CHALMERS

Environmental Aspects of Freight Transportation

A comparison of heavy duty trucks driven on either electricity or diesel in scenarios for the year 2035 along the I-710 corridor in Los Angeles, California, US

Master of Science Thesis in the Master Degree Programme; Sustainable Energy Systems

JOHANNA SEEBERGS

Department of Energy and Environment
Division of Physical Resource Theory
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2013
Report No. 2013:11

REPORT NO. 2013:11

Environmental Aspects of Freight Transportation

A comparison of heavy duty trucks driven on either electricity or diesel in scenarios for the year 2035 along the I-710 corridor in Los Angeles, California, US

Supervisors:
Ass. Prof. Jie (Jane) Lin
University of Illinois at Chicago
Chicago, United States of America
Maria Grahn
Chalmers University of Technology
Gothenburg, Sweden

Examiner:
Ulrika Lundqvist
Chalmers University of Technology
Gothenburg, Sweden

JOHANNA SEEBERGS
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2013

Environmental Aspects of Freight Transportation
A comparison of heavy duty trucks driven on either electricity or diesel in scenarios for the year 2035 along the I-710 corridor in Los Angeles, California, US
JOHANNA SEEBERGS

Technical report no. FRT 2013:11
Department of Energy and Environment
Division of Physical Resource Theory
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Research performed at
Department of Civil and Materials Engineering
University of Illinois at Chicago
842 W Taylor Street
Chicago, IL 60607
United States of America

Chalmers Reproservice
Gothenburg, Sweden 2013

Environmental Aspects of Freight Transportation
A comparison of heavy duty trucks driven on either electricity or diesel in scenarios for the year 2035 along the I-710 corridor in Los Angeles, California, US
JOHANNA SEEBERGS
Department of Energy and Environment
Chalmers University of Technology

Abstract

The use of energy results in different kinds of emissions and the transportation sector is a large contributor. In today's society, for environ-mental and health reasons, it is of high importance to reduce these emissions.

In Los Angeles, California, there is a congested highway, the interstate 710, which is connected to the ports of Los Angeles and Long Beach where a lot of the traffic consists of trucks transporting goods from the ports into the country. To deal with the congestion there is a project called the I-710 corridor project which is looking into reconstructing the highway with a couple of options. The state of California is among the leaders of reducing the environmental impact from transport and among the options there are suggestions to connect electricity to the highway to make it possible for electric trucks to fully run on electricity while driving on the I-710.

The purpose of this study was to make a comparison of the environmental impact of trucks driving along I-710 using the different energy options diesel, which is the most common fuel among trucks today, and electricity in scenarios for the year 2035. This was made by performing a life cycle assessment (LCA) with the help of the programs MOVES and GREET.

The results show that using electricity instead of diesel leads to that about a third less energy is needed, about half the amount of greenhouse gases are emitted and that about a fifth up to half of CO, VOC and NO_x are emitted while emissions of particulate matter as well as SO_x are slightly increased.

With these results, the overall finding is that to use electric (hybrid) trucks on the I-710 instead of diesel trucks is a good option for the environment, both locally and globally.

Key words: electric trucks, air quality, the I-710 corridor project, greenhouse gases, MOVES, GREET, electricity vs. diesel, California

Acknowledgement

I would like to start with the greatest thank you to Ass. Prof. Jie (Jane) Lin for having me and letting me perform my Master's thesis within her group at the Department of Civil and Materials Engineering at the University of Illinois at Chicago, and for guiding me along the way.

A big thank you also to my supervisor Maria Grahn who has been a great support and who has helped me a lot, day and night, with making the report look just as good as possible.

I would also like to thank my examiner Ulrika Lundqvist who helped me with the final touch of the report.

At last I would like to send a big thank you to Per Nilsson with family for letting me stay at their place for some time as well as helping me break in to the American atmosphere.

List of Abbreviations and Acronyms

ARB California Air Resources Board

BTU British Thermal Unit

CFCs Chlorofluorocarbons
CH_4 Methane
CO Carbon monoxide
CO_2 Carbon dioxide

EIR Environmental Impact Report
EIS Environmental Impact Statement
EPA United States Environmental Protection Agency

FHWA (U.S. Department of Transportation) Federal Highway Administration

GREET The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
GVWR Gross Vehicle Weight Rating

I-710 Interstate 710

HEV Hybrid electric vehicle
HFCs Hydrofluorocarbons

LSD Low sulfur diesel

MOVES Motor Vehicle Emission Simulator
mpg Miles per gallon

N_2O Nitrous oxide
NO_x Nitrogen oxides

Pb Lead
PFCs Perfluorocarbons
PM Particulate matter
POLA Port of Los Angeles
POLB Port of Long Beach
PZEV Partial Zero Emission Vehicles

O_3 Ozone

SF_6 Sulfur hexafluoride
SO_x Sulfur oxide

VMT Vehicle Miles Travelled
VOC Volatile Organic Compounds
WTW Well-to-wheel

ZEV Zero Emission Vehicles

List of Tables

List of Figures

Table of Contents

1 Introduction

The World's population is growing which results in expanding cities and the need of transportation in all forms is increasing. Transportation is such a big sector today that the society is depending on it. If people cannot move or goods cannot be transported, the evolution of technology would take a step backwards.

In this report the focus will be on the freight transportation where trucks are used, which is the most common way of transporting freight, on a continent, since it is a very flexible mode whereas the trucks can in a big extent reach the end destination as a single transportation mode which facilitates the transportation process.

Besides being an important tool of transportation the trucks also has side effects, for example, the trucks are influencing the traffic and contributing to congestions and heavy duty trucks are also often involved in severe accidents because of the big difference in mass between a truck and a car. Trucks are also forced by American laws to stay in the two most right lanes slowing down the traffic where most of the traffic is getting on and off the highway at ramps. Above this, trucks generate a lot of noise affecting the nearest surroundings and they also emit a lot of pollutants, which both affects the environment on a local level but also on a global level. A big issue with emissions from the transportation sector is that some of these are causing global warming. The transportation sector is the only sector today that is actually still increasing in amount of emitted greenhouse gases and is also one of the largest emitter of anthropogenic greenhouse gases [1].

In Los Angeles, California, there is an interstate freeway connecting the city of Long Beach to central Los Angeles and beyond, this freeway is called I-710 or more casually the Long Beach Freeway. The I-710 corridor has today practically the same design as when it was first built in the 1950s and 1960s and with the massive expansion of the city (growth in population/employment), and with an increase in goods and passenger movement, the freeway has come to suffer from serious traffic congestion because of the increased traffic volume. Further, with congestion come other problems, such as increased levels of health risks related to high levels of diesel particulate emissions and a high accident rate. So, because of the severe congestion on the I-710 the 'California Department of Transportation (Caltrans), in cooperation with the Los Angeles County Metropolitan Transportation Authority (Metro), the Gateway Cities Council of Governments (GCCOG), the Southern California Association of Governments (SCAG), the Ports of Los Angeles (POLA) and Long Beach (POLB) (collectively known as the Ports), and the Interstate 5 Joint Powers Authority (I-5 JPA) (collectively referred to as the I-710 Funding Partners), proposes to improve Interstate 710 in Los Angeles County between Ocean Blvd. and State Route 60 (SR-60)' [2]. The purpose of the I-710 corridor project is to 'improve air quality and public health, improve traffic safety, modernize the freeway design, accommodate projected traffic volumes, and accommodate project growth for population, employment, and economic activities related to goods movement' [2]. A map of the project area can be seen in Figure 1.

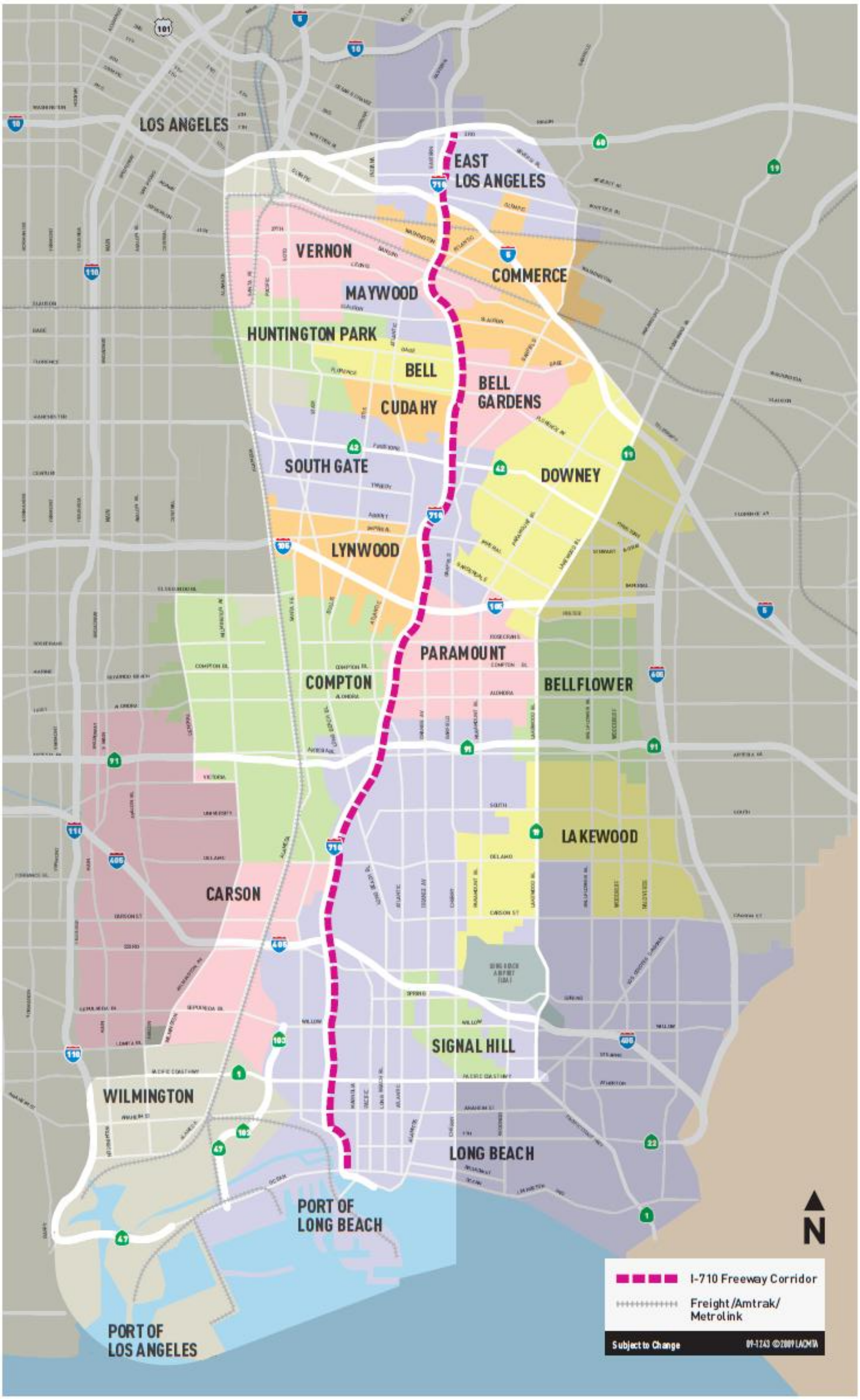

Figure 1: Map of the I-710 corridor project study area [3].

The I-710 corridor project includes four build alternatives and one non-build option, where the non-build option is to leave the freeway as it is today and that option is used as a reference against the other alternatives. The four construction alternatives are called 5A, 6A, 6B and 6C, see Table 4 for more information, but this study was made with the alternative 6B in mind. In short, alternative 6B means extending the freeway to five lanes in each direction and build a separate freight corridor aimed specifically for zero emission trucks with electrical transmission lines, the schematics of the road building alternative 6B can be seen in Figure 2. With this alternative only zero emissions trucks will be allowed to use the freight corridor while the rest of the trucks will continue to use the ordinary lanes.

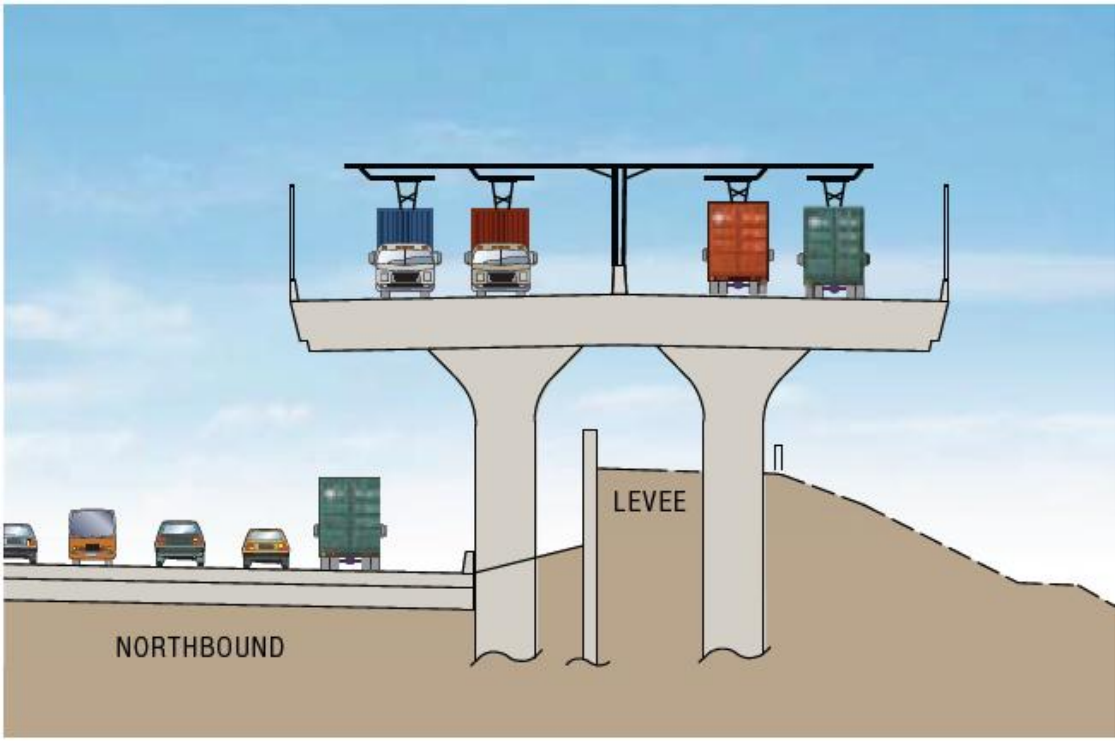

Figure 2: Schematics of alternative 6B as seen in a cross section of one direction of the road [2].

1.1 Purpose and limitations

The purpose with this study is to make a comparison of what effects there would be regarding energy use, climate impact and air quality (environmental aspects) if heavy duty trucks were to be driven by a hundred percent of electricity instead of diesel in scenarios for the year 2035 along the I-710 in Los Angeles, California, US. This comparison will be made by performing a life cycle assessment including energy use and emissions from well (resource depletion) to wheels (vehicle operation) for traffic flows in the years of 2008 and 2035.

This study will focus on heavy duty trucks, meaning that passenger cars, rail, air and ships will not be evaluated.

A comparison of environmental impacts will be on electrified (hybrid) trucks versus standard diesel trucks and in this study other fuels will not be evaluated.

Under the term 'environmental impacts' in this report, emissions affecting air quality (O_3 [VOC + NO_x], PM, CO, NO_x, SO_x and Pb) and emissions affecting global warming (CO_2, CH_4 and N_2O) as well as noise (only mentioned, not quantified or evaluated) and energy use will be included. Indirect effects such as health effects, water pollutants, cost etc. will not be subject to this study.

Since the I-710 corridor project is located in Los Angeles, California, data for the region of California will be used.

2 Theory

To transport goods there are several options and the main modes of freight transportation includes; road, rail, air and sea transportation (also pipelines can be counted as a mode and furthermore there is also an option to use multiple transportation modes which means two or more modes are used for one shipment), but trucks is the dominant mode of freight transportation in the US.

In 2007 the total weight of goods transported were 12,543 million tons[1] (11,379 million tonnes) corresponding to 3,345 billion ton-miles, of these amounts 8,779 million tons (7,964 million tonnes) of goods corresponding to 1,342 billion ton-miles were transported by trucks[2]. So, for 70 % of the goods on a weight basis the transportation mode of trucks is the most common. But when comparing on a weight and distance basis trucks and trains[3] are in a tie with 40 % share of the market each, for numbers used. If looking at the average mileage per shipment, one can also see why the rail mode reaches up to the same levels as the trucks regarding the ton-miles basis, i.e. the distance for the shipping by trains is bigger than for the trucks where the trains have an average per shipment of 728 miles whereas the trucks has an average per shipment of 206 miles. All of these numbers can be seen in Table 1 through Table 3.

As a side comment, it can also be mentioned that while the amount of truck and rail transportations has increased, the amount for air and water shipments has decreased between the years of 1997 and 2007, see Table 1 and Table 2

Table 1: Amount of goods, based on weight, shipped in the US divided by the four main modes between the years of 1997 and 2007 [4].

	Tons (millions)				
	1997	2002	2007	Average annual percent change	Market share (2007)
All modes	11,090	11,668	12,543	1.2 %	100.0 %
Truck	7,701	7,843	8,779	1.3 %	70.0 %
Rail	1,550	1,874	1,861	1.8 %	14.8 %
Water	563	681	404	-3.3 %	3.2 %
Air (incl. truck and air)	4.5	3.8	3.6	-2.2 %	0.0 %

[1] 1 ton = 1 short ton = 2,000 lbs = 907.2 kg ≈ 0.9 tonnes

[2] In the term trucks here, all classes of trucks are included, but only trucks used as a single mode, i.e., trucks used in multimodal transportation, such as truck and rail combined are excluded.

[3] As a single mode, multimodal trains are not included.

Table 2: Amount of goods, based on distance travelled with the weight, shipped in the US divided by the four main modes between the years of 1997 and 2007 [4].

Ton-miles (billions)					
	1997	2002	2007	Average annual per-cent change	Market share (2007)
All modes	2,661	3,138	3,345	2.3 %	100.0 %
Truck	1,024	1,256	1,342	2.7%	40.1 %
Rail	1,023	1,262	1,344	2.8 %	40.2 %
Water	262	283	157	-5.0 %	4.7 %
Air (incl. truck and air)	6.2	5.8	4.5	-3.2 %	0.1 %

Table 3: Average distance travelled for goods shipped in US divided by the four main modes between the years of 1997 and 2007 [4].

Average miles per shipment				
	1997	2002	2007	Average annual percent change
All modes	472	546	619	2.7 %
Truck	144	173	206	3.6 %
Rail	769	807	728	-0.5 %
Water	482	568	520	0.8 %
Air (incl. truck and air)	1,380	1,919	1,304	-0.6 %

Within road transportation there is also different types of vehicles, which are stated as light duty, medium duty and heavy duty trucks. Here the attention will be on the heavy duty trucks which by the US definition are trucks with a minimum GVWR (Gross Vehicle Weight Rating[4] [5]) of 26,001 lbs[5] (Class 7) and 33,001 lbs (Class 8) [6].

The trucks can then also be divided into single-unit trucks and combination trucks, which basically mean that the truck either is built in one part or with trailer(s). For this project, both single-unit and combination trucks will be accounted for.

2.1 Transportation in California

The city of Los Angeles with suburbs is growing (even though the expansion of the inner city itself is nearly fully developed) and the distances between jobs and housing are increasing. This together with that there is a lack of mass transit and that there are a large number of sport utility vehicles running on the roads, the demand for gasoline and diesel is rising [1].

The state of California is in the lead in US regarding alternative fuels, as for example; in California in 2012 there were 3,549 electric recharging stations, where the state with the second most, Texas, had 1208 electric recharging stations [7]. Also for hydrogen California had the most refueling stations in 2012, in this case a total of 24 stations where the state with the second most, New York, had 9 stations. Although these numbers are the highest in California, the main reason why there are so many more hydrogen recharging

[4] The gross vehicle weight rating is the maximum number that the gross vehicle or trailer weight should never exceed

[5] 1 lbs ≈ 0.454 kg

stations in California and New York is because this is where the most research about the topic are located.

The spread of electric and hydrogen recharging stations, in the US, can be seen in Figure 3.

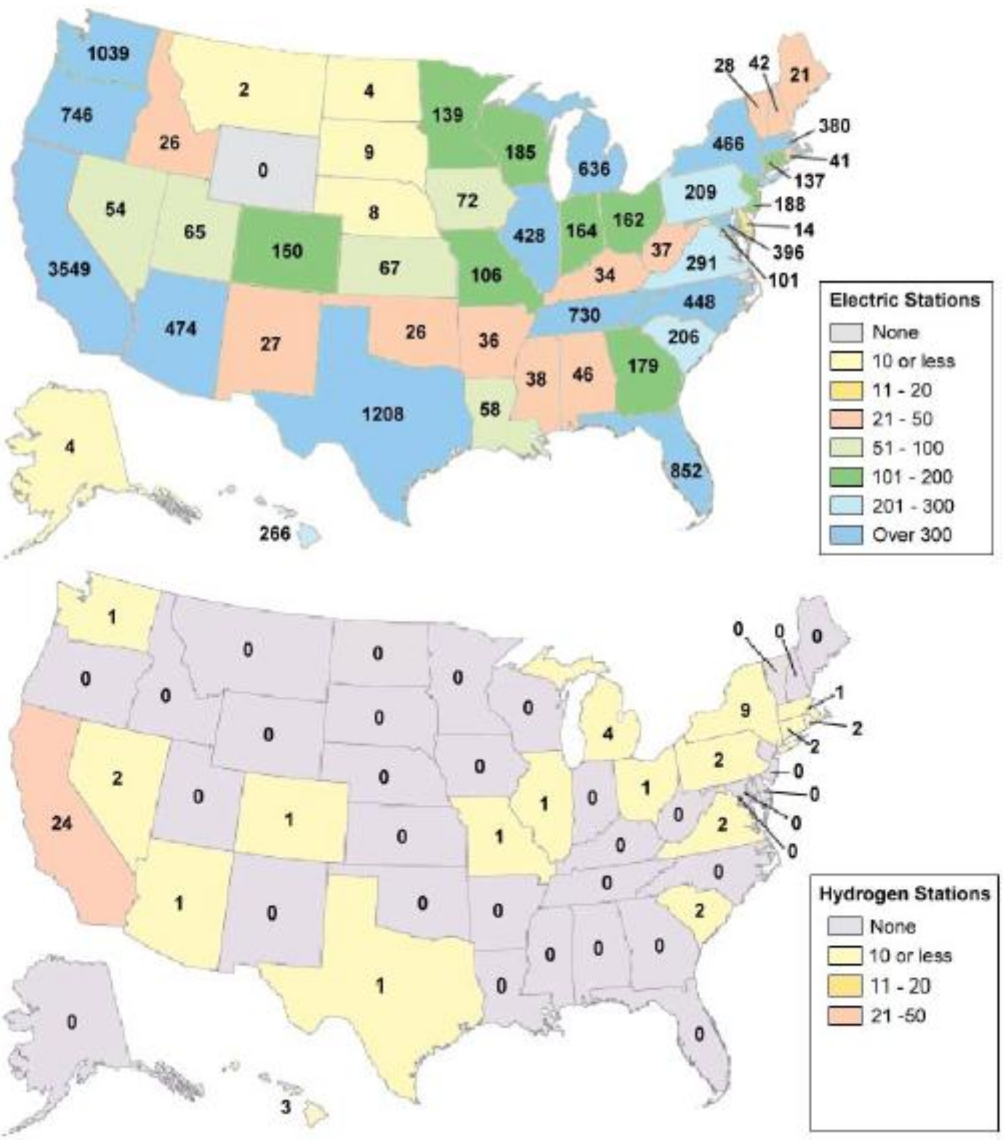

Figure 3: Maps of the US showing numbers of electric and hydrogen recharging stations in the different states. Data as of December 6, 2012 [7].

Above this, the state of California is also known to have strict regulations regarding emissions from and the use of transportation, one of these is the Zero Emission Vehicle (ZEV) regulation which was introduced in 1990 by the California Air Resources Board (ARB). The ZEV regulation is aiming to increase the air quality in California and to reduce emissions of greenhouse gases with a goal that there should be zero vehicle emissions [8] and designates that vehicle manufacturers have to produce a certain amount of ZEVs every year. At first there was an intention that the amount of ZEVs that had to be produced should increase stepwise but that was in 1996 changed into one requirement of 10 % of the vehicles in a large manufacturers' production should be ZEVs in 2003.

Even though the program did not end up as intended, it has been of great importance in reaching the goals of reducing the environmental effects in California since it has spurred many new technologies to be used on Californian roads [9]. For instance, there are today more than 400,000 gas-electric hybrid vehicles on California's roads.

However, the Zero Emission Vehicle regulation does only include the light duty vehicle sector and does not affect the heavy duty trucks which are the focus of this study.

The I-710 corridor project

The I-710 corridor, or the Long Beach Freeway, is a highway in the county of Los Angeles and is today more trafficked than it was originally designed for whereas today the excessive traffic is contributing to congestion. The I-710 was built in the 1950s and 1960s, and to cope with the still increasing traffic volume it is time to act to make it more accessible again; hence, the I-710 corridor project was introduced. With the I-710 corridor project the initiators describes the purpose as to (as gathered from the project description [2]); 'improve air quality and public health, improve traffic safety, modernize the freeway design, accommodate projected traffic volumes, and accommodate project growth for population, employment, and economic activities related to goods movement'.

A main reason for the heavy traffic volume on the highway is the large amount of trucks running on it, see Figure 4 for an example of how the I-710 corridor can look like, which both takes up a lot of space and slows down the traffic. A lot of the trucks running on the I-710 are related to the ports located in the south end of the I-710, and with the increasing amount of goods being imported and unloaded at the ports in Los Angeles also the amount of trucks has increased.

Figure 4: An example of what the traffic on the I-710 corridor can look like. Photo gathered from the I-710 corridor project EIR/EIS (Environmental Impact Report/Environmental Impact Statement) [2].

To improve the highway several alternatives were evaluated and in the current stage of the investigation of the I-710 corridor project there are five alternatives left and still in consideration, the most interesting changes connected to the options related to the subject of this report are listed below in Table 4; (for the I-710 corridor project the highway has been sectioned in two; south of I-405 and north of I-405, where the I-405 is another interstate highway intersecting with the I-710).

Table 4: A brief overview of the construction planned for the alternatives 1, 5A, 6A, 6B and 6C of the I-710 corridor project.

Construction Alternatives	
Alternative 1	Keeping the highway as it is, which means three lanes wide (in each direction) south of the I-405 and four lanes wide north of the I-405. Alternative 1 is used as reference for the new constructing alternatives, i.e., alternatives 5A to 6C.
Alternative 5A	Widen the highway to four lanes south of I-405 and five lanes north of I-405.
Alternative 6A	Same extension of the lanes as in Alternative 5A, plus the building of a new external freight corridor.
Alternative 6B	Same as Alternative 6A but the freight corridor will only be used by zero-emission vehicles.
Alternative 6C	Same construction as Alternative 6B but there will also be a toll for using the freight corridor.

Of these alternatives, this study will be made with Alternative 6B in mind, where the freight corridor will only be used for zero-emission freight vehicles, e.g., electrified trucks.

2.2 Congestion

Traffic congestion occurs when there is more traffic on a road than the road can handle; here the I-710 was built in the 1950s and 1960s and since then the city has grown significantly, thus increasing the amount of travels made every day and as a consequence the amount of congestion has increased as well since the road wasn't originally designed for this amount of traffic load.

Today California's roads are the most congested roads in the US and the inhabitants of California spends approximately 854 million hours a year more on the roads than they should necessarily have to [10]. Los Angeles as a city ends up as the number two most congested city in the US with 61 wasted hours per auto commuter and year due to congestion in 2011, only after Washington which spent in average 67 hours per auto commuter and year [11]. In Los Angeles, this corresponds to 436 pounds (198 kg) extra emissions of CO_2 per auto commuter and year, in total for Los Angeles the CO_2 emitted due to congestion were 3,578 million pounds (1,622 thousand tonnes) [11].

With congestion comes problems; first of all time goes lost which could have been used to other things, e.g., getting more work done or spend time with the family, and it can also cause frustration and anger among the drivers. Above this, congestion also affects the amount of pollutants on the roads since the vehicles get stuck there longer than necessary.

To deal with congestion there are different methods that can be used. One solution could be to extend the road, i.e., to make it wider allowing more vehicles to pass per time unit. Furthermore, policy instruments can be used to make people/companies choose other transportation modes, for example by implementing a tax on the road making it more expensive to use, put a tax on fuel, subsidize other modes etc. which would encourage drivers to use another mode for transportation.

2.3 Energy

Currently, the dominating fuel used in the freight transportation sector is oil-based diesel[6]. In this study an emission comparison will be made where all trucks driving on the I-710 are driven on either diesel or electricity. Read more about the two energy options below.

2.3.1 Petroleum related to the transportation sector

In 2010 and 2011 the transportation sector were accounted for 69.4 % (12.68 million barrels per day) [4] of all the petroleum consumption in the US (18.28 million barrels per day). Of the total petroleum consumption within the transportation sector in 2010 the heavy duty trucks accounted for 17.5 % (2,375 thousand barrels per day) and in total the heavy duty trucks consumed about 12.4 % of all the petroleum consumption in the whole US [4]. The total petroleum production in US was in 2011 7.85 million barrels per day [4] meaning that the transportation sector actually consumes more petroleum than the US is producing every day, see comparison in Figure 5.

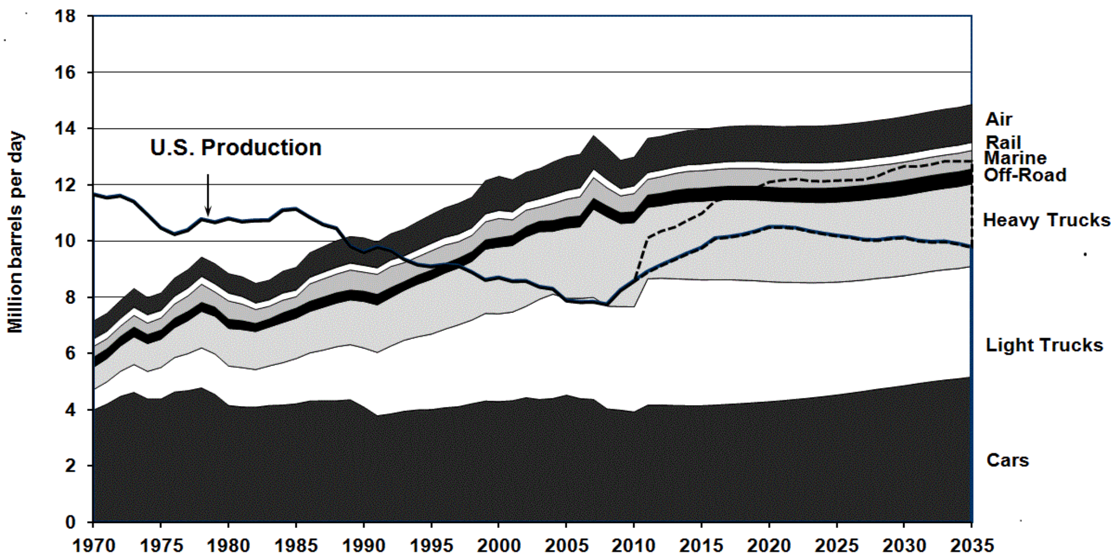

Figure 5: US petroleum production and consumption within the transportation sector from 1970 until today combined with a prognosis for up to year 2035 [4].

In Figure 6 the total petroleum production can be compared with the total consumption over the different sectors and here it is clearly shown that the dominating sector of

[6] In the US the amount of fuel used are commonly measured in British thermal units (BTU) where one BTU equals between 1054 and 1060 Joule, as a conversion factor used in this study the number of 1055 Joules per BTU has been used.

petroleum use is the transportation. Observe that the curve for the transportation sector is the same as in Figure 5, but specified for the specific transportation modes.

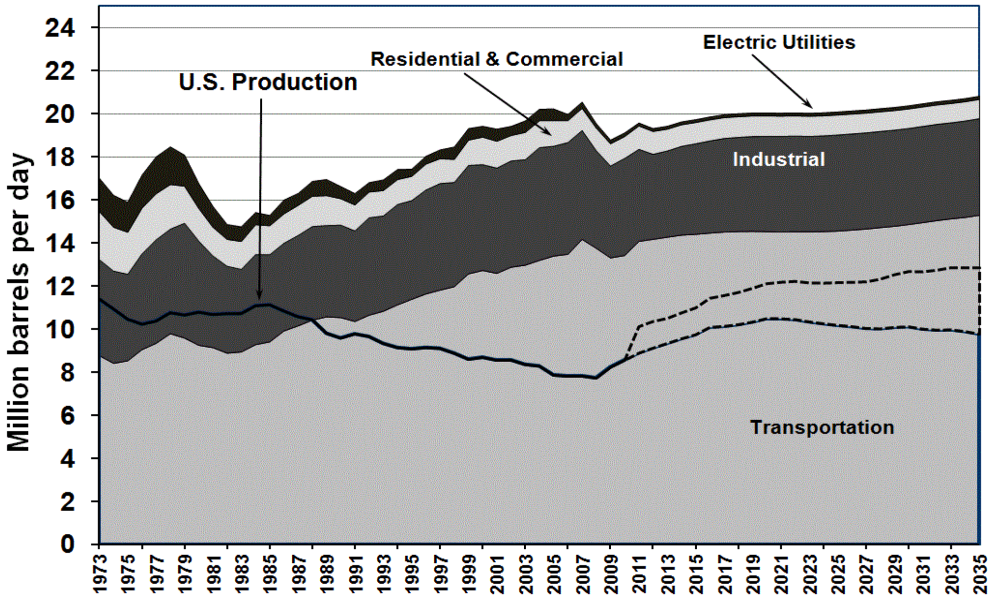

Figure 6: US petroleum production and consumption from 1973 until today combined with a prognosis for up to year 2035 [4].

In California, 96 % of all fuel used within the transportation sector is petroleum-based, making it vulnerable to supply and price changes [1] and supplementing fuels are therefore desirable to be developed and integrated.

Diesel

Diesel is today the most common fuel used for heavy duty trucks as the diesel engines have a very high compression ratio resulting in that the diesel engines has the highest thermal efficiency of any regular internal or external combustion engine [12]. But when looking at emissions, diesel emits more carbon dioxide per weight unit of fuel than for example gasoline, liquefied petroleum gas and even jet fuel, the numbers can be seen in Table 5.

Table 5: Carbon dioxide emissions from a gallon[7] of fuel [4].

Carbon Dioxide Emissions from a Gallon of Fuel		
	Kilograms	Pounds
Gasoline	8.8	19.4
Diesel	10.1	22.2
LPG	5.8	12.8
Propane	5.8	12.7
Aviation gasoline	8.3	18.4
Jet fuel	9.6	21.1
Kerosene	9.8	21.5
Residual fuel	11.8	26.0

Furthermore diesel is a fossil fuel and the amount of fossil fuels on Earth is limited (since they reproduce over such a long amount of time which makes fossil fuels go under the term non-renewable energy sources) and it is therefore essential that the energy supply sooner or later must be produced from renewable resources. Therefore, in a try to reduce the amount of fossil fuels one of the alternatives for the reconstruction is to build an external truck corridor along the I-710 which would support "on-the-run" charging of electric trucks.

2.3.2 Electricity

Electricity per se is not a renewable energy carrier, but can be produced from renewable sources. Whether the electricity is green or not therefore depends on the energy resources that are used in the production of the electricity. Meaning that electricity can be either non-renewable, if produced by fossil fuels, or renewable, if produced by renewable energy resources such as solar or wind power. As for example, in California the electricity use is generated from a mix of different energy resources, which can be seen in Table 12 on page 30 and there it can be seen that in 2008 about a fifth originates from renewable resources which is more than for the diesel fuel which is completely dominated by fossil fuels. If including non-renewable but low emitting sources, i.e., nuclear energy, the amount would be about a third of the total mix.

When using electricity to run a vehicle there are no direct running emissions at the end-user side, making it optimal to use where it is important to keep the air clean. Electricity is usually seen as environmentally friendly for that reason, but as mentioned it is also important to know from what sources the electricity originates.

Hybrid Electric Vehicles

To run a vehicle with electricity as the only energy source can be difficult, since it will require a big and heavy battery. As of now, there is not a sufficient amount of recharging stations so that the vehicles can recharge as often as they need (in 2012 there were only eight electric refueling stations for trucks in the whole California [7]). Furthermore,

[7] 1 gallon ≈ 3.79 liter

charging a battery in an electric vehicle takes longer time than refueling a diesel or gasoline vehicle.

So while in the startup process of introducing electric vehicles it is an option to make the electric vehicles as hybrids, i.e., hybrid electric vehicles (HEVs). By making the vehicles hybrid it is possible to get the advantages from two energy options in one, the vehicle can be run on electricity when possible, and when needed, for example while looking for a recharging station, the vehicle can be run on the other option, in this case diesel.

Hybrid trolley trucks

Alternative 6B in the I-710 corridor project, see Table 4, includes the building of an external truck corridor for ZEVs which is also meant to include electric power lines connected to the truck corridor so that electric trucks can charge while running along the highway and therefore use a hundred percent electricity while running on the I-710. To be able to use these electric power lines there must be some connection between the truck and the lines and this is proposed to be done with overhead catenary wires similar to trams (or trolley cars) in city cores, so these new kind of trucks could be called, e.g., trolley trucks or tram-trucks.

By making the pantograph flexible it is possible to control when to connect the vehicle to the power lines, which makes it possible to run completely on electricity or on diesel depending on the availability of electric power, e.g., using diesel when the electricity is out or on distances lacking power lines.

One manufacturer of this type of trucks is Siemens [13], and an example of their new technique can be seen in Figure 7.

Figure 7: An example of how a hybrid trolley truck could look like; connected to the grid at the left and without a connection at the right [14]**.**

As the development of this kind of hybrid trolley trucks proceeds and the number of roads supporting the system increases; the trucks can run more and more using electricity and decrease the amount of diesel needed.

2.4 Air pollutants (O_3, CO, NO_x, SO_x, Pb, PM)

The terms of air pollutants can include several different substances, for this project the criteria pollutants included in the National Ambient Air Quality Standards (NAAQS) [15], as defined by the U.S. Environmental Protection Agency (EPA); ozone (O_3) [VOC (volatile organic compounds) + NO_x], carbon monoxide (CO), nitrogen dioxide (NO_2) [results presented in nitrogen oxides (NO_x)], sulfur dioxide (SO_2) [results presented in sulfur oxides (SO_x)], lead (Pb) and particulate matter (PM) [PM10 and PM2.5] are the ones of interest. The transportation sector has a big share for several of these, as for example; the transportation sector was in 2011 responsible for almost two thirds of the national emissions of CO, and more than half of the NO_x emissions, see Table 6 for national shares of CO, NO_x, VOC, PM and SO_2.

Table 6: Emissions from the transportation sector compared to the national values. Data from 2011 [4].

	Millions of short tons[a]/percentage					
Sector	**CO**	**NO_X**	**VOC**	**PM-10**	**PM-2.5**	**SO_2**
Transportation total	38.56	6.11	3.61	0.21	0.19	0.17
	61.8 %	*50.9 %*	*29.8 %*	*2.7 %*	*4.2 %*	*2.1 %*
Total of all sources	62.42	12.01	12.13	7.84	4.63	8.06
	100.0 %	*100.0 %*	*100.0 %*	*100.0 %*	*100.0 %*	*100.0 %*

[a] 1 short ton (or only "ton" in American English) = 2,000 lbs = 907.2 kg

The air pollutants and their effects will be presented in more detail below.

2.4.1 Ozone, O_3

Ozone can be both good and bad, it is needed in the upper atmosphere to protect the Earth from the sun's rays but ozone on a ground level on Earth is one of the main components that are contributing to smog. The ozone is not emitted directly as ozone, but arises from chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOC) and can be extra harmful during hot summer days when the ozone grows faster [16]. The exact production of ozone from NO_x and VOC is unknown and therefore the results were calculated as NO_x and VOC separately and remained separate in the presentation of the result.

Ozone is harmful to the human's body in such a way that it can trigger several different health problems such as chest pain, coughing, throat irritation and congestion when being drawn into lungs, it can also worsen bronchitis, emphysema and asthma [17]. After repeatedly breathing ozone, scar tissue can be permanently attached in the lungs.

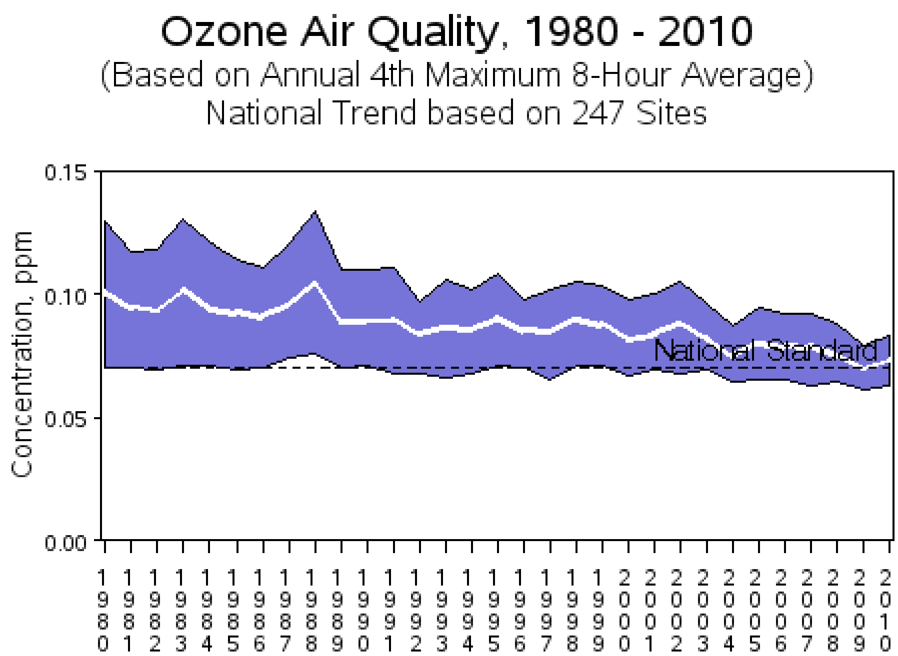

Figure 8: The national trend, based on 247 sites, for ozone in the air between 1980 and 2010 [18]. Based on annual 4th maximum 8-hour average.

2.4.2 Carbon monoxide, CO

Carbon monoxides are emitted directly from the exhaust gas from vehicles. Carbon monoxides are a big health concern since they decrease the amount of oxygen in the inhaled air to the lungs, which in turn gives less oxygen to for instance the heart and brain which can cause serious effects and too much carbon monoxide in the air can even cause death.

Because of the awareness of CO emissions they have since the 1980s been reduced substantially which can be seen in Figure 9 which shows the national trends in CO emissions in the US [19].

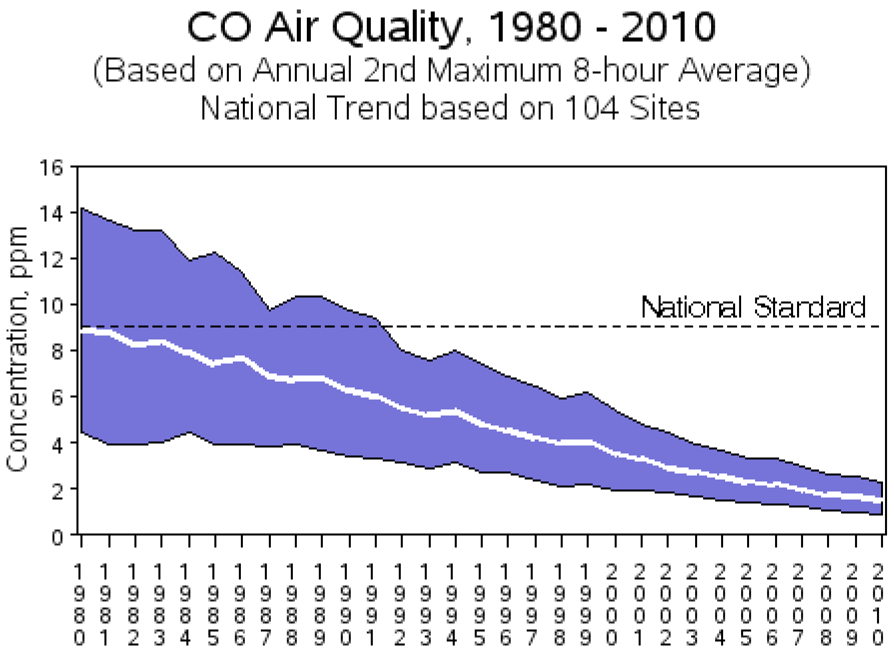

Figure 9: The national trend, based on 104 sites, for CO in the air between 1980 and 2010 [18]. Based on annual 2nd maximum 8-hour average.

2.4.3 Nitrogen oxides, NO_x

The nitrogen oxides include several compounds where the nitrogen dioxide (NO_2) is the largest. Other compounds are, e.g., nitric oxide (NO), nitrous acid and nitric acid [20]. NO_x can be produced directly from for example; vehicles, plants and off-road equipment and will furthermore form ground-level ozone together with VOC, heat and sunlight.

NO_x has been shown to affect the respiratory system causing for example airway inflammation in otherwise healthy people and it can be especially dangerous for elderly and people with asthma.

The concentration of NO_2 has been decreasing in the country because of regulations of the same, the national trend can be seen in Figure 10, and is supposed to further decrease as several new regulations of mobile sources will take effect [20].

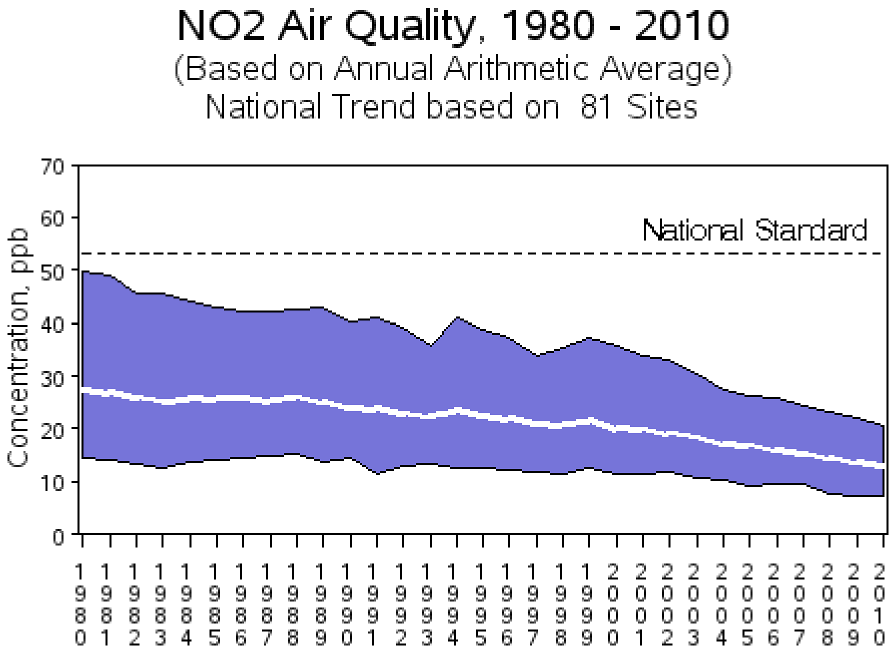

Figure 10: The national trend, based on 81 sites, for NO_2 in the air between 1980 and 2010 [18]. Based on annual arithmetic average.

2.4.4 Sulfur oxides, SO_x

The sulfur oxides, SO_x, are just as nitrogen oxides a collection of different compounds, in this case the sulfur dioxide, SO_2, is the largest, others are for example SO and SO_3. SO_2 are released during combustion of fossil fuels, but can be reduced if removed before burning the fuel. Furthermore, SO_x can also be released at for example metal extraction from ore [21].

SO_x can form small particles when reacting with other compounds and can then penetrate sensitive parts of the lungs and cause health effects such as bronchoconstriction, increased asthma symptoms and can also aggravate an existing heart disease which can lead to premature death.

From 1980 until 2010 the SO_2 concentration has decreased about 83 percent in national average, the national trend of SO_2 concentration can be seen in Figure 11.

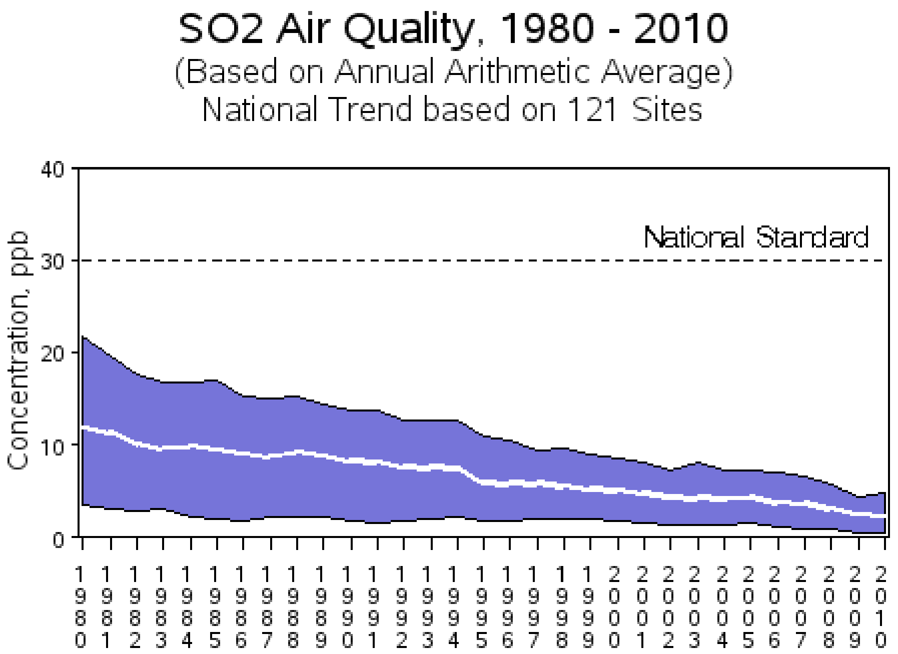

Figure 11: The national trend, based on 121 sites, for SO_2 in the air between 1980 and 2010 [18]. Based on annual arithmetic average.

2.4.5 Lead, Pb

Lead is a metal and is one of the six most common air pollutants, but not much of it is related to the on-road transportation, most of it originates from the aircraft. Above that, the highest air concentrations of lead are found near lead smelters [22].

Lead in the blood system accumulates in the bones and can affect the nervous system, kidney function, immune system reproductive and developmental systems and the cardiovascular system. Having lead in the blood system does also affect the oxygen carrying capacity of the blood.

To mention is that historically on-road motor vehicles was a big contributor to lead emissions but regulations made by the EPA has successfully removed lead from on-road vehicle gasoline, resulting in a decrease of about 95 percent in lead emissions from the transportation sector between 1980 and 1999 [22]. The decline in national average of lead concentration in the air can be seen in Figure 12.

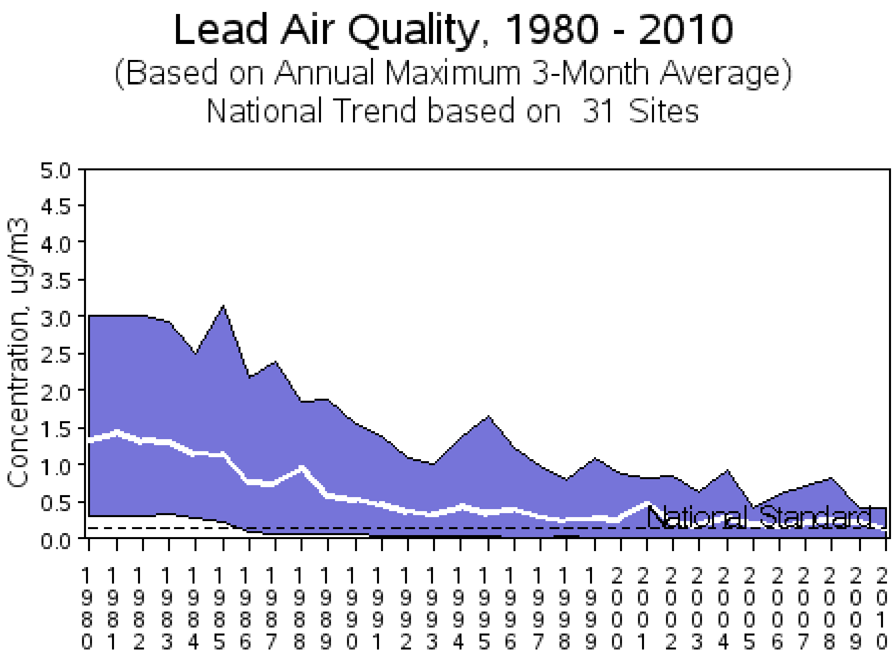

Figure 12: The national trend, based on 31 sites, for lead in the air between 1980 and 2010 [18]. Based on annual maximum 3-month average.

2.4.6 Particulate matter, PM

Particulate matter, PM, is a mixture of extremely small particles and liquid droplets in the air which includes acids, organic chemicals, metals and soil or dust particles among others, they are not necessarily visible to the eye but can be where there is heavy pollution. The PM are usually divided in two sections; PM10 and PM2.5, which reflects the size of the particles; PM10 are particles less than 10 micrometers and PM2.5 are particles less than 2.5 micrometers.

Particulate matter can arise directly from a source, such as construction sites or smokestacks but can also get formed in the atmosphere when chemicals react with each other. These particles, less than 10 micrometers, can be dangerous because they are so small and have the possibility to pass down to the lungs and in some cases also get through to the blood system. Inhaling PM can thus cause serious health problems such as for example heart attacks, decreased lung function and aggravated asthma [23].

The decline in national average of PM concentration in the air can be seen in Figure 13 and Figure 14. Observe that the data for PM2.5 starts in 2000 since it was first about then they realized that it was the smallest particles that were the most dangerous.

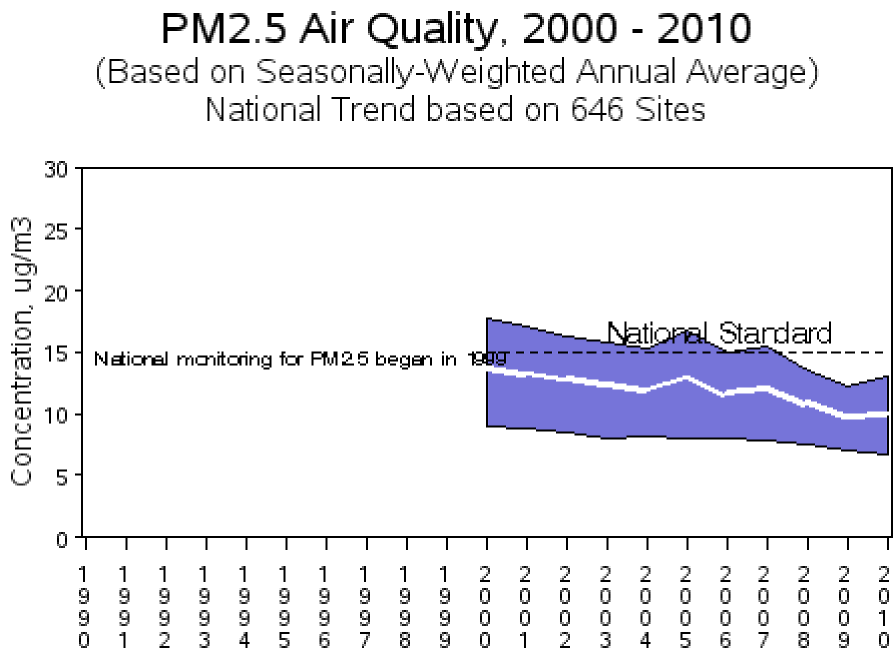

Figure 13: The national trend, based on 646 sites, for PM2.5 in the air between 2000 and 2010 [18]. Based on seasonally-weighted annual average.

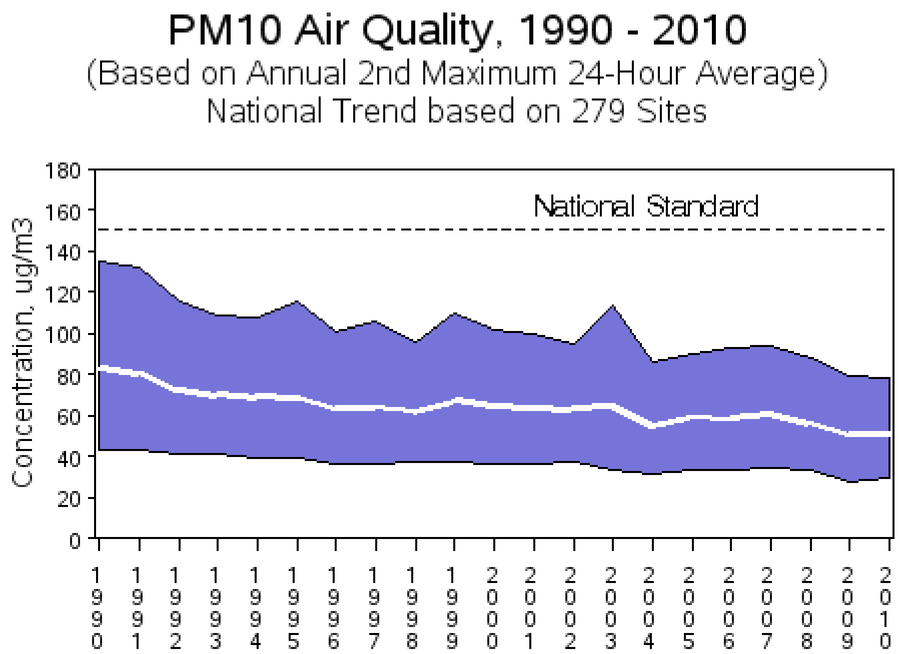

Figure 14: The national trend, based on 279 sites, for PM10 in the air between 1990 and 2010 [18]. Based on annual 2^{nd} maximum 24-hour average.

2.4.7 Summary of air quality trends in the US

In Table 7 a summary of the national average changes in air quality that was shown for the different pollutants has been gathered. In Table 8 the changes in emissions are shown.

Table 7: Percent change in air quality in US 1980 to 2010 [18], where a negative number represents an improvement in air quality. A blank space means that there are no trend data available.

Percent Change in Air Quality			
	1980 vs. 2010	1990 vs. 2010	2000 vs. 2010
Carbon Monoxide (CO)	-82	-73	-54
Ozone (O3) (8-hr)	-28	-17	-11
Lead (Pb)	-90	-83	-62
Nitrogen Dioxide (NO2) (annual)	-52	-45	-38
PM10 (24-hr)		-38	-29
PM2.5 (annual)			-27
PM2.5 (24-hr)			-29
Sulfur Dioxide (SO2) (24-hr)	-76	-68	-48

Table 8: Percent change in emissions in US 1980 to 2010 [18], where a negative number represents an improvement in air quality. A blank space means that there is no trend data available.

Percent Change in Emissions			
	1980 vs. 2010	1990 vs. 2010	2000 vs. 2010
Carbon Monoxide (CO)	-71	-60	-44
Lead (Pb)	-97	-60	-33
Nitrogen Oxides (NOx)	-52	-48	-41
Volatile Organic Compounds (VOC)	-63	-52	-35
Direct PM10	- 83[a]	-67	-50
Direct PM2.5		-55	-55
Sulfur Dioxide (SO2)	-69	-65	-50

[a] Direct PM10 emissions for 1980 are based on data since 1985

2.5 Global Warming/the Greenhouse Effect

Today the global warming is a big and hot topic among governments and other important authorities. The global warming is a result of the so called greenhouse effect. Only talking about the greenhouse effect per se it may not be such a bad thing since it is needed for the living creatures' existence, because without it the average temperature of the Earth's surface would be about 30 degrees Celsius colder than it is today. The greenhouse effect practically means that some gases build a shield within the atmosphere of the Earth and traps sun rays from leaving the atmosphere, meaning that more heat is forced to stay on Earth than was intentionally meant, resulting in that the temperature raises which in turn affects all living beings. The last two hundred years, with the introduction of the industrialization, the amount of greenhouse gases released has been increasing at a pace higher than ever before [24], resulting in the term 'global warming' which in popular speech refers to the unnatural increase in temperature.

In the term ‘greenhouse gases’ several gases are included, the major ones are (in order of magnitude); water vapor, carbon dioxide (CO_2), methane (CH_4) and ozone (O_3), and also some less contributing greenhouse gases are; nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and chlorofluorocarbons (CFCs) [25]. But for this study, when talking about ‘global warming’, the three anthropogenic gases that affect the greenhouse effect most (CO_2, CH_4 and N_2O) are of main interest.

Among sectors producing a lot of greenhouse gases the transportation sector is one of the largest and in 2010 the transportation sector accounted for about 27 percent of the total US greenhouse emissions [24].

2.6 Noise

The term ‘noise’, in this context, is defined as excessive and unwanted sounds [26] and noise from traffic affects more people than any other environmental noise source and is also one of the most common complaints in the American society [27]. Excessive noise can contribute to mental and physical health problems in such a way that it can affect the ability to work, learn and rest etc. Most of the traffic noise originates from the tires against the road and among large trucks also the engine and exhaust noises are large [27].

To cope with noise the receiver can increase the isolation quality (in homes it is mainly windows that are leaking) or using a technique that masks the noise by sending out different types of “counter-sounds” with the aim to neutralize the incoming sound-waves. This technique can, however, be perceived as there is even more noise than before.

Other options of reducing the noise is by dealing with it from the source, for example to use noise-reducing asphalt, which is the most economic alternative (even though the lifetime is not as high for this kind of asphalt as for regular asphalt) [28], or by building barrier walls. For barrier walls it is important that they are high enough (about the eye sight of the source, which means it must be higher for trucks where noise comes from the motor and exhaust pipe than for regular cars where the noise mainly derives from the tires) and that there is no holes, such as for example gates, which will reduce the effect drastically. The most preferred material is concrete but that is not necessary and the wall can for example be a large earthen berm but regular vegetation does not affect the noise level unless it is really thick and dense.

In the I-710 corridor project it is also presented suggestions of placements of barrier walls and these can be seen in Figure 15 [2].

Figure 15: A map of the I-710 with suggestions of where to place barrier walls according to the I-710 corridor project [2].

3 Method

The goal of this project was to make a comparison of emissions and energy use from trucks fueled with diesel as well as trucks driven by electricity for the traffic volumes in 2008 and in scenarios for the year 2035. To do this an LCA (Life Cycle Assessment) was made to find the emissions and energy use related to diesel and electricity as energy options for heavy duty trucks on the I-710. In the case of this project the, transportation specific LCA program, GREET model was chosen to perform the calculations. To be able to run GREET, to get some of the input data needed, the program MOVES had to be used as well. The I-710 corridor project EIR[8]/EIS[9] (hereafter referred to as the 'EIR/EIS') was used as a base for this whole project and several data were gathered from that report. In the EIR/EIS the data used are from 2008 and calculations have been made for 2035, which is why also in this project the years of 2008 and 2035 were used for the calculations and comparisons.

The approach of finding the results include the programs MOVES and GREET and then later additional parameters to complete the calculations to emissions and energy use for diesel and electricity for a whole year of 2008 and 2035, see Figure 16 for a quick overview of the procedure to reach the results.

[8] Environmental Impact Report

[9] Environmental Impact Statement

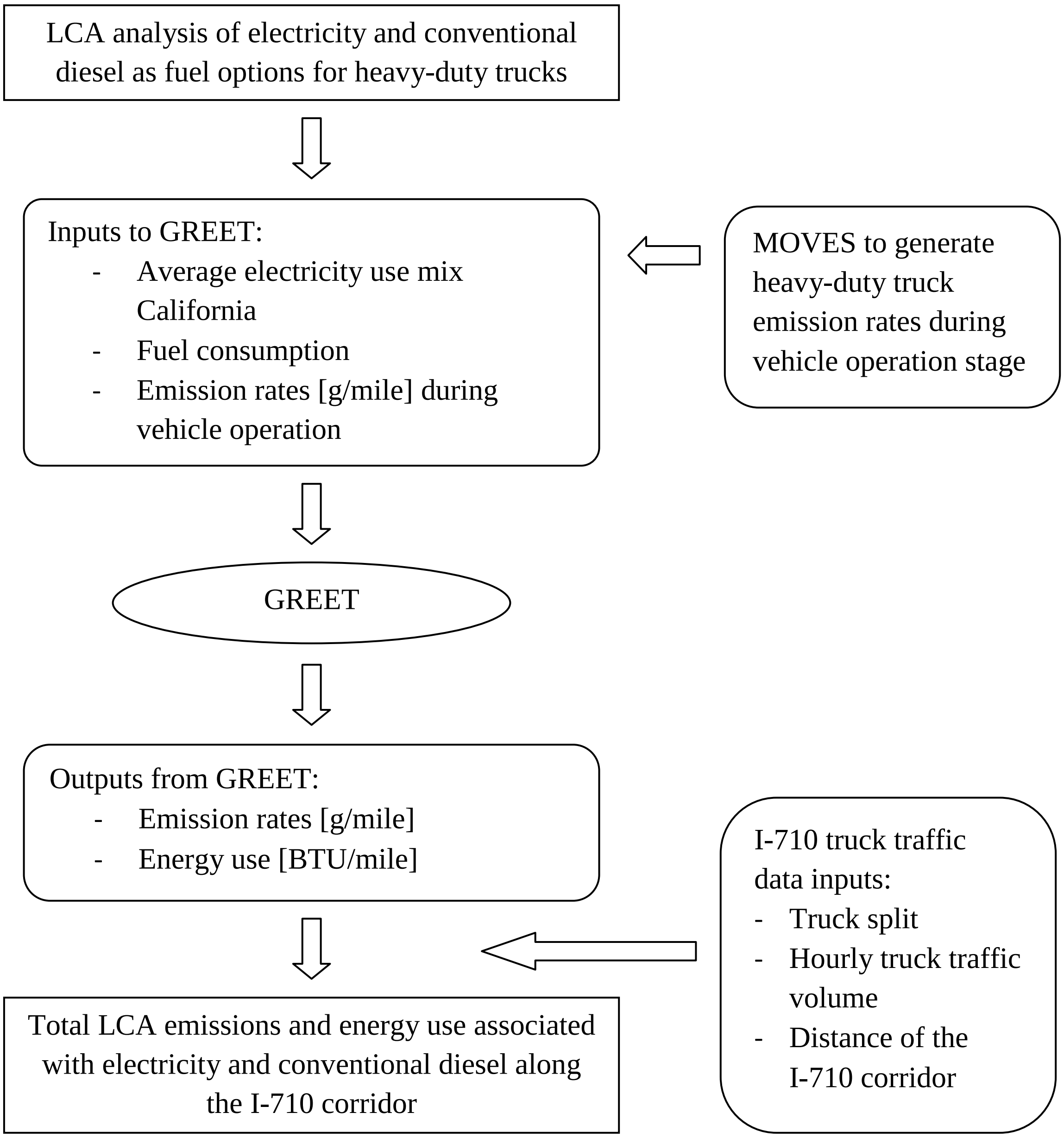

Figure 16: Flowchart of the methodology used for the study of a comparison between electricity and conventional diesel used as fuels in heavy-duty trucks running along the I-710 corridor in Los Angeles, California, US.

The scenarios that are used can be divided into three groups with diesel and electricity included in each group. The first group of scenarios (a1 and a2 in Table 9 below) represents the emissions and energy use in 2008. The second group of scenarios (b1 and b2in Table 9) represents the emissions and energy use in 2035. The third and last group of scenarios (c1 and c2 in Table 9) show the results in 2035 if the truck volume on the I-710 would be the same as in 2008. The third group of scenarios was included to easier see the difference from 2008 and 2035 if the truck volume would not increase as projected so to easier see the difference between 2008 and 2035.

Table 9: An overview of the scenarios that are performed in this study

Scenario	Year	Traffic flow as in	Comments
a1	2008	2008	Assuming all trucks fueled with diesel
a2	2008	2008	Assuming all trucks run on electricity
b1	2035	2035	Assuming all trucks fueled with diesel
b2	2035	2035	Assuming all trucks run on electricity
c1	2035	2008	Assuming all trucks fueled with diesel
c2	2035	2008	Assuming all trucks run on electricity

With these scenarios it was then possible to compare the results against each other. Comparisons was made between diesel and electricity in 2035 (comparison 1 in Table 10 below), between diesel and electricity for all scenarios (comparison 2 in Table 10) and between the years of 2008 and 2035 for diesel and electricity separately (comparison 3 in Table 10).

Table 10: An overview of how the scenarios are combined to perform quantitative comparisons

Comparison	Scenarios	Comments	Can be found in
0	a1, a2, b1, b2, c1, c2	All the results presented in one table to get an overview of the scenarios	Table 15
1	b1, b2	To see the effect of using electricity instead of diesel in 2035	Table 15
2	a1, a2, b1, b2, c1, c2	To see the effect of using electricity instead of diesel, for all scenarios	Table 17
3	a1, a2, b1, b2, c1, c2	To see the differences between 2008 and 2035, presented with the fuels separate	Table 18

So the programs of MOVES and GREET as well as the approach of producing these scenarios and comparisons presented above will be presented below in the subsections of the Method’s chapter.

3.1 MOVES

MOVES is the acronym of ‘Motor Vehicle Emission Simulator’ and was developed by the United States Environmental Protection Agency’s Office of Transportation and Air Quality [29]. The program was developed to make estimations of emissions for mobile sources. Currently emissions for cars, trucks and motorcycles are available and the program can be used to be run in different ways. As for this project, emissions from heavy duty trucks were the only ones of interest. So by using the MOVES model, the specific emissions could be found for four different kinds of heavy duty trucks; combination short-haul trucks, combination long-haul trucks, single-unit short-haul trucks and single-unit long-haul trucks, see Chapter 2 for definitions of the different truck types.

3.1.1 Input

To perform a run in MOVES several input data are needed, this section will go through how several input data were chosen.

For the runs used in this project, the 'project scale' was used, which gives more freedom to the user to choose desirable parameters, compared to the 'national' or 'county' scales in which most of the data are predefined.

For the project scale, the program can only simulate a scenario of one hour at a time, which meant that several runs had to be made to later get a combined result over a whole year. So for this project the four separate hours of 00.00-01.00, 07.00-08.00, 12.00-13.00 and 17.00-18.00 were chosen in order to get a spread in the results. The hours of 00.00-01.00 and 12.00-13.00 were used to represent non-peak hours while 07.00-08.00 and 17.00-18.00 were used to represent the peak hours. To get a spread also over the year the two months of January and July were chosen. Because of a limitation in time, these four hour spans and two months were chosen and were later combined to represent a year, more hours or months chosen would have quickly multiplied the number of total calculations. As specified earlier the years of 2008 and 2035 should be represented, so with these hours, months and years all combined there were a total of 16 runs that had to be made. The I-710 goes through the Los Angeles County in California and the calculations were therefore made for the zone of the Los Angeles County in California. Other zones would have resulted in different conditions, such as different temperatures and humidities, giving different results.

Since electricity driven vehicles does not have any local emissions (more than PM2.5 and PM10 produced by break and tire wear which would be the same as for any same sized vehicle), MOVES were only used to perform calculations for diesel fueled trucks.

The I-710 is a closed urban highway and the calculations were therefore made with the road type named 'urban restricted access'. Another choice of road type would have used for example other rates of number of ramps in connection to the road.

The distance of the simulated road was set to one mile, since the results desired from MOVES were grams per mile. For the same reason the number of vehicles on the road was set to one. Since the results would be per mile, these numbers could basically have been set to any numbers, the output would still have been the same. For simplicity, the slope was assumed to be 0° over the whole distance.

A speed of 55 mph was used for the simulations in the non-peak hours since this is the speed limit for trucks in California. A speed of 45 mph was used for the peak hours, which is a slight speed reduction and was chosen with congestion in mind.

For the age distribution of the trucks the default for trucks in MOVES was used, the data can be seen in Table 19 in Appendix 1.

As mentioned earlier, MOVES were only used to find emissions from diesel trucks, and the diesel used was the low sulfur diesel (LSD) containing 11 ppm sulfur.

Meteorology data used was based on average meteorology data in Los Angeles County over 30 years, these data were stored in the default of MOVES. The meteorology data varies for the different time spans but are assumed to be the same for both years of 2008 and 2035, the meteorology data that were used can be seen in Table 11.

Table 11: Meteorology data used as input to MOVES.

	January				July			
	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Temperature [°F[a]]	49.4	45.1	66.3	62.5	69.4	68.2	84.6	84.3
Relative humidity [%]	64.4	65.1	45.9	52.1	60.8	66.2	46.1	45.1

[a] $T_{°C} = (T_{°F} - 32) \times 5/9$

To summarize, key inputs in MOVES were (for diesel calculations only);

- Project scale
- Two years; 2008 and 2035
- Two months; January and July
- Four hours; 00.00-01.00, 07.00-08.00, 12.00-13.00 and 17.00-18.00
- Los Angeles County
- Urban restricted access
- 1 mile
- 1 vehicle
- Slope of 0°
- Two speeds; 55 mph for non-peak hours and 45 mph for peak hours
- Low sulfur diesel containing 11 ppm sulfur
- Meteorology data from an average over 30 years in Los Angeles County

3.1.2 Output

The output from MOVES was delivered in 16 different sheets where every sheet contained the results for all emissions for each of the four different truck types.

The results that was wanted as input to GREET and that were produced by MOVES were for diesel;

- Exhaust VOC
- Evaporative VOC
- CO
- NO_x
- Exhaust PM10
- Brake and tire wear PM 10
- Exhaust PM2.5
- Brake and tire wear PM2.5
- CH_4
- N_2O

The results were given in grams per mile and did not include emissions from parked vehicles (such as fuel evaporation). These, now in total 64 different, results (with all emissions listed above counted as one result) could then be used as input for GREET, the input data from MOVES to GREET can be seen in Table 20 to Table 23 in Appendix 2.

3.2 GREET

GREET is the acronym for 'The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model' and was developed by Argonne National Laboratory's life cycle analysis team [30]. GREET is an LCA program specifically designed for evaluating emissions and usage of primary resources associated with transportation fuels production and use. The GREET model that was used for this project was the GREET 1 Series, also called Fuel-Cycle Model, which is mainly used for modeling cars and light duty trucks' emissions. There is a GREET 3 Series which handles heavy duty trucks, but that program is not open to the public and therefore the GREET 1 series had to be used. However, the data were modified to match the heavy duty trucks'.

The results produced by GREET include the steps from well to wheels and is here including; resource depletion, fuel and electricity production and running emissions, as well as transportation between the different steps in the energy conversion chain. See Figure 17 for an illustration of the steps where GREET 1, as mentioned, only includes the horizontal steps in the figure; from well to wheels.

Since MOVES delivered 64 different results also 64 runs had to be made in GREET.

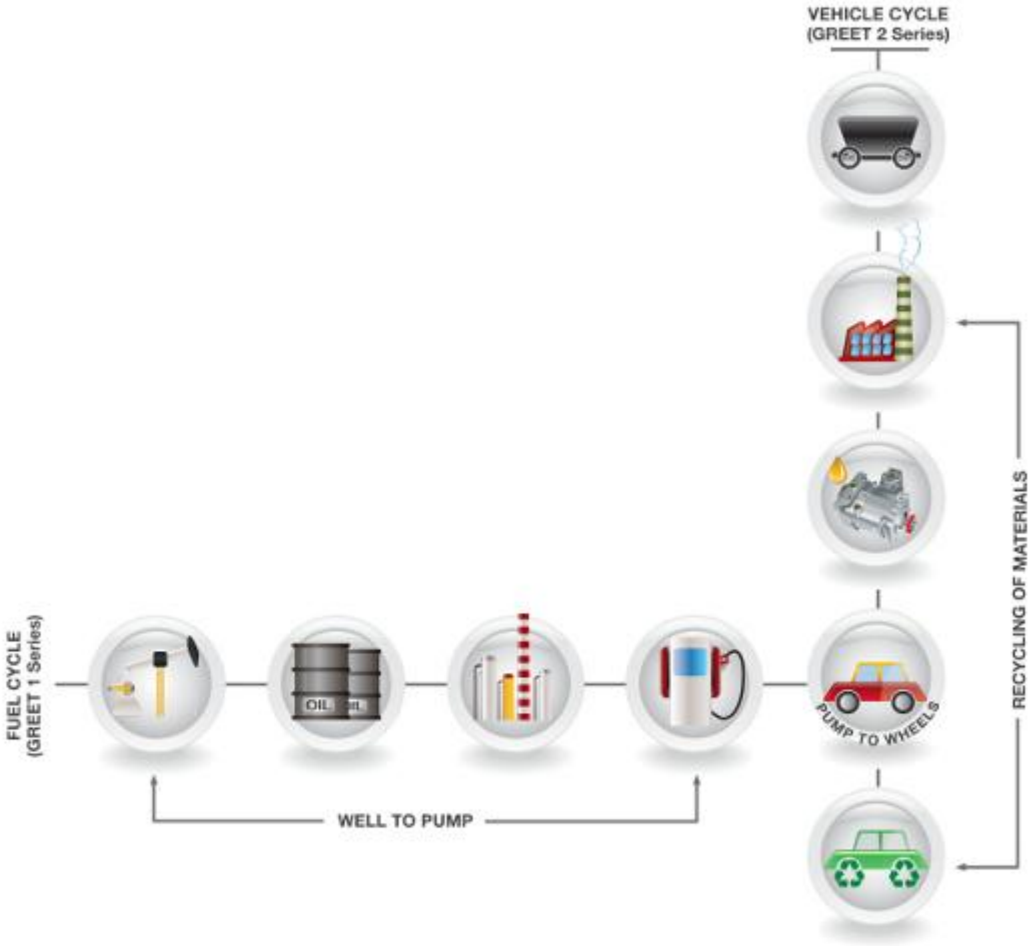

Figure 17: The steps included in a life cycle in GREET [30] where the GREET 1 series include the steps from well to wheel.

3.2.1 Input

The GREET model does only include forecasts up until the year of 2020, this means that for the calculations of the fuel productions made in GREET in this study, the year of 2020 was used to find the results for the year of 2035. However, the emissions emitted during vehicle operations will be the ones that were calculated for 2035 in MOVES. The year of 2008 is included in GREET so all in all the year of 2008 in GREET will be used for the calculations of 2008 and the year of 2020 will be used to perform the calculations for 2035.

As mentioned earlier, the GREET 1 model is supposed to be used for cars or light duty trucks and in the model there are three vehicle options to choose from; car, light duty truck 1 and light duty truck 2. For this project the vehicle type 'light duty trucks 2' were used, but again; the specific truck data were modified at a later stage as to match data for heavy duty trucks.

On the contrary to MOVES, runs were in GREET made for both diesel and electricity and for the diesel, the low sulfur diesel containing 11 ppm sulfur was used as a single fuel for the diesel trucks. For electricity, the assumption was made that the vehicle was an electric vehicle connected to the grid.

The electricity mix should in GREET be specified in percentages between the resource options of; 'Oil', 'Natural gas', 'Coal', 'Nuclear', 'Biomass' and 'Others', where 'Others' include other unspecified renewable sources than biomass. The electricity mix used in this study for 2008 was the total energy use, including imports, in California in the year of 2008 [1]. These numbers, given in GWh, was then recalculated to percentages.

To find the electricity mix in 2035 the default mixes of 2008 and 2020 in GREET was used. First, the difference in percentage points between the years were found, and then the percentage points were added to the electricity mix of 2008 and the sum was then used as the electricity mix for 2035, see Table 12 for the electricity mixes used.

Table 12: The electricity mix shares that were used as average and marginal electricity mixes in GREET.

	2008 **Total system power [GWh]**	**2008** **% of TSP**	**2035** **% of TSP**
Oil	0	0	0
Natural gas	140,215	45.74%	44.83%
Coal	55,829	18.21%	13.33%
Nuclear	44,268	14.44%	12.74%
Biomass	6,377	2.08%	2.46%
Others	59,888	19.53%	26.64%

It is possible to specify both the marginal and average electricity mix in GREET, but in this study the average electricity mix has been used for both the average as well as the marginal electricity mix. In GREET the marginal mix is used for the electrical vehicles while the average mix is used in the well-to-pump stage of the fuel cycle, for all fuels. By using the average electricity mix also for the marginal mix means that the electricity production would be assumed to not be affected of the extra amount of electric vehicles that would demand more electricity than produced today.

Furthermore, for the diesel and electricity production respectively, several other assumptions were made. The GREET defaults were used here and these can be seen in Table 24 for 2008 and 2035 in Appendix 3.

As for the fuel economy, an assumption was made that the heavy duty trucks fueled with diesel had a number of 6.0 miles per gallon (mpg) for the combination trucks and 7.4 miles per gallon for single-unit trucks. These numbers were collected from the Highway Statistics 2008 put together by the Federal Highway Administration [31]. The fuel economy has over the years been varying, going up and down, and there cannot be seen any special pattern or course, so the same values were used for 2008 as well as for 2035.

For the electricity the fuel economy was assumed to be three times better than the diesel. The fuel economy for electric vehicles seems to vary a lot, but it seemed as it should be between two to four times better than for diesel [32], so as to keeping it simple here the assumption was made to be three times better than the diesel, i.e. the mpg was set to 300 % as for the diesel.

The emission rates were those gathered from MOVES, and one set of emission rates (where one set include rates for exhaust VOC, evaporative VOC, CO, NO_x, exhaust PM10, brake and tire wear PM 10, exhaust PM2.5, brake and tire wear PM2.5, CH_4, N_2O

as mentioned in Section 3.1.2) were used for each run, i.e. 64 runs were made, one for each truck type, year, month and hour. Since the electric vehicles do not emit anything while running, these values were set to be zero, except for the brake and tire wear which were set to be the same values as for the diesel vehicles.

In summary, key inputs to GREET were;

- Two years; 2008 and 2020 (representing 2035)
- Light duty trucks (later modified to represent heavy duty trucks)
- Sulfur content of 11 ppm in the diesel
- Average electricity mix use of California
- Two numbers of fuel consumption for diesel; 6.0 mpg for combination trucks and 7.4 mpg for single-unit trucks
- Fuel consumption for electricity 300 % better than diesel
- Emission rates gathered from MOVES

3.2.2 Output

From making the runs in GREET, finally the results were found for the total well-to-wheel cycle. The results were in units of grams per mile for the emissions and BTU per mile for energy use. In the results, there were now values per mile for each truck type and time frame. The results were divided in three categories; feedstock (including feedstock recovery, transportation and storage), fuel (including fuel production, transportation, storage and distribution) and vehicle operation [33]. Output data from GREET can be seen in Table 25 to Table 32 in Appendix 4.

Key outputs from GREET were;

- Total energy
- Fossil fuels
- Coal
- Natural gas
- Petroleum
- CO_2 (with C in VOC and CO)
- CH_4
- N_2O
- GHGs
- VOC
- CO
- NO_x
- PM10
- PM2.5
- SO_x

3.3 Traffic Data Processing

To analyze the environmental impact from a change in the vehicle stock a comparison has been carried out assuming a traffic flow with either all heavy duty trucks run on diesel or on electricity. The results can then be used to indicate the maximum environmental benefits if an external truck corridor was built with electricity support along the I-710.

After the results from GREET were presented per mile, further calculations had to be made and the results also had to be combined since there were 64 different results (four truck types and sixteen time spans of an hour each) produced by GREET. To make these results into one, several parameters had to be taken into account;

- To make the results valid for the whole projected area, the distance of the I-710 had to be included
- To combine the different truck types to get one result, the truck split for the I-710 had to be found
- To combine the different time spans, the hourly truck traffic volume on the I-710 had to be found

Average daily truck traffic and distance of the I-710

The amount of trucks running on the I-710 was gathered from the EIR/EIS where the average daily truck traffic had been collected on the I-710 in 2008, for both south and north direction. Also, the EIR/EIS contains a prediction of how many trucks are assumed to be running on the highway in 2035 if the I-710 were kept without changes. The data were spread over 19 segments along the I-710 corridor, which is why also the distances had to be accounted for separately. The data for the average daily truck traffic used can be seen in Table 13.

Because of the average daily truck traffic being represented for 19 different segments of the highway, the highway also had to be measured for the19 different segments which later were used for the aggregation of the results. The distances were measured through Google Maps' built in measuring distances tool, and can be seen in Table 13 together with the average daily truck traffic.

Table 13: The segments of the I-710 highway used for the calculations and the data used for average daily truck traffic (ADTT) and the distances connected to each segment. The numbers for the ADTT are the total values for both directions. In the EIR/EIS the segments are also called; north of PCH (#14-16), north of I-405 (#11-13), north of SR-91 (#8-10), north of I-105 interchange (#2-7) and north of I-5 interchange (#1).

Truck volume on I-710					
	Mainline segment			**ADTT [number of trucks]**	
			Distance		*(no build)*[a]
#	**From**	**To**	**[miles]**	**2008**	**2035**
1	SR-60	I-5	1.4	17,600	23,200
2	I-5	Washington Blvd.	0.8	20,100	25,300
3	Washington Blvd.	Atlantic Blvd.	0.5	19,400	27,800
4	Atlantic Blvd.	Florence Ave.	2.2	28,600	37,800
5	Florence Ave.	Firestone Blvd.	1.3	28,600	37,800
6	Firestone Blvd.	Imperial Hwy.	1.4	30,400	39,700
7	Imperial Hwy.	I-105	1.3	31,500	43,200
8	I-105	Rosecrans Ave.	0.7	31,700	43,400
9	Rosecrans Ave.	Alondra Blvd.	1.0	26,300	38,500
10	Alondra Blvd.	SR-91	1.0	36,700	59,300
11	SR-91	Long Beach Blvd.	1.0	37,000	60,100
12	Long Beach Blvd.	Del Amo Blvd.	1.2	42,100	74,100
13	Del Amo Blvd.	I-405	1.4	42,000	74,300
14	I-405	Wardlow Rd.	0.3	41,600	74,400
15	Wardlow Rd.	Willow St.	1.2	41,200	71,600
16	Willow St.	Pacific Coast Hwy.	1.0	41,400	71,800
17	Pacific Coast Hwy.	Anaheim St.	0.5	33,900	60,100
18	Anaheim St.	9th St.	0.3	26,000	46,600
19	9th St.	Ocean Blvd.	0.8	10,300	20,100
	Total distance		**19.3**	**miles**	

[a] Numbers calculated as if there would be no construction on the I-710

Since the EIR/EIS only includes the average daily truck traffic volumes, and the results were found for four different hours over the day, it was also necessary to find the hourly truck traffic variations so that the results could be combined into a whole day, and later also an approximation for a whole year. For this purpose, numbers were used that had been found during the Port Peak Pricing Program Evaluation [34] made by the FHWA. In the evaluation there were hourly traffic truck volumes displayed in shares of the day (percentage) from 06:00 in the morning to 20:00 in the evening, and they were displayed separately for February and September in 2007 and also separately for the north and south directions. So with these percentages the shares could be found that were later used for the aggregations, to see how the shares that were finally used were composed; see the section below.

Average hourly truck volume

The calculations for finding the useful shares was made by first combining the hours of which we wanted to have the final shares, these were decided to be distributed as follows;

- for the morning peak hour (07:00-08:00) the hours between 06:00 and 09:00 would be combined,
- for the mid-day non-peak hour (12:00-13:00) the hours 09:00 to 15:00,
- for the evening peak hour (17:00-18:00) the hours 15:00 to 18:00 and
- for the night non-peak hour (00:00-01:00) the rest of the hours would be used, i.e., 18:00 to 06:00.

So these merges were made for both February and July and for both directions, and after that they were fused by making the average between them, until only the four hour periods remained. As mentioned earlier, the hours only stretched from 06:00 until 20:00, so for the remaining hours (20:00 to 06:00) the remaining shares were used and distributed evenly over the hours. The average hourly truck volume distribution as well as the aggregated shares over the periods that were used is illustrated in Figure 18.

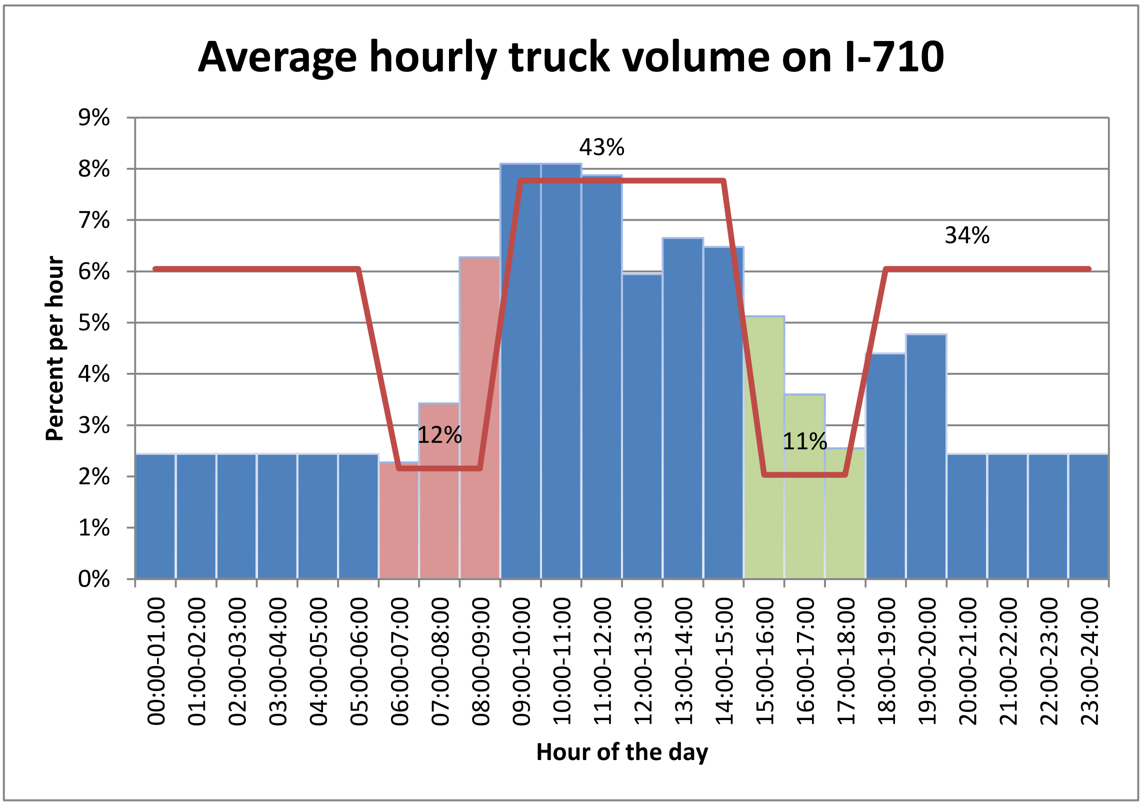

Figure 18: The average hourly truck volume distribution on I-710, as calculated from The Port Peak Pricing Program Evaluation in 2007 [34], as well as the four aggregated periods (the red line) presenting the periods' shares of the total 24 hour traffic volume that were used in the calculations to get the total results for the whole I-710.

Truck split

The results so far were for the four different truck types separately and therefore it were now needed to find how many of all trucks running on the highway that are combination short-/long-haul and single-unit short-/long-haul, i.e., the ‘truck split’. By using the vehicle miles traveled (VMT) gathered from FHWA’s highway statistics 2008 [31], the split between the combination and single-unit trucks were found by looking at the share of how many VMT they had respectively against the total of these two. The finding was that 47 percent of the short distances were made by single-unit trucks while 53 percent were made by combination trucks. For the long distances the split was 41 percent for single-units and 59 percent for the combination trucks.

The split between how many short and long distance vehicles there is, was found by looking at the share of (combination) vehicles visiting the Port of Los Angeles (POLA). Informed by Mr. Tim DeMosst, the Clean Trucks Program Manager of the Port of Los Angeles, the long-haul trucks have a share of 8.3 percent of all trucks visiting POLA. So with this number as a reference, for this project the share over the total I-710 was assumed to have the same split as the POLA and the number were rounded to 10 percent which means that the amount of short-haul trucks were assumed to be 90 percent. Since only combination vehicles visits POLA in the purpose of transporting the goods, these numbers were for combination trucks. Not only combination trucks are running on the highway, but these numbers was also assumed for the split of distance for the single-units as well.

By combining these numbers the final truck split was found and used to divide the amount of trucks between the different truck types, the final truck split can be seen below in Table 14;

Table 14: The truck split used to separate the amount of trucks between the four different truck types.

Truck split		
	Combination trucks	Single-unit trucks
Short-haul	48%	42%
Long-haul	6%	4%

Aggregation of the parameters

By taking all these parameters presented above into account, the results could now be shown in BTU and grams for the whole I-710 highway. The base year was calculated with all the values that were found for 2008, but for the year of 2035 two calculations were made; one calculation was made for all the data specified so far for 2035 and another calculation was made with all the same data except for one; the traffic volume. So, to make it easier to compare the differences between the years of 2035 and 2008 an additional calculation was made for 2035 using identical data as before but assuming the same traffic volume data as for the base year, see Table 9 for an overview of the different scenarios.

Conversion to results per year

The results now available were still only calculated for one day in one month; one day in January and July respectively, for both fuels and years. So, to give a better and more clear understanding over the results these were aggregated once more to one year for each fuel and year by assuming the January results are valid for 90 days of the year (January, February and December), the July results for 92 days (June, July and August) and then the average of the January and July results for the rest of the days (183 days) in a year. Hence, after this there were only six results left; one for each fuel per year calculated and with these results it were now easy to perform comparisons.

4 Results

The final results, see Table 15, include all emissions/energy use for a whole year and for the total distance of the I-710 highway that was defined in the project area (in total a distance of 19.3 miles (31 km) has been accounted for). The results include the emissions/energy use from the heavy duty trucks and also takes into account how many of the trucks that belongs to each category of truck types (combination/single-unit long-/short-haul trucks). The calculations were made where all of the trucks used the same fuel, i.e., for the results of diesel all trucks running on the I-710 were assumed to be fueled by diesel, and for electricity all trucks running on the I-710 were assumed to be fueled by electricity, see more in Section 3.

For the results of the year 2035 the traffic volumes used were those that had been calculated for the EIR/EIS, see Table 13 for the numbers. For comparison, the results for 2035 were also calculated with the same truck volume as 2008. Those results can be seen in the figures as the bars in the front of 2035, in Table 15 these numbers are presented under '2035 with 2008 truck volume'. These results make it easy to see how much of a difference there would be if the traffic volume conditions were the same as of 2008.

Table 15: The results presenting the total energy use and emissions for the whole distance of I-710 including estimated traffic volume, see Table 13 for numbers, for a year assuming all trucks fueled with a hundred percent diesel or fully driven on electricity respectively. The sum of the greenhouse gases, i.e., 'GHGs', are in CO_2-equivalents.

	The results [per year]							
	2008		2035			2035 with 2008 truck volume		
	Diesel	Electricity	Diesel	Electricity	(%)[a]	Diesel	Electricity	Unit
Total energy	4 749	3727	7247	4814	(-33.6%)	4680	3108	TJoule
Fossil fuels	4 731	2975	7216	3485	(-51.7%)	4660	2250	TJoule
- Coal	21	908	24	993	(4095.0%)	15	641	TJoule
- Natural gas	395	2037	591	2456	(315.8%)	382	1586	TJoule
- Petroleum	4 316	30	6602	36	(-99.5%)	4263	23	TJoule
GHGs	372	232	567	271	(-52.2%)	366	175	kilotonnes
- CO2[b]	358	206	546	242	(-55.7%)	353	156	kilotonnes
- CH4	545	999	815	1104	(35.5%)	526	713	tonnes
- N2O	1 059	3679	1568	3383	(115.7%)	1013	2185	kg
VOC	178	23	54	24	(-56.3%)	35	15	tonnes
CO	721	104	163	132	(-19.3%)	106	85	tonnes
NOx	2 914	257	542	236	(-56.4%)	350	153	tonnes
PM10	165	184	43	230	(430.2%)	28	148	tonnes
PM2.5	147	64	25	95	(274.9%)	16	62	tonnes
SOx	78	375	74	327	(338.7%)	48	211	tonnes

[a] difference of using electricity instead of diesel with 2035 data, where a negative difference indicates a decrease and a positive difference indicates an increase

[b] including C in VOC and CO

To facilitate a comparison of the different emissions, the results in Table 15 have also been illustrated, using bar charts, presenting one emission at a time, these can be seen in Figure 19 to Figure 28. In the figures, the values in the two left most bars represent the data that has been calculated for the year 2008, which was selected to be used as the base year, so hereinafter these results will be referred to as the base year.

Energy use

The total energy use will be higher in 2035 than for the base year, see Figure 19, but when the traffic data are the same as for the base year, the energy use would be less. This can be explained by that the programs takes into account different developments, such as for example an increased efficiency in the fuel production, and the reason why the total in 2035 is higher than 2008 is only because of the increase in traffic volume. When looking at 2035 the energy use for the electricity case would be about 34 percent less than for diesel (observe that the percentage would be the same for 2035 regardless of which traffic volume is being used, since the production of the diesel and electricity would still be the same). For the base year the savings in using electricity instead of diesel would be about 22 percent. The differences between diesel and electricity for all years and for both the energy use as well as for the rest of the results (emissions) presented in this chapter, can be seen in Table 16.

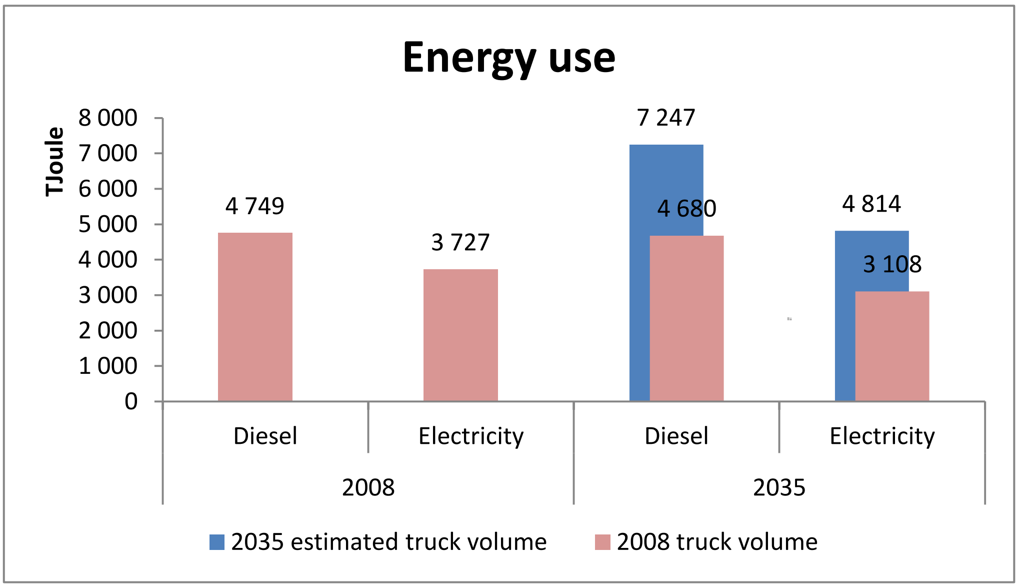

Figure 19: The energy use in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the energy use with a constant truck volume and the back bars indicating the energy use with an estimated truck volume in 2035.

The use of diesel as fuel for heavy-duty trucks means a fossil fuel use of about 99.6 %, see Table 16, while for the electricity production the use of fossil fuels would be less than 80 percent, whereas the rest would be produced by renewable resources. Furthermore in Table 16 the composition of the fuels' resource use can be seen, displaying the shares of coal, natural gas and petroleum, and the difference up to a hundred percent is non-defined renewable resources.

Table 16: Shares of energy sources used in a well-to-wheel (WTW) perspective per scenario for the I-710 corridor project.

Energy use [TJoule]								
	2008				2035			
Energy source	Diesel		Electricity		Diesel		Electricity	
Total Energy	4749	100.0 %	3727	100.0 %	7247	100.0 %	4814	100.0 %
Fossil Fuels[a]	4731	99.6 %	2975	79.8 %	7216	99.6 %	3485	72.4 %
- Coal	21	0.4 %	908	24.4 %	24	0.3 %	993	20.6 %
- Natural Gas	395	8.3 %	2037	54.7 %	591	8.2 %	2456	51.0 %
- Petroleum	4316	90.9 %	30	0.8 %	6602	91.1 %	36	0.7 %

[a] The rest of the energy use not defined is consisting of renewable resources

Air quality emissions (VOC, CO, NO_x, PM10, PM2.5 and SO_x)

In the base year the difference between diesel and electricity for VOC is rather big (87 %) whereas in 2035 there is still a difference, just not as big, but still a quite large number of 56 % less emissions for electricity than for diesel, see Figure 20. Furthermore, the VOC emissions for diesel have decreased significantly from 2008 to 2035.

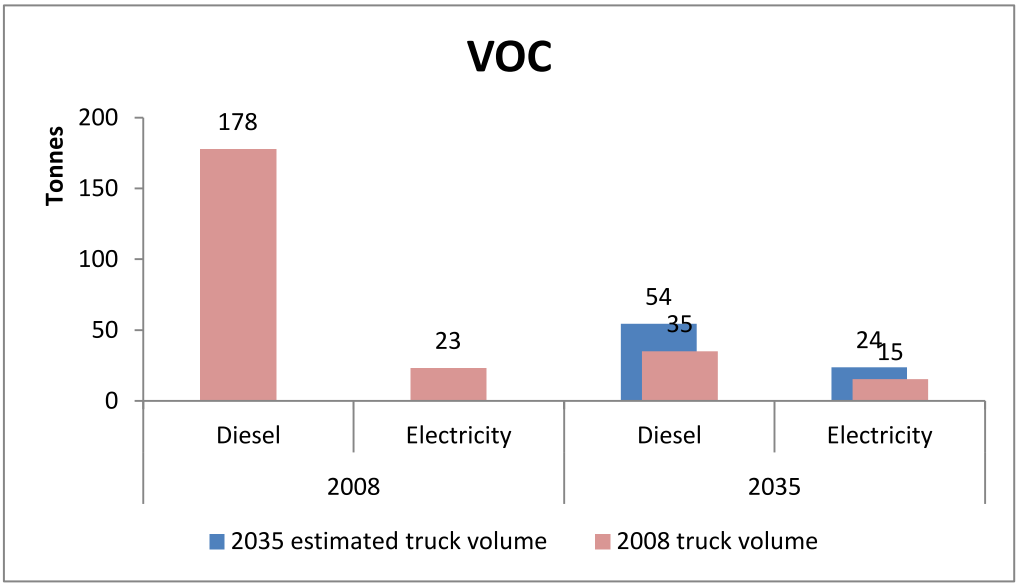

Figure 20: The VOC in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the energy use with a constant truck volume and the back bars indicating the energy use with an estimated truck volume in 2035..

Also for CO there is a bigger difference between diesel and electricity in 2008 than in 2035; 86 % and 19 % respectively, see Figure 21. There is a significant decrease in CO emissions for diesel from 2008 to 2035 as well.

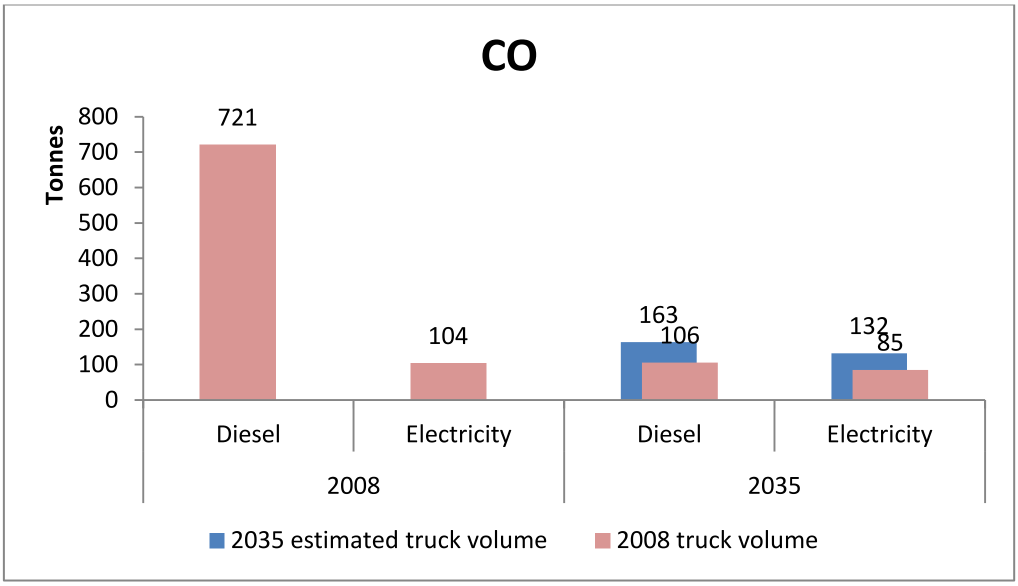

Figure 21: The of CO in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the CO with a constant truck volume and the back bars indicating the CO with an estimated truck volume in 2035.

Again, for NO_x, the difference between diesel and electricity in 2008 is larger than 2035, with a 91 % and 56 % difference respectively, see Figure 22. Also, the total emissions for 2035 with the larger truck volume is smaller than for the base year with smaller truck volume. Once again, there is a significant reduction in NO_x emissions for diesel between 2008 and 2035.

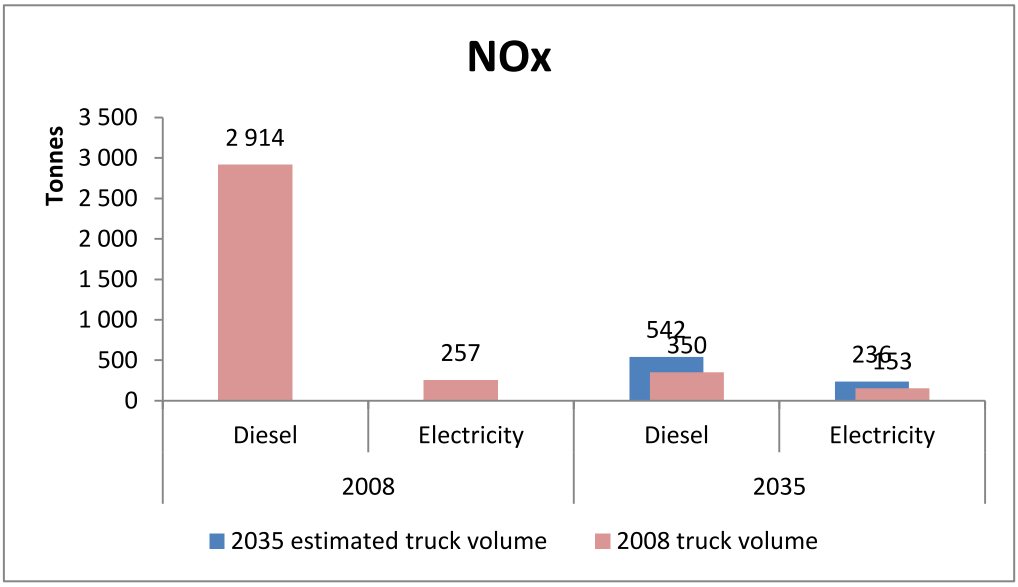

Figure 22: The NO_X in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the NO_x with a constant truck volume and the back bars indicating the NO_x with an estimated truck volume in 2035.

For the PM10 emissions the differences are looking different compared to VOC, CO and NO_x presented above; instead of a smaller amount for electricity the diesel has the lower emissions, see Figure 23, and the diesel scenarios in 2035 has the lowest emission rate of all. The PM10 emissions will however still decrease (20 %) between 2008 and

2035 for electricity if assuming the same traffic volume. The difference between diesel and electricity is that there is 4.3 times more emissions for electricity than diesel.

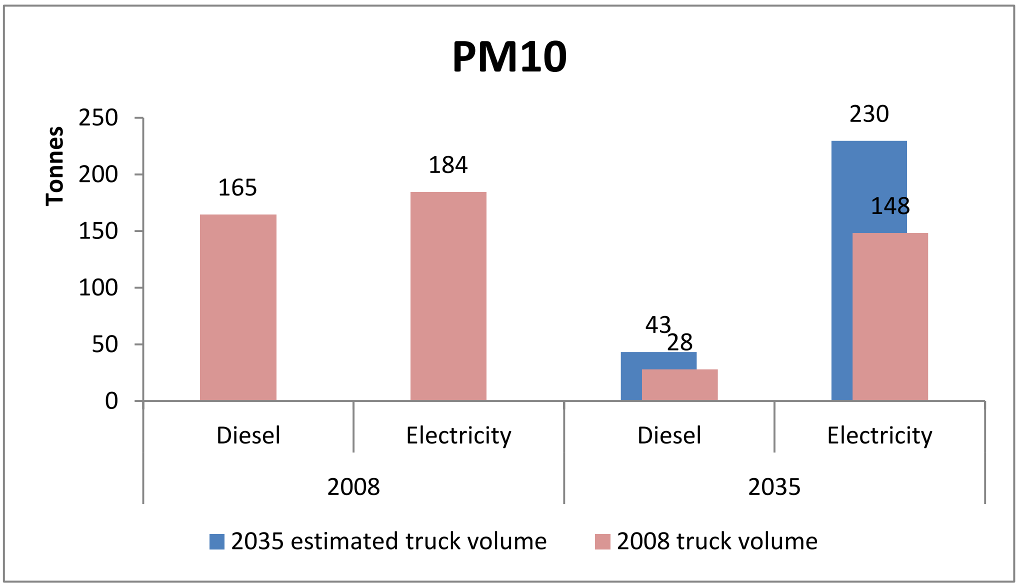

Figure 23: The PM10 in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the PM10 with a constant truck volume and the back bars indicating the PM10 with an estimated truck volume in 2035.

For PM2.5 electricity has the lower value in 2008 but in 2035 this changes and diesel has the lower value of PM2.5, see Figure 24. The emissions for electricity are about 2.7 times higher than for diesel in 2035 and the diesel scenarios in 2035 has just as for PM10 the lowest emission rate of all scenarios.

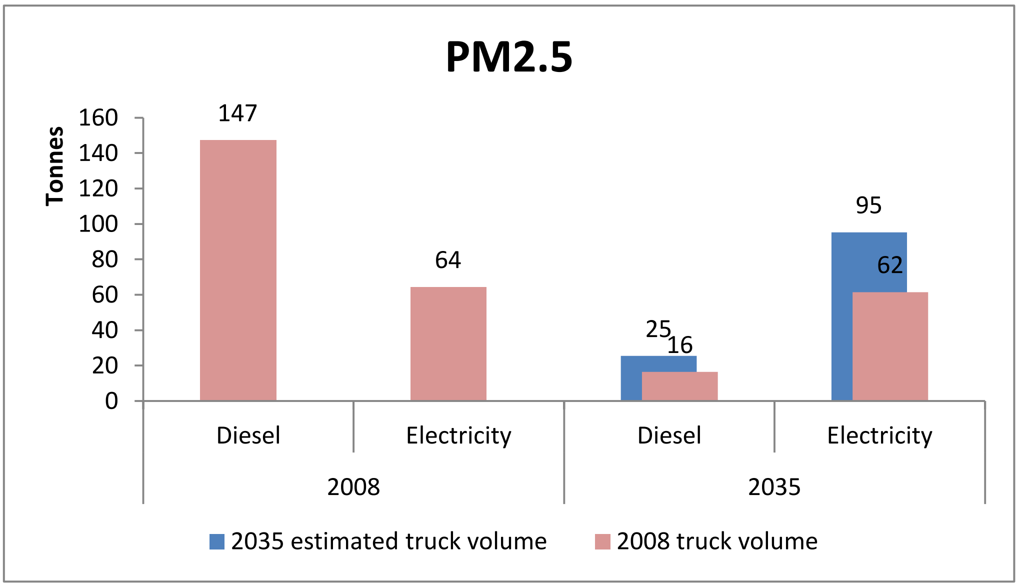

Figure 24: The PM2.5 in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the PM2.5 with a constant truck volume and the back bars indicating the PM2.5 with an estimated truck volume in 2035.

For SO_x, the electricity has higher emissions than diesel, for both 2008 and 2035, but decreases the difference from 382 % to 339 %, see Figure 25. Interesting to see is that for

SO_x also the total emissions in 2035 with the estimated truck volume in 2035 is smaller than the total in 2008 with a lower truck volume.

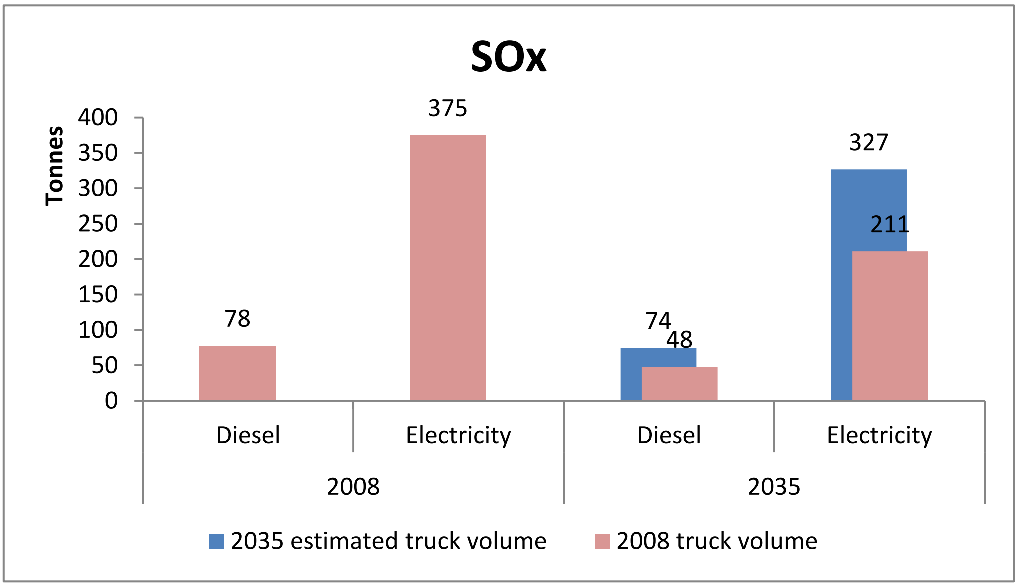

Figure 25: The SO_X in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the SO_x with a constant truck volume and the back bars indicating the SO_x with an estimated truck volume in 2035.

Greenhouse gas emissions

The results also include values for the three greenhouse gases; CO_2, CH_4 and N_2O, which will be presented further, below.

For CO_2 the results show that electricity has lower emissions than diesel, both in 2008 and 2035, in 2035 the CO_2 emissions from electricity is 56 % lower than from diesel, see Figure 26.

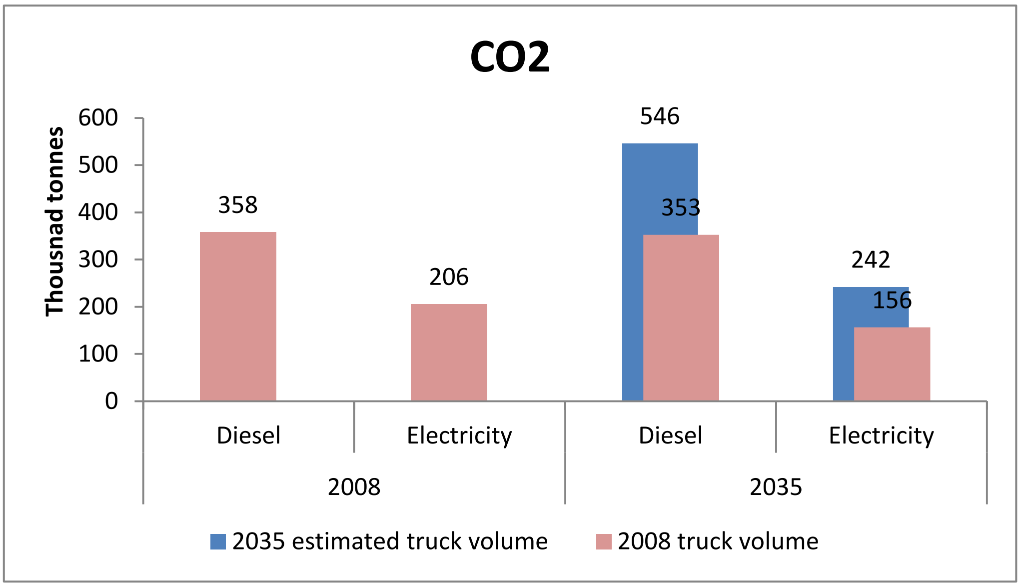

Figure 26: The CO_2 (including C in VOC and CO) in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the CO_2 with a constant truck volume and the back bars indicating the CO_2 with an estimated truck volume in 2035.

For CH_4 the emissions for electricity is higher than for diesel, and the difference in 2035 is 36 % more emissions for electricity than diesel, see Figure 27.

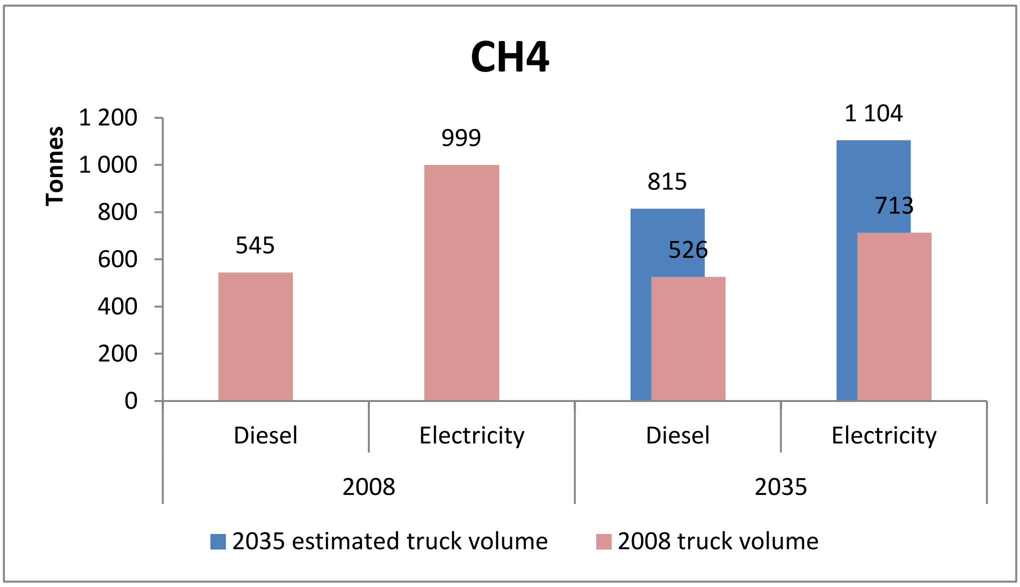

Figure 27: The CH_4 in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the CH_4 with a constant truck volume and the back bars indicating the CH_4 with an estimated truck volume in 2035.

Also for N_2O the emissions are higher for electricity than diesel and the difference is 116 % more emissions for electricity than diesel in 2035.

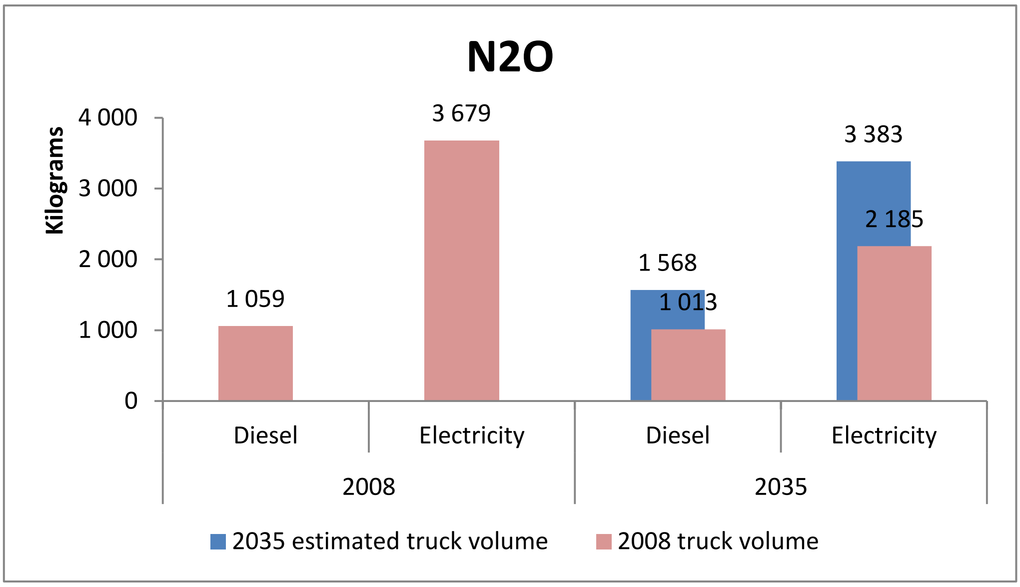

Figure 28: The N_2O in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the N_2O with a constant truck volume and the back bars indicating the N_2O with an estimated truck volume in 2035.

Even though the CH_4 and N_2O emissions are larger for electricity than for diesel, the total greenhouse gas emissions in CO_2-equivalents[10] is 52% lower for electricity than for diesel in 2035, see Figure 29.

[10] CH_4 about 25 times more powerful than CO_2 and N_2O about 298 times more powerful than CO_2 [37].

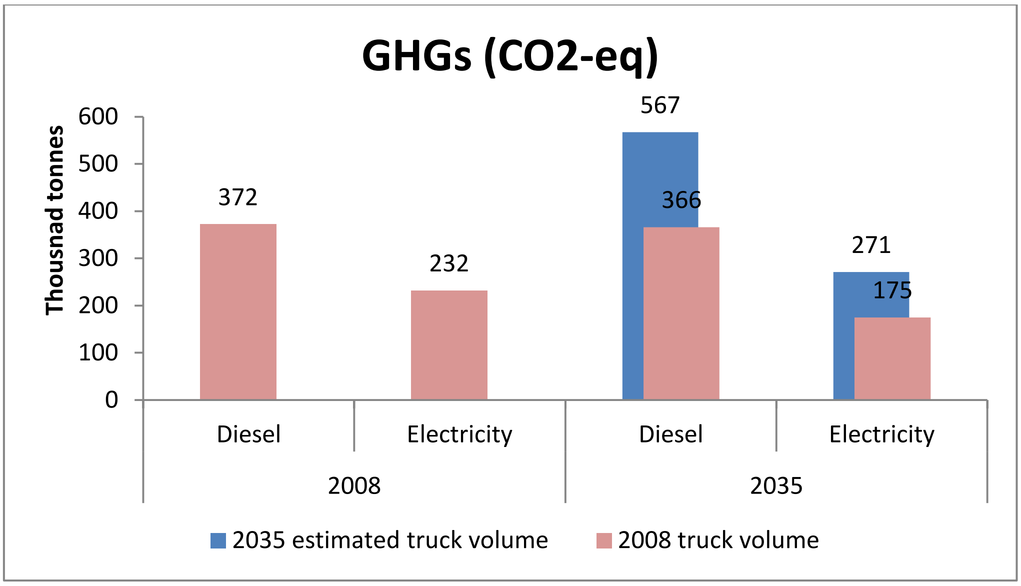

Figure 29: The total greenhouse gases (including CO_2, CH_4 and N_2O) in the scenarios that were produced from a well-to-wheels perspective. The front bars indicating the total greenhouse gases with a constant truck volume and the back bars indicating the total greenhouse gases with an estimated truck volume in 2035.

Summary of the comparisons

The comparisons that were made in this chapter can all be seen in numbers here below in Table 17 and Table 18. It can be seen that for all scenarios there will be a reduction of energy use (and fossil fuel use) and greenhouse gas emissions by using electricity instead of diesel. It can also be seen that for all emissions/energy use related to electricity will be less in 2035 compared to 2008.

Table 17: Total savings when all diesel trucks on the I-710 are being replaced with electric trucks. Observe that the percentage rates are also valid for any amount of vehicles exchanged. A negative number represents a decrease while a positive number represents an increase.

Total savings with electricity instead of diesel							
	2008		2035		2035 with 2008 truck volume		
Total Energy	-1 022	-22 %	-2 433	-34 %	-1 571	-34 %	TJoule
Fossil Fuels	-1 756	-37 %	-3 731	-52 %	-2 409	-52 %	TJoule
- Coal	887	4182 %	969	4095 %	626	4095 %	TJoule
- Natural Gas	1 643	416 %	1 866	316 %	1 205	316 %	TJoule
- Petroleum	-4 286	-99 %	-6 566	-99 %	-4 240	-99 %	TJoule
GHGs	-140	-38 %	-296	-52 %	-191	-52 %	thousand tonnes
- CO2[a]	-152	-43 %	-304	-56 %	-196	-56 %	thousand tonnes
- CH4	455	83 %	290	36 %	187	36 %	tonnes
- N2O	2 620	247 %	1 815	116 %	1 172	116 %	kg
VOC	-155	-87 %	-31	-56 %	-20	-56 %	tonnes
CO	-617	-86 %	-31	-19 %	-20	-19 %	tonnes
NOx	-2 657	-91 %	-306	-56 %	-198	-56 %	tonnes
PM10	20	12 %	186	430 %	120	430 %	tonnes
PM2.5	-83	-56 %	70	275 %	45	275 %	tonnes
SOx	297	382 %	252	339 %	163	339 %	tonnes

[a] including C in VOC and CO

Table 18: Difference between the years of 2008 and 2035 presented with the diesel and electricity separately, meaning diesel is compared with diesel and electricity with electricity.

Difference between 2008 and 2035									
	2035				2035 with 2008 truck volume				
	Diesel		Electricity		Diesel		Electricity		
Total Energy	2 498	53 %	1 087	29 %	-69	-1 %	-619	-17 %	TJoule
Fossil Fuels	2 485	53 %	510	17 %	-72	-2 %	-725	-24 %	TJoule
- Coal	2	12 %	84	9 %	-6	-28 %	-267	-29 %	TJoule
- Natural Gas	196	50 %	419	21 %	-13	-3 %	-451	-22 %	TJoule
- Petroleum	2 286	53 %	6	21 %	-53	-1 %	-7	-22 %	TJoule
GHGs	195	52 %	39	17 %	-6	-2 %	-57	-25 %	thousand tonnes
- CO2[a]	188	53 %	36	18 %	-5	-1 %	-49	-24 %	thousand tonnes
- CH4	270	50 %	105	10 %	-19	-3 %	-286	-29 %	tonnes
- N2O	510	48 %	-296	-8 %	-46	-4 %	-1 495	-41 %	kg
VOC	-123	-69 %	1	2 %	-143	-80 %	-8	-34 %	tonnes
CO	-557	-77 %	28	27 %	-615	-85 %	-19	-18 %	tonnes
NOx	-2 372	-81 %	-20	-8 %	-2 564	-88 %	-104	-41 %	tonnes
PM10	-121	-74 %	45	24 %	-137	-83 %	-36	-20 %	tonnes
PM2.5	-122	-83 %	31	48 %	-131	-89 %	-3	-4 %	tonnes
SOx	-3	-4 %	-48	-13 %	-30	-38 %	-164	-44 %	tonnes

[a] including C in VOC and CO

5 Discussion

The purpose of this study was to find what impacts the use of a new external freight corridor for zero-emission vehicles along the I-710 could be regarding energy use, climate impact and air quality. To see what the effect would be of introducing electric trucks instead of diesel trucks in the future, the differences between the diesel and the electricity case, for year 2035, is shown in parenthesis in Table 15.

The results clearly show that less energy is needed for electricity than for diesel, about 33.6 percent less, but for the pollutions the results were not as consistent. The PM and SO_x pollutants for electricity were much higher, which can be explained by that these emissions are high from the electricity production for the electricity mix used in this study, see Table 12 for the electricity mix used. Using electricity instead of diesel means that the pollution does not take place on the highway per se but somewhere else at a power plant, meaning that the air quality around the highway will not get worse even if the PM and the SO_x emissions are higher. Also; once the PM, which basically is dust, has settled on the ground it is no longer dangerous (since it is no longer in the inhalable air), meaning if there is no high volume of vehicles or such around the power plants that can release the particles into the air again (from whirls around the vehicles' tires) it settles and the nature will take care of it. So, these particles will not be a health threat once sunken down to earth, i.e., not airborne anymore, and therefore if the power plants are put distant from humans or roads where it could easily get released again from the ground, the negative effects of it can be neglected. A smaller amount of the PM will still be polluted at the highway since they also include particles from break and tire-wear. However, these amounts are the same as they would be if diesel would have been used.

The difference between electricity and diesel regarding coal and natural gas was an increase for electricity compared to diesel of about 4000 and 300 percent respectively, but the decrease of petroleum use around 99 % is even bigger so that the total decrease in fossil fuel use is about 52 %. The reason why the numbers of coal and natural gas are so much higher for electricity is that there are power plants using that in the production, while for diesel it is not used that much at all.

In this study, the results for the electric trucks were calculated with the average electricity mix in California in 2008, meaning that there has been no consideration of how a probable increase in electricity demand could change the electricity mix. So it is important to remember that if a considerable amount of new electric vehicles, or electricity demand in general, would enter the market also the new electricity needed would have to be produced somewhere. If a large amount of extra electricity is needed it is not certain that the existing power plants could handle the extra demand and therefore new power plants would have to start up. To afford new power plant(s) at an urge of more electricity it is likely that the new power plants would be cheap and the cheapest technologies for electricity production today are the worst for the environment, such as coal power plants. Assuming the existing power plants would be enough to produce also the extra demand might also likely lead to a worse composition of resources used. Since the renewable (and therefore also the most environmentally friendly) options are used first because they are hard to control and has to produce electricity as often as possible.

Examples could be that solar cells can only be used when the sun is shining and wind turbines only when the wind is blowing. This means that what is left to fill up an extra demand in electricity production would be the most expensive, which are usually coal and natural gas. So a higher rate of fossil fuels in the electricity mix (regardless of if it is newly built or existing unused capacity) would mean worse results for electricity than with a current electricity mix. The conclusion of this is that the results of a study like this are directly influenced by the electricity mix and if the new demand is so high that it is needed to use even more fossil fuels in the electricity production, then the gains of using electricity would be less, if any at all with a big increase of fossil fuels. Furthermore, an important aspect that will affect the electricity mix in the future is national and regional environmental policy instruments, i.e., how hard authorities are willing to tighten rules and laws to achieve better conditions to succeed in environmental goals set. Policy instruments can beside tighten rules about large emitting options also include for example subsidies for low emitting options.

In this study the total results found are based on scenarios where all trucks are either fueled by diesel or run on a hundred percent electricity, which might not be a realistic scenario regarding the nearest future whereas a lot of trucks will probably still be driven on diesel in 2035. But in a long run it might still be a reasonable assumption as the development goes more and more towards zero-emission vehicles. When the transportation development has come so far, it is also reasonable to believe that also the electricity production, i.e., the average/marginal electricity mix, has changed as well, hopefully for the better with more renewable sources such as wind and solar power, and that the coal and natural gas use will have decreased. Even though the scenarios were based on a hundred percent use of either energy option, the results can still be used for the I-710 if looking at the percentage reductions/increases, since the new corridor would include a possibility to use a hundred percent of electricity with the connection to the electricity grid.

Unfortunate with this study was that it was quite difficult to find good and consequent data, meaning that the input data that has been used may not be the best to get a good result. As for example the data that were used for the hourly truck traffic volume was from 2007 and measured over two different time spans (two months) whereas here these numbers were used in an average. Another parameter can for example be the truck split (the distribution of truck types) which were gathered looking at the truck split at POLA located in the south end of I-710, but actually the truck load on the I-710 which is correlated to the ports is much higher at the south part of the I-710 (94.1 % between PCH and Willow St.) and is less valid for the northern part of the I-710 (4.2 % between I-5 and SR-60) [34]. Additionally, there was an assumption in the calculations of the slope of the road to be 0° which could favor the results of diesel, since diesel use more energy per travelled length unit than electricity, meaning that the difference in the results of electricity and diesel could be less than it should. These three are only examples and the rest of the data may neither be fully accurate, see Section 3 for more information on where the data were gathered from. However, data used were the best available. Even though the data might not be ideal the study can still be valuable since the differences would not be so big that it would affect the conclusions of using electricity instead of diesel. Additionally, the future scenario per se is very uncertain since it is always difficult to know how the future will look like.

Furthermore, there are a lot of hidden parameters in the background of GREET which are not shown to the user. Going under the surface of the program though, it is possible to change also these parameters. So, there are several parameters in the calculations that have not been updated with the latest and most appropriate data, also making the results less exact.

It is hard to make a distinct conclusion of what is the better option, electric driven trucks or diesel driven trucks, from a health and environmental perspective when the results are differing in favor and not always show for example a decrease for electricity compared to diesel as in this case. So, when saying that one of the options is better than the other; a weighing of the results importance would have to be done. But even if a weighing would be done it would not necessarily show an appropriate result and there would still be pros and cons with either option, i.e., no option would be ideal. Even though, it is quite easy to say that electric trucks is a better option than diesel trucks when looking at that total fossil fuel use as well as greenhouse gases from electric trucks are less than half (-51.7 % and -52.2 % respectively) compared to diesel. Also the total energy use would be much less with a reduction of about a third (-33.6 %) of the energy use for the electric trucks compared to diesel.

Further thoughts on the highway and truck transportation

Regarding building an external truck corridor only meant for zero-emission trucks it can be questioned in the matter of that if the switch from fossil fuel trucks to zero-emission trucks is very slow; then the truck corridor will be running quite empty and the effect of it will not be as big as wanted, i.e., a big load of trucks will still be running with the cars along the I-710. But as with everything, changes take time, and it is only a matter of time before it would be needed to be done and then it might be a good option to build an external freight corridor now when changes are anyway planned to be done to the highway.

If it is desirable to further decrease emissions from trucks, one big aspect could be to increase the length of the vehicles. Here there is a big difference between US's and Sweden's trucks whereas US only allows a total truck length of 19.81 m (65 feet) [35] while Sweden allows up to 25.25 m (about 82.84 feet) [36]. An effect of longer truck bodies is that one truck can carry more goods in one run resulting in fewer trucks needed and lower fuel consumption per goods and mile, this would be the case regardless of energy option used.

Furthermore, by extending the freeway and move trucks to separate, external, files it allows an increase in civil transportation to happen, it is indicated that it is ok with a lot of traffic, i.e., the problem with congestion and environmental effects from transportation will not be solved since less trucks on the highway allows more civil vehicles to use the roads and then the problems will only be moved from one spot to another. So instead of opening up the highway it could for example be an idea to expand and promote public transportation by for example giving these vehicles privileges in the traffic. Another way to decrease traffic volume would be to encourage carpooling/carsharing so that the cars will have a higher average number of people per car, instead of only one person per car which generally seems to be today.

Even if the amount of cars would decrease, the amount of trucks will still increase with more goods coming to the ports. Above trucks going to the ports, there is a rail system connected to the ports as well, but this cannot handle much more traffic whereas the trucks will have to take care of the higher flow. So in addition to this I-710 corridor project it would also be important to look over possibilities to also extend the rail system.

6 Conclusion

The conclusion of this study is that using heavy duty hybrid electric trolley trucks on the I-710 instead of heavy duty diesel trucks is a good option for the environment, regarding energy use, climate impact and air quality. The results indicate that there would be;

- A decrease in energy use,
- A decrease in fossil fuel use,
- A decrease in greenhouse gases,
- A decrease in VOC, CO and NO_x and
- An increase in PM10, PM2.5 and SO_x.

References

[1] CA.GOV, "Energy Almanac," [Online]. Available: http://energyalmanac.ca.gov. [Accessed 5 April 2013].

[2] State of California Department of Transportation & Los Angeles County Metropolitan Transportation Authority, "I-710 Corridor Project," The State of California - Department of Transportation, Los Angeles, California, 2012.

[3] Metro.net, "I-710 Corridor Project," [Online]. Available: http://www.metro.net/projects/i-710-corridor-project/. [Accessed 20 March 2013].

[4] Oak Ridge National Laboratory, Transportation Energy Data Book, Edition 31 ed., Oak Ridge, Tennessee: UT-BATTELLE, LLC, 2012.

[5] Changin' Gears - Trading city lights for the RV lifestyle , "Glossary of RV Terms," [Online]. Available: http://changingears.com/rv-sec-learn-glossary_g.shtml#_gvwr. [Accessed 16 April 2013].

[6] Changin' Gears - Trading city lights for the RV lifestyle, "Truck Classification," [Online]. Available: http://changingears.com/rv-sec-tow-vehicles-classes.shtml. [Accessed 16 April 2013].

[7] Oak Ridge National Laboratory, 2012 Vehicle Technologies Market Report, L. UT-BATTELLE, Ed., U.S. Department of Energy, 2013.

[8] CA.GOV, "Zero-Emission Vehicle Legal and Regulatory Activities and Background," 14 September 2012. [Online]. Available: http://www.arb.ca.gov/msprog/zevprog/zevregs/zevregs.htm#background. [Accessed 9 April 2013].

[9] California Environmental Protection Agency, "The California Zero Emission Vehicle Regulation," 26 January 2011. [Online]. Available: http://www.arb.ca.gov/msprog/zevprog/factsheets/zev_fs.pdf. [Accessed 9 April 2013].

[10] Transportation California, "Resources," 5 June 2012. [Online]. Available: http://transportationca.com/current-issues/resources-links/. [Accessed 25 April 2013].

[11] Texas A&M Transportation Institute, "Summary Tables - Congestion Levels and Trends," 2012. [Online]. Available: http://mobility.tamu.edu/ums/national-congestion-tables/. [Accessed 26 April 2013].

[12] Princeton.edu, "Diesel Engine," [Online]. Available: http://www.princeton.edu/~achaney/tmve/wiki100k/docs/Diesel_engine.html. [Accessed 29 April 2013].

[13] Siemes, "Electric Trucks," 1012. [Online]. Available: http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2012/_html_en/electric-trucks.html. [Accessed 2 October 2013].

[14] Showtimes, "Siemens Promotes eHighway Catenary Concept," *ShowTimes Daily,* 18

September 2012.

[15] U.S. Environmental Protection Agency, "Air and Radiation," 14 December 2012. [Online]. Available: http://www.epa.gov/air/criteria.html. [Accessed August 2013].

[16] Environmental Protection Agency, "Basic Information," 1 November 2012. [Online]. Available: http://www.epa.gov/glo/basic.html. [Accessed 26 April 2013].

[17] Environmental Protection Agency, "Health Effects," 1 November 2012. [Online]. Available: http://www.epa.gov/glo/health.html. [Accessed 26 April 2013].

[18] Environmental Protection Agency, "Air Trends," [Online]. Available: http://www.epa.gov/airtrends/index.html. [Accessed April 2013].

[19] Environmental Protection Agency, "Carbon Monoxide," 28 November 2012. [Online]. Available: http://www.epa.gov/airtrends/carbon.html#coloc. [Accessed 26 April 2013].

[20] Environmental Protection Agency, "Nitrogen Dioxide," 4 April 2013. [Online]. Available: http://www.epa.gov/airquality/nitrogenoxides/. [Accessed 11 August 2013].

[21] Environmental Protection Agency, "Sulfur Dioxide," 2013. [Online]. Available: http://www.epa.gov/airquality/sulfurdioxide/. [Accessed April 2013].

[22] Environmental Protection Agency, "Lead in Air," 2012. [Online]. Available: http://www.epa.gov/airquality/lead/. [Accessed April 2013].

[23] Environmental Protection Agency, "Particulate Matter (PM)," 2013. [Online]. Available: http://www.epa.gov/air/particlepollution/. [Accessed April 2013].

[24] United States Environmental Protection Agency, "Transportation and Climate," 23 January 2013. [Online]. Available: http://www.epa.gov/oms/climate/basicinfo.htm. [Accessed 10 April 2013].

[25] National Earth Science Teachers Association, "Windows to the Universe," 1 June 2007. [Online]. Available: http://www.windows2universe.org/earth/climate/greenhouse_effect_gases.html. [Accessed 11 April 2013].

[26] Acoustical Solutions, Inc., "Transportation Noise," [Online]. Available: http://www.acousticalsolutions.com/transportation-noise . [Accessed 15 April 2013].

[27] trafficnoise.org, "trafficnoise.org," 2003. [Online]. Available: http://www.trafficnoise.org/. [Accessed 15 April 2013].

[28] NCC, "Viaco(R)," [Online]. Available: http://www.ncc.se/Material-och-service/Asfalt-och-belaggning/specialprodukter-belaggning-asfalt/VIACO/tyst-asfalt/. [Accessed 16 April 2013].

[29] United States Environmental Protection Agency, "MOVES (Motor Vehicle Emission Simulator)," 30 May 2013. [Online]. Available: http://www.epa.gov/otaq/models/moves/index.htm. [Accessed July 2013].

[30] Argonne National Laboratory, "GREET Model," 21 December 2012. [Online]. Available: http://greet.es.anl.gov/. [Accessed July 2013].

[31] U.S. Department of Transportation Federal Highway Administration, "Highway Statistics 2008," 3 January 2012. [Online]. Available: http://www.fhwa.dot.gov/policyinformation/statistics/2008/vm1.cfm. [Accessed July 2013].

[32] U.S. Department of Energy, "All-Electric Vehicles (EVs)," 5 April 2013. [Online]. Available: http://www.fueleconomy.gov/feg/evtech.shtml. [Accessed April 2013].

[33] M. Wang, Y. Wu and A. Elgowainy, "Operating Manual for GREET: Version 1.7," Argonne National Laboratory, Argonne, 2007.

[34] U.S. Department of Transportation Federal Highway Administration, "FHWA Operations Support - Port Peak Pricing Program Evaluation," 2013. [Online]. Available: http://ops.fhwa.dot.gov/publications/fhwahop09014/sect2.htm. [Accessed July 2013].

[35] U.S. Department of Transportation Federal Highway Administration, "Federal Size Regulations for Commercial Motor Vehicles," [Online]. Available: http://ops.fhwa.dot.gov/freight/publications/size_regs_final_rpt/index.htm#length. [Accessed 19 September 2013].

[36] S. Hedberg, "Swedish Road Adminstration (SRA)," [Online]. Available: http://www.unece.org/fileadmin/DAM/trans/wp24/wp24-presentations/documents/pres08-04.pdf. [Accessed 19 september 2013].

[37] Climate Change Connection, "CO2 equivalents," 10 August 2009. [Online]. Available: http://www.climatechangeconnection.org/emissions/CO2_equivalents.htm. [Accessed January 2014].

Appendix 1

Here the age distribution of the trucks that were used in MOVES can be seen.

Table 19: Age distribution of the trucks used in MOVES, collected from the default in the same program.

Age distribution				
Age	Single Unit Short-haul Truck	Single Unit Long-haul Truck	Combination Short-haul Truck	Combination Long-haul Truck
0	6.22 %	16.97 %	8.43 %	16.68 %
1	5.20 %	14.19 %	6.72 %	13.31 %
2	4.12 %	11.24 %	5.76 %	11.40 %
3	4.66 %	5.85 %	5.06 %	11.40 %
4	5.59 %	6.09 %	6.93 %	11.86 %
5	5.72 %	10.17 %	5.62 %	8.04 %
6	4.34 %	7.83 %	4.88 %	6.43 %
7	3.44 %	1.85 %	3.79 %	4.03 %
8	3.51 %	1.38 %	4.53 %	3.04 %
9	4.35 %	6.86 %	5.35 %	3.15 %
10	5.78 %	7.48 %	5.60 %	3.20 %
11	5.31 %	5.17 %	5.50 %	2.90 %
12	4.60 %	1.29 %	5.97 %	0.80 %
13	5.80 %	0.31 %	5.28 %	0.87 %
14	4.30 %	0.64 %	4.87 %	1.15 %
15	2.51 %	0.67 %	4.00 %	0.62 %
16	4.09 %	0	1.67 %	0.13 %
17	2.20 %	0.32 %	1.47 %	0.11 %
18	2.19 %	0.24 %	1.33 %	0.35 %
19	2.39 %	0	1.80 %	0.12 %
20	1.90 %	0.02 %	1.12 %	0.10 %
21	2.25 %	1.01 %	0.90 %	0.06 %
22	0.88 %	0.06 %	0.99 %	0.10 %
23	1.12 %	0.11 %	0.38 %	0
24	1.15 %	0.05 %	0.48 %	0.09 %
25	1.25 %	0	0.48 %	0.03 %
26	1.30 %	0.21 %	0.40 %	0.03 %
27	2.65 %	0	0.36 %	0
28	0.59 %	0	0.26 %	0.02 %
29	0.32 %	0	0.06 %	0
30	0.26 %	0	0	0
Total	100.00 %	100.00 %	100.00 %	100.00 %

Appendix 2

In this appendix the output data from MOVES can be seen as after they were sorted and aggregated into the corresponding group of emissions that was needed in GREET, i.e., these data were then used as input to GREET. These data were only gathered for diesel, which is shown in the tables, since the running emissions for electricity are zero. However, the brake and tire wear of particulate matter found are used for electricity as well.

Table 20: Output data from MOVES for combination short-haul trucks. Data in grams per mile.

Combination Short-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Exhaust VOC	0.6483	0.7055	0.6483	0.7055	0.6483	0.7055	0.6483	0.7055
Evaporative VOC								
CO	3.6554	4.1944	3.6554	4.1944	3.6554	4.1944	3.6554	4.1944
Nox	19.0634	20.5962	18.5806	19.8648	17.6160	18.6756	16.8331	18.1098
Exhaust PM10	0.7319	1.0094	0.7319	1.0094	0.7319	1.0094	0.7320	1.0095
Brake and Tire Wear PM 10	0.0309	0.0644	0.0309	0.0644	0.0309	0.0644	0.0309	0.0644
Exhaust PM2.5	0.7100	0.9792	0.7100	0.9792	0.7100	0.9792	0.7100	0.9793
Brake and Tire Wear PM2.5	0.0077	0.0165	0.0077	0.0165	0.0077	0.0165	0.0077	0.0165
CH4	0.0068	0.0079	0.0068	0.0079	0.0068	0.0079	0.0068	0.0079
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018
2035								
Exhaust VOC	0.0273	0.0326	0.0273	0.0326	0.0273	0.0326	0.0273	0.0326
Evaporative VOC								
CO	0.3115	0.3422	0.3115	0.3422	0.3115	0.3422	0.3115	0.3422
Nox	1.3877	1.5435	1.3526	1.4887	1.2824	1.3995	1.2254	1.3571
Exhaust PM10	0.0216	0.0293	0.0216	0.0293	0.0217	0.0293	0.0217	0.0294
Brake and Tire Wear PM 10	0.0305	0.0636	0.0305	0.0636	0.0305	0.0636	0.0305	0.0636
Exhaust PM2.5	0.0210	0.0285	0.0210	0.0285	0.0210	0.0285	0.0211	0.0285
Brake and Tire Wear PM2.5	0.0076	0.0163	0.0076	0.0163	0.0076	0.0163	0.0076	0.0163
CH4	0.0367	0.0438	0.0367	0.0438	0.0367	0.0438	0.0367	0.0438
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018

Table 21: Output data from MOVES for combination long-haul trucks. Data in grams per mile.

Combination Long-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Exhaust VOC	0.4215	0.4661	0.4215	0.4661	0.4215	0.4661	0.4215	0.4661
Evaporative VOC								
CO	2.4274	2.7411	2.4274	2.7411	2.4274	2.7411	2.4274	2.7411
Nox	11.9512	12.9338	11.6485	12.4745	11.0438	11.7278	10.5530	11.3724
Exhaust PM10	0.4715	0.6662	0.4715	0.6662	0.4715	0.6662	0.4716	0.6663
Brake and Tire Wear PM 10	0.0329	0.0693	0.0329	0.0693	0.0329	0.0693	0.0329	0.0693
Exhaust PM2.5	0.4573	0.6463	0.4573	0.6463	0.4574	0.6463	0.4574	0.6464
Brake and Tire Wear PM2.5	0.0082	0.0177	0.0082	0.0177	0.0082	0.0177	0.0082	0.0177
CH4	0.0112	0.0133	0.0112	0.0133	0.0112	0.0133	0.0112	0.0133
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018
2035								
Exhaust VOC	0.0258	0.0307	0.0258	0.0307	0.0258	0.0307	0.0258	0.0307
Evaporative VOC								
CO	0.2963	0.3258	0.2963	0.3258	0.2963	0.3258	0.2963	0.3258
Nox	1.2807	1.4231	1.2483	1.3726	1.1835	1.2904	1.1309	1.2513
Exhaust PM10	0.0215	0.0298	0.0215	0.0298	0.0215	0.0299	0.0215	0.0299
Brake and Tire Wear PM 10	0.0329	0.0693	0.0329	0.0693	0.0329	0.0693	0.0329	0.0693
Exhaust PM2.5	0.0208	0.0290	0.0208	0.0290	0.0208	0.0290	0.0209	0.0290
Brake and Tire Wear PM2.5	0.0076	0.0163	0.0076	0.0163	0.0076	0.0163	0.0076	0.0163
CH4	0.0367	0.0438	0.0367	0.0438	0.0367	0.0438	0.0367	0.0438
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018

Table 22: Output data from MOVES for single unit short-haul trucks. Data in grams per mile.

Single Unit Short-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Exhaust VOC	0.7192	0.8242	0.7192	0.8242	0.7192	0.8242	0.7192	0.8242
Evaporative VOC								
CO	2.4136	2.7508	2.4136	2.7508	2.4136	2.7508	2.4136	2.7508
Nox	7.0938	9.0444	6.9141	8.7232	6.5552	8.2010	6.2639	7.9525
Exhaust PM10	0.4686	0.5380	0.4686	0.5380	0.4686	0.5380	0.4686	0.5381
Brake and Tire Wear PM 10	0.0316	0.0488	0.0316	0.0488	0.0316	0.0488	0.0316	0.0488
Exhaust PM2.5	0.4545	0.5219	0.4545	0.5219	0.4545	0.5219	0.4546	0.5220
Brake and Tire Wear PM2.5	0.0080	0.0125	0.0080	0.0125	0.0080	0.0125	0.0080	0.0125
CH4	0.0061	0.0072	0.0061	0.0072	0.0061	0.0072	0.0061	0.0072
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018
2035								
Exhaust VOC	0.0335	0.0395	0.0335	0.0395	0.0335	0.0395	0.0335	0.0395
Evaporative VOC								
CO	0.3132	0.3455	0.3132	0.3455	0.3132	0.3455	0.3132	0.3455
Nox	0.8099	0.9379	0.7894	0.9046	0.7484	0.8504	0.7151	0.8247
Exhaust PM10	0.0143	0.0156	0.0143	0.0156	0.0143	0.0156	0.0143	0.0157
Brake and Tire Wear PM 10	0.0315	0.0485	0.0315	0.0485	0.0315	0.0485	0.0315	0.0485
Exhaust PM2.5	0.0139	0.0152	0.0139	0.0152	0.0139	0.0152	0.0139	0.0152
Brake and Tire Wear PM2.5	0.0080	0.0124	0.0080	0.0124	0.0080	0.0124	0.0080	0.0124
CH4	0.0405	0.0477	0.0405	0.0477	0.0405	0.0477	0.0405	0.0477
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018

Table 23: Output data from MOVES for single unit long-haul trucks. Data in grams per mile.

Single Unit Long-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Exhaust VOC	0.4719	0.5442	0.4719	0.5442	0.4719	0.5442	0.4719	0.5442
Evaporative VOC								
CO	1.6746	1.8883	1.6746	1.8883	1.6746	1.8883	1.6746	1.8883
Nox	4.5585	5.5732	4.4430	5.3753	4.2124	5.0535	4.0252	4.9004
Exhaust PM10	0.2576	0.2858	0.2576	0.2858	0.2576	0.2858	0.2576	0.2859
Brake and Tire Wear PM 10	0.0317	0.0483	0.0317	0.0483	0.0317	0.0483	0.0317	0.0483
Exhaust PM2.5	0.2499	0.2772	0.2499	0.2772	0.2499	0.2772	0.2499	0.2773
Brake and Tire Wear PM2.5	0.0081	0.0124	0.0081	0.0124	0.0081	0.0124	0.0081	0.0124
CH4	0.0123	0.0145	0.0123	0.0145	0.0123	0.0145	0.0123	0.0145
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018
2035								
Exhaust VOC	0.0277	0.0325	0.0277	0.0325	0.0277	0.0325	0.0277	0.0325
Evaporative VOC								
CO	0.2733	0.3012	0.2733	0.3012	0.2733	0.3012	0.2733	0.3012
Nox	0.6080	0.7084	0.5926	0.6832	0.5618	0.6423	0.5369	0.6229
Exhaust PM10	0.0105	0.0115	0.0105	0.0115	0.0105	0.0115	0.0106	0.0115
Brake and Tire Wear PM 10	0.0318	0.0484	0.0318	0.0484	0.0318	0.0484	0.0318	0.0484
Exhaust PM2.5	0.0102	0.0111	0.0102	0.0111	0.0102	0.0111	0.0102	0.0112
Brake and Tire Wear PM2.5	0.0081	0.0124	0.0081	0.0124	0.0081	0.0124	0.0081	0.0124
CH4	0.0377	0.0443	0.0377	0.0443	0.0377	0.0443	0.0377	0.0443
N2O	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018	0.0015	0.0018

Appendix 3

Here some of the parameters that were used in GREET can be seen.

Table 24: Assumptions in GREET for 2008 and 2035.

Pathway Options		
Items	***2008***	***2035***
NG turbine combined cycle share of total NG power plant capacity (%):	64.7	87.8
Simple-cycle NG turbine share of total NG power plant capacity (%):	17.9	6.2
Advanced coal technology share of total coal power plant capacity (%):	0	3
Advanced biomass technology share of total biomass power plant capacity (%):	0	3
LWR Plant Technology Shares for Electricity Production: Gas Diffusion (%):	27	10
LWR Plant Technology Shares for Electricity Production: Centrifuge (%):	73	90
HTGR Plant Technology Shares for Electricity Production: Gas Diffusion (%):	27	10
HTGR Plant Technology Shares for Electricity Production: Centrifuge (%):	73	90
Woody Biomass Plant Technology Shares for Electricity Production (%):	0	0
Herbaceous Biomass Plant Technology Shares for Electricity Production (%):	100	100

Petroleum		
Items	***2008***	***2035***
Share of Oil Sands Products in Crude Oil Feed	6.7 %	16.0 %
Share of Surface Mining in Oil Sands Recovery Methods	57.2 %	45.0 %
Crude Recovery Efficiency	98.0 %	98.0 %
Surface Mining: Bitumen Recovery Efficiency	94.8 %	95.2 %
Surface Mining: Bitumen Upgrading Efficiency	98.6 %	98.7 %
In Situ Production: Bitumen Recovery Efficiency	84.3 %	85.6 %
In Situ Production: Bitumen Upgrading Efficiency	99.2 %	98.7 %
LSD Refining Efficiency	90.60 %	90.60 %

Electricity		
Items	***2008***	***2035***
Residual Oil Utility Boiler Efficiency	32.8 %	32.8 %
NG Utility Boiler Efficiency	31.9 %	31.9 %
NG Simple Cycle Turbine Efficiency	32.6 %	33.0 %
NG Combined Cycle Turbine Efficiency	49.8 %	56.4 %
Coal Utility Boiler Efficiency	34.3 %	34.8 %
Advanced Coal Power Plant Efficiency		46.7 %
Biomass Utility Boiler Efficiency		21.0 %
Advanced Biomass Power Plant Efficiency		45.0 %
Electricity Transmission and Distribution Loss	6.5 %	6.5 %
Energy intensity in HTGR reactors (MWh/g of U-235)	8.704	8,704
Energy intensity in LWR reactors (MWh/g of U-235)	6.926	6,926
Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for LWR electricity generation	2 400	2 400
Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for LWR electricity generation	50.0	50,0
Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for HTGR electricity generation	2 400	2 400
Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for HTGR electricity generation	50	50
Electric Charger Efficiency (%)		85

Appendix 4

In this appendix the output from GREET can be seen for the four different truck types; combination short-haul, combination long-haul, single unit short-haul and single unit long haul trucks. The numbers in the tables below are the sum of the numbers in the three categories; feedstock, fuel and vehicle operation.

Table 25: Output from GREET for combination short-haul trucks fueled with diesel. Energy data in BTU/mile and emission data in g/mile.

Combination Short-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	22452	22452	22452	22452	22452	22452	22452	22452
Fossil Fuels	22370	22370	22370	22370	22370	22370	22370	22370
Coal	100	100	100	100	100	100	100	100
Natural Gas	1865	1865	1865	1865	1865	1865	1865	1865
Petroleum	20404	20404	20404	20404	20404	20404	20404	20404
CO2 (w/ C in VOC & CO)	1786	1786	1786	1786	1786	1786	1786	1786
CH4	2.7159	2.7170	2.7159	2.7170	2.7159	2.7170	2.7159	2.7170
N2O	0.0051	0.0054	0.0051	0.0054	0.0051	0.0054	0.0051	0.0054
GHGs	1855	1855	1855	1855	1855	1855	1855	1855
VOC: Total	0.7952	0.8524	0.7952	0.8524	0.7952	0.8524	0.7952	0.8524
CO: Total	3.8785	4.4175	3.8785	4.4175	3.8785	4.4175	3.8785	4.4175
NOx: Total	19.7753	21.3144	19.2953	20.5753	18.3353	19.3953	17.5453	18.8253
PM10: Total	0.8562	1.1667	0.8562	1.1667	0.8562	1.1668	0.8563	1.1678
PM2.5: Total	0.7761	1.0540	0.7761	1.0541	0.7761	1.0541	0.7761	1.0542
SOx: Total	0.3882	0.3882	0.3882	0.3882	0.3882	0.3882	0.3882	0.3882
2035								
Total Energy	22125	22125	22125	22125	22125	22125	22125	22125
Fossil Fuels	22032	22032	22032	22032	22032	22032	22032	22032
Coal	72	72	72	72	72	72	72	72
Natural Gas	1804	1804	1804	1804	1804	1804	1804	1804
Petroleum	20156	20156	20156	20156	20156	20156	20156	20156
CO2 (w/ C in VOC & CO)	1759	1759	1759	1759	1759	1759	1759	1759
CH4	2.6171	2.6242	2.6171	2.6242	2.6171	2.6242	2.6171	2.6242
N2O	0.0048	0.0051	0.0048	0.0051	0.0048	0.0051	0.0048	0.0051
GHGs	1826	1826	1826	1826	1826	1826	1826	1826
VOC: Total	0.1683	0.1736	0.1683	0.1736	0.1683	0.1736	0.1683	0.1736
CO: Total	0.4907	0.5214	0.4907	0.5214	0.4907	0.5214	0.4907	0.5214
NOx: Total	1.9593	2.1153	1.9243	2.0665	1.8533	1.9713	1.7963	1.9283
PM10: Total	0.1298	0.1706	0.1298	0.1706	0.1299	0.1706	0.1299	0.1707
PM2.5: Total	0.0797	0.0959	0.0797	0.0959	0.0797	0.0959	0.0798	0.0959
SOx: Total	0.2399	0.2399	0.2399	0.2399	0.2399	0.2399	0.2399	0.2399

Table 26: Output from GREET for combination long-haul trucks fueled with diesel. Energy data in BTU/mile and emission data in g/mile.

Combination Long-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	22452	22452	22452	22452	22452	22452	22452	22452
Fossil Fuels	22370	22370	22370	22370	22370	22370	22370	22370
Coal	100	100	100	100	100	100	100	100
Natural Gas	1865	1865	1865	1865	1865	1865	1865	1865
Petroleum	20404	20404	20404	20404	20404	20404	20404	20404
CO2 (w/ C in VOC & CO)	1786	1786	1786	1786	1786	1786	1786	1786
CH4	2.7203	2.7224	2.7203	2.7224	2.7203	2.7224	2.7203	2.7224
N2O	0.0051	0.0054	0.0051	0.0054	0.0051	0.0054	0.0051	0.0054
GHGs	1855	1855	1855	1855	1855	1855	1855	1855
VOC: Total	0.5684	0.6130	0.5684	0.6130	0.5684	0.6130	0.5684	0.6130
CO: Total	2.6505	2.9645	2.6505	2.9645	2.6505	2.9645	2.6505	2.9645
NOx: Total	12.6653	13.6453	12.3653	13.1844	11.7553	12.4453	11.2653	12.0853
PM10: Total	0.5978	0.8289	0.5978	0.8288	0.5978	0.8289	0.5979	0.8290
PM2.5: Total	0.5239	0.7224	0.5239	0.7223	0.5240	0.7224	0.5240	0.7225
SOx: Total	0.3882	0.3882	0.3882	0.3882	0.3882	0.3882	0.3882	0.3882
2035								
Total Energy	22125	22125	22125	22125	22125	22125	22125	22125
Fossil Fuels	22032	22032	22032	22032	22032	22032	22032	22032
Coal	72	72	72	72	72	72	72	72
Natural Gas	1804	1804	1804	1804	1804	1804	1804	1804
Petroleum	20156	20156	20156	20156	20156	20156	20156	20156
CO2 (w/ C in VOC & CO)	1759	1759	1759	1759	1759	1759	1759	1759
CH4	2.6155	2.6222	2.6155	2.6222	2.6155	2.6222	2.6155	2.6222
N2O	0.0048	0.0051	0.0048	0.0051	0.0048	0.0051	0.0048	0.0051
GHGs	1826	1826	1826	1826	1826	1826	1826	1826
VOC: Total	0.1668	0.1717	0.1668	0.1717	0.1668	0.1717	0.1668	0.1717
CO: Total	0.4755	0.5050	0.4755	0.5050	0.4755	0.5050	0.4755	0.5050
NOx: Total	1.8585	1.9943	1.8193	1.9505	1.7553	1.8675	1.7023	1.8223
PM10: Total	0.1330	0.1768	0.1321	0.1777	0.1321	0.1778	0.1321	0.1769
PM2.5: Total	0.0807	0.0978	0.0801	0.0984	0.0801	0.0984	0.0802	0.0978
SOx: Total	0.2399	0.2399	0.2399	0.2399	0.2399	0.2399	0.2399	0.2399

Table 27: Output from GREET for single unit short-haul trucks fueled with diesel. Energy data in BTU/mile and emission data in g/mile.

Single Unit Short-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	18204	18204	18204	18204	18204	18204	18204	18204
Fossil Fuels	18138	18138	18138	18138	18138	18138	18138	18138
Coal	81	81	81	81	81	81	81	81
Natural Gas	1513	1513	1513	1513	1513	1513	1513	1513
Petroleum	16544	16544	16544	16544	16544	16544	16544	16544
CO2 (w/ C in VOC & CO)	1448	1448	1448	1448	1448	1448	1448	1448
CH4	2.2027	2.2038	2.2027	2.2038	2.2027	2.2038	2.2027	2.2038
N2O	0.0044	0.0047	0.0044	0.0047	0.0044	0.0047	0.0044	0.0047
GHGs	1504	1504	1504	1504	1504	1504	1504	1504
VOC: Total	0.8383	0.9433	0.8383	0.9433	0.8383	0.9433	0.8383	0.9433
CO: Total	2.5952	2.9322	2.5952	2.9322	2.5952	2.9322	2.5952	2.9322
NOx: Total	7.6740	9.6240	7.4940	9.3030	7.1350	8.7810	6.8440	8.5330
PM10: Total	0.5759	0.6625	0.5759	0.6625	0.5759	0.6625	0.5759	0.6626
PM2.5: Total	0.5099	0.5818	0.5099	0.5818	0.5099	0.5818	0.5100	0.5819
SOx: Total	0.3147	0.3147	0.3147	0.3147	0.3147	0.3147	0.3147	0.3147
2035								
Total Energy	17939	17939	17939	17939	17939	17939	17939	17939
Fossil Fuels	17864	17864	17864	17864	17864	17864	17864	17864
Coal	59	59	59	59	59	59	59	59
Natural Gas	1463	1463	1463	1463	1463	1463	1463	1463
Petroleum	16342	16342	16342	16342	16342	16342	16342	16342
CO2 (w/ C in VOC & CO)	1426	1426	1426	1426	1426	1426	1426	1426
CH4	2.1327	2.1399	2.1327	2.1399	2.1327	2.1399	2.1327	2.1399
N2O	0.0042	0.0045	0.0042	0.0045	0.0042	0.0045	0.0042	0.0045
GHGs	1481	1481	1481	1481	1481	1481	1481	1481
VOC: Total	0.1478	0.1538	0.1478	0.1538	0.1478	0.1538	0.1478	0.1538
CO: Total	0.4585	0.4908	0.4585	0.4908	0.4585	0.4908	0.4585	0.4908
NOx: Total	1.2782	1.4011	1.2526	1.3678	1.2116	1.3136	1.1783	1.2879
PM10: Total	0.1095	0.1271	0.1088	0.1271	0.1088	0.1271	0.1088	0.1272
PM2.5: Total	0.0638	0.0690	0.0633	0.0690	0.0633	0.0690	0.0633	0.0690
SOx: Total	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945

Table 28: Output from GREET for single unit long-haul trucks fueled with diesel. Energy data in BTU/mile and emission data in g/mile.

Single Unit Long-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	18204	18204	18204	18204	18204	18204	18204	18204
Fossil Fuels	18138	18138	18138	18138	18138	18138	18138	18138
Coal	81	81	81	81	81	81	81	81
Natural Gas	1513	1513	1513	1513	1513	1513	1513	1513
Petroleum	16544	16544	16544	16544	16544	16544	16544	16544
CO2 (w/ C in VOC & CO)	1448	1448	1448	1448	1448	1448	1448	1448
CH4	2.2089	2.2111	2.2089	2.2111	2.2089	2.2111	2.2089	2.2111
N2O	0.0044	0.0047	0.0044	0.0047	0.0044	0.0047	0.0044	0.0047
GHGs	1504	1504	1504	1504	1504	1504	1504	1504
VOC: Total	0.5910	0.6633	0.5910	0.6633	0.5910	0.6633	0.5910	0.6633
CO: Total	1.8562	2.0692	1.8562	2.0692	1.8562	2.0692	1.8562	2.0692
NOx: Total	5.1390	6.1530	5.0230	5.9550	4.7920	5.6340	4.6050	5.4800
PM10: Total	0.3650	0.4098	0.3650	0.4098	0.3650	0.4098	0.3650	0.4099
PM2.5: Total	0.3054	0.3370	0.3054	0.3370	0.3054	0.3370	0.3054	0.3371
SOx: Total	0.3147	0.3147	0.3147	0.3147	0.3147	0.3147	0.3147	0.3147
2035								
Total Energy	17939	17939	17939	17939	17939	17939	17939	17939
Fossil Fuels	17864	17864	17864	17864	17864	17864	17864	17864
Coal	59	59	59	59	59	59	59	59
Natural Gas	1463	1463	1463	1463	1463	1463	1463	1463
Petroleum	16342	16342	16342	16342	16342	16342	16342	16342
CO2 (w/ C in VOC & CO)	1426	1426	1426	1426	1426	1426	1426	1426
CH4	2.1299	2.1365	2.1299	2.1365	2.1299	2.1365	2.1299	2.1365
N2O	0.0042	0.0045	0.0042	0.0045	0.0042	0.0045	0.0042	0.0045
GHGs	1481	1481	1481	1481	1481	1481	1481	1481
VOC: Total	0.1420	0.1468	0.1420	0.1468	0.1420	0.1468	0.1420	0.1468
CO: Total	0.4186	0.4465	0.4186	0.4465	0.4186	0.4465	0.4186	0.4465
NOx: Total	1.0712	1.1716	1.0558	1.1464	1.0250	1.1055	1.0001	1.0861
PM10: Total	0.1053	0.1229	0.1053	0.1229	0.1053	0.1229	0.1054	0.1229
PM2.5: Total	0.0597	0.0649	0.0597	0.0649	0.0597	0.0649	0.0597	0.0650
SOx: Total	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945

Table 29: Output from GREET for combination short-haul trucks driven on electricity. Energy data in BTU/mile and emission data in g/mile.

Combination Short-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	17621	17621	17621	17621	17621	17621	17621	17621
Fossil Fuels	14067	14067	14067	14067	14067	14067	14067	14067
Coal	4294	4294	4294	4294	4294	4294	4294	4294
Natural Gas	9632	9632	9632	9632	9632	9632	9632	9632
Petroleum	141	141	141	141	141	141	141	141
CO2 (w/ C in VOC & CO)	1026	1026	1026	1026	1026	1026	1026	1026
CH4	4.9853	4.9853	4.9853	4.9853	4.9853	4.9853	4.9853	4.9853
N2O	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
GHGs	1156	1156	1156	1156	1156	1156	1156	1156
VOC: Total	0.1160	0.1160	0.1160	0.1160	0.1160	0.1160	0.1160	0.1160
CO: Total	0.5191	0.5191	0.5191	0.5191	0.5191	0.5191	0.5191	0.5191
NOx: Total	1.2812	1.2812	1.2812	1.2812	1.2812	1.2812	1.2812	1.2812
PM10: Total	0.9181	0.9181	0.9181	0.9181	0.9181	0.9181	0.9181	0.9181
PM2.5: Total	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206
SOx: Total	1.8701	1.8701	1.8701	1.8701	1.8701	1.8701	1.8701	1.8701
2035								
Total Energy	14696	14696	14696	14696	14696	14696	14696	14696
Fossil Fuels	10640	10640	10640	10640	10640	10640	10640	10640
Coal	3031	3031	3031	3031	3031	3031	3031	3031
Natural Gas	7499	7499	7499	7499	7499	7499	7499	7499
Petroleum	110	110	110	110	110	110	110	110
CO2 (w/ C in VOC & CO)	780	780	780	780	780	780	780	780
CH4	3.5568	3.5568	3.5568	3.5568	3.5568	3.5568	3.5568	3.5568
N2O	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109
GHGs	872	872	872	872	872	872	872	872
VOC: Total	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766
CO: Total	0.4252	0.4252	0.4252	0.4252	0.4252	0.4252	0.4252	0.4252
NOx: Total	0.7617	0.7617	0.7617	0.7617	0.7617	0.7617	0.7617	0.7617
PM10: Total	0.7373	0.7373	0.7373	0.7373	0.7373	0.7373	0.7373	0.7373
PM2.5: Total	0.3062	0.3062	0.3062	0.3062	0.3062	0.3062	0.3062	0.3062
SOx: Total	1.0523	1.0523	1.0523	1.0523	1.0523	1.0523	1.0523	1.0523

Table 30: Output from GREET for combination long-haul trucks driven on electricity. Energy data in BTU/mile and emission data in g/mile.

Combination Long-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	17621	17621	17621	17621	17621	17621	17621	17621
Fossil Fuels	14067	14067	14067	14067	14067	14067	14067	14067
Coal	4294	4294	4294	4294	4294	4294	4294	4294
Natural Gas	9632	9632	9632	9632	9632	9632	9632	9632
Petroleum	141	141	141	141	141	141	141	141
CO2 (w/ C in VOC & CO)	1026	1026	1026	1026	1026	1026	1026	1026
CH4	4.9853	4.9853	4.9853	4.9853	4.9853	4.9853	4.9853	4.9853
N2O	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
GHGs	1156	1156	1156	1156	1156	1156	1156	1156
VOC: Total	0.1160	0.1160	0.1160	0.1160	0.1160	0.1160	0.1160	0.1160
CO: Total	0.5191	0.5191	0.5191	0.5191	0.5191	0.5191	0.5191	0.5191
NOx: Total	1.2812	1.2812	1.2812	1.2812	1.2812	1.2812	1.2812	1.2812
PM10: Total	0.9181	0.9181	0.9181	0.9181	0.9181	0.9181	0.9181	0.9181
PM2.5: Total	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206
SOx: Total	1.8701	1.8701	1.8701	1.8701	1.8701	1.8701	1.8701	1.8701
2035								
Total Energy	14696	14696	14696	14696	14696	14696	14696	14696
Fossil Fuels	10640	10640	10640	10640	10640	10640	10640	10640
Coal	3031	3031	3031	3031	3031	3031	3031	3031
Natural Gas	7499	7499	7499	7499	7499	7499	7499	7499
Petroleum	110	110	110	110	110	110	110	110
CO2 (w/ C in VOC & CO)	780	780	780	780	780	780	780	780
CH4	3.5568	3.5568	3.5568	3.5568	3.5568	3.5568	3.5568	3.5568
N2O	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109
GHGs	872	872	872	872	872	872	872	872
VOC: Total	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766
CO: Total	0.4252	0.4252	0.4252	0.4252	0.4252	0.4252	0.4252	0.4252
NOx: Total	0.7617	0.7617	0.7617	0.7617	0.7617	0.7617	0.7617	0.7617
PM10: Total	0.7373	0.7373	0.7373	0.7373	0.7373	0.7373	0.7373	0.7373
PM2.5: Total	0.3062	0.3062	0.3062	0.3062	0.3062	0.3062	0.3062	0.3062
SOx: Total	1.0523	1.0523	1.0523	1.0523	1.0523	1.0523	1.0523	1.0523

Table 31: Output from GREET for single unit short-haul trucks driven on electricity. Energy data in BTU/mile and emission data in g/mile.

Single Unit Short-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	14287	14287	14287	14287	14287	14287	14287	14287
Fossil Fuels	11406	11406	11406	11406	11406	11406	11406	11406
Coal	3482	3482	3482	3482	3482	3482	3482	3482
Natural Gas	7810	7810	7810	7810	7810	7810	7810	7810
Petroleum	114	114	114	114	114	114	114	114
CO2 (w/ C in VOC & CO)	832	832	832	832	832	832	832	832
CH4	4.0421	4.0421	4.0421	4.0421	4.0421	4.0421	4.0421	4.0421
N2O	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149
GHGs	937	937	937	937	937	937	937	937
VOC: Total	0.0941	0.0941	0.0941	0.0941	0.0941	0.0941	0.0941	0.0941
CO: Total	0.4209	0.4209	0.4209	0.4209	0.4209	0.4209	0.4209	0.4209
NOx: Total	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388
PM10: Total	0.7484	0.7484	0.7484	0.7484	0.7484	0.7484	0.7484	0.7484
PM2.5: Total	0.2612	0.2612	0.2612	0.2612	0.2612	0.2612	0.2612	0.2612
SOx: Total	1.5163	1.5163	1.5163	1.5163	1.5163	1.5163	1.5163	1.5163
2035								
Total Energy	11916	11916	11916	11916	11916	11916	11916	11916
Fossil Fuels	8627	8627	8627	8627	8627	8627	8627	8627
Coal	2457	2457	2457	2457	2457	2457	2457	2457
Natural Gas	6081	6081	6081	6081	6081	6081	6081	6081
Petroleum	89	89	89	89	89	89	89	89
CO2 (w/ C in VOC & CO)	632	632	632	632	632	632	632	632
CH4	2.8839	2.8839	2.8839	2.8839	2.8839	2.8839	2.8839	2.8839
N2O	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
GHGs	707	707	707	707	707	707	707	707
VOC: Total	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621
CO: Total	0.3447	0.3447	0.3447	0.3447	0.3447	0.3447	0.3447	0.3447
NOx: Total	0.6176	0.6176	0.6176	0.6176	0.6176	0.6176	0.6176	0.6176
PM10: Total	0.6018	0.6018	0.6018	0.6018	0.6018	0.6018	0.6018	0.6018
PM2.5: Total	0.2496	0.2496	0.2496	0.2496	0.2496	0.2496	0.2496	0.2496
SOx: Total	0.8532	0.8532	0.8532	0.8532	0.8532	0.8532	0.8532	0.8532

Table 32: Output from GREET for single unit long-haul trucks driven on electricity. Energy data in BTU/mile and emission data in g/mile.

Single Unit Long-Haul Truck								
	January				July			
2008	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00	00.00-01.00	07.00-08.00	12.00-13.00	17.00-18.00
Total Energy	14287	14287	14287	14287	14287	14287	14287	14287
Fossil Fuels	11406	11406	11406	11406	11406	11406	11406	11406
Coal	3482	3482	3482	3482	3482	3482	3482	3482
Natural Gas	7810	7810	7810	7810	7810	7810	7810	7810
Petroleum	114	114	114	114	114	114	114	114
CO2 (w/ C in VOC & CO)	832	832	832	832	832	832	832	832
CH4	4.0421	4.0421	4.0421	4.0421	4.0421	4.0421	4.0421	4.0421
N2O	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149
GHGs	937	937	937	937	937	937	937	937
VOC: Total	0.0941	0.0941	0.0941	0.0941	0.0941	0.0941	0.0941	0.0941
CO: Total	0.4209	0.4209	0.4209	0.4209	0.4209	0.4209	0.4209	0.4209
NOx: Total	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388
PM10: Total	0.7484	0.7484	0.7484	0.7484	0.7484	0.7484	0.7484	0.7484
PM2.5: Total	0.2612	0.2612	0.2612	0.2612	0.2612	0.2612	0.2612	0.2612
SOx: Total	1.5163	1.5163	1.5163	1.5163	1.5163	1.5163	1.5163	1.5163
2035								
Total Energy	11916	11916	11916	11916	11916	11916	11916	11916
Fossil Fuels	8627	8627	8627	8627	8627	8627	8627	8627
Coal	2457	2457	2457	2457	2457	2457	2457	2457
Natural Gas	6081	6081	6081	6081	6081	6081	6081	6081
Petroleum	89	89	89	89	89	89	89	89
CO2 (w/ C in VOC & CO)	632	632	632	632	632	632	632	632
CH4	2.8839	2.8839	2.8839	2.8839	2.8839	2.8839	2.8839	2.8839
N2O	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
GHGs	707	707	707	707	707	707	707	707
VOC: Total	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621
CO: Total	0.3447	0.3447	0.3447	0.3447	0.3447	0.3447	0.3447	0.3447
NOx: Total	0.6176	0.6176	0.6176	0.6176	0.6176	0.6176	0.6176	0.6176
PM10: Total	0.6018	0.6018	0.6018	0.6018	0.6018	0.6018	0.6018	0.6018
PM2.5: Total	0.2496	0.2496	0.2496	0.2496	0.2496	0.2496	0.2496	0.2496
SOx: Total	0.8532	0.8532	0.8532	0.8532	0.8532	0.8532	0.8532	0.8532

Appendix 5

Here the results can be seen as they were first produced in BTU for the energy use.

Table 33: The results, with the energy presented in BTU.

The results							
	2008		2035		2035 with 2008 truck volume		
	Diesel	Electricity	Diesel	Electricity	Diesel	Eletricity	
Total Energy	4 501	3 533	6 869	4 563	4 436	2 946	billion BTU
Fossil Fuels	4 485	2 820	6 840	3 303	4 417	2 133	billion BTU
- Coal	20	861	22	941	14	608	billion BTU
- Natural Gas	374	1 931	560	2 328	362	1 503	billion BTU
- Petroleum	4 091	28	6 258	34	4 041	22	billion BTU
GHGs	372	232	567	271	366	175	thousand tonnes
- CO2[a]	358	206	546	242	353	156	thousand tonnes
- CH4	545	999	815	1 104	526	713	tonnes
- N2O	1 059	3 679	1 568	3 383	1 013	2 185	kg
VOC: Total	178	23	54	24	35	15	tonnes
CO: Total	721	104	163	132	106	85	tonnes
NOx: Total	2 914	257	542	236	350	153	tonnes
PM10: Total	165	184	43	230	28	148	tonnes
PM2.5: Total	147	64	25	95	16	62	tonnes
SOx: Total	78	375	74	327	48	211	tonnes

[a] including C in VOC and CO