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Life Cycle Assessment of Scenarios for the Icelandic Vehicle Fleet

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Abstract

Environmental issues, foremost global warming and climate change, are attracting more and more attention in world' discussion as the global community constantly works on an agreement for actions to limit it. Global warming and climate change are human induced greenhouse effects that are a direct result of burning fossil fuels. Global warming is not the only problem of using fossil fuels. It is estimated that recoverable fossil energy reserves can only meet the demand for energy until 2050, if demand stabilizes at a current level. Iceland has commitments to reduce emissions contributing to global warming and as the transportation sector makes up a considerable proportion of the total emissions therefore the analysis of that sector is important. The overall aim of this report is therefore to analyze the life cycle emissions of the Icelandic vehicle fleet from 1990 to 2010 and then to develop possible and necessary scenarios for the future development of the fleet. Emissions of the Icelandic vehicle fleet are calculated using a life cycle approach. First the historical model used to calculate past emissions is defined along with the relevant parameters. Additional parameters for the scenario model, for three different scenarios: the reference; the green and the target, are presented and further calculations explained. The results show that emissions in the reference scenario increases continually and by 2050 it is over three and a half times higher than the emission reduction target, while the green scenario, which assumes moderate measures, is over 2.6 times higher. The target scenario, being the only scenario getting close to the target, has a reduction in emissions at 67% by 2050 compared to 2010. The model gives a clear indication of the development of the service provided, and shows that there is little reduction in the population's overall mobility in the reference and green scenarios, while the kilometers driven per person returns to 1990 level in the target scenario. The model indicates that reaching the emission reduction goal that the Icelandic government has announced seems very unlikely if all sectors are to reduce emissions equally. It is clear that action needs to be taken immediately in Iceland and elsewhere if international goals are to be kept.

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1 INTRODUCTION

Environmental issues are attracting more and more attention in world' discussion today, and one of the most pressing issues is global warming (Houghton, 2009). Global warming and climate change are a direct result of burning fossil fuels: the gases released by burning absorb solar radiation (heat) that would normally be retransmitted into space, causing the greenhouse effect. Without any greenhouse effect the average surface temperature on Earth would be close to -6°C, 20°C cooler than it actually is. The greenhouse effect therefore heats the earth and the natural greenhouse effect is desirable while the enhanced, human induced greenhouse effect, which causes global warming, is not. The potential effects of global warming include an increase in sea levels, floods, droughts and more frequent and extreme heat waves than in the past. It will affect the supply of fresh water and human health and increase extinction rates and desertification in the twenty-first century (Houghton, 2009).

Environmental issues are not the only problem resulting from the increasing use of fossil fuel in the world. Energy prices (Orkustofnun, 2005) are rising and will continue to rise with increased global demand. The importance of access to energy cannot be understated, because without it, it would be almost impossible to continue social-economic development (Fermann et al., 2009). The importance of access to energy became very clear during the 1970s, when supply did not keep up with demand and the public became aware that fossil fuel reserves would not last forever (Environmental Protection Agency, 1974). It is estimated that recoverable fossil energy reserves will meet the demand for energy until 2050 if demand stabilizes at a current level (Houghton, 2009).

Motivation for finding an alternative energy source is very high due to fossil fuel depletion and environmental issues. It is unlikely that one single alternative to fossil fuels will be adopted: a mix of different technologies and energy carriers could be best suited to reducing dependence on fossil fuels while at the same time reducing emissions.

GLOBAL PROBLEM

With increasing globalization, nations have many commitments to various multinational or international treaties and agreements. These influence the development of emissions in all sectors of the economy and it is therefore of outmost importance to take them into account when looking at the development of past and future emissions in all sectors of the economy.

The global community is constantly working on an agreement that will limit climate change. However, before emission reduction can be made, the source must be known. On a global level greenhouse gas (GHG) emission from households accounts for 72% of the overall emissions, government consumption (10%) and investments (18%) making up the rest. A breakdown of household consumption shows that of the total 20% of GHG emissions are from food, 19% are caused by maintenance of residences and 17% by mobility (Hertwich & Peters, 2009).

The United Nations Framework Convention on Climate Change (UNFCCC, 2010a) is an international treaty concerned with mitigating climate change as well as predicting the effect of it. The Kyoto Protocol, which came into force in February 2005, was a result of this framework and contains legally binding GHG reduction targets for each nation (UNFCCC, 2010a). The UNFCCC organizes intergovernmental negotiations, which include the Conference of the Parties (CoP) and the Meeting of the Parties to the Kyoto Protocol (CMP). The CoP is the highest decision-making authority of the Convention and meets every year. The aim of its work is to keep international climate change mitigation efforts on track and follow up on submitted emission figures, as well as keeping up to date on the newest knowledge about climate change (UNFCCC, 2010b). It gathers information related to climate change from various sources including the Intergovernmental Panel on Climate Change (IPCC), a scientific body that reviews the most recent knowledge relating to understanding climate change (IPCC, 2010). At the CoP15, the 15th Conference of the Parties, in Copenhagen 2009 the Copenhagen Accord was drafted, suggesting that anthropogenic emissions should be stabilized at a level that would allow global temperature to stabilize at a maximum of 2°C above pre-industrial levels (UNFCCC, 2009). More aggressive suggestions have been made which propose a reduction in developed countries by up to 40% by 2020 and 90% by 2050 compared to base year, 1990 (Nicaragua, 2009).

The Kyoto Protocol includes binding GHG mitigation targets with an average of 5% reduction in emissions of 1990 levels over the period 2008-2010 (UNFCCC, 2010b). The European Environment Agency (2007) estimates that emission reductions in developed countries need to be reduced by 15-50% by 2050 compared to base year. As mobility is a significant contributor to overall emissions, reduction in that sector is of utmost importance.

There is a wide range of possibilities for reducing emission in the transport sector, including greater engine efficiency, pollutant control, alternative fuels and new powertrain concepts such as internal combustion engine and fuel cells (Röder, 2001). One of the most effective measurements for reducing vehicle emissions is the implementation of emission standards around the world. Unfortunately not all regions use the same standards, but one of the strictest standards is that used in Europe (An & Sauer, 2004). The current standard, Euro 5, and the future standard, Euro 6, are measurements to reduce emissions from the road transport sector. The European Union considered it important to give vehicle producers a clear message about both present and future emission limits in order to enable them to develop their designs and make the necessary adjustments to their future models. Manufacturers are obliged to demonstrate that all new vehicles conform to these standards (European Automobile Manufacturers' Association, 2009). It shows how the allowed emission limits on personal vehicles have changed since they first came into force in 1992. As can be seen, air pollutants have been reduced significantly in the last two decades.

Table 1.1 shows the past, present and future emission standards that personal vehicle manufacturers must follow. The table is crude but gives a clear picture of the development of the standard. It shows how the allowed emission limits on personal vehicles have changed since they first came into force in 1992. As can be seen, air pollutants have been reduced significantly in the last two decades.

Table 1.1: European emission limits on new passenger vehicles in grams per kilometer set by the European Union

		Diesel (Compressed Ignition)			Gasoline (Positive Ignition)		
Standard	Year	CO	NOx	PM	CO	NOx	PM
Euro 1	1992	2,72	-	0,14	2,72	-	-
Euro 2	1996	1	-	0,08	2,2	-	-
Euro 3	2000	0,64	0,5	0,05	2,3	0,15	-
Euro 4	2005	0,5	0,25	0,025	1	0,08	-
Euro 5	2009	0,5	0,18	0,005	1	0,06	0,005
Euro 6	2014	0,5	0,08	0,005	1	0,06	0,005

Source: DieselNet (2010)

This has been achieved through higher engine efficiency as well as after-treatment of the exhaust. There are also emission limits on commercial vehicles, with the first one, Euro I, coming into force in 1992, and Euro 5 valid today. Along with the stricter limits the cost of developing and manufacturing the vehicles also tends to rise, and it is important that it does not rise too much because this could lead to a lower fleet renewal rate which again would means greater emissions per distance driven according to the European Automobile Manufacturers Association (ACEA) (ACEA, 2009). What is not taken into account in these standards is the emissions embedded in the production and therefore also the renewal of the fleet.

Vehicle manufacturers tend to surpass current emission standards at any given time in preparation for meeting future limits. A good example of this is the Mercedes-Benz A150 gasoline vehicle, a small city car, whose CO and NOx emissions are 86% and 81% respectively, lower than the standard valid at the time of production, Euro 4 (Mercedes-Benz, 2008a).

LOCAL PROBLEM

At the last CoP in Copenhagen December 2009 the European Union (EU) put forward an ambitious GHG reduction pledge. The Icelandic government followed this with an announcement that in cooperation with the EU its emissions reduction target for 2020 would be 30% below base year level (Umhverfisráðuneytið, 2010). The Icelandic government has also put forward a long-term goal to reduce emissions by 50-75% by 2050 compared to base year (Brynhildur Davíðsdóttir, 2009).

In the reference year, 1990, Iceland's emissions were 3,367,149 t CO_2 equivalent (eq.) (UNFCCC, 2010c). This means that by 2020 the reduction in GHG would have to be 1,010,392 t CO_2 eq. and by 2050, approximately 1,683,574 t CO_2 eq. if the 50% target is to be reached.

In order to fulfill its commitment the Icelandic government has in accordance with the Kyoto-protocol and UNFCCC, put up a GHG quota system in which each production company is allowed to emit a certain quantity of GHGs each year, and if this is exceeded it is liable to pay a government fine. Companies are allowed to increase their emission quotas through other routes, for example by financially supporting projects that aim to bind CO_2 in living materials or soil or by participating in projects abroad aimed at reducing emissions in developing countries (Law nr. 65/2007).

Usually when the government of a country considers reducing its GHG emissions the focus is on the energy sector. This, however, is not the sector to focus on in Iceland, which relies on renewable energy sources such as hydropower (72.9%) and geothermal power (27.0%) for both its electricity and district heating (Orkustofnun, 2009). Electricity generation and district heating emissions are responsible for only about 4% of Iceland's total emissions: by far the largest emitter is the industry and chemical sector with a share of 41%. The transport sector has been the fastest growing source of GHGs and was responsible for 23% of GHG emissions in 2007. From 1990 to 2007, emissions from road transport increased by 81% while those of sea transport increased by 1% and air transport decreased slightly (Brynhildur Davíðsdóttir et al., 2009). Figure 1.1 shows the increase in emissions with transport by road in green, by sea red and by air blue.

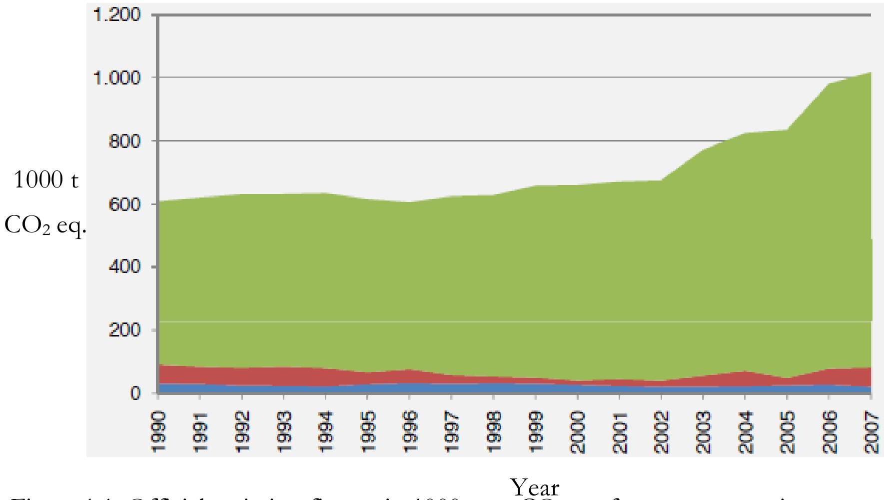

Figure 1.1: Official emission figures in 1000 tons CO_2 eq. from transportation sector in Iceland 1990-2007
Source: Brynhildur Davíðsdóttir et al., 2009 p. 31

Figure 1.1 shows that the largest share of transport emissions is from road transport at 92% (1,017,000 tons CO_2 eq.). Comparing this to the reduction needed for 2020 of 1,010,392 t CO_2 eq. it is clear that the transport sector offers a great opportunity for emission reduction. The official emission figures for the transport sector for years 1990 through 2006 can be seen in Table 1.2.

Table 1.2: Official emission figures from transportation sector in Iceland 1990-2006

Year	’90	’91	’92	’93	’94	’95	96	97	’98	’99	’00	’01	’02	’03	’04	’05	’06
1000 ton CO_2 eq.	608	620	630	631	634	615	605	624	627	657	659	670	674	770	823	834	979

Source: Table 2.9 in National Inventory Report: Iceland 2008, submitted by Umhverfisráðuneytið

Table 1.2 shows how emissions from the use-phase of vehicles have been increasing overall despite decreasing from 1994-1996. For Iceland, the opportunity is therefore in reducing emissions from the transport sector and dependency on fossil fuels as soon as it is economically feasible in order to increase energy security and comply with international agreements. To reach both goals the Icelandic government has put forward a target of being for most part a fossil-fuel-free economy by 2030 (Umhverfisráðuneytið, 2007).

Emissions per kilometer driven are generally higher using gasoline than using diesel oil. From gasoline use the emissions are commonly from 140-280 grams CO_2 eq./km (Pehnt, 2000; Rolf et al., 2007) while diesel emits around 123-260 CO_2 eq./km; however, as can be expected, it depends on the size of the vehicle in question. Regarding reducing emissions per kilometer driven, the ACEA has made a voluntary commitment to reduce emissions from new vehicles. The target was 140g CO_2 eq./km by 2008 and, is now 130g CO_2 eq./km by 2012 and 95g CO_2 eq./km by 2020. This commitment has been made because of the possibility of stricter EU regulations might give those participating competitive advantage on the market (Bandivadekar, 2008).

The use of fossil fuels is closely monitored by the National Energy Authority (NEA) (Orkustofnun) which follows up on both their importation and their distribution, therefore information about how much each sector uses of fuel is readily available. Figure 1.2 shows the development of fuel usage in the transportation sector.

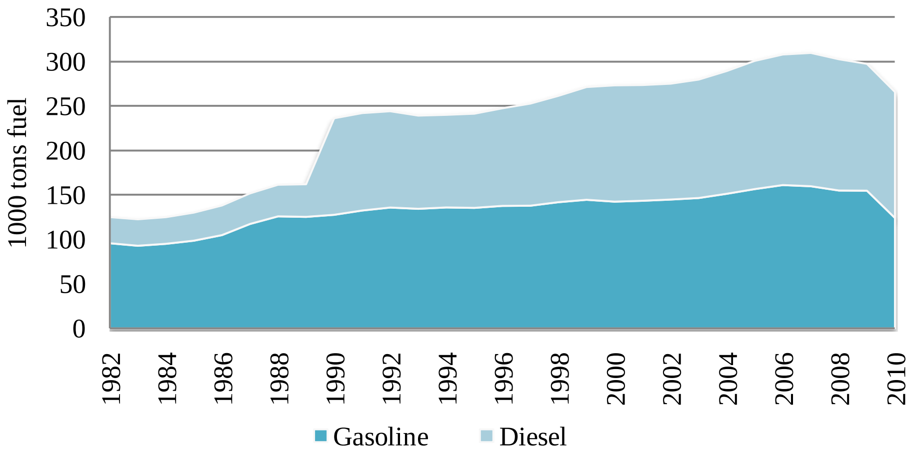

Figure 1.2: Fossil fuel in thousands of tons use in road transport sector in Iceland 1982-2010
Note: Information from Orkustofnun and figures for 2010 are preliminary

Figure 1.2 shows that there has been an increase in the use of fossil fuels as far back as the information goes and the share of diesel has been growing. Gasoline use increased by 25% and diesel use by 38% from 1990 to 2007. Comparing this figure to Figure 1.2 reveals a correlation between the reduction of emissions and the goal of reducing dependency on fossil fuels.

In 2007 a new policy was published by the Ministry for Environment (Umhverfisráðuneytið) regarding action to reach set emission reduction targets. The targets for 2050 are to reduce the net emission of GHGs by 50-75% compared to 1990 levels with an emphasis on reaching the targets at the lowest possible cost by adopting new technologies, binding CO_2 and taking part in emission reduction projects in developing counties (Umhverfisráðuneytið, 2007).

Possible measures to reduce emissions from the Icelandic economy include ways of reducing the use of fossil fuels for example:

- continual use of incentives to invest in vehicles that emit less and that use fuel that releases less GHG. Incentives include temporary discount on public charges on vehicles using environment friendly technologies such as hybrids, electric, methane and hydrogen vehicles;

- government-owned companies to use environmentally-friendly vehicles as far as possible;
- providing the public with more information about emissions from vehicles and their effect on global warming;
- increased efforts to make cycling and public transport a real option (Umhverfisráðuneytið, 2007).

Scenarios may be developed to present the suggested solutions and what emissions could look like in the future. They are often used for groups of 2-5 possible developments in order to compare different solutions (Godet & Roubelat, 1996; Phelps, Chan & Kapsalis, 1998).

VEHICLES AND ENERGY CARRIERS

A wide range of vehicle technologies is available today, including those using traditional gasoline and diesel fuel but also electric vehicles and hybrids. A range of energy carriers have also been developed, for example biofuels such as biodiesel, and methane, hydrogen, methanol and ethanol. In Iceland the latter two have not yet been used to any significant degree.

Now presenting the energy carriers and technologies analyzed in the report. First, looking at the fuel and technologies that are used the most, g*asoline* and *diesel* are often referred to as traditional fuels since they have been the most commonly used vehicle fuels. In July 2005 taxation on diesel was changed in Iceland to encourage an increase in the use of diesel vehicles. The new law aimed to reduce the cost of diesel buses and trucks and to simplify the use of diesel passenger vehicles (Umhverfisráðuneytið, 2007).

Electric vehicles (EVs) have been on the market since 1834, when the first EV was invented. During the 1930s they almost vanished from the market, but their development started again during the energy crisis in the 1970s. The main obstacles to the rapid development of this technology over the years are considered to be low oil price and short driving distance (Chan, 1999). Since electricity in Iceland is generated by hydropower (72.9%) and geothermal power (27%) (Orkustofnun, 2009), as mentioned above, the use of electric vehicles is a very appealing option. The first electric vehicle was registered in Iceland in 1991 (Umferðastofa, 1992), and since then they have become increasingly popular.

Hybrid technology involves vehicles that use traditional fuel but in addition use the energy normally lost during braking to produce electricity, which is then used to partially or fully power the vehicle. This can save a significant amount of fuel and therefore reduce emissions during the service life of the vehicle. Hybrid vehicles vary from micro hybrids to full hybrids. In micro hybrids the electric motor does not provide driving power but aids, for example, in managing engine stop/start and can save 4-10% on fuel. Mild hybrid can assist with acceleration in addition to the functions provided by micro hybrids, providing fuel savings of 10-20%. In the full hybrid vehicle the electric motor and the engine can work either together or separately. The most common types of technologies used in such vehicle are parallel hybrid, series hybrid and power-split hybrids. The fuel use of a full hybrid vehicle can be 15-25% less than that of compatible vehicles using only traditional fuel (European Commission, 2008; London Borough of Camden, 2006).

Biodiesel, in the form of vegetable oil, was used as early as 1900, and the first diesel engine built was tested at the World Fair that year using peanut oil. Interest in biofuels can be traced back to the need for energy security when countries that produced oil-rich vegetables saw an opportunity in the fuel market. Used vegetable oil and animal fats are also used (Songstad et al., 2009).

Methane is often collected from waste disposal sites and used for district heating or electricity generation, since the release of methane has more effect on global warming then burning it and releasing carbon dioxide. Waste disposal regulations regarding Iceland's largest landfill make it necessary to collect and use the gas coming from it (Metan, 2010). Methane has therefore been collected and used for some time, and the decision to use it as fuel for the transportation sector was made on the basis that electricity is already supplied from domestic, environmentally-friendly resources and district heating is supplied from geothermal heat sources. The first vehicles using methane appeared in the year 2000, and since 2005 some of the buses and waste collection vehicles in Reykjavík have only used methane. Methane is attractive in Iceland because it aids both in the attempt to reduce GHG emission and reduce import of fossil fuels for the transportation sector (Metan, 2010).

Hydrogen has been tested and used as a fuel in Iceland for several years (Umferðastofa, 2010). The biggest obstacle to using it as an energy carrier in the transportation sector is that it is highly flammable and not easy to store either in the vehicle or at the service station. Hydrogen is currently also a very expensive option. However, a benefit to using hydrogen is that it releases energy by reacting with oxygen and returning water (H_2O) (Ásgeir Þorsteinsson, 2001).

Ethanol can be used on unmodified vehicles mixed with gasoline at 10-30% of the fuel volume (Bonnema et al., 1999). Ethanol, however, is not used extensively in Iceland yet.

Report Aim and Structure

Emissions from the Icelandic vehicle fleet make up a considerable proportion of the total emissions in Iceland or around 23%. Usually when fleet emissions are analyzed or measures to reduce emissions are suggested this is done only in the light of the vehicles' use phase and not for their whole life cycle (Brynhildur Davíðsdóttir, 2009; Fjármálaráðuneytið, 2008; Samgönguráðuneytið, 2009).

There are many possibilities when it comes to the future development of the Iceland's vehicle fleet. The mix of vehicles and fuel technologies best suited to reduce emissions and dependency on fossil fuel import cannot be determined without careful analysis of the situation today. The overall aim of this report is to assess the environmental burden of the Icelandic vehicle fleet from 1990 to 2010 and then to develop possible and necessary scenarios for the future development of the fleet. The results will be compared to Iceland's and international emission reduction targets. The focus in this report will be on existing technologies that could be used more extensively.

The past and current situation in the transport sector is analyzed from an environmental perspective because knowledge of the situation today and its development to date is very important when future emissions developments are to be estimated. It is also important to compare technologies with a consistent environmental assessment in which the whole life cycle of a product is taken into account and not only the emissions from its service life. Emissions from vehicles in use are substantial, but emissions from their production and end-of-life treatment are also a considerable part of overall vehicle emissions, especially where electric vehicles are concerned (Strømman, 2009).

A life cycle assessment (LCA) takes into account the total emissions directly and indirectly caused by the vehicle during its lifetime (Hertwich, 2005; Röder, 2001), meaning that the overall emissions are identified and not just those that are today accounted for in Iceland's emission inventory. LCA is therefore a good tool to use to estimate where emissions originate from and to discover the best path to take without problem shifting, that is solve one problem but in doing so creating another one (Strømman, 2009). The assessment method is widely recognized and is standardized by International Organization for Standardization (2006) (ISO). One of the challenges of using LCA is accepting that it only shows the situation as it is at that point in time with current production methods, usage and disposal (Röder, 2001).

LCA is used in this report to model emissions from the transportation sector in Iceland from 1990 to 2010 in order to understand what has the greatest effect on the overall emission of pollutants, in particular GHGs. When the past has been analyzed, possible future scenarios will be identified and examined in the light of Iceland's emission reduction targets for 2050.

The purposes of scenarios are to describe possible future developments and in this way to reduce surprise and broaden thinking about future possibilities (Phelps, Chan & Kapsalis, 2001). Even though scenarios do not give a glimpse into the future, it is helpful to know some of what the future holds (Zetner, 1982) in order to successfully evaluate possible action and estimate the potential result of measures already implemented (Hertwich, 2005). Scenarios have been explained by Godet and Roubelat (1996, p. 166) as:

> …a description of a future situation and the course of events which allows one to move forward from the original situation to the future situation.

According to Godet and Roubelat there are two main types of scenarios exploratory and anticipatory. The former is based on past trends and leads to a likely future, while the second is built on a different vision of the future which may be desirable or undesirable. There are many ways of developing scenarios (Godet & Roubelat 1996). Before developing a scenario it is important to gather information about the relevant parameters for development and to see if any of these are known or regularly forecasted by the government. Doing this reduces uncertainty in the scenario. If, however, there is no official information about the parameters they can be assumed to follow the development of other known parameters, for example population or economy growth, in similar proportions to past growth (Phelps, Chan & Kapsalis, 2001). It is also possible to forecast the development of the wanted parameter based on its past behavior.

Together the analysis of emissions from 1990 to 2010 and the possible future development of emissions from road transport in Iceland should aid in the attempt to reduce overall emissions from Icelandic society, bearing in mind that only when the results are used for real action, do the scenarios become meaningful (Godet & Roubelat, 1996).

Chapter 2 presents the theoretical model and the method used to calculate transport sector emissions, both historical and in the scenarios. LCA is explained in more detail along with advantages and disadvantages of using it.

Chapter 3 presents data. First, however, the segmentation used for the vehicle fleet is explained. Then the development of each vehicle segment is analyzed with respect to fleet renewal time, average age and increase in numbers. Fuel development is briefly presented with fuel consumption per vehicle per distance. Then the emissions from each segment are presented along with emission figures for each energy carrier that is and has been of importance in the Icelandic transport sector. After that the parameters used in the scenarios are presented and their development explained.

The results of the analysis are shown in Chapter 4. The development of the amount of emission over the years from each vehicle segment is presented as well as total emissions from the vehicle fleet in the different scenarios.

Chapter 5 discusses the model and its components, how it can be used and what can be built on it for further research. Official figures for emissions from vehicle fleet are compared to the results given in the previous chapter. The scenarios are discussed in the light of the country's action plan for the reduction of emissions from the road transport sector. Possible additional action is also introduced.

2 Model Description

In this chapter the model is defined along with all variables necessary to calculate emissions from the road transportation sector in Iceland. The chapter is divided into two parts with description of the historical and future model. In both parts all the variables are first listed with a short description. After that the method of calculation is shown step by step.

Historical Model Description

This part describes the historical development of the vehicle fleet from 1990 to 2010 by using historical data regarding the total number of vehicles of each types in the fleet, and the proportion of fuel within these types. Table 2.1 shows the variables with a short description of each that were used to calculate the emissions from Iceland's vehicles. To be clearer on how the vehicle fleet is divided down for a more accurate results Figure 2.1 shows how all vehicles in Iceland are divided down to type of vehicle (parameter b) and then each of those is divided down on fuel type (parameter f), which again is divided down to segments (parameter s).

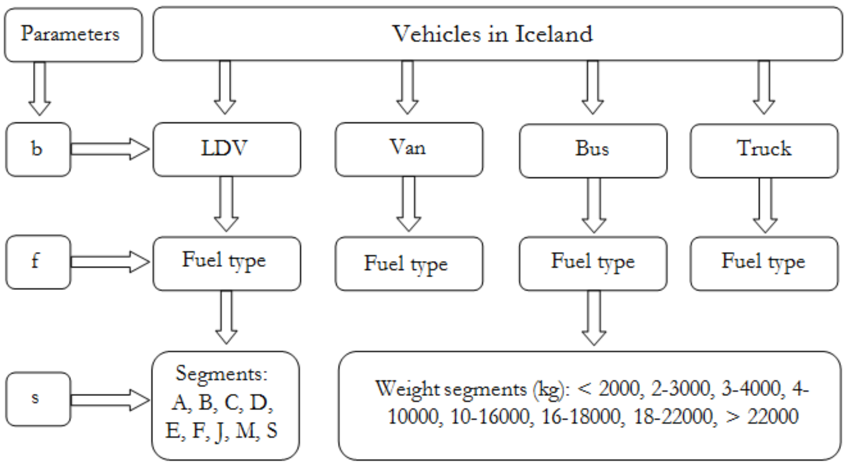

Figure 2.1: Aggregation of the Icelandic vehicle fleet by parameters *b* (type), *f* (fuel type) and *s* (segment)

The figure shows the parameters on the left side and the aggregation on the right hand side.

Table 2.1: Variables for the historical model used in calculating emissions from the Icelandic vehicle fleet

Variable	Description
t	Year
b	Vehicle type
s	Segment
f	Fuel Type
i	Impact category (GWP, AP, EP, POCP and ADP)
Θ_{bf}	Share of vehicles in each fuel type of the total of each type (b)
Θ_{bfs}	Share of vehicles in segments of each type (b), and fuel type (f)
e_{bs}	Emissions from segment per kg vehicle
e_{bf}	Emissions from fuel use per unit fuel
W_{tbs}	Average weight of segment at a given year
W_{tbs}^{T}	Segments total weight by year
U_{tbfs}	Use of vehicle by year, segment and fuel (distance)
F_{tbfs}	Vehicle fuel consumption of each segment at a given year
Q_{tbf}	Quantity of each type by fuel and year
Q_{tbfs}	Quantity of each segment in LDV and fuel type by year
E_{tbsi}^{CE}	Emissions from production and end of life treatment of a vehicle by year, segment and impact
E_{tbfsi}^{O}	Emissions from operation of a vehicle by year, segment and impact
$ALDV_t$	Light Duty Vehicles: Fleet age composition by year
$AOTH_t$	Other then LDV: Fleet age composition by year
S_i	Emissions per unit output needed for production by impact category
L	Output needed for production
y_s	Demand per average unit of mass of vehicle in segment s
y_f	Fuel demand per 100 km
p	Population

The method of calculation can be seen below. When LCA is performed the whole life cycle of the product is taken into account, from the exploration and extraction of the materials to the product's end of life (EoL) treatment after its useful lifetime. Emissions from a product are calculated in the following manner in LCA:

$$e_i = S \times L \times y \tag{1}$$

where *e* is emissions, *S* stressors; *L* is the material need to produce *y* units of the good. In this case the emissions from production and EoL as well as from fuel production and use were obtained from various sources and not calculated directly for each product. Physical information such as, vehicle weight and fuel consumption, was also needed in order to be able to calculate the overall emissions.

First the number of vehicles in each segment by fuel type and year is necessary in order to be able to multiply this by the average weight and find the total weight of the segments, as well as using the number of vehicles to find the total distance that each segment covers in a year (see Table 2.1: Variables for the historical model used in calculating emissions from the Icelandic vehicle fleet for the meaning of the symbols used). Note that a segment is an further aggregation of vehicle types and is explained in next chapter.

$$Q_{tbf} = \theta_{bf} \times Q_{tbf} \quad \forall tbf \tag{2}$$

$$Q_{tbfs} = \theta_{bs} \times Q_{tbf} \quad \forall tbfs \tag{3}$$

The second step was to find the total weight of each segment in each year, which was used in turn to find the emissions from vehicle production for a given year.

$$W_{tbs}^{T} = \sum_f W_{tbs} \times Q_{tsf} \quad \forall tbs \tag{4}$$

The emission calculations start in the third step. Knowing the total weight, fuel consumption and distance driven each year for each segment, the emissions can be calculated for the production from the y_{bs} which is demand for average unit of mass for each segment within a vehicle type (LDV, van, bus or truck).

$$e_{bs} = S \times L \times y_{bs} \quad \forall bs \tag{5}$$

In the same manner the emissions from the y_f demand for fuel per kilometer driven is calculated.

$$e_{bf} = S \times L \times y_{bf} \quad \forall bf \tag{6}$$

Next the total emissions are calculated starting with total emissions in each segment in order to see the contribution of each to overall emissions. Production and EoL emissions are calculated for each year by segment and impact category, which are explained in Chapter 2.1. In the formula *CE* represents the production and end-of-life phases of the life cycle.

$$E^{CE}_{tbsi} = e_{bsi} \times W^{T}_{tbs} \quad \forall tbsi \tag{7}$$

Next emissions from the operation phase of the life cycle are calculated for every year by segment, fuel consumption and impact category:

$$E^{O}_{tbfsi} = e_{fi} \times U_{tbfs} \times F_{tbs} \times Q_{tbfs} \quad \forall tbfsi \tag{8}$$

The objective of this first part of the model is to visualize the emissions from the goods and passenger transport sector in Iceland from the year 1990 to 2010, broken down into fuel consumption and production and EoL treatment for the relevant impact categories.

Future Model Description

This part focuses on the possible future increase of emissions due to development of the vehicle fleet. First, further variables are listed in Table 2.2 and then they are used in order to find changes over time in the variables listed previously. The variables in Table 2.1 are still valid. After listing the new variables the calculations are described step by step and possible scenarios for the years 2011-2050 are found. The following variables were added to calculations for the future model in order to visualize changes over time.

Table 2.2: Additional variables used to describe changes over time in the Icelandic vehicle fleet and its emissions

Variable	Description
$V_{bp\ final}$	Vehicle per person for each type at year 2050 (final year)
$\Theta_{bf\ final}$	Share of vehicle fuel type in total quantity at year 2050
$\Theta_{bfs\ final}$	Share of vehicle segment in each fuel type at year 2050
$\Theta_{f\ final}$	Final fuel consumption percentage share at year 2050
$U_{b\ final}$	Final use of vehicle by at year 2050 segment and fuel
n	Number of years changes are calculated for (40 years)

The first step of the second part of the model determines the total number of vehicles, which are then be broken down based on fuel type and then on vehicle segment/weight. The number is calculated from the official forecast of population development (Hagstofa, 2011b) and past development in number vehicles per person in Iceland. The latter is calculated according to Equation 11 in which the total number of each vehicle type is divided by the size of the population:

$$V_{bt} = Q_{bt}/p_t \quad \forall bt \tag{9}$$

The change in number of vehicles per person is calculated as follows:

$$\Delta V_b = (V_{b2010} - V_{b\,final})/n \quad \forall b \tag{10}$$

The result from equation (12) can then be used to calculate the total number of vehicles from year 2010 to the final year 2050:

$$Q_{tb} = \left(V_{(bt-1)} - \Delta V_b\right) \times p_t \quad \forall b, t = 2011 - 2050 \tag{11}$$

Next the divisions between the different fuel categories are determined with a similar method in which the change in proportion of fuel types between the years is calculated and then subtracted from the share in 2010 to know the share in 2011. This is then carried out for all years from 2011 to 2050.

$$\Delta\theta_{bf} = (\theta_{bf\,final} - \theta_{bft})/n \quad \forall bf, t = 2010 \tag{12}$$

Equation 12 shows how the fuel share change from year to year is calculated; the result is then used to determine the yearly fuel share of the total number of vehicles in each fuel type.

$$\theta_{tbf} = \theta_{t-1} - \Delta\theta_{bf} \quad \forall bf, t = 2011 - 2050 \tag{13}$$

The next step is to find the segment share of the total vehicle number of each fuel type so the vehicles can be broken down into segments after the fuel type has been determined.

$$\Delta\theta_{bfs} = (\theta_{bfs\,final} - \theta_{bfst})/n \quad \forall bf, t = 2010 \tag{14}$$

$$\theta_{tbfs} = \theta_{t-1} - \Delta\theta_{bfs} \quad \forall bf, t = 2011 - 2050 \tag{15}$$

It should be noted here that the result is a 3-D matrix in which the axes show the fuel share of the total number of vehicles within each type, the segment share of each fuel type and the year. When the total quantity is known as well as the fuel and segment/weight share of the total the number of vehicles in each can be determined. First the number of vehicles in each fuel type is calculated:

$$Q_{tbf} = \theta_{tbf} \times Q_{tb} \quad \forall bs, t = 2011 - 2050 \tag{16}$$

Then that result is used to calculate the number of vehicles in each segment within that fuel type:

$$Q_{tbfs} = \theta_{tbfs} \times Q_{tbf} \quad \forall bsf, t = 2011 - 2050 \tag{17}$$

It is now possible to calculate the total weight of each segment within fuel types as well as the total weight of each fuel type. Since the impacts of electric and hybrid electric vehicles are calculated outside the segments, these need to be summed up and calculated separately.

$$W_{tbfs}^{T} = \sum_{f} W_{ts} \times Q_{tbsf} \quad \forall bsf, t = 2011 - 2050 \tag{18}$$

From the weight the impact from the production, EoL treatment can be calculated according to equation 19 and onwards for the years 2011 to 2050.

$$E_{tbsi}^{CE} = e_{bsi} \times W_{tbfs}^{T} \quad \forall tbfsi \tag{19}$$

The calculations in this part have so far focused on emissions from production and EoL treatment. Next are calculations of emissions from the use of the vehicles. The first step is to calculate the emissions per kilometer where the fuel use per kilometer changes over time because of increased engine efficiency for years 2010 to 2050.

$$\Delta y_{bfs} = \left(f_{bfs} \times \theta_{f\,final}\right)/n \quad \forall bfs \tag{20}$$

The result is used to find the fuel use in years 2011 to 2050 by taking information about fuel use per kilometer from the year before, subtracting the fuel use change per year from that to get the fuel use for the current year.

$$e_{tbf} = S \times L \times (y_{bfs,t-1} - \Delta y_{bfs}) \quad \forall bf, t = 2011 - 2050 \tag{21}$$

Equation 21 represents emissions per kilometer driven for each fuel type, with demand for fuel represented by the result in the brackets. The distance change over time is then needed in order to calculate the distance driven by each vehicle segment in each year.

$$\Delta U_{bfs} = (U_{bfs\,final} - U_{bfst})/n \quad \forall bf, t = 2010 \tag{22}$$

$$U_{tbfs} = U_{bfs,t-1} - \Delta U_{bfs} \quad \forall bs, t = 2011 - 2050 \tag{23}$$

Now all the variables needed to calculate the emissions from operation of the vehicle so the emissions from operation for each year, vehicle type, fuel and segment can be shown for each impact category.

$$E_{tbsfi}^{O} = e_{bfi} \times U_{tbfs} \times F_{tbs} \times Q_{tbfs} \quad \forall bfsi, t = 2011 - 2050 \tag{24}$$

The two parts are then put together to form a visual representation of the emissions from 1990 to 2050. The last calculation sums up all segments in equations that represent emissions during operation, production and EoL and add them together to show total emissions from all Icelandic vehicles throughout their entire life cycle. To show the operation emissions for each year for all impact categories, first sum up emissions for all segments and fuel types for all types of vehicle: that is, LDVs, vans, buses and trucks. Note that the years in this equation are 1990 to 2050.

$$E_{ti}^{TO} = \sum_{bsf} E_{tbfsi}^{O} \quad \forall tbfsi \qquad (25)$$

The emissions caused by production and EoL treatment are added together for each segment to find the overall emissions from production for each year.

$$E_{ti}^{TCE} = \sum_{bs} E_{tbsi}^{CE} \quad \forall tbi \qquad (26)$$

Finally, these last two equations added together represent the overall emissions in each year from all impact categories:

$$E_{ti}^{T} = E_{ti}^{CE} + E_{ti}^{O} \quad \forall ti \qquad (27)$$

These formulas can be used many different ways in order to show different aspects of the life cycle or of a fuel or segment. It is possible to see all years, for example, summed up, but with emissions in total from each segment, or to see the emissions from fuel use divided by sectors or fuel type as well as many other possibilities. The impact categories are the following:

- global warming potential (GWP) measured in CO_2 equivalents.
- acidification potential (AP) measured in SO_2 equivalents.
- eutrophication potential (EP) measured in phosphate equivalents.
- photochemical ozone creation potential (POCP) measured in ethane equivalents.
- abiotic depletion potential (ADP) measured in antimony (Sb) equivalents (Ford, 2007).

3 APPLICATION

The transportation sector in Iceland has the potential to reduce GHG emissions from the Icelandic economy and significant potential to reduce household emissions. In order to do so some measures have been put in place to encourage the use of alternative fuels, for example by the reduction of annual fees for those vehicles and taxes on new vehicles running on alternative fuels. However, to confirm which measures are most likely to reduce emissions it is necessary to look at the emissions released by the road transport sector throughout the whole life-time of the vehicles. In this chapter the vehicle fleet is presented along with emissions per vehicle kilogram and per fuel unit. The vehicle fleet is first aggregated in order to represent the most realistic possible size and weight of the vehicles and their fuel consumption. Then the fuel consumption is shown and finally the emission figures for each segment are presented along with fuel emission figures. All this information is then used to find the overall emissions from goods and passenger road transport in Iceland from 1990 to 2010. After the past and present developments of the vehicle fleet have been identified the variables used to build the scenarios are presented and justified.

Information about vehicle fuel type and the number of each type of vehicle (LDV, van, bus and truck) registered in Iceland, as well as age distribution by year, are from Umferðastofa (2010-2011), the institute in Iceland that handles vehicular administration such as regulations, vehicle registration, driving licenses, casualty listings and more.

VEHICLE SEGMENTATION

To be able to represent Iceland's vehicle fleet it was considered important to take all the types of vehicles registered in Iceland into account. First the fleet was divided into categories based on type of vehicle, i.e. LDV, van, bus and transportation truck (see parameter b in Chapter 2). Other vehicles were not taken into account since they are mainly heavy machinery and leisure vehicles (motor homes).

It became clear early in the project that the LDV fleet in Iceland needed further segmentation. It includes a very wide range of vehicle types that would not be properly represented in the LCA unless they were divided into segments and LCA data found for each segment to properly represent them.

There are many possibilities when it comes to segmenting the vehicle fleet. In Iceland segmentation has been used in the past to aggregate the LDV fleet for insurance purposes. The segmentation divides the vehicles into six segments based on the number of seats and doors and the division between passengers and cargo. This method of segmentation was not considered useful for this report because each segment includes a wide variety of weights and engine sizes and these factors are of importance to represent each segment and thereby, the fleet properly (Umferðastofa, 2010-2011).

The European Commission (1999) uses nine segments based on criteria such as engine size and length of the car for market segmentation: however, a final definition has not been established in Europe leaving room for manufacturers and others to define the segments themselves. The dividing lines between the segments are therefore blurred, and factors such as image, price, the presence of airbags, central locking etc. affect what segment a car falls into.

Therefore the classification used by the European Commission (Council Regulation, 1999) was used for this report. In order to clarify the divisions each segment is described briefly below. The following table shows the segments and their definitions, which is based on image (parameter s, as defined in Chapter 2).

Table 3.1: European Commission unofficial vehicle segments and their description

Segment	Description
A-Segment	Mini and city cars
B-Segment	Small cars
C-Segment	Medium cars
D-Segment	Large cars
E-Segment	Executive cars/Full-size cars
F-Segment	Luxury cars
J-Segment	Sport Utility Vehicle, including off-road vehicles
M-Segment	Multi Purpose Vehicle (MPV)
S-Segment	Sport coupés

The Internet (Google, 2010) was used to determine which segment vehicles of each type (LDVs, vans, buses and trucks) are usually put in. Pictures were also used to decide what segment was appropriate. The majority of the vehicles were found with this method; however, the data had some inconsistencies in spelling and inadequate information about model names and manufacturers' names which were resolved by comparing the vehicles' weight range and power, and the segment assumed from that. Vehicles weighing over 4000 kg were not considered to belong to the LDV segment, as driving them requires additional driver training.

After segmenting all the vehicles the results were checked against a bus statistics to see if number of buses fitted (Umferðastofa, 2010-2011) and also randomly. The overall number of such vehicles was also checked with the statistics already known for year 2009 (Umferðastofa, 2010-211). From this it was found that there was a small error in the number of vehicles in the LDV category, as some should have been in the van category. Despite this knowledge the error could not be properly fixed, mainly because each year an adjustment is made after the January 1st and the data are from the two different dates: that is, the vehicle segmentation data are from the 31st of December 2009 and the total, correctly adjusted, data are from February/March 2010.

Next the average weight of the LDV fleet (parameter W_{tbs}) per segment was found by finding the weight of the most common vehicles in each segment which account for at least 50% of the total number of vehicles in that particular segment. However, in some cases due to limited information regarding subtype it became necessary to assume the weight closest to the mean weight. The weight of the vehicles was mostly retrieved from Carfolio.com (2010). Difficulty in finding the weights for individual segments varied considerably mainly because some of the segments did not seem to be dominated by few models but rather had an even distribution across all models. This applied mainly to segments S (sports vehicles) and F (luxury vehicles), as could be expected because of their aim is to be unique. However, segments C and J have a few more dominant models which can be explained by word of mouth recommendation of their reliability and other desirable aspects. The average weight and share (parameter Θ_{bs}) of the total fleet is shown in Table 3.2.

Table 3.2: Percentage share of each segment of the LDV fleet in Iceland and the segments average weight

Passenger vehicles	Share	Avarage weight
A-segment	0.7 %	883
B-segment	11.4 %	1 009
C-segment	27.3 %	1 224
D-segment	13.5 %	1 393
E-segment	3.0 %	1 512
F-segment	2.5 %	1 760
J-segment	0.0 %	1 800
M-segment	6.4 %	731
S-segment	1.0 %	1 361

Source: Umferðastofa (2010).

The heaviest segment is J (SUVs) which makes up 34% of the total LDV fleet and is the largest segment. Segment C is also quite large at 27%, and together these two represent 61.5% of the LDV fleet. The smallest segment is A at only 0.7% which is probably due to long distances and small cities where larger vehicles are a better option.

It is necessary to know the average weight of each segment in order to find the overall weight of the fleet. Change in segment share, described in formula 14 in Chapter 2, can affect the overall weight of the vehicle fleet, and it is people's choice of vehicle that controls that change. An increase in the number of SUVs in Iceland is a real possibility. For example, in 1996 the sale of jeeps increased by 45%, involving the importation of 1188 large vehicles that year (Morgunblaðið, 1996). In 2000 sales of vehicles decreased, but the sale of jeeps decreased by only 2.8% while smaller vehicle sales decreased by 10.1%. Around 3385 jeeps were bought that year compared to 3484 the year before (Morgunblaðið, 2000)

Finding the average weight and number of vans, buses and transportation trucks required more assumptions then finding the same for the LDV fleet. The weight is given in a range, as shown in the first column of Table 3.3 (part of parameter s as defined in Chapter 2) and then parameter Θ_{bs}, share of each weight range of total number of was known. The weight of each segment here is assumed to be closer to the higher range of the segment numbers which is shown in brackets behind the range to the left in the table (parameter W_{ts} in Chapter 2).

Table 3.3: Percentage share of each weight class of total number of commercial vehicles by type

	Trucks	Busses	Vans
< 2 (2000)	0 %	0 %	4 %
2-3000 kg (3000)	4 %	3 %	54 %
3-4000 kg (4000)	3 %	6 %	22 %
4-10000 kg (8000)	19 %	38 %	19 %
10-16000 kg (14000)	14 %	23 %	1 %
16-18000 kg (17000)	19 %	26 %	0 %
18-22000 kg (20000)	5 %	3 %	0 %
> 22000 kg (25000)	37 %	1 %	0 %

Source: The table is based on information from Alþingi (1994)

As can be seen in the table, trucks weighing over 22,000 kg represent the largest share of vehicles. According to information from Umferðastofu (2010-2011) many vehicles weigh well above 22,000 kg, and therefore the average weight of that range was assumed to be around the mean of all weighing more than 22,000 kg at 25,000 kg. The average weight of transportation trucks in Iceland is therefore assumed to be 17036 kg.

The largest share of buses falls in the weight category 4000-10,000 kg, or 38%. Buses weighing 10,000-18,000 kg (two weight categories) representing 49% of buses by weight. The average weight of this segment is 11798 kg.

Vans are generally lighter then both buses and trucks, and 54% of vans are between 2000 and 3000 kg in weight. In total only 20% of the fleet weighs more than 4000 kg, which still increases the average weight of the segment to 4266 kg.

HISTORICAL VEHICLE FLEET DEVELOPMENT

When looking at the development of road transportation the change in the number of vehicles change over the years is one of the most important variables, but factors such as the age of the vehicles, fleet composition, fuel consumption and distance driven can also affect overall emissions. The development of number of registered vehicles in Iceland is presented in Figure 3.1, with the vehicles broken down into types and the LDVs broken down on segments are divided down into segments.

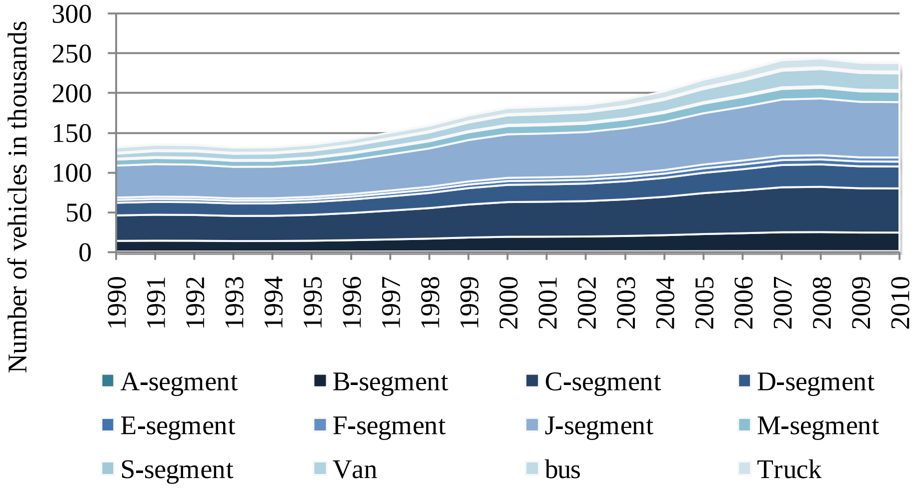

Figure 3.1: Number of registered vehicles broken down into types and LDVs segments 1990 to 2010

Figure 3.1 shows that the overall number increases from 1990 to 2008, when it reaches a high and levels out. The largest absolute increase is in the LDV category, with segments B and J increasing the most. After 2008 the share of trucks slightly reduces while the share of vans increases. The increase in total number of vehicles from 1990 to 2010 is 105,802 vehicles or 80%. Looking at the individual types of vehicles the LDVs and trucks increase the least at 73% and 50% respectively. The biggest increase is in the number of vans, at 237%, while buses increased by 109%. This total increase in vehicle numbers is important in the light of population development. It is interesting to look at the development of vehicles per 1000 inhabitants where the increase in car ownership is also clear, as shown in Figure 3.2.

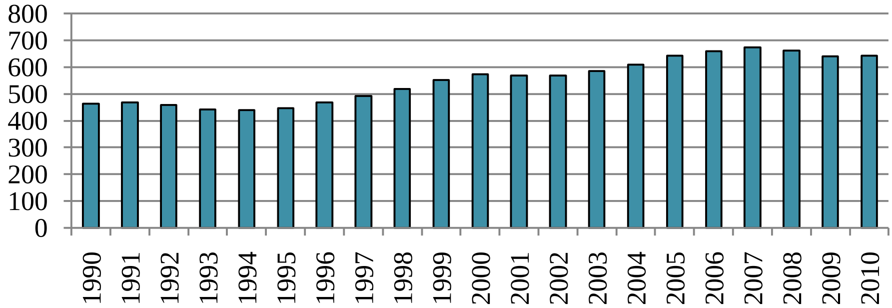

Figure 3.2: Number of LDVs per 1000 inhabitants in Iceland
Source: Hagstofa Íslands (2011b) and Umferðastofa (2010-2011)

Figure 3.2 shows the increase in personal vehicles per 1000 inhabitants, but with the increased number of vehicles the distance driven per vehicle (parameter U_{tbfs}) has dropped from around 13.300 km/year in 1994 to around 12.200 km/year in 1999 (Hreinn Haraldsson, 2001). This can simply be explained by assuming that the overall distance covered by each household has increased, but since many now have two or more vehicles these share fulfillment of the household's needs for transportation which reduces the average number of kilometers that each vehicle is driven per year.

To determine emissions from the year 1990 to 2010 the fraction of each segment in each fuel type in 2009 is assumed to correspond to the composition of the fleet preceding years. However, fleet composition is not the only factor that can affect emissions. The age of the vehicles in use is considered important because of the potential increase in efficiency in newer models (Natural Resources Canada, 2007). Therefore the renewal rate is important as well as the age of the vehicles. In this chapter this is considered more closely.

It is important to visualize the age distribution of the vehicles and how this has changed over the last decade in order to arrive at the renewal rate of the fleet. In Figure 3.3 the distribution in age of LDVs is shown in absolute numbers.

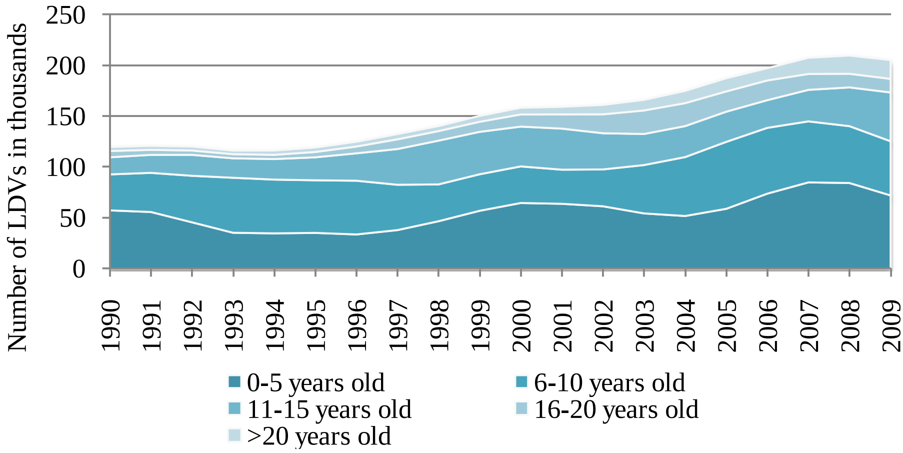

Figure 3.3 Number of LDVs in thousands in Iceland broken down on age, Parameter $ALDV_t$ in Chapter 2

It is clear from Figure 3.3 that the LDV fleet has grown over the last two decades to reach a peak in 2008, which may be explained by the financial crisis that started in the fall of 2008 when three of the major banks in Iceland collapsed (Capell, 2008). In order to analyze the fleet thoroughly it is useful to look at the change in the number of vehicles in each age group over the years and the relative changes in the age of the fleet. New vehicles (0-5 years old) seem to have entered the LDV fleet at a fairly regular interval, peaking around 1990, 2000 and 2007/2008. Despite these small peaks this group forms a fairly stable proportion of the fleet at 30-40% of the total. Vehicles up to 10 years old make up the biggest part of the fleet, usually at around 60-78% of the total. The percentage of vehicles older than 20 years is small but has increased from 3% in the 1990 to 9% in 2009. From this the conclusion could be drawn that the lifetime of an LDV in Iceland is most commonly under 20 years, with most such vehicles leaving the fleet when 11-15 years old. For the purpose of this report the lifetime of LDV vehicles is considered to be 15 years.

According to the 2007 Canadian Vehicle Survey the fuel consumption of vehicles 15 years old or older is approximately 10% more than that of vehicles under 3 years old (Natural Resources Canada, 2007). Bearing in mind that vehicles seem to leave the Icelandic fleet at 11 to 15 years old and those in the age category 0-5 years form 30-40% of the fleet, it is assumed that this increase is negligible in the historical model. When looking further into the future, however, the change in fuel consumption is taken into account as development in fuel consumption over the longer periods is important (parameter $\Theta_{f\,final}$ in scenario model).

The LDV fleet composition by fuel type is shown in Figure 3.4 (parameter Q_{tbf} in Chapter 2) and it is clear that gasoline has been the dominant fuel type, followed by diesel. The number of diesel vehicles has been increasing: whereas in 1990 the diesel vehicles made up 5% of the fleet this has grown steadily and in 2009 had risen to 18%. The increase may be due to a change in the law on diesel taxation in 2005 (Fjármálaráðuneytið, 2008).

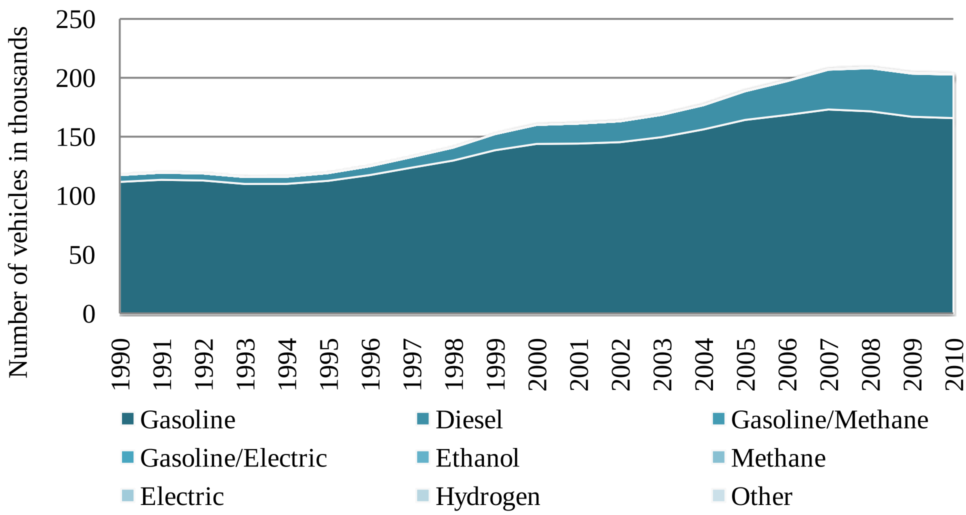

Figure 3.4: Icelandic LDV fleet composition by fuel type shown in thousands of vehicles 1990-2010
Source: Umferðastofa (2010)

The division and development of alternative fuel driven vehicles are not clear in this figure as the overall share of alternative energy carriers and the use of newer vehicle technology do not represent a significant share of the LDV fleet today. The number of alternative fuel-driven vehicles has increased rapidly since 2003, even though today they make up less than 1% of the fleet. It should be noted that the average weight was assumed to be the same for all vehicle types and fuel types as weight within segments does not vary greatly.

The number of vans in the Iceland's vehicle fleet has been rising steadily over the years, as can be seen in Figure 3.5. The proportion of alternative energy carriers and fuel cell (FC) vehicles in this category is quite small.

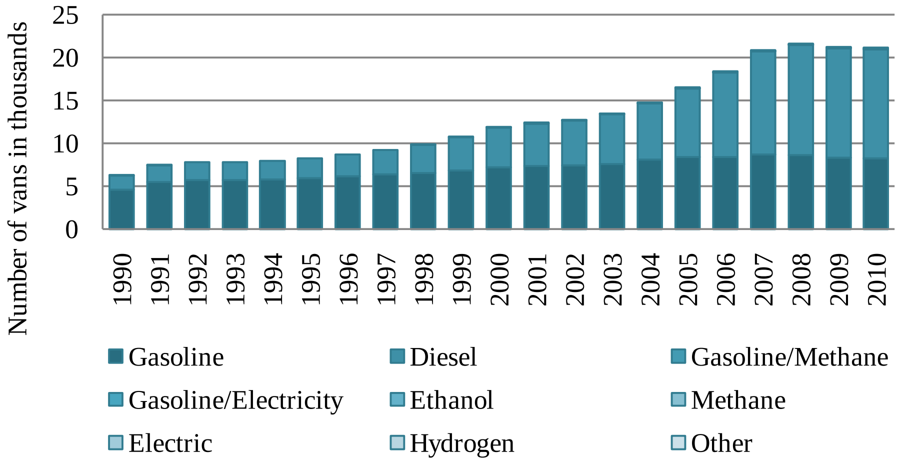

Figure 3.5: Number of vans in Iceland by fuel type (parameter Q_{btf}), 1990-2010
Source: Umferðastofa (2010)

Figure 3.5 shows that diesel vehicles make up the majority of vehicles in Iceland today and that their numbers have been increasing more than those of gasoline vehicles. There has also been a noticeable increase in the number of vans running on alternative energy carriers; even though these do not occupy a large enough share to be registered in the figure. However, even though the proportion of alternative fuel is small the increase in quantity has been significant in the last years. Methane is the fuel of choice, which can be explained by regulations, introduced that required landfill companies to collect and use the gas from the landfills. In 2007 alone, 23 methane vehicles were registered. In 2007 too, registrations peaked with over 3000 new registered vans.

Similar trends exist in the bus segment, with the total number of vehicles increasing over the years but only two buses run on methane and three on hydrogen. The registration of buses seems to have reached its peak in 2005 and has been gradually slowing since. Figure 3.6 shows this development.

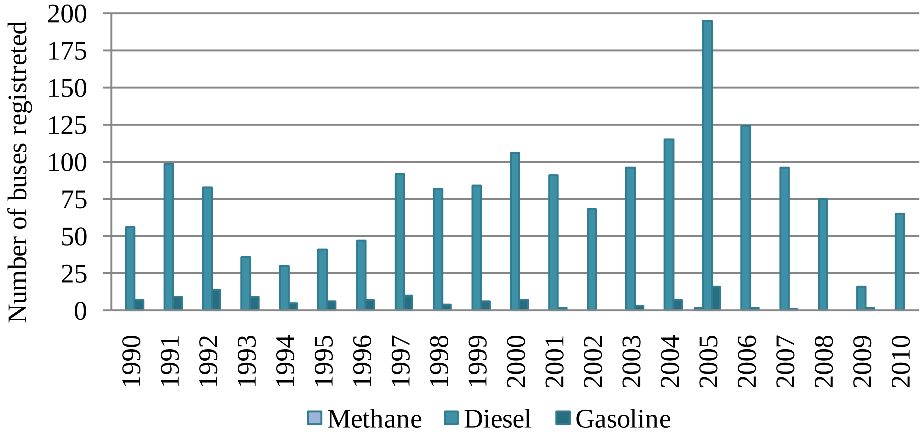

Figure 3.6: Newly registered new buses in Iceland sorted by fuel type 1990-2010
Source: Umferðastofa, 2010-2011

Figure 3.6 also shows that buses running on diesel are the most common and have made up about 90% of the fleet since 1990 (Umferðastofa, 2010-2011). The first hydrogen buses were put to use in 2003 and methane buses have been in use since 2005.

The truck segment covers such a large range of vehicles that is difficult to find one type to represent them. This is due to their size and weight range, but also mostly to the wide range of usage. This segment ranges from light duty trucks such as those used to transport goods between stores in a city to long distance transportation lorries and waste collection vehicles. There are 13 trucks running on methane, more than the methane fuelled buses. Figure 3.7 shows the overall development in the number of trucks registered by year.

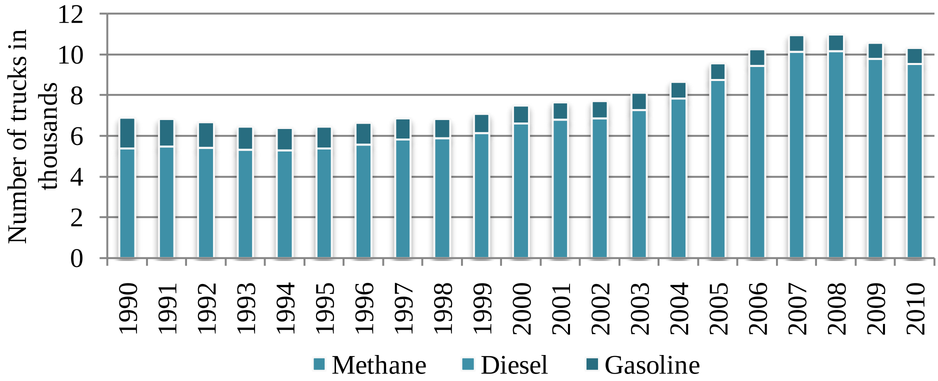

Figure 3.7: Number of trucks registered in Iceland by fuel type (parameter Q_{btf}), 1990-2010
Source: Umferðastofa, 2010

The trucks running on methane are not visible because they form such a small proportion of the total trucks registered. Road transport in general has been increasing since 1995 which may be explained by the reduction in sea transport along the coast of Iceland (Þorkell Helgason, 2005), thus contributing to the increase in the number of trucks on the road.

Service Life: Distance and Fuel Consumption

Over the years vehicles have been developed to use increasingly less fuel per kilometer driven and therefore the renewal of the vehicle fleet plays an important role in reducing its yearly emissions in the service of transporting people and goods. As explained, earlier the lifetime of a vehicle in Iceland is considered to be 15 years, consistent with the average lifetime of personal vehicles in Europe (Félag íslenskra bifreiðaeiganda, 2010). Therefore an important aspect of annual emissions from road transport is the distance driven per year. Table 3.4 shows average distance driven per year broken down into each type of vehicle. As Table 3.4 shows, commercial vehicles are driven further than personal ones. Buses and trucks respectively cover up to 3 and 4 times the distance that personal vehicles travel. This is understandable, since buses and trucks follow a schedule and serve more than one person or a single household at a time.

Table 3.4: Average kilometers driven per year in Iceland 2006-2008 by type (parameter U_{ts})

Distance	Average [km/year]
LDV	11,803
Van	14,723
Bus	32,797
Truck	37,485

Source: Umferðastofa, 2010 (passenger vehicles and vans); Þorvaldur H. Auðunsson & Gestur Pétursson, 2005 (buses and trucks)

The distance driven per vehicle has changed since 1990 and as the distance driven is unknown the figures needed some adjustment so that the fuel consumption in this sector would match those reported by Orkustofnun (2011).

In order to also include emissions from the use of fuel throughout vehicles' service lives it is necessary to find the average fuel consumption per kilometer, and from that to calculate the emissions per year. Table 3.5 shows fuel consumption per 100 kilometers driven (parameter F_{tsf} in Chapter 2). Starting from the left in Table 3.5, figures for gasoline and diesel consumption by LDVs and the vehicles' weights were found on Carfolio.com (2010) and in Orkusetur (2010). The consumption of the larger vehicles (Alþingi, 1994) was scaled appropriately according to weight. Types of fuel not found were calculated using their energy content compared to other fuels. Methane consumption was found by comparing gasoline energy content to the energy content in compressed methane, same method was used for electricity (U.S. Department of Energy, 2010). Hybrid electric vehicles' fuel consumption is between 4% and 25% less than that of conventional vehicles per 100 km (Þorvaldur H. Auðunsson & Gestur Pétursson, 2005) and in this report is set to 15%.

Table 3.5: Fuel use per 100 km by vehicle type and weight

Fuel usage per 100 km	Gasoline [l]	Hybrid [l]	Diesel [l]	Methane [kg]	Electricity [kWh]	Hydrogen [kg]
Truck <2 ton	11.3	9.6	10.0	15.3	99.8	1.3
Truck 2-3 ton	13.6	11.5	12.0	18.4	119.8	1.6
Truck 3-4 ton	15.8	13.4	14.0	21.4	139.8	1.8
Truck 4-10 ton	22.6	19.2	20.0	30.6	199.7	2.6
Truck 10-16 ton	31.6	26.9	28.0	42.9	279.6	3.7
Truck 16-18 ton	39.6	33.6	35.0	53.6	349.5	4.6
Truck 18-22 ton	42.9	36.5	38.0	58.2	379.4	5.0
Truck >22 ton	50.9	43.2	45.0	68.9	449.3	5.9
Bus 16-17 ton	41.8	35.5	37.0	56.6	369.4	4.9
Van 1500 kg	9.0	7.7	8.0	12.2	79.9	1.1
Van 2500 kg	15.8	13.4	14.0	21.4	139.8	1.8
A-segment	5.5	4.6	4.5	7.4	48.3	0.6
B-segment	6.2	5.3	4.6	8.4	54.9	0.6
C-segment	6.7	5.7	5.7	9.1	59.3	0.7
D-segment	8.5	7.3	6.5	11.6	75.5	0.9
E-segment	10.0	8.5	8.3	13.5	87.9	1.1
F-segment	10.8	9.2	9.5	14.6	95.4	1.2
J-segment	12.9	11.0	11.4	17.5	114.3	1.5
M-segment	7.7	6.5	6.8	10.4	68.0	0.9
S-segment	10.5	8.9	9.3	14.2	92.4	1.2

Source: Alþingi, 1994; U.S. Department of Energy, 2010; Þorvaldur H. Auðunsson & Gestur Pétursson, 2005; Jón. B. Skúlason, 2001

The gasoline/methane category, which is not shown, was assumed to drive half of the distance on gasoline and half on methane. Hydrogen use was found using a conversion rate from gasoline to hydrogen (Jón. B. Skúlason, 2001).

Scenario Building

Now that the model for the past and present situations has been explained, future developments are considered. There are three scenarios, the reference scenario, the green scenario and a target scenario. The reference scenario describes the development of the vehicle fleet and its use if no special measures are taken to support a change and past trends control the direction of the development. Basically this indicates that change is slow and limited. The green scenario involves more aggressive measures to encourage change in the use of vehicles and in the type of new vehicles entering the fleet, with the emphasis on reducing the number of gasoline vehicles and increasing that of electric vehicles. The target scenario illustrates a possible path that emissions from road transportation could follow when very aggressive policy changes are implemented in order to reach a 30% reduction in emissions by 2050. This target was set as a compromise between the 15 and 50% emission reductions estimated by the EU. The target scenario should fully show the challenges that lie ahead.

There are many parameters in this report. Each parameter for each scenario is explained and presented below, along with the initial value of the parameter for comparison. The first task is to determine the change in numbers of Iceland's vehicles using the population development forecast for Iceland (Hagstofa, 2011a). The official population development (parameter p) forecast is shown in Figure 3.8 with low, medium and high scenarios (Hagstofa, 2011a).

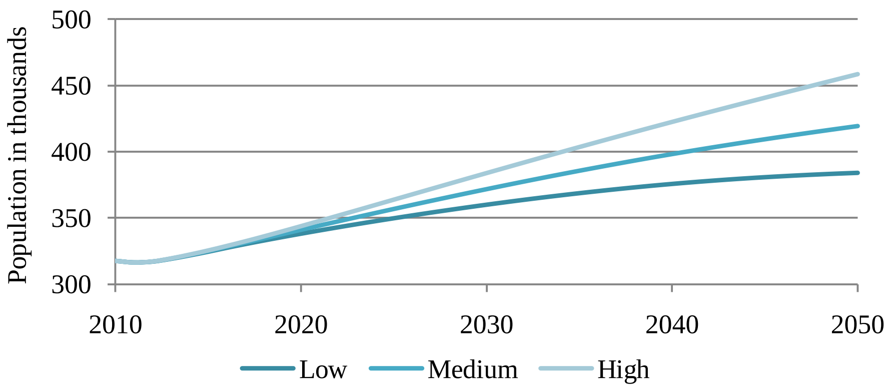

Figure 3.8: Population development scenarios in Iceland in thousands inhabitants 2010-2050
Source: Hagstofa (2011a)

Figure 3.8 shows considerable differences between the population development scenarios. At year 2050 the difference between highest and lowest scenarios is approximately 75,000 inhabitants, with the highest scenario 19% increase on the lowest. For comparison, the total increase from 2010 to 2050 in the lowest scenario is 21%, in the medium 32% and in the highest 44%. The medium population growth scenario was regarded as capturing the actual development from 2010 best in the light of the financial crisis in 2007, which caused increased migration to other countries. The actual population figures for past years (Hagstofa, 2011a) are used to determine the number of vehicles per person from 1990 to 2010.

According to *Europe's Environment: The Fourth Assessment* (2007), in 2050 the rate of vehicle ownership in the world will be around 570 vehicles per 1000 inhabitants. In Iceland in 2010 the rate of ownership of LDVs was already approximately 642 vehicles per 1000 inhabitants, as shown in Table 3.6 (Hagstofa, 2010; Umferðastofa, 2010), making Iceland one of the top vehicle-owning countries in the world (Pentland, 2008). In the light of predicted world development the number of vehicles per person is not expected to change drastically in the reference scenario, where it stabilizes at 660 vehicles per 1000 inhabitants. In the green scenario it is considered more likely that a reduction to 600 vehicles per 1000 inhabitants will come about due to greater public awareness. In the target scenario this parameter was changed drastically since it was necessary to do so in order to reach the emission target. The parameter is therefore set to 350 vehicles per 1000 inhabitants.

Table 3.6: Number of vehicles per person in Iceland in 2010 and in the scenarios by 2050 (parameter $V_{bp\ final}$)

Vehicles per person	2010	Reference	Green	Target
LDV	0.64	0.66	0.6	0.35
Van	0.0664	0.075	0.075	0.05
Bus	0.0073	0.009	0.009	0.001
Truck	0.0326	0.036	0.0326	0.026

The first parameter, the future number of all types of vehicles per person, is shown in Table 3.6. The situation today is shown in the first column while the other columns show the situation at year 2050 for each scenario. The parameter for vehicles per person for each year is calculated by subtracting the value at 2050 from the value today and dividing by the total number of years. This is then added to the vehicles per person for each year from the year 2010. The parameter can now be used along with population scenarios to determine the number of vehicles registered in the years 2011 to 2050.

In both the reference and green scenario, the number of commercial vehicles is expected to grow slowly along with the population because it is possible that with better management in firms and by drivers, such vehicles can be used more efficiently. As can be seen in the table, vans are expected to develop as in the reference and green scenarios, while in the target scenario their numbers drop from 66 to 50 per 1000 inhabitants. The number of buses increases in all scenarios from 7 to 9 per 1000 inhabitants. Truck numbers, however, increase in the reference scenario while they stabilize in the green scenario and decrease by 11% in the target scenario, compared to 2010. The reason for this drop in trucks is that it is considered necessary in order to reach the reduction target by 2050.

The next parameter is the proportion of vehicles using each fuel type in the total fleet. The decision regarding the composition of fuel use in the fleet for the reference scenario is based on the current trend and policies in Iceland (Fjármálaráðuneytið, 2008). Table 3.7 shows the trends considered likely and necessary for LDV vehicles in the different scenarios.

Table 3.7: Percentages share of the different fuel types of total number of LDVs in Iceland in 2010 and for the scenarios by 2050 (parameter $\Theta_{bf\ final}$)

Fuel share of total quantity	2010	Reference	Green	Target
Other	0%	0%	0%	0%
Gasoline	82%	64%	20%	3%
Hybrid (gasoline and methane)	0%	0%	0%	0%
Hybrid Electric	0%	10%	35%	35%
Diesel	18%	20%	15%	2%
Ethanol	0%	0%	0%	0%
Methane	0%	1%	0%	0%
Electric	0%	5%	30%	60%
Hydrogen	0%	0%	0%	0%

Table 3.7 shows the types of fuel used by LDVs and, as before, the column to the left shows the situation today while the others show the different scenarios.

Methane vehicles have been introduced to the public and are used by well-known companies such as Reykjavíkurborg, Sorpa, and Strætó (Reykjavíkurborg, 2011; Sorpa, 2011a; Sorpa, 2011b). Hydrogen vehicles are used by OR, Landsvirkjun and others, and this is raising awareness about them (Íslensk NýOrka, 2011).

Electric vehicles are also in circulation, but more for personal use. These three types of vehicles are therefore getting promoted quite extensively. As can be seen in the table, the percentages of electric and hybrid electric vehicles are expected to rise steadily from under 1% to 5% and 10% respectively in the reference scenario. The increase is more pronounced in the other two scenarios, where they make up 35% and 30% of the total in the green scenario and a huge 95% in the target scenario. This increase is expected to reduce the proportion mainly of gasoline vehicles, which in the reference scenario are down by almost 18%, in the green scenario by 62% and in the target scenario by 79%. This is due to readily available technology for electric and hybrid vehicles and easy access to domestically-produced fuel.

Because ethanol is imported, as are oil-based fuels, it is assumed that ethanol-fuelled-vehicle use will not increase and it is therefore negligible. The fuel category *other* is also so small that it can be considered negligible. The percentages of methane, hybrid methane and hydrogen are expected to fall closer and closer to zero as the concurrence between the different fuel technologies comes to an end. The large vehicle manufacturers have already chosen hybrid electric and electric technologies as the future vehicle technology (Daimler, 2011).

The development described for fuel share applies mainly to the LDV fleet and to a lesser extent to vans, since the van fleet is more traditional regarding fuel type. The change in fleet composition regarding buses and trucks is generally expected to be slower because of the slower renewal of such vehicles and a small increase in number. The reason for this slow change in commercial vehicles, especially trucks, is mainly the knowledge invested in repairing them, the robustness of the traditional engines and their need for high-energy fuel. Fewer new vehicles enter the commercial vehicle fleet and they are often used for longer periods of time than

LDVs. Large construction projects would, however, affect the number of new vehicles entering the fleet as the fleet follows fluctuations in the economy. This could also lead to a faster change in the fleet's fuel composition.

Now that the total number of each vehicle type can be determined as well as the number of vehicles using each fuel type, the next step is to divide these into segments by fuel type, in the case of LDVs, and by weight for commercial vehicles (parameter $\theta_{bfs\ final}$ in Chapter 2). The third parameter, share of each segment of the total number in each fuel type in the LDV fleet, is assumed in general to increase the share of smaller segments A, B and C while reduce the share of larger vehicles such as segment J (SUVs). The change in segment share in the reference scenario is not great at 0-3% from 2010 to 2050 in the case of segment J, which drops the most. Segments E and F also drop slightly. In the green scenario there is a reduction of 0-8% in segment J. The target scenario shows a more noticeable change with a reduction in segment J from 15 to 68% and an increase in segment B to 51% and in segment C from 6 to 41%. Some of the segments seem to shift totally from segment J to B or C, but it should be kept in mind that some of the fuel categories only include a few vehicles today and therefore the shift is not high in absolute numbers. Turning to commercial vehicles, Table 3.8 shows the different scenarios for each.

Table 3.8: Percentage share of each weight category of total commercial vehicles in Iceland, same for all fuel types, in 2010 and by 2050 for the reference (Ref), green (G) and target (T) scenarios.

Vehicle type		VAN				BUS				TRUCK			
		2010	Ref	G	T	2010	Ref	G	T	2010	Ref	G	T
Weight in kilograms	< 2000 kg	4	4	4	4	0	1	1	1	0	1	1	1
	2-3000 kg	54	55	55	55	3	3	3	3	4	3	4	3
	3-4000 kg	22	23	23	23	6	6	6	10	3	3	3	7
	4-10,000 kg	19	18	18	18	38	38	38	40	19	22	21	26
	10-16,000 kg	1	0	0	0	23	23	23	30	14	18	16	30
	16-18,000 kg	0	0	0	0	25	25	25	15	19	20	20	20
	18-22,000 kg	0	0	0	0	3	3	3	0.5	5	3	6	3
	> 22,000 kg	0	0	0	0	1	1	1	0.5	37	30	29	10

As the table shows, the weight of vans is expected to reduce a little but mostly remains the same, since most are in the 2-3 ton category with only one category below 2 tons. These make up 55% and 4% respectively by year 2050. The change in the weight of buses is expected to be small because the benefit of having a smaller bus is offset by needing more buses to fulfill the demand for transport. However, in the target scenario the proportion of lighter buses are expected to increase and to be fuller when in service. The same principle applies to trucks: there is a more pronounced change in the heavier categories with the over 22 ton category dropping from 37% to 10% and the lighter categories from 4 to 18 tons increase in return.

The fourth parameter is distance per year. It was assumed that this distance was the same for all segments of LDV up to 2010, but after 2010 there is a change in distance driven by segments, for example, jeeps are driven less and smaller vehicles more. This is logical because of the high number of vehicles per person in Iceland, and because two vehicles per household is quite common, also it can be assumed that the jeeps are used for leisure travel and during the winter months while smaller vehicles are used for shorter trips in towns and cities and when there is little or no snow on the roads. The distance driven by sport vehicles dropped significantly for similar reasons. Table 3.9 shows the distance that each segment is assumed to drive in a year for each scenario.

Table 3.9: Kilometers driven per year by single LDV by segment in Iceland in 2010 and in 2050 for the scenarios (parameter Ubs final)

Kilometers	2010	Reference	Green	Target
A-segment	11,803	10,000	11,000	6,000
B-segment	11,803	13,000	11,000	6,000
C-segment	11,803	13,000	11,000	6,000
D-segment	11,803	12,000	11,000	6,000
E-segment	11,803	12,000	11,000	6,000
F-segment	11,803	12,000	11,000	6,000
J-segment	11,803	8,000	8,000	4,000
M-segment	11,803	13,000	11,000	6,000
S-segment	11,803	7,000	7,000	4,000

Similar reasoning was used for all scenarios, and only the number of kilometers driven changes. The reference scenario increases the distance driven per year in most categories apart from segments J and S. In the green scenario the distance decreases slightly, while in the target scenario there is an aggressive reduction of nearly 50% in many cases and even more in segments J and S. This is considered realistic with the increase in the number of buses per person as well as greater use of other means of transport such as cycling and walking. This heavy reduction in the target scenario is essential if the 2050 goal is to be reached. The distance driven by buses increases equally in the reference and green scenarios from 33,000 to 35,000 km a year and drops by 2000 km in the target scenario, but with an increase here in the number of buses. For trucks, the distance increases in the reference and green scenarios from 37,500 to 40,000 km a year. In the target scenario, however, it was necessary to drop this to 28,000 kilometers. The transportation of goods is not expected to change much over time and as an increasingly large proportion of the nation's population lives in the Reykjavík area (Hagstofa Íslands, 2011c) it is considered possible to reduce distance driven through better management of the schedule and loading methods.

The distance driven by vans is expected to change considerably in the reference scenario compared to 2010, with a decrease of 12% by 2050. In the target scenario it decreases even more by about 19%. The reason for the decrease is optimized driving distances with better management following fuel price rises.

The last parameter is change in fuel efficiency per driven kilometer. As mentioned earlier, fuel consumption by vehicles 15 or more years old is approximately 10% higher than that of vehicles under 3 years old, and today it is common for vehicles to leave the fleet when about 15 years old. This is interpreted as an average reduction of fuel use of 20% in 2050 compared to 2010 (parameter $U_{b\ final}$), an increase in fuel efficiency, and applies across the whole fleet.

4 RESULTS

In this chapter the emissions from production and EoL per kilogram of each vehicle segment and the emissions per kilometer driven are presented. As explained in Chapter 3, many parameters change from the year 2010 and are used for calculating the emissions. The emission figures for fuel consumption are therefore presented for the year 2010 and then fuel consumption is developed according to the variable (Δy_{bfs}) presented in Chapter 3. After the unit emissions have been presented, overall emissions for the three scenarios are shown and analyzed with regard to the number of vehicles and the service they provide, as well as fleet renewal in the light of necessary changes to the composition of the fleet. Then the impact is broken down into production and EoL on the one hand and on the other, the operation.

Note that it is assumed that LCAs are performed accurately by vehicle manufacturers and that they provide a realistic picture of actual emissions, especially from production. The emissions associated with production and EoL treatment per kg vehicle for all segments are presented and additionally for electric and hybrid vehicles. Information regarding segments A and S was not available but was considered to be very well represented by segments B and F (luxury vehicles) respectively. The latter both contain a high proportion of light metals and their emissions per vehicle kilogram are therefore considered similar. Electric and hybrid vehicles had to be represented separately because of the significantly higher emissions in their production and EoL phases than in use, while other vehicles generally emit more during their service life.

The information about emissions from production and EoL are for the most part from Mercedes Benz (*Environmental Certificates,* 2008a, 2008b, 2008c, 2008d, 2008e), Ford (*Product Sustainability Index,* 2007) and Volkswagen (*The Golf Environmental Commendation,* 2008). It was considered most important to look at global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP) and abiotic depletion potential

(ADP). As some of them did not contain information about ADP an approximation was made from the other reports. Information about emissions from the production of electric vehicles was found using data from a comparison of electric, gasoline and diesel vehicles (Hawkins et al., 2010). For buses, trucks and vans EcoInvent (2007) was used.

UNIT RESULT

The results per unit are presented here, followed by the overall results for the road transportation sector in Iceland. Emissions from burning a unit of fuel in 2010 can be seen in Table 4.1, for which gasoline and diesel emissions were calculated from the use phase emission and fuel consumption in Ford's (2007) Product Sustainability Index. The emissions from methane were found from information about burning and compressing natural gas (NG) (Röder, 2001). Information about electricity use during the production of hydrogen is taken from a report by the National Renewable Energy Laboratory (Ivy, 2004). When finding the emissions from electricity used in various phases the infrastructure of the electricity grid was not taken into account: only emissions linked to the operation and infrastructure of the power-plant were used in these calculations. Since electricity in Iceland is provided by geothermal and hydro power plants (see introduction) the weighted average was found in accordance with their share of electricity production (Frick, Lohse, & Kaltschmitt, 2007; Pehnt, 2006).

Table 4.1: Emissions per unit of fuel in 2009 for all impact categories from production and combustion

Emission per Unit Fuel		Gasoline [l]	Diesel [l]	Electricity [kWh]	Metan [kg]	Hydrogen [kg]
GWP100	g CO_2 eq.	2945	3368	21	1667	1260
AP	g SO_2 eq.	0.27	0.43	0.13	2.09	7.63
EP	g Phosphate eq.	0.37	0.86	0.02	0.26	0.90
POCP	g ethene eq.	3.17	3.54	-	0.41	-
ADP	g Sb eq	0	0	-	0	-

The emissions shown for hydrogen are produced by the electricity used in its production. The infrastructure for producing hydrogen is negligible for the purpose of this report, since it will not have a great affect on overall emissions from the vehicle fleet. However, if the share of hydrogen vehicles in the fleet increases significantly it might become necessary to include their infrastructure emissions.

The unit results for production and EoL treatment are presented in Tables 4.2 and 4.3. Table 4.2 shows that segments F and S produce the highest emissions in all impact categories, with GWP emissions of 472.5 gram CO_2/kg. Meanwhile commercial vehicles produce the lowest emissions per vehicle kg at 88 gram CO_2. The high impact of segment F, luxury vehicles, is most likely due to the proportion of light metals and alloys used in their manufacture rather than steel and iron (Mercedes-Benz, 2008c). The difference across LDVs is surprisingly high with the lowest emissions from segment M only 243.6 gram CO_2 eq. or 51.5% of emission per kilogram of segment F. Segment C, the most common segment, emits 58% of what segment F emits. This makes it very clear that the choice of segment is an important element of the overall emissions from the fleet. On average, emissions per vehicle kilogram are 369.4 gram CO_2 eq.

Table 4.2: Emission per LDV kilogram from production and EoL for all impact categories

LDV Segments →		A	B	C	D	E	F	J	M	S	Electric vehicle	Electric Hybrid
GWP100	g CO_2 eq.	316.4	316.4	274.1	344.3	413.3	472.5	422.6	243.6	472.5	313.9	473.9
AP	g SO_2 eq.	1.25	1.25	1.25	1.54	1.19	2.12	1.37	0.13	2.12	5.35	1.58
EP	g Phosphate eq.	0.19	0.19	0.16	0.13	0.15	0.12	0.17	0.31	0.12	0.30	0.19
POCP	g ethene eq.	0.20	0.20	0.21	0.23	0.18	0.27	0.18	0.11	0.27	0.33	0.20
ADP	g Sb eq	0.61	0.61	0.83	1.05	1.16	1.28	1.18	0.18	1.28	9.11	1.55

Note: See formula 3 in Chapter 2. Variable e_{bs} which does not change over time.

Table 4.3: Emission per commercial vehicle kilogram from production and EoL for all impact categories

		Buss	Truck	Van
GWP100	g CO_2 eq.	169	88	147
AP	g SO_2 eq.	0.81	0.39	0.88
EP	g Phosphate eq.	0.08	0.05	0.07
POCP	g ethene eq.	0.07	0.04	0.05
ADP	g Sb eq	1.33	0.79	1.19

Note: See formula 3 in Chapter 2. Variable e_{bs} which does not change over time.

Looking at the other emissions taken into account, electric vehicles emit more than the others in most categories except GWP and EP, although they are the second highest emitters per kilogram vehicle contributing to EP. The highest emitter affecting EP is segment M, minivans, at 0.31 grams phosphate eq. per vehicle kilogram. Electric vehicles emit 5.35 grams SO_2 eq. (AP) per vehicle kilogram, about 60% higher than the next segment, F. There is little difference between the segments' contribution to POCP, with the smallest difference only 18% and the largest 66.5% in segments F and M respectively. The ADP again is spread across a wide range from 0.18 grams Sb eq. per kilogram in segment M to 9.11 from electric vehicles.

Table 4.3 shows emissions per commercial vehicle kilogram; the difference between types is quite high. Buses emit more than the other types in most categories except AP, in which vans emit only 8.5% more at 0.88 gram SO_2 eq. Buses emit 169 gram CO_2 eq. per kilogram while trucks emit only 52% of this and vans about 87%. A possible explanation for the low emissions per truck kilogram is that trucks are mainly made of steel whereas more expensive and lighter materials are used in buses.

Now that the LCA figures for vehicle production and EoL treatment have been presented, the LCA figures for the user phase can be considered. Because comparison on a unit basis is not very useful as there are differences in how many units are used per kilometer driven, Table 4.4shows GWP per kilometer driven. The unit based LCA figures are available in Appendix A for all impact categories. This allows comparison between the different fuel types.

Table 4.4: Emissions (CO_2 eq.) for each fuel type per kilometer (g/km) broken down on vehicle type and segment

CO_2 eq. gram/km	Petrol	Hybrid Methane	Hybrid Petrol	Diesel	Methane	Electricity	Hydrogen
Truck 2	366	311	283	269	255	21	17
Truck 2-3000	439	373	339	323	306	25	20
Truck 3-4000	512	435	396	377	357	29	23
Truck 4-10000	732	621	566	539	510	42	33
Truck 10-16000	1025	870	792	754	714	59	46
Truck 16-18000	1281	1087	990	943	893	73	58
Truck 18-22000	1391	1180	1075	1024	969	80	63
Truck 22000	1647	1398	1273	1212	1148	94	75
Buss	1354	1149	1047	997	944	78	61
Van small	293	248	226	216	204	17	13
Van large	512	435	396	377	357	29	23
A-segment	177	150	137	130	123	10	8
B-segment	201	171	155	130	140	12	8
C-segment	217	184	168	162	151	12	9
D-segment	277	235	214	186	193	16	11
E-segment	322	273	249	238	225	18	14
F-segment	350	297	270	271	244	20	16
J-segment	419	355	324	328	292	24	19
M-segment	249	212	193	195	174	14	11
S-segment	339	287	262	265	236	19	15

Note: Variable e_{bf} which changes over time

As shown above, overall diesel and gasoline are the largest contributors to GWP per kilometer driven, while the lowest emissions come from electricity- and hydrogen-powered vehicles at only 6% and 5% of gasoline emissions respectively. The table also shows that for a given distance, gasoline emits more than diesel (for fuel required per 100 km see Appendix B). Emissions from methane use are quite a bit lower than those of diesel and gasoline but considerably higher than from electricity and hydrogen use.

EP behaves quite differently, with the largest contributor, diesel use, at around 50% higher than the rest as shown in Appendix A. The second highest contributor is the use of petrol and the lowest, hydrogen, followed closely by electricity. Even though there is still quite a difference between electricity use and petrol, the gap between them is smaller when it comes to EP with emissions from the use of electricity 36% of those from gasoline but only 6% contributing of GWP. The tables turn completely when it comes to emissions contributing to AP. Here the largest contributor by far is the use of methane, followed by electricity, which is 60% lower, and hydrogen, 70% lower than methane. The same fuels contribute to an increase in POCP as GWP or gasoline and petrol, but it should be noted that data about POCP emissions from electricity and hydrogen use are not available. It is peculiar that information about abiotic depletion potential is not available regarding the fuel usage even though known reserves of oil have the potential to be depleted which resulted in the energy crises in 1970's (EPA, 1974).

TOTAL FLEET RESULTS

Now that the emissions per kilometer driven and per vehicle kilogram have been presented, the emissions for the entire fleet along with other useful information can be shown. Each of the following figures shows all three scenarios. The first presents total GWP emission from the road transportation sector and the target considered realistic for Iceland's emissions reduction (see Chapter 1). As the information for years 1990-2010 is calculated from known figures, the scenarios do not start dividing until 2010. The reference scenario increases continually across the years. By 2050 it is over three and a half times, or 1,120,000 tons CO_2 eq., higher than the target.

The green scenario, which assumes moderate measures but not a drastic change in people's behavior, levels out straight away and decreases slowly but surely, ending up with a reduction in emissions of 11,500 tons a year by 2050. This reduction is highest at first at 1.5% and gradually slows down to 0.5% a year. The green scenario is still over 2.6 or 731,000 tons CO_2 eq. higher than the 2050 target.

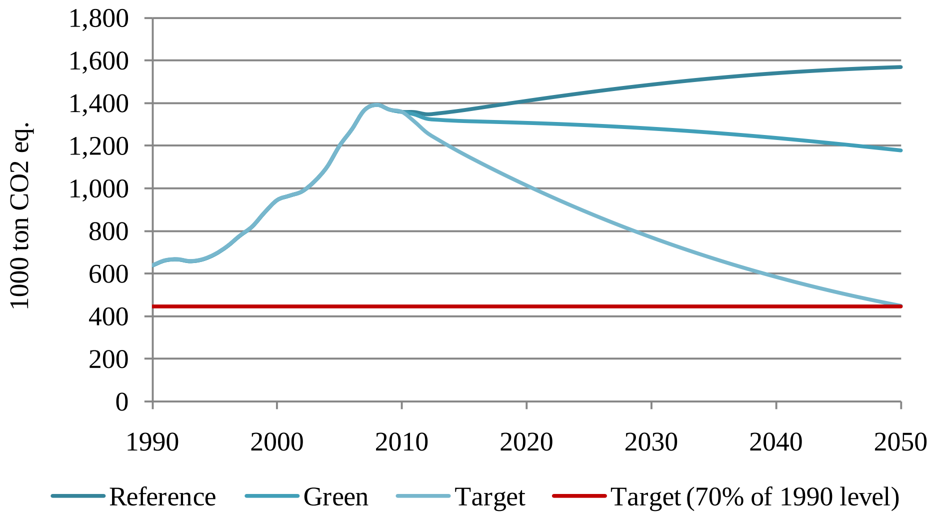

Figure 4.1: Vehicle fleet GWP emissions in Iceland by year 1990-2050
Note: See formula 27 for total GWP emissions in Chapter 2.

As expected, in Figure 4.1 the steepest reduction forecast by 2050 appears in the target scenario at close to 3% each year. The reduction in 2050 is therefore over 11,500 tons CO_2 eq. and the total reduction from 2010 is 67%.

In Appendix C EP slowly increases in the reference scenario to 23% in 2050. In the green scenario the increase is about 4% while the target scenario shows a huge reduction of 49% by 2050. Emissions contributing to AP behave very differently in all scenarios, with an increase of 55% in the reference scenario, and green scenario emissions more than doubling. The target scenario arrives at twice the emissions of 2010, less than in the green scenario only because there are fewer vehicles. POCP emissions increase in the reference scenario and decrease in the other two. The highest POCP reduction is 72% in the target scenario.

Drastic measures are needed if the kind of changes shown in the target scenario are to be achieved. Figure 4.2 shows that the increase in the number of LDVs must be slowed and then reduced to reach the target 30% reduction in the mobility sector by 2050.

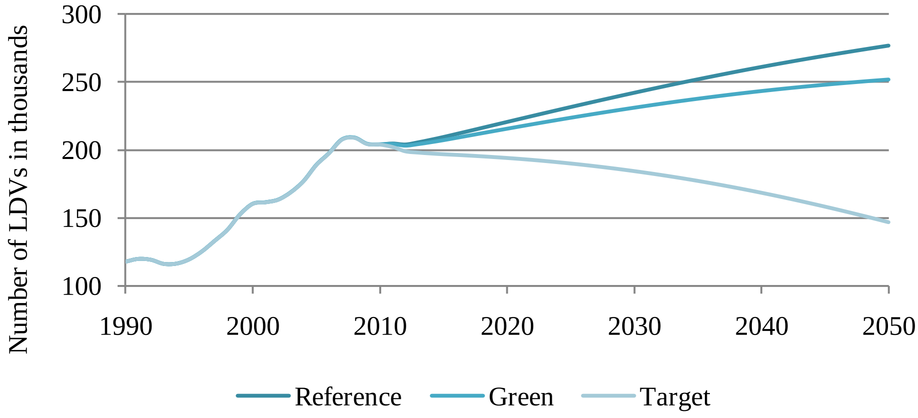

Figure 4.2: Number of LDVs in Iceland 1990-2050
Note: Sum of all segments in variable $Q_{t(LDV)f}$ see Chapter 2.

In Figure 4.2 the green scenario is only 9% lower than the reference scenario, while the target scenario drops by 47% by 2050. From 2010 there is still an increase in the total number of vehicles in both the reference and the green scenarios, with the former increasing by 36%, the latter by 23% and the target scenario dropping by 28% from 2010 to 2050. This is interesting in the light of the forecast for 32% population growth (Hagstofa, 2011b) during these years with the growth in numbers slowing in the green scenario and to some degree in the reference scenario.

The increase in the number of LDVs is mostly due to new vehicles entering the fleet and very few old vehicles being re-registered. In the past, new vehicles registered each year have increased from 3% in 1993 to 16% in 2005-2007, an average of 10% of total registered vehicles each year. According to the scenarios, which follow the same pattern regarding registration of new vehicles: this mainly remains the same from year to year with the new vehicles making up 8-9% of the total registered vehicles. Looking at the number of new vehicles entering the fleet is important in order to visualize how realistic the targeted changes in fleet composition are. According to the size of the share of new vehicles in Iceland it is plausible that these changes could be made only by controlling the type of fuel new vehicles run on. For example, the year that the target scenario assumes the greatest increase in the number of electric and hybrid vehicles is in 2012, where they account for 44% of the total number of new vehicles entering the fleet. It should be noted here that this percentage is only the increase between years in electric and hybrid vehicles of the total new vehicles. It is assumed that once people buy an electric or hybrid vehicle they will keep doing so, and the total number of new electric and hybrid vehicles is therefore higher than the increase between years mention earlier.

These figures do not tell the whole story: the service that a object supplies may be more appropriate measure. It is therefore interesting to look at Figure 4.3.

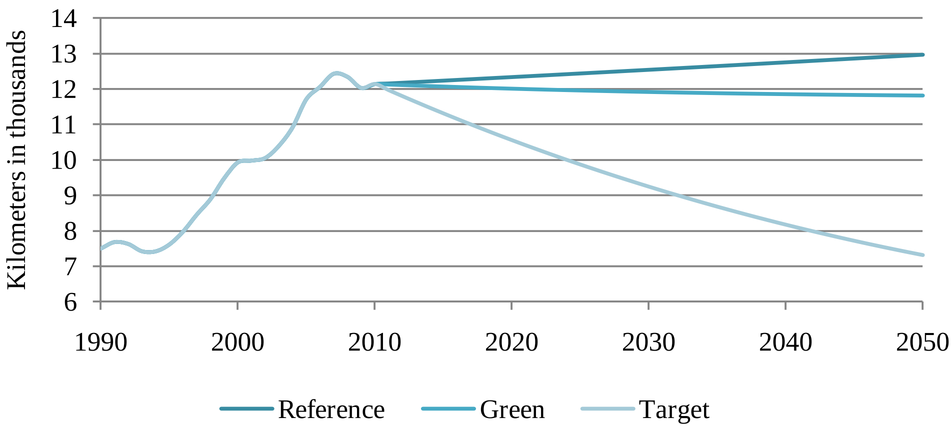

Figure 4.3: Kilometers driven per person per year in Iceland
Note: Use of variables U_{tbfs} and p (see Chapter 2)

The service provided by personal vehicles is the distance travelled per person, and Figure 4.3 shows the total distances driven by buses, vans and LDVs divided by the population. Trucks are not taken into account, since this table is only concerned with people travelling from place to place. Vans are included because they are often used by construction workers, plumbers, electricians and similar professionals who need to transport people and their equipment, just as other people use LDVs or public transport to get to their work. The number of kilometers driven by a bus is multiplied by 15 to present a more realistic picture of the person-kilometers provided. It is assumed that LDVs carry only one passenger. This therefore means that the actual number of kilometers per person could be higher, especially in the target scenario, because the number of people using public transport or sharing vehicles is could be greater. The model does, however, give a clear indication of the development of the service provided, and shows that there is little reduction in the population's overall mobility in the reference and green scenarios. In 2010 the kilometers travelled per person are 12,138 km while for 2050 the reference scenario assumes approximately 13,000 km/person. This is even higher than the historical maximum of 12,400 km per person reached in 2007. The green scenario is only slightly lower than the reference scenario at 11,800 km/person, a reduction of 3% since 2010. The target scenario assumes 7,300 km per person in 2050, similar to the distance driven per person in 1990. The change in distance per person for the target scenario is therefore expected to be attainable, even though some individuals might consider that this will require a drastic change of lifestyle.

As explained in the introduction to this thesis, analysis based on the whole life cycle of a product becomes increasingly important as emissions from product use are reduced, making their other life stages responsible for a greater proportion of their overall emissions. This affects the vehicle fleet as more electric vehicles appear in the fleet as electricity is more environmentally friendly then most oil-based fuels. Table 4.5 shows that today fuel use is responsible for 89.9% of all emissions contributing to global warming, and the reference scenario, though it is not aggressive, shows over 2% change in the share of fuel use. In at the two other scenarios, fuel use as a contributor to total emissions decreases to 67% in the target scenario. Over the years, then, it can be assumed that production and EoL treatment will become more important and should therefore be taken into account. Fuel efficiency has been given a reasonable fuel use per 100 km reduction target of 20%. If, however, fuel use efficiency were greater the importance of other phases of a vehicle's life would increase.

Table 4.5: Percentage share of overall emission by origins, production and EoL or fuel use, for year 2010 and projected 2050 scenarios

	2010	Reference 2050	Green 2050	Target 2050
LDV	7.7 %	9.0 %	10.6 %	13.5 %
Van	1.0 %	1.4 %	3.0 %	7.2 %
Bus	0.3 %	0.5 %	0.9 %	3.5 %
Truck	1.1 %	1.7 %	2.9 %	8.9 %
Fuel Use	89.9 %	87.4 %	82.6 %	66.9 %

Table 4.5 also shows how the importance of trucks increases over time. The reason for this is the reduced use of oil based fuel by LDVs which reduced the importance of fuel use in general. Their share of total emissions from fuel use change and trucks go from 9.6% in 2010 to 55% of the emission from fuel use in the target scenario, and even in the green scenario trucks produce the most emissions from fuel use. As fuel use is still the largest source for emissions in 2050, changing the fuel used by trucks and improving their efficiency becomes very important. The LDVs drop from being responsible for 56% of emissions from fuel use in 2010 to 18% in 2050.

As fuel use is important and one of the goals of the Icelandic government is to reduce fuel dependency, changes to fuel use in the transport sector are important. This is the fastest growing sector and uses mainly imported oil (Orkustofnun, 2010).

Figure 4.4 shows that the path of oil-based fuels is very similar to that of total emissions.

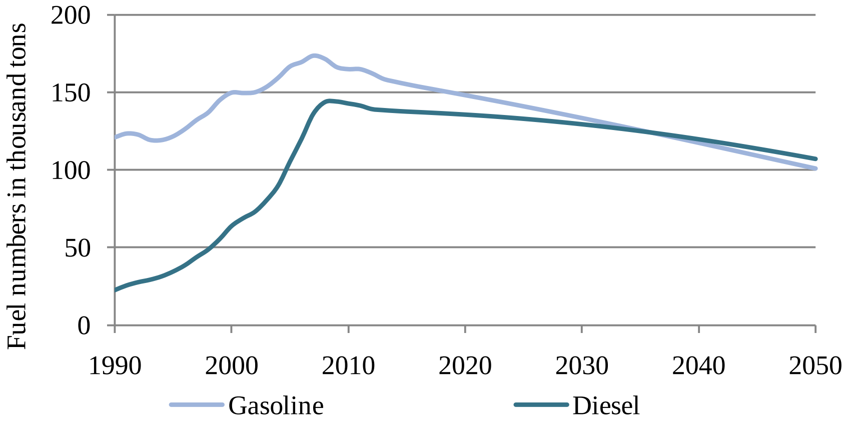

Figure 4.4: Modelled diesel and gasoline numbers 1990 – 2050 in 1000 tons

In 2010 164,724 tons of gasoline were used in Iceland in total, and in the model this drops to 100,718 tons per year by 2050. [1] The use of diesel oil has a quite different pattern: its 142,923 tons in 2010 only decrease to 107,219 tons. The year 2007 saw maximum use of both types of fuel with 173,375 tons of gasoline and 136,286 tons of diesel oil.

Also shown in Figure 4.4 is greater use of diesel than of gasoline by 2050. This can be explained by the fact that as the contribution of trucks increases in overall emissions the effect of the fuel of choice for trucks becomes increasingly dominant. Many trucks drive long distances and therefore need a lot of energy, and they continue the use of oil-based fuel as long as no other option is realistically available.

Sensitivity of the Scenario Model

The sensitivity of the scenario model is important, since a different development to those described is very possible and it is therefore important to visualize how much that might affect the overall result. The sensitivity analysis is based on the green scenario, which is drastic enough to show real changes in emissions but just conservative enough to be able to represent a real possible outcome. All the

[1] Note that information about oil use in 2010 is preliminary.

parameters for the scenarios mentioned in Chapter 2 are tested, as well as the effect of different population development.

First, the sensitivity of the model with regard to changes in the size of the population is considered since there are three different official options to choose from. When the highest population forecast is used, overall emissions increase by 9.4% compared to the green scenario, which is acceptable. It would, however, be more serious if it was 9% higher than the emission target for 2050 because of commitments in international agreements.

Reducing fuel use by 10% reduces 2050 emissions by only 9.5% compared to the original emissions in the green scenario. Uncertainty about fuel efficiency in 2050 is therefore not of great concern. The same effect is accomplished when distance travelled is reduced by 10% as the distance and fuel use go hand in hand. A 10% reduction in LDVs per person affects overall emissions little, reducing them by only 4%.

As trucks become increasingly influential in total emission figures as fuel use in the LDV category changes, it is interesting to see what happens to the green scenario as the number of trucks is reduced by 20%. This only reduces 2050 emissions by 8%, less than distance and fuel reduction, and results in 9% lower emissions in the target scenario.

Finally, in the green scenario if the share of electric vehicles is increased by 10% in the year 2050. For LDVs and vans the increase in electric vehicles was made by decreasing the proportion of gasoline fuelled vehicles, but for buses and trucks proportion of diesel vehicles was decreased. Interestingly this reduces 2050 emissions by 10.4%, is the biggest reduction so far here but still not very impressive, even though in absolute figures this would be a reduction of 122,500 tons CO_2 eq.

5 DISCUSSION

This report calculates the emissions from the Icelandic vehicle fleet using a life cycle approach which covers the whole life cycle of the vehicle, from extraction and processing of raw materials and production, service lifetime and end of life treatment. The results suggest that overall emissions are expected to rise more than three times higher than the emission target in 2050 if drastic measures are not taken, and that action needs to be taken straight away so that the transition towards an economy with less carbon intensity to be gradual so people can adjust to new ways of life.

MODEL LIMITATION

The model used has limitations, as do most models that try to interpret the real world. It accurately shows historical number of vehicles using each fuel type throughout the years examined and the number of vehicles registered. The assumption that the share of each vehicle segment within the LDV fleet has been constant from 1990 to 2010 is a limitation, because the share of, for example, segment F (luxury vehicles) or J (SUVs) has been increasing over the years, emissions before the increase would have been lower as jeeps and luxury vehicles are heavy and contain materials that have greater environmental impact, and both vehicle types generally use more fuel per kilometer driven. Information about the number of SUVs registered is not available, and until this class of vehicle is separated at the vehicle registration office the trend will be difficult to estimate. The other limitation regards fuel consumption, which is also assumed to be constant in the historical model. Changes in fuel consumption would alter the results as, the use of vehicles from 1990 to-2000 produced greater emissions because fuel efficiency has been improved and continues to do so.

However, these two limitations in the historical model are considered to cancel each other out and so do not seriously affect the result. The trend of increasing emissions from the vehicle fleet remains, and visualization of this in tandem with increased vehicle ownership is important from the perspective of GHG reduction targets.

The model visualizes a possible scenario of emissions from Icelandic road transportation to aid in the attempt to reduce them. The biggest uncertainties that could seriously affect overall emissions in all scenarios are the parameters chosen to calculate them: distance driven by each vehicle and thereby distance per person, as well as population development and number of vehicles per person. The sensitivity of the model regarding these uncertainties is examined in Chapter 4, which concludes that sensitivity to an alternative population scenario is quite high with an increase in overall emissions in the green scenario by 9% by 2050 when population development follows the highest path forecast. It also shows that sensitivity to a change in distance driven per vehicle could result in a 9% reduction in emissions in 2050 in the green scenario when the distance is decreased by 10%. Reducing the parameters usually resulted in similar reductions in overall emissions in 2050; however, there are always uncertainties when scenarios are used: they are merely meant to be used as a guide to finding the best option.

Fossil Free Economy

One of the motivations for studying road transportation in Iceland was to see how plausible phasing out the use of oil-based fuel in Iceland would be. First, the use of fuel is compared with official figures for quantities of fuel used by the vehicle fleet, introduced in Chapter 1, in order to determine whether the model gives an accurate picture of the fuel used in the years 1990-2010. As there is fluctuation in the official figures which are hard to simulate there are some differences during these years. The difference in gasoline use is only on average 3% higher in the model then in the historical data, while in the case of diesel the difference is 12% on average. In some years the difference is quite high, although the overall use of gasoline is officially 143,179 tons and the model is only 1% higher than that. For diesel use the official figure is 62,800 tons and the model shows a total of 72,800 tons, 16%

higher. The reason for this is most probably the difference in the distance driven by trucks and buses or their fuel use per kilometer.

According to the model, a reduction in the use of oil-based fuels is significant in the reference scenario. Overall gasoline use in Iceland is reduced by 39% by 2050 and diesel use by 25% compared to the use in 2010. When compared to 2007 the reduction is even greater, at 42% and 21% respectively. The reduction of fuel use per kilometer and change in size of vehicle as well as fuels used by the truck fleet is not aggressive enough to counteract the increased need for good transportation, which is why the reduction does not happen even faster than the reference scenario shows, and why, there is an actual increase in gasoline use in buses and trucks.

However there is an overall reduction, which is very positive because importing of oil require both transport by sea, which involves further CO_2 emissions as well as the possibility of oil spills, and uses foreign exchange. Phasing oil-based fuels out completely is a very ambitious goal, and it is unlikely that this goal will be reached by 2050 because other energy carriers for long-range transport as needed by trucks and most buses are not available today. However, with constant technological development the goal will become more realistic over time.

Unit Emissions

The other motivation for reducing use of oil-based fuels is the environmental side of it in the light of Iceland's goal to reduce its emissions. Taking the model's limitations into account shows how the emissions result per unit of fuel compares to Iceland's official figures. Unit-based emissions from fuel are important, since fuel use is usually how nations measure and calculate emissions from the transport sector. The results compare well with other studies (see Chapter 1), even though the range analyzed in the latter mainly covers vehicles in segments B, C, and D. In this study these segments emit 201-277 grams CO_2 eq./km from gasoline use, while the other studies show a range 140-280 grams. For diesel, the range for these segments is 123-175 gCO_2 eq./km, which also fits well with other studies' results of

123-260 gCO_2 eq./km. The reason other studies show higher emissions than those in this report is that the vehicle' size range included in this report is probably bigger taking segments E and even F into account. Diesel vehicles tend to be larger and therefore this is logical. Taking up to segment F into account, the range in this report increases to 123-255 gCO_2 eq./km. If average emissions per kilometer from diesel use across the whole vehicle fleet were to be calculated the emissions from the Icelandic vehicle fleet would probably be considerably higher than those of other European countries because such a high proportion of diesel vehicles in Iceland are very large SUVs and they tend to be in traffic for a longer time, which increases their emissions even more. As the average emission for the European vehicle fleet is not known this comparison cannot be made as of today.

The ACEA' voluntary commitment sets very ambitious targets by 2012 and 2020 and if manufacturers reach them it could have a lot to say about overall reduction of emission in European countries. Assuming that these goals apply to the two smallest vehicle segments A and B, whose emissions are in the range of 177-201 gCO_2 eq./km, the target for reduction by 2020 is around 50% for both. This is probably to be achieved through cleaner burn as well as structural improvements to the vehicles' weight, resistance and so forth. A 50% reduction in fuel use could bring close to a 50% reduction in overall emissions from the LDV fleet, since the sensitivity analysis has shown that a 10% reduction in fuel use would reduce emissions by 9.5%. Assuming this to be the case in 2050, total emissions would be 762,044 tons CO_2 eq. or only 19% higher, rather than 220% times higher than emissions in 1990 in the reference scenario.

Emissions and Reduction

The figures for overall emissions shown in the model are on average about 9% higher than Icelandic government figures for the years 1990-2006. For 1990 the official figures are 608,000 ton CO_2 eq. while the model shows a total of 638,800 tons; for 2006 the official figure is 979,000 tons compared to the model's 1,278,500 tons CO_2 eq. These differences can be partly explained by the differences in fuel use in the model and in reality. As explained earlier, the average difference in diesel use for the years 1990-2010 is 12% higher in the model. The average difference in overall emissions is 19%, and as fuel use accounts for only 90% of these emissions the actual difference between the model and official figures is only 9%. Using the difference between the fuel use in the model and official fuel use figures to try to compensate for the difference between emissions in the model and official figures does not reduce it. Calculating emissions from the official fuel use and comparing them to the emissions from fuel use in the model, shows that the model only exceeds those emissions by 3% on average.

According to the results from the model, the official figures only account for an average of 80% of total actual emissions caused throughout the whole life cycle of the vehicle fleet in Iceland. This difference can be explained in several ways. The similarity in emissions from fuel use in the model and the official fuel use figures suggests that the difference between the official emission figures and the model lies in emissions per unit. As the unit emissions shown in the report fit well with other studies reviewed in Chapter 1, the official emissions can only be assumed to be underestimated.

As suggested earlier, the 10% of overall emissions accounted for by production and EoL are not included in the official figures but these are nonetheless caused by demand from Icelandic society. At present the Kyoto Protocol holds the producing country responsible for the emissions from production of a product, and therefore emissions from the production of the vehicles used in Iceland are accounted for in other countries. Iceland is currently committed to reducing GHGs from domestic emissions. Assuming that all sectors emitting GHGs need to reduce their individual emissions to apply with Iceland's commitment, a reduction of at least 30% compared to the reference year, 1990, would be required from the transportation sector. In 1990 GHG emissions calculated in this report were 638,800 tons CO_2 eq., which with 30% reduction means that in 2050 the emission level from transport should be around 447,175 tons, somewhat higher than if the official figures are used.

Assuming that the figures in this report are more accurate then the official figures, emissions in 1990 would have been 3,397,970 t CO_2 rather than the official 3,367,149 t CO_2 eq., and a 30% reduction from 1990 of emissions from the road transportation sector would bring about a decrease of 912,000 t CO_2 eq., equal to 27% of all emissions in 1990. Emissions from the transportation sector could become even more important in the future. There is a possibility that international agreements will be adjusted to account for the whole life cycle of a product with the nation demanding the product will be held responsible for all its emissions. If this were to happens, mitigation measures in the transport sector will be even more important, since Iceland's other heavy emitters, aluminum and fish, are to a large extent exported.

According to the model, in the reference scenario, which some call the 'business as usual' scenario, emissions will rise as fast as the population or possibly faster. This means that by 2050 emissions will be 3 times the 30% reduction target. The green scenario is considered to be likely to occur according to current policies and trends, but this would require a change in public opinion through education and incentives. The green scenario is over twice as high as the reduction target for 2050. The target scenario indicates best what needs to be done to reduce emissions by 30% compared to 1990 levels: action needs to be taken right away, since almost the whole of the LDV fleet needs to change to electric or hybrid electric vehicles. Reaching such goal, when today oil-based vehicles prevail, will be challenging.

The shift from oil-based fuels to electric vehicles will probably not be the hardest part for Icelanders. Reducing the number of kilometers driven per person by 22% and reducing vehicle ownership in favour of using public transport, walking and cycling will be the biggest challenge for individuals. For politicians, the greatest challenge is probably convincing the public that it would be beneficial to reduce emissions. If the Icelandic nation, which has access to fairly clean electricity and heat, cannot take advantage of its natural resources it is unlikely that other nations will reach their goals: they may not currently have access to environmentally-friendly energy solutions and it is clear that action needs to be taken immediately in

Iceland and elsewhere if the goal of maximum 2°C above pre-industrial levels (see Chapter 1) is to be kept.

Reaching the goal the Icelandic government has announced, in cooperation with the EU, of a 50-75% reduction in emissions by 2050 seems very unlikely if all sectors are to reduce emissions equally. The 30% reduction might be reached with the right policies and increased public awareness, but a 30% reduction by 2020 is highly unlikely for this sector.

REACHING THE GOALS

Current policy encourages alternative fuel use and this seems to be working, although very slowly. The most popular alternative fuel seems to be methane, but also there is a sharp increase in the number of hybrid (gasoline/electric) vehicles registered in Iceland which could be encouraged by the increase in fuel prices. Methane vehicles probably seem popular because the company that is restricted to gather and preferably use the methane, uses it extensively on its own vehicles. There has also been an increase in the number of diesel vehicles registered after the law was changed in 2005 in their favor.

Comparing different options is important before making policy decisions. The model shows where the emissions originate, whether in the production, EoL or use phase. This is helpful for creating policy aiming to reduce overall emissions over the long term. As the model shows, considerable emissions are linked to vehicle fleet production and EoL treatment, and this should be paid attention. Policy aimed at the overall reduction of emissions instead of single phases of the lifetime, would be more beneficial in global terms.

The first step to achieving any kind of reduction in emissions is to increase public awareness and interest through education and information that is impossible to miss. Accessibility is the next step, with both alternative vehicles and fuel made more accessible to the general public. It is not enough to find ways to increase interest in using vehicles that drive on alternative fuels: these fuels also have to be made accessible in such a way that the use of them would not greatly restrict the mobility of the individual.

The measures that the Icelandic government have already suggested, as mentioned in the introduction to this thesis, include incentives to invest in more environmentally-friendly transport vehicles but lack specific targets. In order to realize these measures, specific goals targeting greater use of alternative fuels and technologies have to be set. Vague and soft goals such as those currently set make it easy to avoid rather than embrace change. Instead of *increase efforts making cycling and public transport a real option* (Umhverfisráðuneytið, 2007) it would be better to make the goal measurable, for example by stating that by 2020 40% of the working public should be using bicycles to get around during the summer.

Other measures could increase access to alternative fuels by regulating regarding fuel stations, aiming at making 50-70% of them supplying alternative fuels such as electricity, methane and hydrogen; and 70% of imported vehicles should be hybrid and electric. The method most likely to succeed is using taxation to make other means of transport such as electric and hybrid vehicles more appealing. This could be done by slightly increasing taxes on oil-based fuels while at the same time lowering taxes on bicycles and cycling safety gear, electric and hybrid vehicles and lowering fares on public transport. Road tolls could also be used in Reykjavík to reduce its traffic load, with the money used to create cycle and pedestrian paths throughout the city.

Some companies have taken measures into their own hands and encourage the use of public transport, walking and cycling to get to work by increasing salaries by the amount that the company would otherwise pay for a parking space for the employee.

Another method used with some success is competition for the highest number of kilometers cycled to and from work by each company's employees over a certain period (Hjólað í vinnuna, 2011). The prize is a certificate for the company and its employees. This could be used as inspiration for a similar contest to reduce emissions from transport to and from work. The competition would begin with a certain amount per day or week, with each person using public transport or other alternative means of getting to work reducing that number and the company achieving the greatest reduction after a set number of months winning, receiving similar prize as in the existing competition (Hjólað í vinnuna). The model presented in this thesis could, with small adjustments, be used for this purpose, as the kilometers driven and types of cars owned by each company could be entered at the beginning and changes over each week measured. The model would only need to add bicycles to the inventory. This would make people more aware of their emissions as well as making reducing them fun and exciting.

Alternative measures that could be undertaken immediately include training in the benefits of better transportation management and how to load trucks better for transport companies and truck drivers. This could reduce number of trips driven to each place.

This study's results make the 75% reduction goal that the Icelandic government has suggested in cooperation with the EU appear very ambitious and perhaps impossible. However, if the goal were to reduce emissions per person, emissions from the transport sector would look different. From a per capita perspective the emissions are 3.7 tons per capita in 2050 in the reference scenario compared to 4.3 tons in 2010 and 2.5 in 1990. With a 30% reduction the levels are down to 1.1 tons per capita, a reduction of 56% from today. This means that the increase in the population is faster than the increase in emissions in the reference scenario, leading to an overall increase in emissions while it is actually a reduction per capita in all scenarios.

Further Research

In order to make the model more accurate, information about fuel usage per kilometer and driving distances for each vehicle type and segment would be beneficial and relatively easy to include in vehicle inspection. To build further on this model it would be possible to expand it to include trams and the future construction and maintenance of roads and bicycle paths. Also the possibility of visualizing the cost associated with a more sustainable community by performing life cycle cost analysis (LCC) could be beneficial while still taking into account the added value that increased activity would create in the form of healthier nation.

Over the years air travel has become increasingly important in transporting the public within the country, and as time spent on travelling becomes more important flying could become even more common. The transport of goods by road replaced the use of sea freighters a few years ago, and if policy changes again it could become important to take these factors into account and expand the model to cover them. The largest share of imported fuel is used by the fishing industry, and it is therefore important to take this into account when seeking to reduce Iceland's emissions and achieve a fossil-fuel free economy.

6 CONCLUSION

This report calculates the emissions of the Icelandic vehicle fleet using a life cycle approach which covers the whole vehicle life cycle from extraction and processing of raw materials; and production, through the service lifetime and EoL treatment. First the historical model used to calculate past emissions is defined along with the relevant parameters. After that additional parameters for the scenario model are presented and further calculations explained. How the vehicles are sorted into types of LDVs, vans, buses and trucks and further segmentation is explained. The LDVs are categorized based on the parameters used by the European Commission, with data for the year 2009 used to find the share of vehicles in each segment. Trucks, buses and vans are categorized by weight with the proportion of each category known for a single year. Other factors that affect emissions, such as development of vehicle lifetime, fuel use and distance driven per year are also discussed. Future emission scenarios, for the vehicle fleet in Iceland, created are then presented with their variables and changes over the years. Finally, the results are shown and discussed in detail.

The report provides an environmental assessment of the Icelandic vehicle fleet by developing a model that calculates the emissions linked to it. Although there are some implications with the model, it represents the fleet's emissions over its entire life cycle in an adequate way as well as pointing out any emission "hot spots". The "hot spots" revealed is the use of fuel mainly by LDVs, which may not come as a surprise. More surprisingly the emissions from trucks become increasingly important as the LDV fleet moves away from using fossil fuels and towards electricity. The information obtained from the model can be used when creating appropriate policies to reduce emissions from the whole life cycle of the vehicle fleet. In decision making the model can be used to test the effects of various policy measures and as a guide to the most sustainable options.

As emphasized in the introduction, a forecast can never be accurate, and the scenarios presented here reveal only possible futures. What can be learned from them is that a significant change in Icelandic society is needed if it is to reduce its emissions by 50% by 2050. The scenarios also show that the problem facing the global community needs to be taken seriously, by everyone, very quickly and action taken straight away, even though, the target would be set to *only* 30% reduction of emissions compared to 1990 levels by 2050. Although the scenarios cannot provide an accurate picture of what *will* happen, they can aid in knowing what to aim for and how drastic the necessary measures and changes must be if they are to reach the targets set.

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APPENDICES

Appendix A: Emissions per kilometer AP, EP, POCP and ADP.

Table 0.1: Acidification potential per kilometer

Acidification Potential	Gasolone	Hybrid Methane	Hybrid Gasoline	Diesel	Methane	Electricity	Hydrogen
Truck < 2	0.033	0.177	0.026	0.034	0.320	0.127	0.100
Truck 2-3000 kg	0.040	0.212	0.031	0.041	0.384	0.152	0.120
Truck 3-4000 kg	0.046	0.247	0.036	0.048	0.448	0.178	0.140
Truck 4-10000 kg	0.066	0.353	0.051	0.069	0.641	0.254	0.201
Truck 10-16000 kg	0.093	0.495	0.071	0.096	0.897	0.356	0.281
Truck 16-18000 kg	0.116	0.618	0.089	0.120	1.121	0.444	0.351
Truck 18-22000 kg	0.126	0.671	0.097	0.131	1.217	0.483	0.381
Truck > 22000 kg	0.149	0.795	0.115	0.155	1.441	0.571	0.451
Buss 16-17000 kg	0.122	0.654	0.094	0.127	1.185	0.470	0.371
Van 1500 kg	0.026	0.141	0.020	0.027	0.256	0.102	0.080
Van >3500 kg	0.046	0.247	0.036	0.048	0.448	0.178	0.140
A-segment	0.016	0.085	0.012	0.016	0.155	0.061	0.046
B-segment	0.018	0.097	0.014	0.016	0.176	0.070	0.046
C-segment	0.020	0.105	0.015	0.019	0.190	0.075	0.057
D-segment	0.025	0.134	0.019	0.022	0.242	0.096	0.065
E-segment	0.029	0.156	0.022	0.029	0.282	0.112	0.083
F-segment	0.032	0.169	0.024	0.033	0.306	0.121	0.095
J-segment	0.038	0.202	0.029	0.039	0.367	0.145	0.115
M-segment	0.023	0.120	0.017	0.023	0.218	0.087	0.068
S-segment	0.031	0.163	0.024	0.032	0.296	0.117	0.093

Table 0.2: Eutrophication potential per kilometer

Eutrophication Potential	Gasolone	Hybrid Methane	Hybrid Gasoline	Diesel	Methane	Electricity	Hydrogen
Truck < 2	0.046	0.043	0.035	0.069	0.040	0.015	0.012
Truck 2-3000 kg	0.055	0.051	0.042	0.082	0.048	0.018	0.014
Truck 3-4000 kg	0.064	0.060	0.049	0.096	0.056	0.021	0.017
Truck 4-10000 kg	0.092	0.085	0.071	0.137	0.079	0.030	0.024
Truck 10-16000 kg	0.128	0.120	0.099	0.192	0.111	0.042	0.033
Truck 16-18000 kg	0.160	0.150	0.124	0.241	0.139	0.053	0.042
Truck 18-22000 kg	0.174	0.162	0.134	0.261	0.151	0.057	0.045
Truck > 22000 kg	0.206	0.192	0.159	0.309	0.179	0.068	0.053
Buss 16-17000 kg	0.169	0.158	0.131	0.254	0.147	0.056	0.044
Van 1500 kg	0.037	0.034	0.028	0.055	0.032	0.012	0.010
Van >3500 kg	0.064	0.060	0.049	0.096	0.056	0.021	0.017
A-segment	0.022	0.021	0.017	0.031	0.019	0.007	0.005
B-segment	0.025	0.023	0.019	0.031	0.022	0.008	0.005
C-segment	0.027	0.025	0.021	0.039	0.024	0.009	0.007
D-segment	0.035	0.032	0.027	0.045	0.030	0.011	0.008
E-segment	0.040	0.038	0.031	0.057	0.035	0.013	0.010
F-segment	0.044	0.041	0.034	0.065	0.038	0.014	0.011
J-segment	0.052	0.049	0.040	0.079	0.045	0.017	0.014
M-segment	0.031	0.029	0.024	0.047	0.027	0.010	0.008
S-segment	0.042	0.040	0.033	0.064	0.037	0.014	0.011

Table 0.3: Photochemical ozone creation potential emissions per kilometer

POCP	Gasolone	Hybrid Methane	Hybrid Gasoline	Diesel	Methane	Electricity	Hydrogen
Truck < 2000 kg	0.39	0.23	0.30	0.28	0.06	0.00	0.00
Truck 2-3000 kg	0.47	0.27	0.37	0.34	0.07	0.00	0.00
Truck 3-4000 kg	0.55	0.32	0.43	0.40	0.09	0.00	0.00
Truck 4-10000 kg	0.79	0.46	0.61	0.57	0.12	0.00	0.00
Truck 10-16000 kg	1.10	0.64	0.85	0.79	0.17	0.00	0.00
Truck 16-18000 kg	1.38	0.80	1.07	0.99	0.22	0.00	0.00
Truck 18-22000 kg	1.50	0.87	1.16	1.08	0.24	0.00	0.00
Truck > 22000 kg	1.77	1.03	1.37	1.27	0.28	0.00	0.00
Buss 16-17000 kg	1.46	0.84	1.13	1.05	0.23	0.00	0.00
Van 1500 kg	0.32	0.18	0.24	0.23	0.05	0.00	0.00
Van >3500 kg	0.55	0.32	0.43	0.40	0.09	0.00	0.00
A-segment	0.19	0.11	0.15	0.13	0.03	0.00	0.00
B-segment	0.22	0.13	0.17	0.13	0.03	0.00	0.00
C-segment	0.23	0.14	0.18	0.16	0.04	0.00	0.00
D-segment	0.30	0.17	0.23	0.18	0.05	0.00	0.00
E-segment	0.35	0.20	0.27	0.24	0.05	0.00	0.00
F-segment	0.38	0.22	0.29	0.27	0.06	0.00	0.00
J-segment	0.45	0.26	0.35	0.32	0.07	0.00	0.00
M-segment	0.27	0.16	0.21	0.19	0.04	0.00	0.00
S-segment	0.36	0.21	0.28	0.26	0.06	0.00	0.00

Table 0.4: Abiotic depletion potential emissions per kilometer

Abiotic Depletion Potential	Gasolone	Hybrid Methane	Hybrid Gasoline	Diesel	Methane	Electricity	Hydrogen
Truck < 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck 2-3000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck 3-4000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck 4-10000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck 10-16000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck 16-18000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck 18-22000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Truck > 22000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Buss 16-17000 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Van 1500 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Van >3500 kg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
E-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
J-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S-segment	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX B: FUEL REQUIRED PER 100 KM

Fuel usage per 100 km	Gasoline [l]	Gasoline (methane) [l]	Methane (Gasoline) [l]	Hybrid Gasoline [l]	Diesel [l]	Ethanol [l]	Methane [kg]	Electricity [kWh]	Hydrogen [kg]
Truck < 2000 t	12.4	6.2	7.7	9.6	8.0	18.8	15.3	99.8	1.3
Truck 2-3 t	14.9	7.5	9.2	11.5	9.6	22.6	18.4	119.8	1.6
Truck 3-4 t	17.4	8.7	10.7	13.4	11.2	26.4	21.4	139.8	1.8
Truck 4-10 t	24.9	12.4	15.3	19.2	16.0	37.7	30.6	199.7	2.6
Truck 10-16 t	34.8	17.4	21.4	26.9	22.4	52.7	42.9	279.6	3.7
Truck 16-18 t	43.5	21.8	26.8	33.6	28.0	65.9	53.6	349.5	4.6
Truck 18-22 t	47.2	23.6	29.1	36.5	30.4	71.5	58.2	379.4	5.0
Truck > 22 t	55.9	28.0	34.4	43.2	36.0	84.7	68.9	449.3	5.9
Buss 16-17 t	46.0	23.0	28.3	35.5	29.6	69.7	56.6	369.4	4.9
Van 1500 kg	9.9	5.0	6.1	7.7	6.4	15.1	12.2	79.9	1.1
Van >3500 kg	17.4	8.7	10.7	13.4	11.2	26.4	21.4	139.8	1.8
A-segment	6.0	3.0	3.7	4.6	3.6	8.5	7.4	48.3	0.6
B-segment	6.8	3.4	4.2	5.3	3.6	8.6	8.4	54.9	0.6
C-segment	7.4	3.7	4.5	5.7	4.5	10.6	9.1	59.3	0.7
D-segment	9.4	4.7	5.8	7.3	5.2	12.2	11.6	75.5	0.9
E-segment	10.9	5.5	6.7	8.5	6.6	15.6	13.5	87.9	1.1
F-segment	11.9	5.9	7.3	9.2	7.6	17.8	14.6	95.4	1.2
J-segment	14.2	7.1	8.8	11.0	9.2	21.6	17.5	114.3	1.5
M-segment	8.5	4.2	5.2	6.5	5.5	12.8	10.4	68.0	0.9
S-segment	11.5	5.7	7.1	8.9	7.4	17.4	14.2	92.4	1.2

APPENDIX C: OVERALL RESULTS AP, EP, POCP AND ADP.

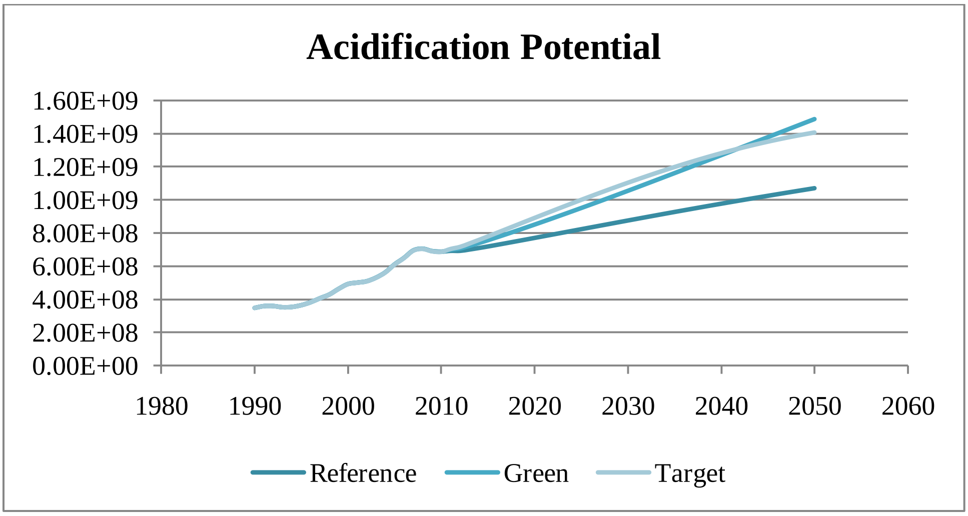

Figure A: Total acidification potential from the Icelandic vehicle fleet

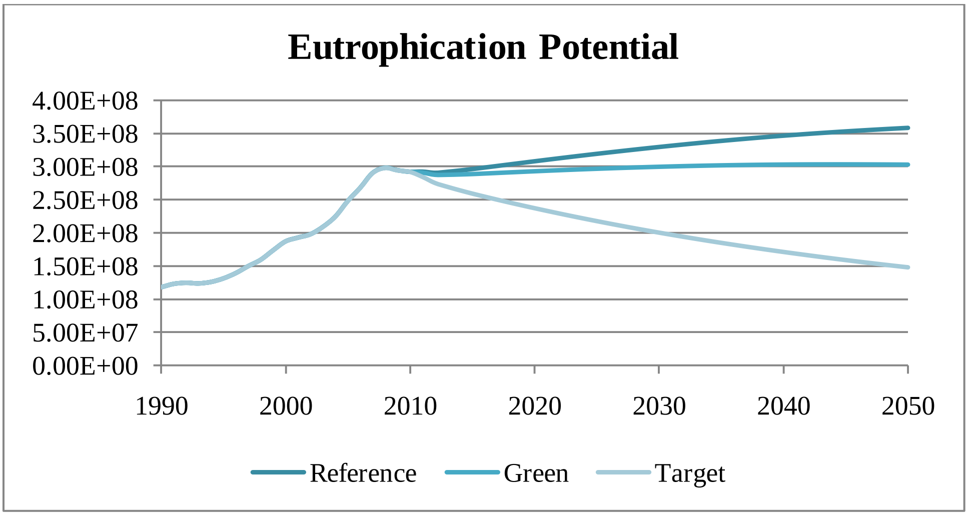

Figure B: Total eutrophication potential from the Icelandic vehicle fleet

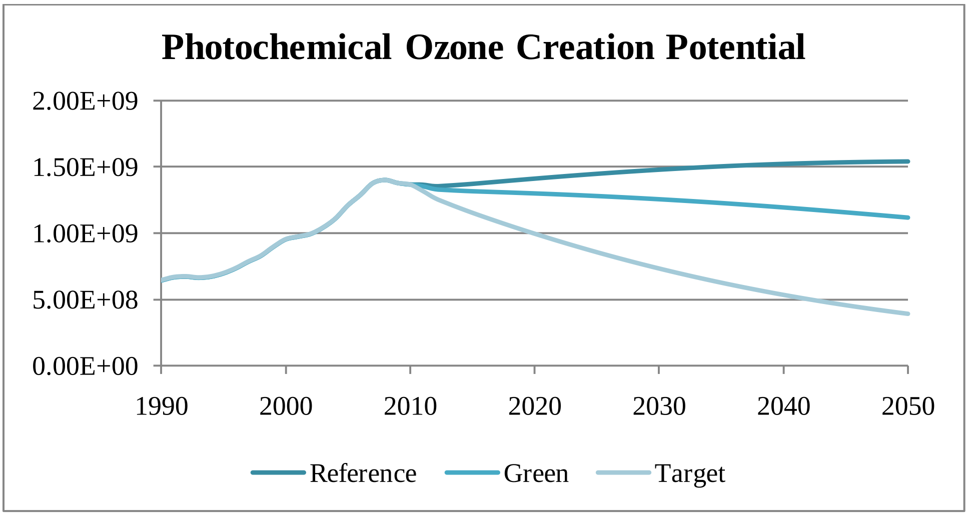

Figure C: Total photochemical ozone creation potential from the Icelandic vehicle fleet

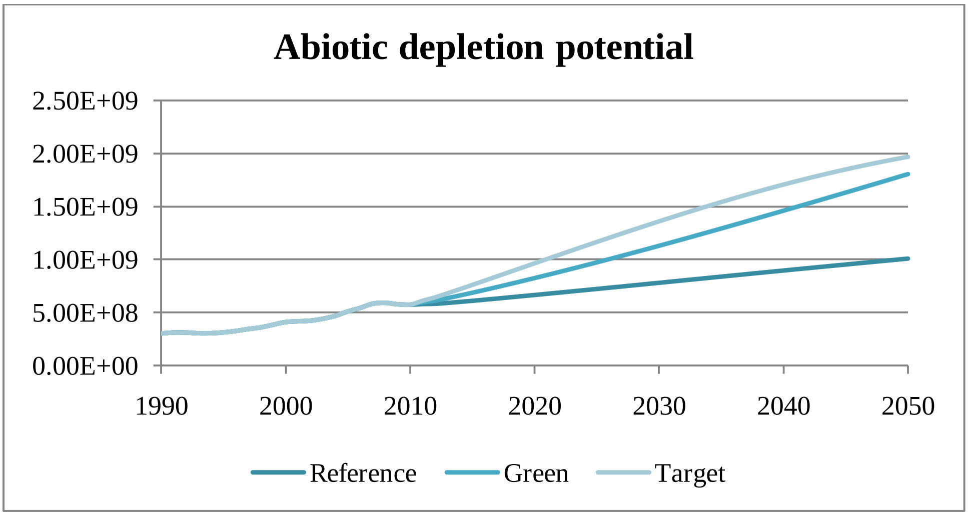

Figure D: Total abiotic depletion potential from the Icelandic vehicle fleet