO_2 emissions.

Biodiesel is chemically different from conventional diesel, and a blended fuel will produce somewhat different emissions. Some studies have shown that tailpipe emissions of PM, CO, and HC are generally lower for biodiesel than regular diesel. However, also studies showing varying and inconsistent effects on other pollutants have been reported [24].

Table 10: Comparison of emissions for selected road vehicles and fuels (per vehicle kilometere). Petrol car w/o catalyst as baseline.

Vehicle/fuel	CO	HC	NOx	PM	CO_2
Petrol Car w/o catalyst	100 1)	100	100	-	100
Petrol Car w catalyst	42	19	23	-	100
Diesel Car w/o catalyst	2	3	31	100	85
CNG Car 2)	~2	N/A	~12	<< 100	~80

1) Baseline 2) Approximated

Additional to the above mentioned pollutants, also cancer risk factors such as formaldehyde and acetaldehyde emissions needs to be considered. Emissions of these substrates could increase with increased use of e.g. ethanol, methanol, and CNG.

The comparison makes clear, that there is no easy formula to decide what fuel is the most advantageous. Especially the more recent concerns about particulate matter have given diesel fuels a less environmental/health-friendly image.

6.3 Fuel cells

There are currently only three fuel cell vehicle manufacturers: Honda, Toyota and Hyundai. Vehicles powered by fuel cells find their advantages when the driving range is high based on the fact that they can be refueled instantly. That makes this technology suitable for long range vehicles while battery driven vehicles are suitable for short/medium range. Hydrogen is normally stored in tanks with 500 bar pressure, which is even higher than the 200 bar for biogas tanks. Biogas refueling station can be modified to be hydrogen refueling station in order to minimize the infrastructure building cost and assure future-proof investments.

The research and innovation in fuel cells is very high and the competition with the batteries is fierce, one should therefore look and follow this technology closely as a game changer could rise in the near future; potentially showing fuel cells more attractive than batteries.

Fuel cell vehicles are often presented as competitor to battery driven vehicles but many technical and economic challenges keep fuel cells as a niche technology. However, as both technologies show different drawbacks and advantages, the combination of the technologies seems prosperous (FCHEV) and hence fuel cells and batteries become complementary and not competing technologies.

6.4 Electrification configuration

Additional to the conclusion if a certain vehicle type and its use case / load cycle is suitable for electrification, the level of electrification and the technology used need to be specified. In Appendix section 1.2 a more detailed explanation of various levels of electrification and a comparison of different battery types can be found.

As an example the push-back truck can be studied. Considering the vehicle life time, vehicle cost, operation hours, specific investment, maintenance and fuel cost, a survey has shown that an electric pushback truck operating around 2000 hours per year would have its overall cost reduced by half in comparison with a conventional diesel pushback truck. Over a 24-hour period pushback trucks have relatively low energy consumption but a comparatively high system power due to very short duty cycles of full system power when the pushback truck is used. These requirements rule out the choice of fuel cell technology for a push-back truck as fuel cell technology is beneficial at long range missions, and due to the fact of slower responsiveness of power request. As also high vehicle weight is an advantage for towing purposes, the benefit of high energy density of hydrogen is less relevant. In a comparison between classical lead-acid batteries vs Li-ion battery technology, the high weight and the low price for Pb-batteries show advantages. However, a Li-ion battery show advantages with regard to longer lifetime, less maintenance, less technical challenge in cold climate, faster and more efficient charging and higher usable charge capacity. Hence for this particular case an electric pushback truck with Li-ion battery would be a well-balanced choice.

6.5 Estimation of environmental benefits

Due to limitations in the airport vehicle fleet data available for and used in this pre-study it was not possible to perform a quantitative estimation of environmental benefits of the proposed steps in the roadmap. For this, detailed information about driving patterns, load cycles and fuel consumption per vehicle is required. The available data was limited to fuel consumption data on subsets of the vehicle fleet, e.g. per airport or per vehicle category, and geographical position data for other subsets of the vehicle fleet. Due to these limitations it also showed impracticable to make estimations on savings potential, both regarding fuel consumption and economically.

APPENDIX I

1.1 Propulsion system

1.1.1 Electric motors

Electric motors, earlier mainly used for short range local delivery vehicles are now also used in vehicle capable of highways speeds, are unbeaten with regard to efficiency. Due to limited battery capacity/storage, the duration and range is limited. The decision of choosing the right battery type and size depends on the use case properties, e.g. requirements for capacity and recharging time, with the latter deciding the usage frequency of the vehicle.

The most promising technology for improved range of electrically propelled vehicles is the fuel cell. But with it being relatively expensive, it is still not seen as a feasible option.

1.1.2 Electric propulsion

Hybrid electric vehicles (HEV's) are powered by two power sources, one of which is electricity, producing high mileage per liter of fuel and low-emission drive. The second power source could be conventional fuels (gasoline, diesel, or hydrogen). There are two types of HEV's, series and parallel hybrid, respectively.

In the series hybrid vehicles, the ICE runs the generator and is not mechanically connected to the driving wheels, which means the engine is isolated from road load/demand, allowing it to operate at its efficient point to charge the battery. The traction power is generated through the battery coupled to the traction motor. This also means a smaller engine/generator can be used compared to a conventional direct drive engine which then reduces the fuel consumption and lesser carbon dioxide content into the atmosphere. This allows a vehicle with an engine/generator that only operates when needed, such as when the battery is depleted, or to charge the batteries.

In the parallel hybrid vehicles, both ICE and electric motor work together to power the vehicle. Both ICE and electric motor are connected to the transmission shaft. The controller decides when to use the electric motor or the ICE to power the vehicle. Parallel hybrid vehicles rely more on regenerative braking and the ICE can also acts as generator for interval recharging. This makes them more efficient in 'stop-and-go' conditions in urban environment.

The hybrid can be categorized based on the degree of hybridization. They are:

a) Mild hybrid vehicles

Mild hybrids are conventional vehicles with limited hybrid features. They are usually parallel hybrid with start-stop only or regen braking or model level of engine assistance [25], equipped with a relatively small battery (additional to normal starter-battery).

b) Full hybrid vehicles

Full hybrids are vehicles that run full on ICE or electric motor or in combination. Usually a high capacity battery provides the battery only mode of operation. A split path allows more flexibility in the drivetrain by converting mechanical and electric power at the same time [25].

c) Plug-in hybrid vehicles (PHEV)

A PHEV can be plugged into an electric outlet the charge the vehicle and they are full hybrid able to run on battery stand alone. They not only offer greater battery capacity but also the ability to recharge from the grid. The main benefit of using PHEV is that they can be gasoline/diesel independent for significant distances and the ICE adds up for extended ranges for longer trips [25].

1.2 Battery technology

1.2.1 Lead-acid Battery

Lead acid batteries are made from a mixture of lead plates and sulfuric acid. This was the first type of rechargeable battery, invented way back in 1859. There are two types of lead-acid batteries. First one is the automobile engine starter batteries and second one is the deep cycle batteries. Alternators are designed for starter batteries with high charge for fast charging where as deep cycle batteries are used in electric vehicles like golf carts or fork lifts. Lead-acid battery life depends largely on the usage level [26]. It is greatly affected if it is discharged below 50%. Flooded batteries which are the cheapest lead-acid batteries also require regular inspection of electrolyte level and occasional replacement of water which gases away during the normal charging cycle

1.2.2 Nickel metal hydride Battery

A nickel metal hydride battery or NiMH is a rechargeable battery. The efficiency is around 60-70%, which is less than lead-acid but the energy density is 30-80 Wh/kg, much higher than lead acid (30 Wh/Kg). If used properly, these batteries can have longer lives than other battery technologies [27].

1.2.3 Lithium-ion Battery

A lithium-ion or Li-ion battery is a rechargeable battery in which the lithium ions move from the negative electrode to the positive electrode when discharging and vice versa while charging. These batteries are widely used now-a-days in Electric vehicle development. With charging/discharging efficiency of 80-90%, the Li-ion cells yield greater than 200 Wh/kg energy density and good power density. These can however be dangerous under some conditions and can be a safety hazard since they contain a flammable electrolyte which is kept pressurized [28].

1.2.4 Iron-phosphate battery

The lithium iron phosphate (LiFePO4) battery is a rechargeable battery. These batteries have a constant discharge voltage which potentially makes them to deliver full power until it's discharged. The use of phosphate avoids cobalt's entering into the environment through improper disposal. Automaker BYD says that these batteries can be charged in 15 minutes up to 80% in fast charging stations and they use these batteries to power their PHEV's [29].

1.3 Fuel cell technology

There are a number of different fuel cells types: alkaline fuel cells (AFC), direct methanol fuel cell (DMFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC), and proton exchange membrane fuel cell (PEMFC). The PEM fuel cell (PEMFC) uses hydrogen and oxygen gases as its reactants. The oxygen gas is simply extracted from the surrounding air. Hydrogen gas serves as the "fuel" of a PEMFC, and when compressed, it is much more energy dense than even the most advanced batteries (in both a volumetric and gravimetric sense). This means that for a given volume and mass, more energy is contained - well beyond what batteries are expected to achieve for the foreseeable future.

The PEMFC is seen as the most suitable type for vehicular applications for the following reasons:

1. The electrolyte is solid, and so leaking of corrosive fluids is not an issue and the fuel cell can operate in any orientation
2. The operating temperature is relatively low (80-100°C), meaning start-up times are short.
3. Relatively high power density (compared to other fuel cell types)
4. 99,999% H_2 is required, but air can be used to supply the required O_2

REFERENCES

[1] sweden.se, "Energy use in Sweden," [Online]. Available: https://sweden.se/society/energy-use-in-sweden/. [Accessed 21 02 2017].

[2] Swedavia, "Zero Vision 2020," Swedavia, [Online]. Available: https://www.swedavia.com/about-swedavia/environment/. [Accessed 01 03 2017].

[3] PPMC, "Electric Buses and Taxis at Schiphol Airport in the Netherlands," [Online]. Available: http://www.ppmc-transport.org/electric-buses-and-taxis-at-schiphol-airport-in-the-netherlands/. [Accessed 06 02 2017].

[4] "Case Studies: Low Emissions Vehicles," Heathrow Airport, [Online]. Available: http://www.heathrow.com/company/community-and-environment/responsible-heathrow/case-studies/low-emissions-vehicles. [Accessed 06 02 2017].

[5] "Sydney Airport unveils Australia’s first electric airport bus," Sydney Airport, [Online]. Available: http://www.sydneyairport.com.au/corporate/media-centre/media-releases/media-release-detail/2016/media-releases/20160831-sydney-airport-unveils-australia-s-first-electric-airport-bus?lst=%7BC313C142-0E4E-4269-A2FB-BDEB95B3BC9E%7D. [Accessed 06 02 2017].

[6] R. Edwards, H. HASS, J.-F. Larive, L. Lonza, H. Mass and D. Rickeard, "Well-toWheels anaylissi of future automotive fuels and powertrains in the European context," 2014.

[7] B. S. Unsal, "ELECTRIC OPERATED VEHICLES ON TURKISH AIRPORT APRON OPERATIONS," 2016.

[8] IPCC, "2006 IPCC Guidelines for National Greenhouse Gas Inventories," IGES, Japan, 2006.

[9] E. E. Protal, "Glossary of Energy Related Terms," [Online]. Available: https://www.energy.eu/dictionary/. [Accessed 09 03 2017].

[10] H. Aatola, M. Larmi, T. Sarjovaara and S. Mikkonen, "Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-off between NOx, Particulate Emission, and Fuel Consumption of Heavy Duty Engine," SAE, 2008.

[11] SEKAB, "BioFuel," [Online]. Available: http://www.sekab.com/biofuel/. [Accessed 20 02 2017].

[12] SEKAB, "ED95," [Online]. Available: http://www.sekab.com/biofuel/ed95/. [Accessed

22 02 2017].

[13] Ecotraffic ERD3 AB, E. Larsson, L. Eriksson, P. Ahlvik and Å. Brandberg, "Safety aspects with E85 as a fuel for vehicles," City of Stockholm, Environment and Health Administration, Stockholm, 2006.

[14] H. Persson, P. Bremer, L. Rosell, K. Arrhenius and K. Lindström, "Fuel vapout composition and flammability properties of E85," SP Technical Research Institute of Sweden, Stockholm, 2008.

[15] E. E. &. R. Energy, "Alternative Fuels Data Center: Hydrogen," [Online]. Available: http://www.afdc.energy.gov/fuels/hydrogen.html. [Accessed 14 02 2017].

[16] Scandinavian Hydrogen Highway Partnership, "Hydrogen Data - Scandinavian Hydrogen Highway Partnership," [Online]. Available: http://www.scandinavianhydrogen.org/shhp/h2-tech/. [Accessed 01 03 2017].

[17] D. J. Wishart, "Fuel Cells vs Batteries in the automotive sector," Intertek, 2014.

[18] "http://kth.diva-portal.org/smash/get/diva2:588875/fulltext01.pdf%7C," [Online].

[19] IEC, "Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles -".

[20] Siemens, "Charging systems for ebus," Siemance, [Online]. Available: http://w3.siemens.com/topics/global/en/electromobility/pages/charging-ebuses.aspx. [Accessed 03 04 2017].

[21] Webasto, "New Heating Concept_Heating System," Webasto, [Online]. Available: https://www.webasto.com/gb/markets-products/car/heating-systems-for-automotive-industry/vehicle-heaters/. [Accessed 18 02 2017].

[22] D. Zisimopoulos, "En elektrifiering av den interna busstrafiken på Stockholm Arlanda Airport," Uppsala Universitet, 2016.

[23] Dept for Environment, Food and Rural Affairs, "The UK National Air Quality Strategy," 2000. [Online]. Available: http://www.air-quality.org.uk/26.php.

[24] Health Canada, "Health Canada - Environmental and Workplace Health," 2013. [Online]. Available: http://www.hc-sc.gc.ca/ewh-semt/air/out-ext/sources/fuels-carburants-eng.php. [Accessed 31 05 2017].

[25] ""What is a Hybrid Vehicle?". What-is-what.com," [Online]. Available: http://what-is-

what.com/what_is/hybrid_vehicle.html. [Accessed 22 03 2017].

[26] H. Barre, "Managing 12 Volts: How To Upgrade, Operate, and Troubleshoot 12 Volt Electrical Systenms.," Summer Breeze Publishing, (1997)., p. 63–65.

[27] "In search of the perfect battery,," The Economist, 6 March 2008. [Online]. Available: http://www.economist.com/node/10789409. [Accessed 27 03 2017].

[28] C. Millsaps, "Second Edition of IEC 62133: The Standard for Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes is in its Final Review Cycle," 10 January 2014. [Online]. Available: http://www.batterypoweronline.com/main/markets/manufacturing-materials/second-edition-of-iec-62133-the-standard-for-secondary-cells-and-batteries-containing-alkaline-or-other-non-acid-electrolytes-is-in-its-final-review-cycle/. [Accessed 27 03 2017].

[29] "Building safer Li ion batteries".," houseofbatteries.com., [Online]. Available: http://www.houseofbatteries.com/articles.php?id=27. [Accessed 27 03 2017].

[30] ACI, "Airport Carbon Accreditation Annual Report 2015-2016".