Emissions modeling of electric urban transit

Analysis of environmental effects of electric public transit in Johanneberg by using the software PTV Vissim and EnViVer

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

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Cover:
The electric bus Route 55 operating on zone management in Gothenburg between the campus areas of Chalmers University of Technology in Johanneberg and Lindholmen. The photo is provided by Volvo Bus Corporation.

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Abstract

One of the major health problems in Sweden is air pollution. The road transport sector stands for 30 % of carbon dioxide emissions and is a major source of nitrogen oxides. The high amount of emissions is mainly due to the fossil fuel combustion and it is therefore important to focus on renewable energy and electrified vehicles.

In Gothenburg, the implementation of electric urban transits is already ongoing. Route 55 between the campus areas of Chalmers University of Technology, Johanneberg and Lindholmen, consist of electric and hybrid electric driven buses. The hybrid buses operate on a zone-based management system, which means that the system automatically can regulate the speed and control the buses operation depending on pre-defined geographic zones.

This study investigates how carbon dioxide and nitrogen oxides emissions in Johanneberg, Gothenburg, can be reduced by electric urban transits and increased areas of zero-emission zones. A representative traffic simulation of the current state during peak hour is set up in PTV Vissim. The vehicle data from the traffic simulation are used as input data in the emission modeling software EnViVer to calculate emissions. Two new scenarios are set up, one with Route 55 as full electric and the second with all public transit buses as electric. Sub-scenarios are created for each individual bus line as electric and the result is compared in between.

The result identifies the stretch along Aschebergsgatan, between Chalmersplatsen and Kapellplatsen, and Läraregatan as favorable to include in a zone management system as zero-emission zones. Buses around Johanneberg can reduce carbon dioxide emissions by 6 % and nitrogen oxides by 23 %. Bus line 19 has the highest potential to reduce emissions within the area by running on electricity, followed by bus line 16. Route 55 has the lowest potential due to already running on bio-fuels and being partly electric. In conclusion, bus line 16 would be most beneficial to include in the zone management system as it runs solely on the identified areas of interest while being the most used bus line in Gothenburg region.

Key words: Emission modeling, EnViVer, zone management system, electric urban transit, traffic simulation, PTV Vissim, Route 55, public transit buses

Utsläppsmodellering av eldrivna transportmedel

En analys av miljöeffekterna med eldrivna transportmedel i Johanneberg, beräknat med hjälp av datorprogrammet PTV Vissim och EnViVer

Examensarbete inom masterprogrammet Infrastruktur och Miljöteknik

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Sammanfattning

Ett av de största hälsoproblemen i Sverige är luftföroreningar. Vägtransportsektorn står för 30 % av koldioxidutsläppen och är en stor källa till kväveoxider. Den stora mängd utsläpp beror främst på förbränning av fossila bränslen och det är därför viktigt att fokusera på att använda förnybar energi och eldrivna fordon.

I Göteborg har man redan börjat införa eldrivna transportmedel. Busslinje 55, som sträcker sig mellan Chalmers Tekniska högskolans två campusområden Johanneberg och Lindholmen, trafikeras av både hybrid- och elbussar. Hybridbussarna styrs av ett zonbaserat system, vilket innebär att systemet automatiskt kan reglera hastigheten och styra bussens drift beroende på fördefinierade geografiska zoner.

Denna studie undersöker hur mängden koldioxid- och kväveoxidutsläpp i Johanneberg, Göteborg kan minska med hjälp av eldrivna transportmedel och större utsläppsfria zoner. En representativ simulering av nulägestrafiken under maxtimmen har tagits fram i PTV Vissim. Fordonsdata från trafiksimuleringen används som inmatningsdata i utsläppsmodelleringsprogrammet EnViVer för beräkning av utsläpp. Utöver nuläget har ytterligare två scenarion tagits fram; ett där busslinje 55 enbart trafikeras av elbussar och ett där samtliga kollektivtrafikbussar i området kör på el. Dessutom undersöktes varje enskild busslinje som eldriven och dess resultat jämförs med varandra.

Resultatet visar att det är mest fördelaktigt om sträckan längs med Aschebergsgatan, mellan Chalmersplatsen och Kapellplatsen, samt Läraregatan ingår i ett zone management system som utsläppsfri zon. Bussar kring Johanneberg har möjlighet att reducera kolidoxidutsläpp med 6 % och kvävedioxidutsläpp med 23 %. Busslinje 19 har störst potential att minska utsläppen inom området genom att köra på el, tätt följt av busslinje 16. Busslinje 55 har den lägsta potentialen på grund av att den redan nu kör på biobränslen och är delvis eldriven. Sammanfattningsvis skulle busslinje 16 vara mest fördelaktig att inkludera i ett zone management system med utsläppsfria zoner eftersom den kör i de mest utsatta områdena sett till utsläpp, samtidigt som den är den mest använda busslinjen i Göteborgsregionen.

Nyckelord: Utsläppsmodellering, EnViVer, zone management system, eldrivna transportmedel, trafiksimulering, PTV Vissim, Busslinje 55, kollektivtrafik bussar

Contents

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Firstly, we would like to thank our examiner and supervisor Ivana Tasic, assistant professor at the Division of Geology and Geotechnics at Chalmers, for supporting us throughout the thesis and giving us guidance and feedback. We also want to thank all colleagues at COWI who have supported us and shown interest in our study, which has driven us forward.

Thanks to PTV Group, who gave us licenses to the traffic simulation program PTV Vissim and access to the emission modeling program EnViVer, crucial to complete the project. Moreover, thanks to the research group at Chalmers and especially to Bára Gudmundsdóttir, for sharing your traffic simulation model that we could continue to work on and use in our thesis.

Stefan Widlund, City Mobility Manager at Volvo Bus Corporation, contributed with in-depth knowledge of the zone management system and the currently running electric urban transits in Gothenburg.

Finally, we want to thank our opponent Olivera Puljic for feedback and advice along the project.

Gothenburg, June 2019

Mattias Blomgren
Paula Jungbjer

Nomenclature

API – Application Program Interference
CNG – Compressed Natural Gas
CO_2 – Carbon Dioxide
EUT – Electric Urban Transit
EV – Electric Vehicles
GHG – Green House Gases
HVO – Hydrogenated Vegetable Oil
kW - Kilo Watt
kWh – Kilo Watt Hours
LPG – Liquefied Petroleum Gas
NO – Nitrogen Monoxide
NO_2 – Nitrogen Dioxide
NO_x – Nitrogen Oxides, collection name for nitrogen monoxide and nitrogen dioxide
O_3 - Ozone
PPK – Per Person Kilometer
RME - Rape-seed Methyl Ester
TTW – Tank-To-Wheel
WTT – Well-To-Tank
WTW – Well-To-Wheel

Definitions

Electric vehicle – An electric vehicle, is a vehicle using one or more electric motors for propulsion. Depending on type of vehicle, motion may be provided by wheels or propellers driven by rotary motors, or in case of tracked vehicles, by linear motors.

Hybrid vehicle - A hybrid vehicle is a vehicle using two different forms of power, such as an electric motor and an internal combustion engine, or an electric motor with a battery and fuel cells for energy storage.

1 Introduction

Air pollution is a major health problem in Swedish cities. The ongoing urbanization contributes to an increased population in large cities, which also increases the transports to, from and within the urban areas (Naturvårdsverket, 2018). The road transport sector, consisting of trucks, buses, cars and motorcycles, is currently responsible for about 30 % of the total carbon dioxide (CO_2) emissions in Sweden (Trafikverket, 2017) and one of the major sources of nitrogen oxides (NO_x). Elevated concentrations of NO_x are known to cause respiratory related problem, commonly experienced in dense urban areas where the dispersion is low (Hertel, Berkowicz, Vignati, & Palmgren, 1995).

The main reason for the high amount of emissions is the combustion of fossil fuels. Since 1970, the passenger transport has increased by 70 % and is expected to increase further (Trafikverket, 2017). It is therefore important that large cities invest in providing good clean public transport with incentives to decrease the environmental and health impact both globally and locally. At the same time, it is important to focus on sustainable transport driven by renewable energy instead of fossil fuel (Trafikverket, 2017).

The operator of public transport in Gothenburg, Västtrafik, has set up target goals based on the Västra Götaland Region's overall environmental transport goals. With long term target to electrify the fleet of buses and ferries, they aim to reduce the Green House Gases (GHG) with 80 % per person kilometer (ppk) between 2006 and 2020 (Västtrafik, n.d.). It is also stated to decrease the energy usage by 25 % ppk and that 95 % of public transport will be operated on renewable energy by 2025 (Västtrafik, n.d.).

With the current urban initiatives for sustainable transport, it is essential for the traffic management systems to keep up. Gothenburg is with the project ElectriCity, one of the leaders with implementation of electric bus transits. ElectriCity is a collaboration between 14 actors from academy, industry and society (ElectriCity, n.d.-b). The purpose of ElectriCity is to develop and test solutions for a more sustainable transport system and to increase the attractiveness of public transport in the city. By using electric powered public transport systems, it contributes towards handling future problems caused by noise, air quality, consumption of energy and climate impact. The buses are manufactured by Volvo and they are currently operating on Route 55 between the two campus areas of Chalmers University of Technology in Lindholmen and Johanneberg, as well as a part of bus line 16. Route 55 consists of 3 completely electric driven buses while 7 are electric hybrids (ElectriCity, n.d.-a).

For Route 55, the first ever zone base management system has been implemented for the hybrid buses in order to automatically control the buses operation. The system can automatically regulate the speed and control when the buses operate fully electric or use its diesel engine by specifying the bus route into zones with different requirement. With the zone management system, zero emission zones can then be created where the air quality is inadequate (ElectriCity, 2016).

1.1 Background

This study will be based on a traffic simulation from an ongoing research study about zone management for electric urban transit called *Transition to Transport System of the Future: Air Pollution-based Zone Management System for Electric Urban Transit*. The study is conducted by a research group consisting of members from the Architecture and Civil engineering department, Chalmers University of Technology. The research group have during the autumn of 2018 developed a traffic simulation based on current vehicle data on a fixed route in Gothenburg, by using the software PTV Vissim. The chosen simulation area, as can be seen in Figure 1.1, is a part of the electric Route 55 where a zone management system has been implemented. The thesis is proposed to aid the research study by conducting an additional emission modeling with the software EnViVer. The thesis is performed in cooperation with the Architecture and Civil engineering department at Chalmers University of Technology as well as with aid from the COWI Group Traffic section in Gothenburg. The thesis is written with aid from COWI group as the company is dedicated towards creating sustainable transport solutions and hold expertise in both fields of urban public transport and emission modeling.

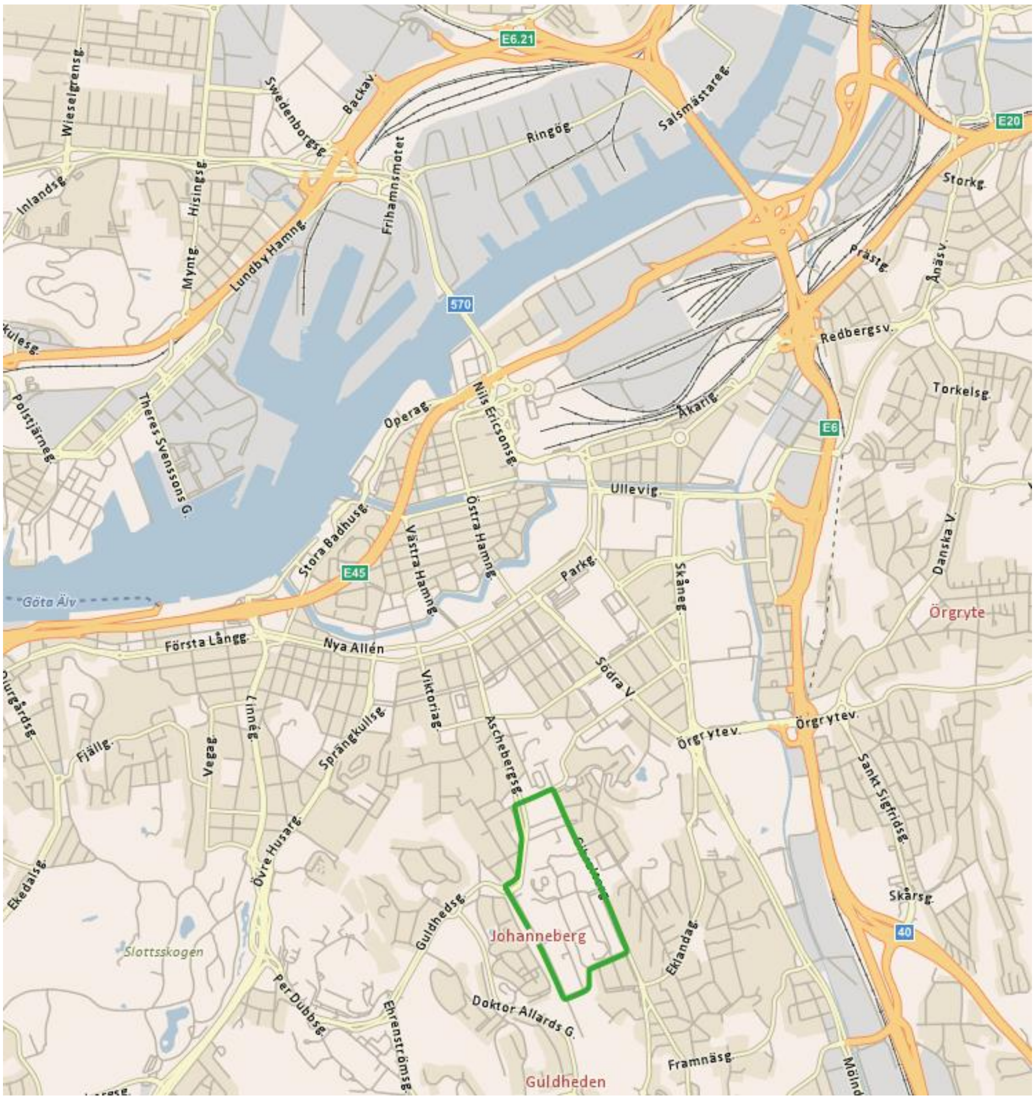

Figure 1.1 A map showing the simulation area located in Johanneberg, south of Gothenburg centre (Trafiken.nu, 2017).

1.2 Aim

The aim of the Master thesis is to investigate how electric urban transits and the change of bus fleet engine types can contribute to the emission reduction in Johanneberg, central Gothenburg. The master thesis intends to provide an extensive understanding of how traffic and emission modeling is done in PTV Vissim and by using the software EnViVer. It will investigate how the software and the models are built up as well as how it can be improved. The Master's Thesis intends to:

- Based on traffic data, create representative models of the current traffic and emission situation in Johanneberg, Gothenburg, in the software PTV Vissim and EnViVer
- Create a new scenario representing increased area of zero-emission in Route 55's zone management system
- Create a second scenario representing increased area of zero-emission including all the public transit buses
- Present comparative results for carbon dioxide (CO_2) and nitrogen oxides (NO_x) for each operative bus line
- Describe the parameters which can be added/changed in order to improve the emission modeling

1.3 Disposition

The thesis begins with a background and introduction which aims to introduce the problem of urban emissions and electric urban transit. The objective of the thesis is presented with following limitations and assumptions necessary for the study. The next chapter presents a literature review with examples of similar project regarding electric buses, together with a description of the programs used in the methodology and the focused emissions. In the methodology the underlying model and data is presented, followed by a section of the traffic simulation work in Vissim and the emissions modeling in EnViVer. A traffic simulation is created and used to calculate emissions for carbon dioxide and nitrogen oxides for three different scenarios in EnViVer. The simulation data, numerical values and explanation of parameters used in the simulation are presented. The simulation results are presented for each scenario and displayed in comparative charts. The thesis is concluded with an analytic part regarding all previous sections and results before references and appendices.

1.4 Limitations and Assumptions

The study area is the campus of Chalmers University of Technology in Johanneberg, located in the central part of Gothenburg. The area is surrounded by the streets Gibraltargatan, Engdahlsgatan, Sven Hultins Gata, Aschebergsgatan and Läraregatan, which today is a part of the Route 55 operation. The public transport lines, consisting of buses and trams, is assumed to operate in accordance with the timetables presented by Västtrafik. The bus fleet of Route 55 is set to operate based on the zone management system, as described in Section 2.1.2.

For the simulation and emissions calculation, values for one hour during afternoon peak hour are investigated. During this peak hour, the air pollution emitted is estimated to be the highest and changes to the traffic configuration will be the most noticeable. The traffic data obtained from observations is based on both morning and afternoon traffic, and is applied to afternoon traffic during the peak hours at 4 pm to 6 pm. In addition to traffic observations, data from Gothenburg City is used.

In this study, CO_2 and NO_x will be the investigated emissions. EnViVer is, besides CO_2 and NO_x, able to calculate particulate matter with a diameter of 10 micrometers or less (PM_{10}), but it will not be included in the study. Due to the fact that PM_{10} emissions are not linearly connected with the use of combustion engines and depends on non-investigated factors such as road type, road surface structure and tire friction, PM_{10} is disregarded (Lawrence et al., 2013).

For the emission calculations, only air pollution created at operation, Tank-To-Wheel (TTW), will be considered. The source of energy used for fuel could have large impact seen to a life cycle analysis or emissions created Well-To-Wheel (WTW). With Västtrafik and the public transit buses operating in Gothenburg, together with the buses in project ElectriCity, only green electricity is used. The Swedish Energy Agency certify that all energy used to charge the buses for ElectriCity comes from renewable energy sources (ElectriCity, 2016). With current ongoing initiatives, it is safe to assume that the future electric public transport fleet also will use green electricity in Gothenburg.

Lastly, this study does not include economic or social aspects of the implementation of electric urban transits buses, only the environmental perspective. The focus is on emissions and not on costs or travelers' perceptions.

2 Literature review

In the literature review, the electric urban transits, its benefits and challenges and the case study of ElectriCity Route 55 will be presented to give a background to the project. The Route 55's zone management system will be described in detail together with the simulation and modeling software used during the methodology. Lastly, the two air pollutants CO_2 and NO_x will be presented with its local and global effects connecting to the resulting emission maps from the simulation and calculation of emissions.

2.1 Electric urban transit

With rapid technology development of electric driven vehicles, the interest to study electric powered urban transits has consequently increased. Together with more and more focus on air pollution, GHG from different sources and the significant potential to reduce CO_2 emissions within transport, electric vehicles (EV) stand out. According to McKenzie & Durango-Cohen (2012), electric urban transits (EUT) have the advantage of not producing any tail-pipe pollutant emissions during TTW operation. The only emissions produced are connected to the production of the vehicles as well as the Well-To-Tank (WTT) production of the electricity. This is especially advantageous in urban areas with heavy traffic flows and faulty air quality.

McKenzie & Durango-Cohen (2012) emphasize the decreased operating cost and decreased emissions with EUT, in comparison to the increased life cycle cost. The current development of the fuel economy has put pressure on diesel buses as well as the stricter emissions regulation to force a technological advancement. EVs are now considered to have reached high technology maturity and the choice of procurement comes down to a matter of cost (McKenzie & Durango-Cohen, 2012).

EUTs have already been successfully implemented at various large cities which strive for more sustainable transport modes, such as Seoul, (Choi, Jeong, & Jeong, 2012) and Shenzhen. In Shenzhen, a fully electric bus fleet has been acquired with 16000 buses with over-night charging and a range of 200 kilometers (Keegan, 2018). Volvo, being one of the biggest actors within EUT, is besides Gothenburg with ElectriCity also supplying electric buses model 7900 to Birmingham, Hamburg, Malmö (Volvo Bus Corporation, 2016a) and Leiden in the Netherlands (Volvo Bus Corporation, 2019). Gothenburg City also recently ordered 30 new fully electric 7900 buses to take over the operation of several bus lines in central regions of the city (Bussmagasinet, 2018).

When looking at a life cycle cost assessment and CO_2 emissions, Lajunen & Lipman (2016) compares different types of city buses including diesel, electric hybrid diesel and electric urban transits. The engine configuration types are evaluated on bus routes in two different operating environments; one in California and one in Finland. For the bus route H550, it corresponds to an urban driving cycle in Helsinki region, which is considered to have similar environment and climate conditions as in Gothenburg. Seven bus configurations are used in the measurements; Diesel (Di), Compressed natural gas (CNG), Parallel hybrid (PAR), Series hybrid (SER), Fuel cell hybrid (FCH) and two electric vehicles (EV1, EV2). The comparison of energy efficiency and accumulated CO_2 can be seen in Figure 2.1. EV1 has an electric motor power of 170 kilowatt (kW), a low energy battery capacity of 62,6 kilowatt hour (kWh) and uses rapid charging at designated bus stops during operation (Lajunen & Lipman, 2016). EV2 has a longer range with an electric motor power of 200 kW, a high energy battery capacity of 333,6 kWh and uses low power charging over night for an uninterrupted full-day operation. All buses share the same general specifications besides engine, transmission and fuel (Lajunen & Lipman, 2016).

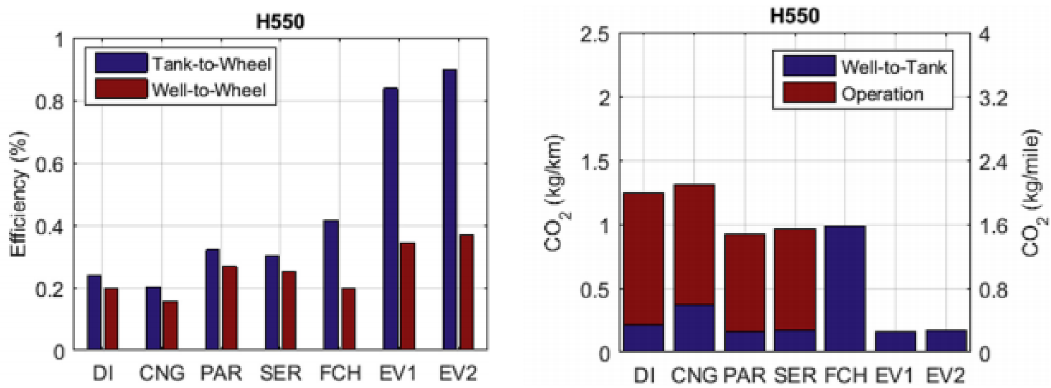

Figure 2.1 Energy efficiency in percentage and accumulated CO_2 during WTT and WTW. Applied for different energy source constellations DI, CNG, PAR, SER, FCH, EV1, EV2 on bus line H550 Helsinki (Lajunen & Lipman, 2016).

EUT are becoming more and more popular but have not yet been able to replace conventional diesel buses seen to large scale. Lajunen & Lipman (2016) present two key challenges with the implementation of hybrid and EUT; battery charging and energy storage capacity.

In recent years, a rapid development of battery powered vehicles have been seen and several different operation methods exist based on different options for charging (Göhlich, Kunith, & Ly, 2014). The charging options can be concluded to either high-power or low-power charging. High-power charging, also known as opportunity charging, is carried out during operation at end stops or along the route at dedicated stations for a short period of time. Low-power charging is on the other hand done during a longer time, preferably overnight at depots. There is also the possibility of battery swapping to maintain operation, which however require considerable effort and investment for battery swapping stations. Out of the commercially sold systems, overnight charging is the commonly used (Göhlich et al., 2014).

The current technological advancement regarding high energy batteries makes them the most viable option with higher energy capacity to weight ratio, enabling a full day of service. There is a possibility to replace high energy with high power batteries while using rapid charging during operation, thus having high power to weight ratio but less total energy carried. According to Lajunen & Lipman (2016), the main advantages of low-energy, high power batteries, are lower battery cost, lower total weight and more room for passengers. With opportunity charging it must however also fit within a short time slot in the bus daily schedule and require scattered high-power charging infrastructure along the routes. For high energy battery vehicles, they can rely on collected charging stations at a depo for overnight charging. (Lajunen & Lipman, 2016).

The energy storage development for EUT goes hand in hand with developments within general battery aspects. The relative cost depends if batteries are the primary energy source, i.e. fully electric vehicle, or a side component in a hybrid constellation. As a primary energy source, it requires the battery to have a higher energy density compared to a secondary energy source requiring a high-power density but lower energy density (Lajunen & Lipman, 2016). Higher power batteries have a higher cost per kWh but lower cost per kW, thus using several low power batteries is cheaper investment with high volume production series (Lajunen & Lipman, 2016).

According to Ellingsen et al. (2014) , EUT has a generally high implementation cost but less emissions during both WTT and operation. They are promoted as zero-emission vehicles regarding operation and local impacts, and the production emissions are often neglected (Ellingsen et al., 2014). Due to the high cost of technology, the full electric buses have both a higher life cycle cost as well as a more than doubled implementation cost compared to conventional buses. A solution can be to invest in hybrid vehicles where the life cycle cost is similar to the conventional buses and still tackle the problem with local emissions in urban regions (Lajunen & Lipman, 2016).

2.1.1 ElectriCity, Route 55

The aim of ElectriCity is based on a shared vision of sustainable transport in urban environment between cities, regions, corporations and academic institutions. The partnership initiative wants to make use of electric buses and develop connected service and products in order to create an environmentally friendly, attractive public transport system. ElectriCity consists of several components; Route 55 with electric buses operating in Gothenburg area, a demo arena for new bus technologies, bus stop configurations, transport management systems, safety concepts and networks, a new platform for research within urban planning, development and behavior, and a place for inspiration and motivation for future urban technologies (ElectriCity, 2016).

The cooperation initiative was started by Volvo Group and does now consist of 14 other members besides Volvo Group; Keolis, Chalmers University of Technology, Chalmersfastigheter, Akademiska Hus, the Swedish Energy Agency, Lindholmen and Johanneberg Science Park, Region Västra Götaland, Västtrafik, the City of Gothenburg, the Urban Transport Administration in Gothenburg Trafikkontoret, Business Region Gothenburg, Göteborg Energi, Älvstranden Utveckling and Ericsson (ElectriCity, n.d.-b).

For Route 55, there are in total 10 operating buses, whereof 3 buses are electric powered and 7 electric hybrids (ElectriCity, 2016). According to ElectriCity (2016), the hybrid buses run on electricity and hydrogenated vegetable oil (HVO). They also state that all the energy used for Route 55 comes from renewable energy supplies and generated green electricity. The buses running for Route 55 are produced by Volvo, where the Volvo 7900 Electric Hybrid are commercial products and the 7900 Electric are concept vehicles. Special features for the 7900 Electric are centrally positioned driver seat, extra wide doors with low entry step in the middle of the bus, provision of information on screens about news, weather reports, updated travel and arrival times and seamless Wi-Fi together with the possibility to charge your phone (ElectriCity, 2016).

The electric buses for Route 55 are, compared to conventional diesel buses, more energy-efficient, create less noise, have less impact on the environment and create less air pollutants (ElectriCity, 2016). The fully-electric buses are estimated to be 80 % more energy-efficient compared to similar diesel-powered buses, while the electric hybrid buses are estimated to be around 50 to 65 % lower in energy consumption (ElectriCity, 2016). They also state that for the 7900 Electric Hybrid, the operation is 77 % driven by electricity. The vehicles use electricity at bus stops equivalent to 36 % of the total time, electricity in movement equivalent to 41 % of the total time and HVO-diesel for a share of 23 % of the total time when driving, see Figure 2.2 (ElectriCity, 2016).

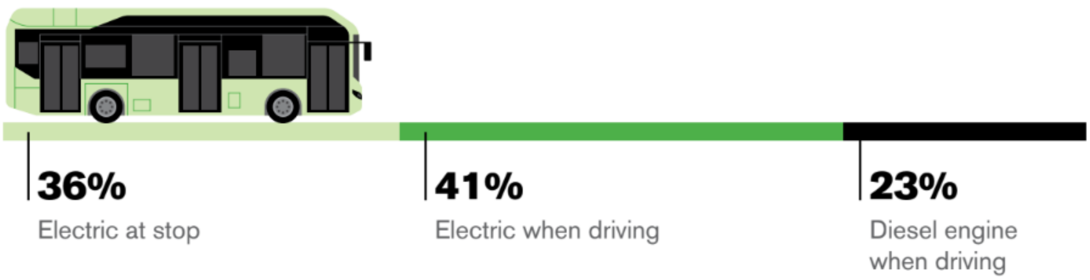

Figure 2.2 Schematic distribution between electric and diesel operation for Route 55 model 7900 Electric Hybrid (ElectriCity, 2016).

ElectriCity with Route 55 put emphasis in reduction of both CO_2 and NO_x emissions with the possibility of complete zero-emissions during operation (ElectriCity, 2016). The hybrid buses running on HVO-diesel create, compared to conventional fossil fuel diesel buses, 97 % less carbon dioxide WTW (ElectriCity, 2016) and 90 % less during operation TTW (Biofuel Express, n.d.), see Figure 2.3. Based on Figure 2.1 for bus line H550, it gives an estimated CO_2 emission TTW of 0,105 kg per kilometer. The emission rates are predominantly determined by the length of the vehicle route and consequently how long they can run on electricity or hybrid electricity before charging. Emission rates of NO_x was measured on two normal round trips for Route 55, resulting in an accumulated average of below 0,5 g per kilometer (ElectriCity, 2016). The result is compared with estimated emissions for a corresponding diesel bus of class Euro VI, see Figure 2.4.

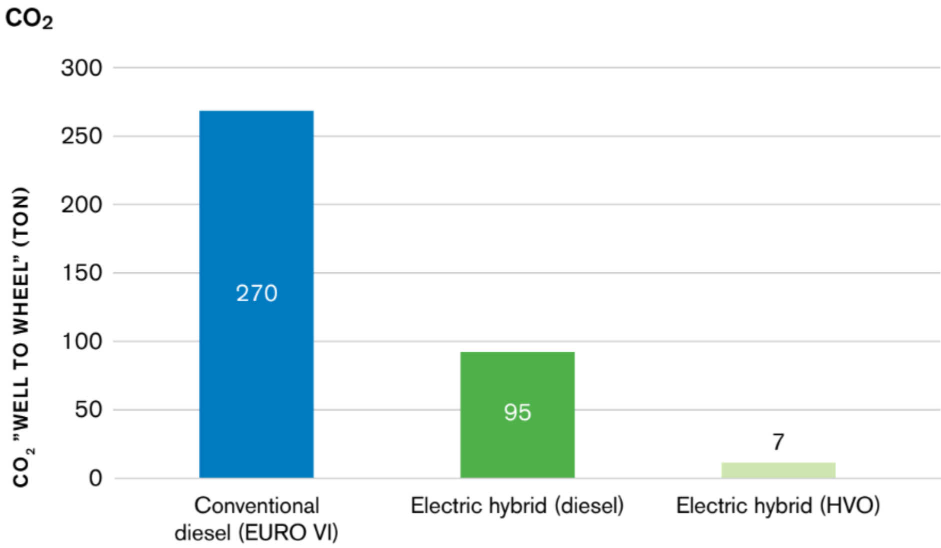

Figure 2.3. Accumulated CO_2 Well-To-Wheel for conventional diesel buses class EURO VI, electric hybrid (diesel) buses and electric hybrid (HVO) buses (ElectriCity, 2016).

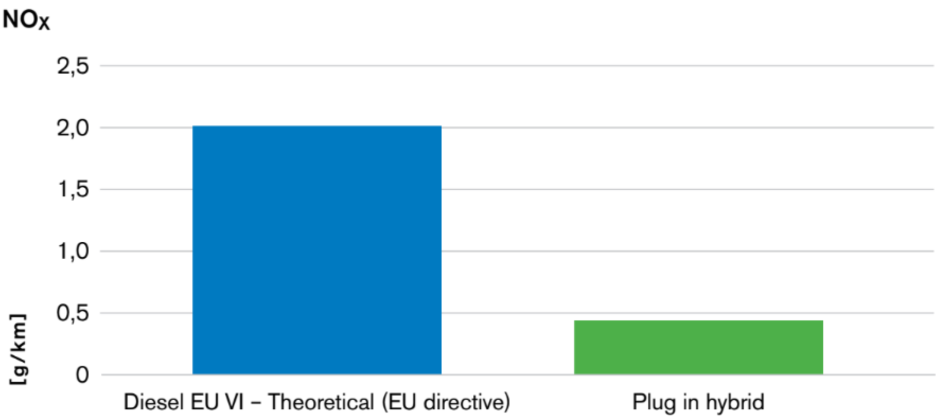

Figure 2.4 Accumulated NO_x during two round trips of the Route 55 for a fossil diesel bus class EURO VI and an electric hybrid bus. Emissions calculated as gram per kilometer (ElectriCity, 2016).

The Volvo 7900 Electric Hybrid is equipped with a diesel engine together with a 150 kW electric engine and battery capacity of 19 kWh (Volvo Bus Corporation, 2016b). The Volvo 7900 Electric is solely equipped with a 160 kW electric engine and battery capacity of 76 kWh (Volvo Bus Corporation, 2016a). For charging the batteries in both bus types, opportunity charging is used. The buses charge at the bus station at both ends of the route, located at Teknikgatan and Sven Hultins Plats, several times a day which enable secure, uninterrupted operation. During operation hours, the charging stations enable high-power charging where the process takes 3 to 4 minutes (ElectriCity, 2016). During night-time when the bus is unused, low-power charging takes place. The buses also recover energy during braking, giving additional power supply. The battery capacity provides a range of around 20 km compared to the route length of 7,6 kilometers (ElectriCity, 2016), allowing the bus to miss one charging and still be able to carry out the following trip. Stefan Widlund, City Mobility Manager at Volvo Bus Corporation, explains the buses at Route 55 often charge even though they necessarily do not need to. He elaborates that it ensures the uninterrupted operation if the next charging time slot needs to be skipped due to unexpected delays in the schedule, a.k.a. operational flexibility. It also prolongs the battery life length as the bus can operate within the efficient span of 20-80 % power while an overnight-charged bus would have to return to the depo.

As mentioned, the route is 7,6 kilometers long one-way from Chalmers Johanneberg Sven Hultins Gata to Chalmers Lindholmen Teknikgatan. The end stop at Lindholmen Teknikgatan is designed as an indoor bus stop in an annex connected to the existing building. Passengers can comfortably sit in a café lounge in a calm and pleasant environment, non-effected by the outside weather, waiting and accessing their bus departure. The stop is also the first indoor charging station for the buses being tested and evaluated (ElectriCity, 2016). To enter the indoor charging station, electric drive is necessary. The route end to end takes around 25 minutes depending on current conditions (Västtrafik, 2019c) giving an average speed of 18 kilometers per hour. Along the travel route, a zone management system has been applied in order to optimize the bus movements accordingly with the need of the surroundings.

2.1.2 Zone management system

For Route 55, the first ever zone management system has been implemented which automatically control the buses operation and speed in designated areas (Volvo Bus Corporation, n.d.). The system is used to make sure that the vehicles fulfil the restrictions and specific demands based on its geographic position. By creating a network with delimitations connected to a map, it can be downloaded to the vehicles fleet management system and generate different zones. The real time location of the bus is identified via GPS-tracking and notifies the driver as he is approaching a new zone (Volvo Bus Corporation, n.d.).

The zones are given different attributes such as speed limitations, a time frame or a calendar which control other parameters. The zone affects singular vehicles or the whole fleet and several zones can overlap creating multiple requirement scenarios (ElectriCity, 2016). For the Route 55, three special zones are identified which restricts the passing; safety zones, silent zones and zero-emission zones, see Figure 2.5.

Figure 2.5 Principles of the zone management controlling the Route 55 electric operations. Not representative of the real itinerary (ElectriCity, 2016).

Volvo Bus Corporation (n.d.) states that the safety zones are primarily defined by speed limitations and the automatic system has the possibility to define lower limit zones, to make the driver aware of the current conditions. The system warns the driver and rapports if the vehicle speed exceeds the given limit, but it has also the possibility to actively control the vehicle speed without the drivers need of action (Volvo Bus Corporation, n.d.).

Furthermore, the silent zones are defined with restrictions of noise level in order to create a calm environment for the surrounding residents. Cities can have different reasons to apply noise restrictions such as in connection to residential areas, recreational areas or around hospitals. The vehicle then changes to silent mode when it approaches and return to standard operation when it has left the zone (Volvo Bus Corporation, n.d.). As displayed in Figure 2.5, electric drive is applied around both silent zones and zero-emission zones. At lower speeds, the perceived noise level is reduced to half in comparison between electric and diesel operation. Outdoor measurements indicate that during regular operation speed, there is a difference of 5-9 dBA in urban environment (ElectriCity, 2016). This difference can be regarded as a perceived doubling of the noise level. With higher operation speeds the difference between electric and diesel become less noticeable, as the vehicle structure becomes the predominant sound source (ElectriCity, 2016).

Increasing number of cities are applying restrictions of combustion engines in sensitive areas. With geofencing, vehicles are hindered to enter the zone unless they fulfils the set requirements of either speed or in this case emission rates (Volvo Bus Corporation, n.d.). For Route 55, the zero-emission zones are defined so a vehicle cannot enter a zero-emission zone unless it operates fully electric. Traffic data is used to calculate and estimate the coming energy consumption along the route, enabling the hybrid vehicles to maintain electric drive through the zero-emission zones (Volvo Bus Corporation, n.d.). For the Route 55's zone management system, zero-emission areas have been located around both Chalmers campus Lindholmen and campus Johanneberg, a loop at Frihamnen and the stretch through the inner-city between Gullbergsvass and Götaplatsen (ElectriCity, 2016). As seen in Figure 2.6, a low-speed zone has also been defined between campus Lindholmen and towards Frihamnen.

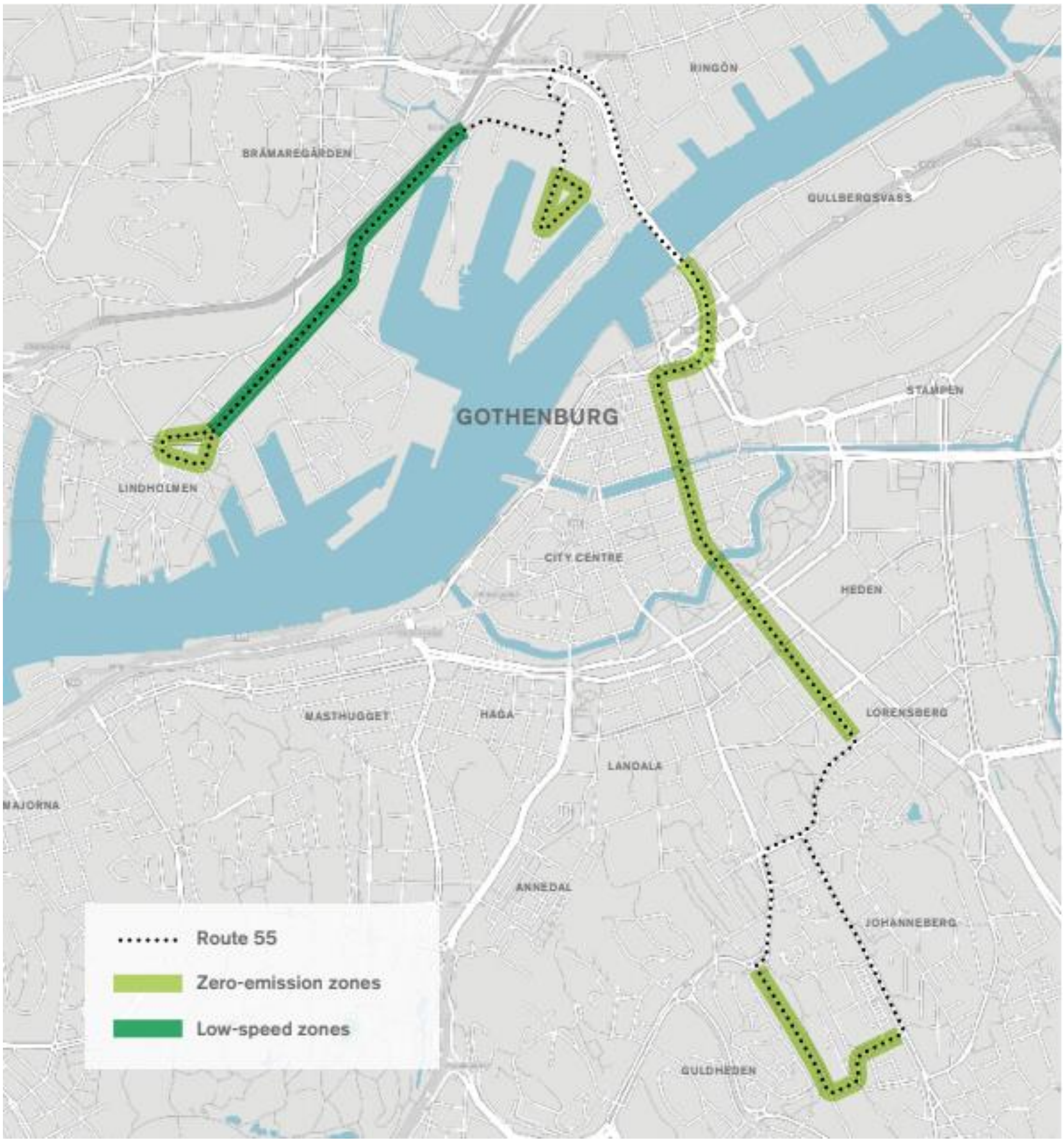

Figure 2.6 Map showing the zone management system for Route 55 with zero-emission zones displayed in light green and low-speed zones displayed in dark green (ElectriCity, 2016).

Stefan Widlund, City Mobility Manager at Volvo Bus Corporation, elaborates that with the Route 55 pilot project, features such as the zone management system was initially implemented for testing and visual purposes but is now a commercial offering and implemented in other countries and used in daily operation. In Gothenburg, the zones have been defined manually where it for larger networks in the future, could be done automatically using API. Besides safety and emission purposes, Route 55 then operates with a focus on perception of the passengers, using electric mode at both end- and main stations. According to Stefan Widlund, data has been collected through logging of the route with a collection of altitudes and speeds together with visual judgements. The compilation of data is compared with the electric capacity and creates a recommendation of zone division.

The zero-emission zones have, according to Stefan Widlund, consequently been identified where the electric mode have the biggest impacts, such as the crowded areas around each campus and the main street of Gothenburg, the avenue. It is done through the passenger and impression perspective, and currently not with focus on local street pollutants. For safety and low-speed zones, the only parameter changed is the speed limit where it deemed to be a lot of pedestrians or where the bus should have lower speed than the current legal speed limit. Speed restriction are also used to promote obedience of speed limits and create a high level of road safety in areas with heavy flows of pedestrians and cyclists. Since the start of model 7900 and Route 55, Stefan Widlund explains that large improvements have been done regarding electric capacity, growing from initially 76 kWh to 200 kWh today.

2.2 Simulation and modeling

The simulation software used in this study is Vissim, a time step and behavior-based model for traffic flow simulations (PTV Group, n.d.-b). It is a traffic and transport planning tool, developed in Germany and used worldwide. Vissim can be used for emission modeling by using the add-on module EnViVer. The vehicle data from the simulation in Vissim is imported into EnViVer and is the basis of the emission modeling (PTV Group, n.d.-a). In this chapter, the traffic simulation and emission model are explained in more detail. It describes how the models are built up and which parameters that are included. Moreover, it explain what types of vehicles that are involved in the models and what the output result consists of.

2.2.1 Traffic simulation in PTV Vissim

Vissim is a microscopic traffic simulation model, which means that the model focuses on each individual vehicle and their interactions with each other (Siddharth & Ramadurai, 2013). The model is able to simulate traffic flows within an area at a high level of detail and gives an overview of the movements in the entire road network. In Vissim, both private and public transport operations can be analyzed, as well as pedestrian flows (PTV Group, n.d.-b).

The road network in Vissim consists of links and connectors and are build up to mimic the real road network within the area to be investigated. The links are set to one or multilane links and can also be given a gradient to take the elevation into account (Fellendorf, 1994). The difference in elevation affects the driving behavior of the vehicles in the simulation. According to Siddharth & Ramadurai (2013), lane restrictions for the road network can be added in Vissim to represent the actual traffic conditions by specifying the characteristics of the links. This makes it possible to define if the road is lane or space oriented, on which side overtaking is acceptable, on which lanes the different vehicle types are allowed to drive and if the speed on the road is link or vehicle based.

To generate vehicles in the network, entry points are placed at the arriving locations and defined with a specific volume and vehicle composition (Fellendorf, 1994). The time interval between the arriving vehicles can also be defined, otherwise Vissim assumes a Poisson distribution. At each intersection, routing decision for static routes can be determined so that the vehicles are distributed in a particular way. For adding public transport lines in the network, consisting of buses and trams, routes are generated with a time-table including the departure time (Fellendorf, 1994).

Different types of signal control logic can be used in Vissim to define how the traffic signals should operate in the network. The signals can operate with a fixed time or be dependent on the amount of traffic (Fellendorf, 1994). Depending on what types of signals that will be used in the simulation, add-on programs or a signal generator program called VAP may be needed in addition to the built-in signal control software in Vissim (Fellendorf, 1994). By using vehicle-dependent signal controls, detectors have to be placed in front of the signals in order to measure the traffic. When a detector recognizes a public transport line, the logic file turns on and the signals for the public transport lines applies (PTV Planung Transport Verkehr AG, 2011).

In order to represent the actual traffic conditions, the simulation made in Vissim has to be calibrated and validated. According to Park & Schneeberger (2007), the calibration is done by adjusting parameters until the outputs from the simulation replicate the observed data in field. Possible parameters to change are for example vehicle speed, acceleration and distance between vehicles. To validate the traffic simulation, Park & Schneeberger (2007) states that data from the field has to be collected, either visually or by using measurements. Performance measurements that can be used to ensure the simulation is representative are travel time between two locations and queue lengths at specific links (Park & Schneeberger, 2007).

In addition of simulating traffic movements in terms of interactions of different vehicle types and analyzing queues, Vissim can also be used to model emissions by using EnViVer (PTV Group, n.d.-b). To be able to calculate emissions in EnViVer, a data file including information of the vehicle type, name, number, coordinates and speed is needed (Eijk, Ligterink, & Inanc, 2013). The gradient can also be added to include the elevation of the network. This data is obtained from the recorded traffic simulation result in Vissim where data for each vehicle per time step is presented. The vehicle recording is saved as a specific text file and imported into EnViVer to calculate the emissions (Eijk et al., 2013).

2.2.2 Emission modeling in EnViVer

EnViVer is a software used to calculate emissions by combining the result from a traffic simulation with emission models. The emissions that can be calculated are CO_2, NO_x and PM_{10} (TNO, n.d.). The Netherlands Organization for applied scientific research, TNO, has developed the emission model Versit+ which is based on collected emission data from more than 20000 vehicles (Eijk et al., 2013). By using equipment to measure vehicle emissions, different vehicles in various traffic situations have been analyzed and compiled in a database. This database is continuously updated with emission results from new vehicles entering the market. According to Eijk et al. (2013), the vehicle emissions vary depending on driving behavior and traffic conditions such as highways, traffic jams and free flow traffic. Thanks to the extensive database, Versit+ takes these conditions into account and is thus able to model real world scenarios.

In order to calculate vehicle emissions from a microscopic traffic simulation, a dedicated model called Versit+ micro has been developed by TNO (Eijk et al., 2013). The Versit+ micro model calculates emissions based on velocity-time profiles for different vehicle types. EnViVer interface links the microscale emission model to the microscopic traffic data from Vissim to get emissions results (Eijk et al., 2013). Figure 2.7 shows a flowchart of how EnViVer works when calculating emission in a microscale.

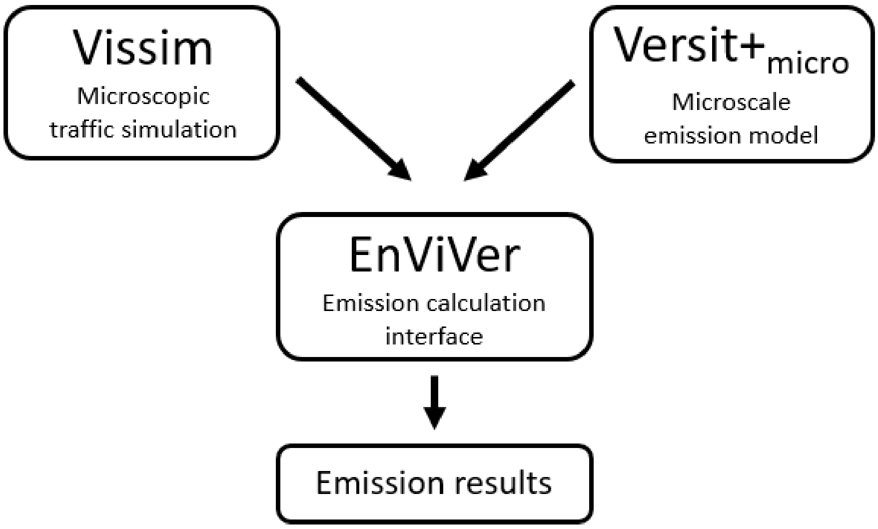

Figure 2.7: Flowchart of how emissions are calculated trough EnViVer

The calculation of traffic emission, TE, (g/h) is based on Equation (2.1), where E^F is the mean emission factor (g/km), TV is the traffic flow (vehicles/h) and L is the section's length (km) (Quaassdorff et al., 2016). j represent the specific pollutant, k is the vehicle class, l is the speed-time profile and m represent the specific section.

Equation (2.1) $$TE_j = \sum_{k,m}\left(E^F_{j,k,l} * TV_{k,m} * L_m\right)$$

Eijk et al. (2013) states that the emission models used in EnViVer are based on the Dutch fleet, as well as the default vehicle emission classes. However, the vehicle fleet composition can be modified by creating vehicle classes to represent a local vehicle fleet instead of the Dutch fleet. To create an own vehicle fleet, several parameters must be added which is done in the Custom Vehicle Park editor in EnViVer (Eijk et al., 2013).

The road type can be set to either urban or highway and the type of vehicle can be defined as a light-duty vehicle, bus or heavy-duty vehicle (Eijk et al., 2013). Fuel type can be added where the different options for a light-duty vehicle are petrol, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG) and electric. However, for buses and heavy-duty vehicles, there are no available models for other fuels than diesel and CNG which means that petrol, LPG and electric should be set to zero (Eijk et al., 2013). The era and the vehicle age distribution can be defined by including information of how many vehicles that are newer than 1 year, the average vehicle age, average exit age and maximum age, which results in a certain distribution of the euro classes (Eijk et al., 2013). The introduction years can be adjusted to change the distribution of euro classes to match the real case scenario (TNO, 2016). Lastly, for light-duty vehicles, the average regional CO_2 emission can be determined in g/km to be used in the emission calculations.

The results are presented in emission maps for each pollutant, together with a summary with tables of total emissions for the input data from Vissim (TNO, 2016). The emission values are also divided between each vehicle class contribution.

2.3 Emissions and their environmental impacts

Sweden follow the European emission standard for classifying vehicles and engine specific characteristics in terms of emissions. For heavy-duty engines, defined as motor vehicles above 3,500 kg mass operation weight, emissions standards are divided into six classes, referred to as Euro I to VI. For each stage, vehicle emission pattern limits regarding CO, HC, NO_x and particle matter is measured in g per kWh. There are limitations for smoke in 1/m for emission class Euro III to VI. For class Euro VI, particle number is limited to $8.0*10^{11}$ per kWh (DieselNet, n.d.). For each specific emission class limits, see Figure 2.8.

Stage	Date	Test	CO	HC	NOx	PM	PN	Smoke
			g/kWh				*1/kWh*	*1/m*
Euro I	1992, ≤ 85 kW	ECE R-49	4.5	1.1	8.0	0.612		
	1992, > 85 kW		4.5	1.1	8.0	0.36		
Euro II	1996.10		4.0	1.1	7.0	0.25		
	1998.10		4.0	1.1	7.0	0.15		
Euro III	*1999.10 EEV only*	ESC & ELR	*1.5*	*0.25*	*2.0*	*0.02*		*0.15*
	2000.10		2.1	0.66	5.0	0.10[a]		0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02		0.5
Euro V	2008.10		1.5	0.46	2.0	0.02		0.5
Euro VI	2013.01	WHSC	1.5	0.13	0.40	0.01	8.0×10^{11}	

[a] PM = 0.13 g/kWh for engines < 0.75 dm^3 swept volume per cylinder and a rated power speed > 3000 min^{-1}

Figure 2.8 EU emission standards for heavy-duty diesel engines from steady-state testing (DieselNet, n.d.).

Anthropogenic activities during the last century's and the increase in combustion of fossil fuel, is responsible for the developing change in the atmosphere composition a.k.a the global warming. With origin of combustion engines, air pollutants are defined as a substance which potentially might harm humanity, wildlife or the environment. Two of the major ones when focusing on global respectively local emissions, are carbon dioxide and nitrogen oxides (Kampa & Castanas, 2008).

2.3.1 Carbon dioxide

CO_2 is appointed the main GHG with the largest contribution towards climate change and consequently have large scale environmental impact. It is the fourth most abundant gas in Earth's atmosphere and involved in normal cell functions (Wisconsin Department of Health Services, 2018).

Even though CO_2 low radiative forcing, it stands for the largest contribution because of the magnitude of emissions and the residual time of up to 230 years in the atmosphere. Being the main GHG, CO_2 global warming potential is used as a reference when explaining various other air pollutants effect. CO_2 alone accounts for more than 80 % of the contribution towards global warming of present GHGs (Lashof & Ahuja, 1990). Being the main residual gas from fossil fuel combustion such as diesel and petrol, transport and traffic accounted for 24 % out of the worlds CO_2 emission in 2015 (International Energy Agency, 2017).

Global temperatures continue to rise and there is a need to decrease the amount of emitted GHGs, mainly CO_2. Being one of the main contributors of GHGs, there is a shared responsibility to implement sustainable ways of living and a need for change within transportation. Most effectively, this can be done with EVs and countries can invest in EUTs as a changing mode of transport (Nasa Science, n.d.).

2.3.2 Nitrogen oxides

With today's densely populated large cities, high exposures of both natural and anthropogenic air pollutants occur (Brunekreef & Holgate, 2002). The largest anthropogenic source of NO_X is the combustion of fossil fuel in the transportation sector representing 46 % of the total emissions in Europe (Boningari & Smirniotis, 2016).

Within transport, traffic is the major source, with special regards to urban areas where the traffic density is high. The dispersion of NO_X emissions depends on the surrounding environment and is in urban areas highly dependent of wind conditions. Around 80 to 95 % of NO_X emitted are in form of harmless nitrogen monoxide (NO) in measured concentration, both in low and heavily polluted areas. The remaining 5 to 20 % is emitted as nitrogen dioxide (NO_2). Emitted NO is either at street level or in the atmosphere oxidized by ozone (O_3) to NO_2 and eventually converted to other nitrogen-based compositions (Hertel et al., 1995).

In the troposphere and stratosphere, NO_X interacts with trace gases relevant to the absorbance of infrared wavelengths, resulting in an enhancement of the greenhouse effect. For parts of the troposphere already rich in NO_X, additional introduction causes an increase in O_3 concentration. A new equilibrium is rapidly achieved with a balance between the reactions with O_3 and photolysis of NO_2 (Lammel & Graßl, 1995).

NO_X has various impacts on human health, environment and biological ecosystems such as degradation of ozone layer and acidic rain. Common effects of acid rain are dying trees and damaged eco-systems. Especially aquatic environments are sensitive to nitrogen pollution wherein streams, lakes and ponds wildlife take harm. NO_X are known to be partially responsible for disturbance of fish and shellfish populations (Boningari & Smirniotis, 2016).

Exposure to high-intensity amount of NO_2 has caused fatal injuries to humans. Regular and ambient exposure of NO_2 are known to increase risks of respiratory tract infections through having effects on the immune system (Chen, Kuschner, Gokhale, & Shofer, 2007). The pollutant spread to all parts of the respiratory system and diffuse through the alveolar cells and capillary vessels. Ultimately, it interferes with the alveolar structures and the primal functions in lungs. Minor particles which infiltrate to the lungs can cause diseases and stresses such as bronchitis and heart problems. The effects can be divided due to either short or long-term exposures. Short-term exposure from high levels of NO_x leads to respiratory morbidity, increased chance of inflammations and decreased function of the lungs. It can be experienced as irritation in throat, eyes or skin, difficulty to breathe, nausea or headaches. Long- term exposure can cause asthma and various respiratory infections and consequently rapid pulse rates and stress (Boningari & Smirniotis, 2016).

Gothenburg City Environmental Management frequently measure current levels of air pollutants around the city and summarize the data into yearly reports (Miljöforvaltningen, 2017). For the study area of Johanneberg, the hourly average levels of NO_2 can be observed in Figure 2.9. The Swedish environment agency has set corresponding limits of 90 µg/m^3 per hour which should not be exceeded more than 175 hours per year (Naturvårdsverket, 2019).

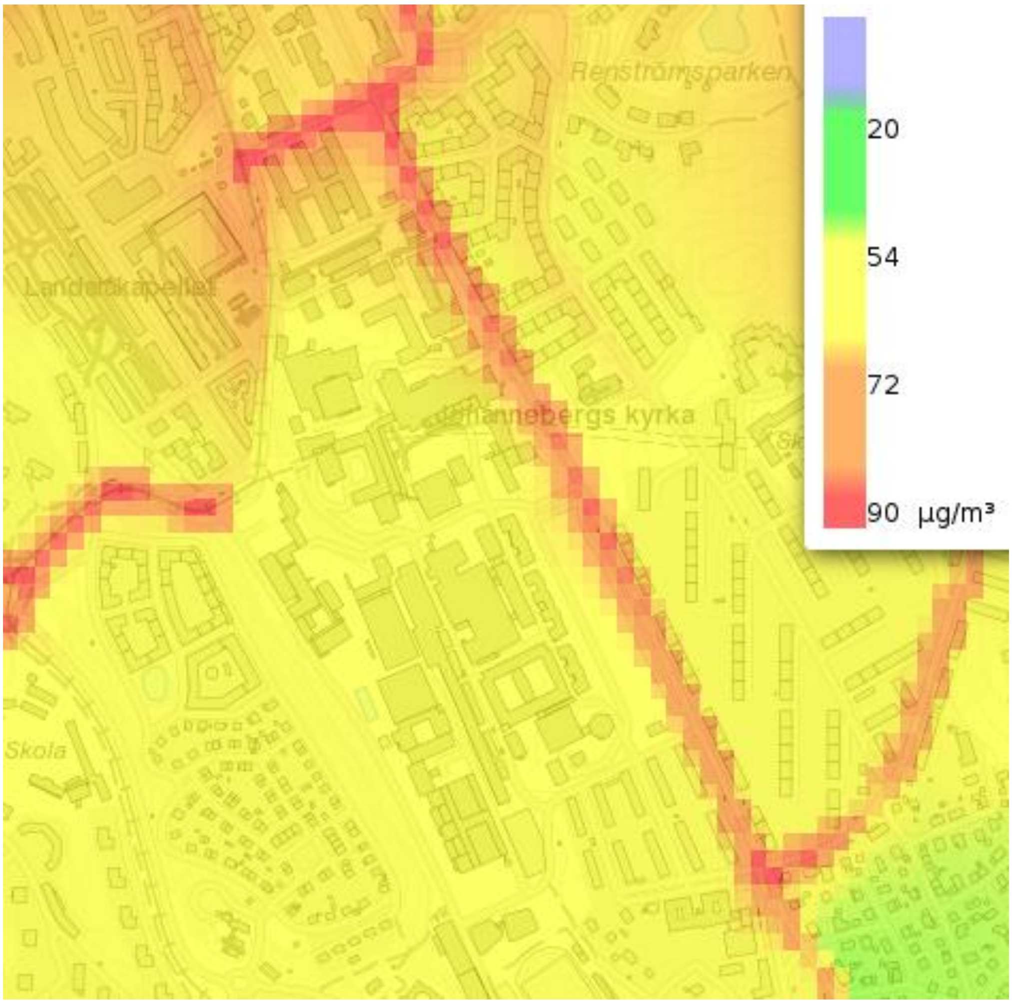

Figure 2.9 Map of nitrogen dioxide levels (NO_2 µg/m^3) Johanneberg, 98 percentile hourly average value from 2015 (Miljöforvaltningen, 2017).

3 Methodology

To create a realistic traffic model, the methodology begins with a detailed description of the simulation area together with how data was collected for the simulation. Continuously the work progress and the creation of the traffic model in Vissim is described with its changes of parameters and calibration process. The next section regarding emission calculation begins with an explanation of the different scenarios and how they are set up. In order to create a representative emission calculation according Swedish standards, all the changes in EnViVer is lastly presented together with how the result will be displayed.

3.1 Data description

This section describes the study area Johanneberg and the activities along the streets included in the simulation. The received traffic simulation is also described in terms of the underlying data collections used as input values in Vissim and how the simulation has been built.

3.1.1 Simulation area Johanneberg campus

The analyzed study area Johanneberg campus is located south of Gothenburg centre and can be seen in Figure 3.1. Within the area, Chalmers University of Technology has a large part of its business, with focus on both education and research (Chalmers University of Technology, n.d.). The campus area has limited traffic and is mainly occupied by pedestrians and cyclists. Several student apartments are located within the area as well as a few restaurants and cafes. There are also other activities, such as fitness centers, secondary school, library and a medical centre.

Figure 3.1 A map showing the simulation area Johanneberg, Gothenburg (Göteborgs Stad, 2019)

In total, the campus area is surrounded by a 2,5 km long stretch consisting of the streets Gibraltargatan, Engdahlsgatan, Sven Hultins Gata, Aschebergsgatan and Läraregatan (Eniro, n.d.). Route 55 operates on all these streets, while the amount of other public transport lines varies depending on the street. The traffic flow including all vehicle types is very different in the road network, as well as the surrounding environment and activities.

Gibraltargatan runs along the entire east side of Johanneberg campus and has an average traffic flow of up to 7700 vehicle per day (Göteborgs Stad, 2014b). The street is trafficked by public transport bus lines 19 and Route 55. On the opposite side of Johanneberg campus are apartment buildings with businesses on the ground floor such as shops, hairdressers, cafes and restaurants. Chalmers main parking lot and library is located in the middle of Gibraltargatan connected to a small green area and Johanneberg church on the other side. Due to the activities around Gibraltargatan, there are high flows of both pedestrians and cyclists with sidewalks on both sides and a separate bicycle lane on the west side. In total, there are eight pedestrian crossings along Gibraltargatan.

South of the campus area, the route goes along Engdahlsgatan for 205 meters. It has mainly apartment buildings and a sidewalk along the south side of the street and an entrance to Chalmers main parking lot on the north side. At the end it connects to one of Chalmers park garage buildings. Only Route 55 operates on this street and the average traffic flow is just above 2000 vehicles per day (Göteborgs Stad, 2014a).

Engdahlsgatan switches on to Sven Hultins Gata which stretches along the southern and western side of Johanneberg campus. The average daily traffic flow at Sven Hultins Gata is 3500 vehicles (Göteborgs Stad, 2010b) and the charging stop for Route 55, Sven Hultins Plats, is placed along this street. At the beginning of this street, Johanneberg Science Park is located, and along the western side, there is a wooded area with walking paths all the way to Chalmersplatsen.

Chalmersplatsen is a multimodal intersection consisting of all different vehicle types such as cars, vans, trucks, motorbikes, buses and trams. Here, five different tram lines pass with high frequency in both directions; three through the tunnel to and from Korsvägen and two lines to and from Kapellplatsen. Four buses pass this intersection; bus 16, 158, 753 and Route 55 (Västtrafik, 2019a). There are 4 separate public transport stops for trams and buses, as well as separate lanes in both directions for the rest of the vehicles. Four original lanes turn into seven at Chalmersplatsen, and then go back to four lanes again. Chalmersplatsen is a signal-controlled intersection with associated detectors that react to the vehicles and give public transport priority. The large traffic flow, the varying vehicle types, the high frequencies of public transport and the traffic signals with detectors makes Chalmersplatsen a highly complex intersection.

At Chalmersplatsen, the street Aschebergsgatan starts and stretches along the rest of the western side of campus to Kapellplatsen. The route between Chalmersplatsen and Kapellplatsen is the most trafficked stretch within the area and according to Gothenburg City the average traffic flow is 11200 vehicles per day (Göteborgs Stad, 2016a). Along this stretch, four buses and three trams operate. Bus 16 is the most frequent bus line within the area with up to 27 departures during a two-hour period on the afternoon. The buses run all day long, except for a few hours in the middle of the night (Västtrafik, 2018a). On the western side of Aschebergsgatan are mainly apartment buildings and on the eastern side it consists of a mountain wall and office buildings of campus Johanneberg. Both sides have a shared pedestrian and cycle path. At both Chalmersplatsen and Kapellplatsen there are large flows of pedestrians and cyclists, being the two main connections to Campus Johanneberg. In the northwest of Kapellplatsen it connects to a square with shops and grocery stores. Kapellplatsen is also a signal-based intersection with detectors that give priority to public transport.

On the north side of the campus area, Läraregatan is located with a traffic flow of 5000 vehicles per day (Göteborgs Stad, 2016c). On Läraregatan, only two buses operate; bus 19 and Route 55. It is mainly office buildings along the street, with a pre-school and a secondary school nearby. The north side of the road has a separated pedestrian and bicycle path, and the south side has a shared sidewalk. In the eastern part of the street it connects to Gibraltargatan with a signal controlled intersection.

All public transport buses within the area are managed by Västtrafik; including Route 55, bus 16, bus 19, bus 158 and bus 753. Route 55 is operated by electric and electric hybrid buses as described in Section 2.1.1 and bus line 16 are testing 2 fully electric articulate buses running the main section of the stretch. Besides the electric and hybrid vehicles, the bus fleet of Västtrafik has a fuel usage distribution of 45 % rape-seed methyl ester (RME), 24 % HVO, 17 % biogas and 11 % diesel (Holm, 2017). A more detailed description of the bus routes and distances can be seen in Table 3.1.

Table 3.1 The entire route and distance for the buses involved within the study area.

Bus line	Route	Distance	Distance within study area
Bus 16	Eketrägatan - Sahlgrenska - Högsbohöjd	16,0 km one way	0.45 km
Bus 19	Backa - City - Fredriksdal	11,2 km one way	1 km
Bus 158	Skintebo - Sahlgrenska - Vasastan	14,0 km one way	0,45 km
Bus 753	Heden - Chalmers - Mölndal - Heden	24,0 km round route	0,45 km
Route 55	Lindholmen - Johanneberg	7,6 km one way	2,5 km

3.1.2 Data collection

Data was collected together with the research group at Chalmers who initiated the simulation network in Vissim. Data of vehicle movements was collected for the four intersections; Kapellplatsen, Läraregatan/ Gibraltargatan, Gibraltargatan/ Engdahlsgatan and Chalmersplatsen. From the first, second and third intersection, traffic data was collected through empirical studies and observation on site. The observations were done in the autumn of 2018 during the morning between 7 am and 9 am and during the afternoon between 4 pm and 6 pm. The maximum flow hour for each intersection was calculated based on the maximum quarter with a correction factor of 0.9, see Equation (3.1). The maximum hour traffic data is presented in Table 8.1-8.3 in Appendix 8.1.

Equation (3.1) $\quad$ *Maximum flow hour = Maximum flow 15 min * 4 * 0.9*

The data for the fourth intersection, Chalmersplatsen, was acquired from Gothenburg City due to time limitation, see Figure 8.1-8.2 in Appendix 8.1. The data from Gothenburg City consider the total amount of vehicles but not the specific type of vehicle. Therefore, the vehicle type ratio at Chalmersplatsen was estimated based on the average values of the vehicle type ratio from the other intersections. The vehicle type ratio at the intersections can be seen in Table 8.4-8.7 in Appendix 8.1. The calculated vehicle type distribution can also be seen in Appendix 8.1, Table 8.8-8.9.

No on-site measurements were done regarding the speed on the road network for the different vehicle types. Instead, the traffic speed was estimated based on data from Gothenburg City. The estimated vehicle speed can be seen in Table 3.2.

Table 3.2 Estimated vehicle speed on the streets within the study area.

Vehicle	Speed [km/h]
Cars	30
Vans	30
Trucks	25
Motorbikes	30
Buses	20
Trams	20

Signal phase programs and an intergreen matrix for the signal-regulated intersections Chalmersplatsen, Kapellplatsen and Läraregatan/Gibraltargatan was obtained from Trafiksystem. The intergreen matrix, see Table 8.10 in Appendix 8.2, ensures that the traffic signal shifts do not lead to conflicts between the vehicles. The signal phase program for Chalmersplatsen is presented in Appendix 8.2, Figure 8.3-8.8 where the different stages can be seen. Stage 1, 2 and 3 is for common vehicles while stage 4, 5 and 6 is for public transport.

3.1.3 Simulation

The road network was set up in Vissim to represent the reality. The geometry of the simulation area was based on Open Street Map, Google Maps and visual estimations to mark the locations of roads. Estimated width of bus and tram lanes was set to 3,5 meters while the other roads were set to around 3 meters. One-way bicycle path was set to 2 meters, two-way bicycle path was set to 3 meters and pedestrian paths to 2 meters.

The maximum hour traffic data from each intersection was the basis for the vehicle input values in the simulation. The distribution of vehicles for each intersection was based on the maximum hour traffic data as well.

Vehicles used in the simulation model was the default vehicles included in Vissim. Since no standard vehicle for van was defined, the characteristics of a Toyota Tundra from 2008 was set as the default vehicle. All the buses in the simulation were modeled as the same type and no exception was made for the electric and electric hybrid Route 55.

The data obtained from Trafiksystem was used to model the traffic signals and its logic file. Detectors was added in front of the traffic signals to be able to measure the traffic and thus control the traffic signals.

At last, the traffic flow between the intersection was regulated to match the in- and outflow of vehicles. The total traffic in the system was also adjusted to maintain a mass balance of the in and out flow.

3.2 Vissim traffic model

When the traffic simulation was received, the vehicles in the network were based on data from the maximum quarter recalculated into maximum hour, which led to a high number of vehicles in the network. The public transport lines were not fully developed regarding the frequencies. In order to improve the traffic simulation and make it more representative, several parameters were changed, which are presented in this section. All the changes can be seen in more detail in the tables in Appendix 8.3.

The vehicles used in Vissim are based on default vehicle specifications. The vehicle properties, with focus on how the vehicles are modeled in the network, were changed for cars and trams to achieve a correct illustration of the specific vehicles, see A.8.3.1. Data regarding vehicle input and vehicle routes were missing at specific locations in the simulation and was therefore added, see A.8.3.2 and A.8.3.3. The departure times for the public transport lines during peak hour were defined based on data from Västtrafik's travel planner (Västtrafik, 2019b) and some frequencies were changed in Vissim, see A.8.3.4. The summary of the frequencies used in Vissim for all public transport lines can be seen in Table 3.3. Since all the tram lines with the same route are merged into one tram line in the simulation, the frequencies are based on the total amount of lines.

Table 3.3 Frequencies of the public transport lines

Public transport lines	Amount of departures to centrum	Frequency to centrum [seconds]	Amount of departures from centrum	Frequency from centrum [seconds]
Bus 16	23	313	27	267
Bus 19	22	327	22	327
Route 55	-	-	12	600
Bus 158	-	-	8	900
Bus 753	8	900	5	1440
Tram 6, 8, 13	37	195	37	195
Tram 7, 10	27	267	27	267

The traffic signals at Chalmersplatsen were investigated since the trams did not have priority at the intersection, see A.8.3.5 and A.8.3.6. The logic file that determines how the traffic signals operates was adjusted to achieve the state where trams take precedence over other vehicles. The intergreen matrix were changed so that the time gap between the traffic signals are consistent with data from Gothenburg City, see Appendix 8.2.

To include the elevation in the road network, links were given a gradient. An elevation map received from the Urban Planning Department in Gothenburg was used to define the meter above sea level at different points along the roads within the study area (Göteborgs Stad, 2019). Based on the length of the links in addition to the difference in elevations, the average gradients were calculated and added in Vissim, as can be seen in Figure 3.2 and A.8.3.7.

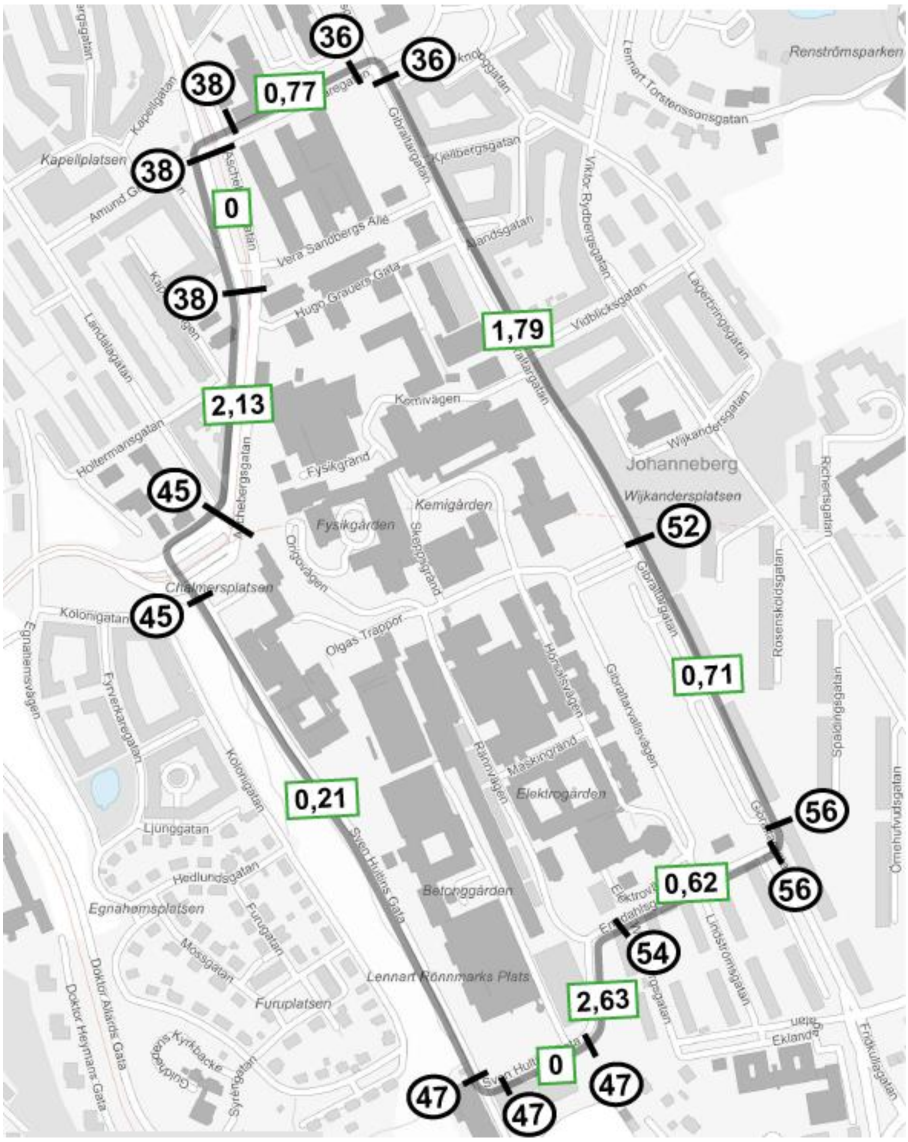

Figure 3.2 A map showing the elevation at campus Johanneberg. The black circles show the meter above sea level at specific point along the route and the green boxes show the average gradient of the road between the points.

The vehicle input values, based on the observed traffic count data, were compared to data from Gothenburg City (Göteborgs Stad, n.d.). Maximum hour traffic data was found for vehicles at the streets Aschebergsgatan, Läraregatan, Gibraltargatan and Guldhedsgatan. Since the data from Gothenburg City is for all types of vehicles, the specifically vehicle input values for cars were calculated based on the average percentage of cars within the road network. Table 3.4 shows the vehicle input values from the traffic observation and the given data from Gothenburg City for cars. As can be seen, there is a big difference between the two methods and the data from Gothenburg was used as new vehicle input values to achieve a more accurate simulation. The same process was made for vans and trucks as well, since there was a significant difference even for those vehicles. The result for vans and trucks can be seen in Table 8.13-8.14 in Appendix 8.4.

Table 3.4 Vehicle input and output values based on traffic observations and the given data from Gothenburg City.

Entry location	Vehicle input from traffic observation	Maximum hour traffic data from Gothenburg City, vehicle input	Vehicle output from traffic observation	Maximum hour traffic data from Gothenburg City, vehicle output
Amund Grefwegatan	223	-	320	-
Aschebergsgatan	253	352 [1]	400	296 [2]
Rännvägen	53	-	72	-
Läraregatan	486	208 [3]	579	208 [4]
Gibraltargatan	597	368 [5]	414	368 [5]
Guldhedsgatan	440	464 [6]	312	-

[1] (Göteborgs Stad, 2010a)
[2] (Göteborgs Stad, 2017)
[3] (Göteborgs Stad, 2014c)
[4] (Göteborgs Stad, 2016c)
[5] (Göteborgs Stad, 2014b)
[6] (Göteborgs Stad, 2016b)

The new vehicle input values were then used to recalculate the distribution of the number of vehicles in the relevant intersections in order to match the vehicle flow. The same process was made for the outflow of vehicles at the streets Aschebergsgatan, Läraregatan and Gibraltargatan, where data was available. The principle of the calculation can be seen in Figure 3.3. Since the new vehicle input values changed the distribution of vehicles at the intersections, great emphasis was placed on keeping the original distribution of vehicles from the traffic count. To be able to keep the original distribution in addition to the new vehicle input values, regulation regarding the flow was needed. The flow adjustment led to new routes in the simulation, see A.8.3.8. The final result of the distribution for cars, vans and trucks within the area can be seen in Appendix 8.5, Figure 8.9-8.11.

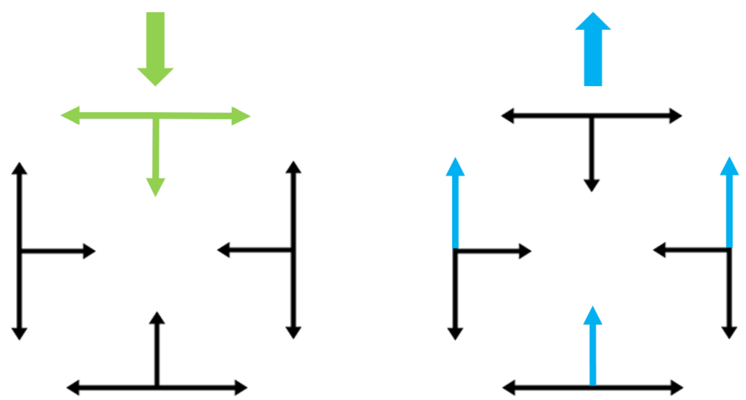

Figure 3.3 An illustration showing the principle of how the distribution in number of vehicles was recalculated. The green arrows represent a scenario with a new vehicle input value and the affected driving alternatives while the blue arrows represent a scenario with a new vehicle output value.

Parameters related to vehicle speed were changed and some roads were assigned a faster link-based speed that applies for all vehicle types instead of being vehicle based, see A.8.3.9. The affected roads were Läraregatan and Amund Grefwegatan where the vehicles drove slowly and formed queues. One of the lanes along Guldhedsgatan and Aschebergsgatan is dedicated solely for tram traffic and the specific lanes where therefore blocked for all vehicles except for trams, see A.8.3.10. To ensure that no trams covered any crossing lanes or blocked other types of vehicles, the distance between trams that stood still in the system was extended to 15 meters at Chalmersplatsen. The intersection consists of all different vehicle types, such as cars, vans, trucks, motorbikes, buses and trams. Figure 3.4 shows the multi-modal intersection at Chalmersplatsen, after one hour simulation.

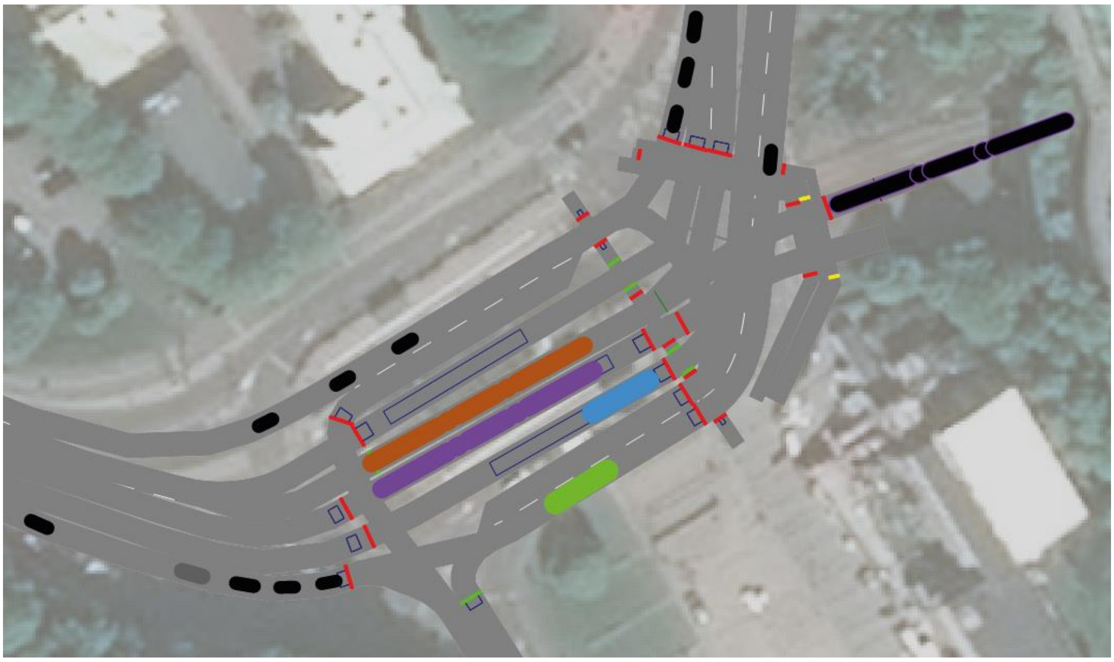

Figure 3.4 An illustration of Chalmersplatsen from the simulation in Vissim after one hour. The intersection is for the moment occupied by cars (black), a van (grey), trams (orange and purple), a bus (blue) and an electric bus (green). The black tram to the right indicates a tram that stands still.

Route 55 operates on both electricity and HVO diesel, and there is no possibility to model the vehicle to change power dynamically along the stretch. The power relates to the specific vehicle type and the bus stretch was therefore divided into different parts to be representative for the zone management. To be able to separate electric and hybrid buses from conventional buses in EnViVer, the definition of the vehicle type was changed in Vissim. Two new vehicle types were created to represent Route 55 along the stretch; one fully electric vehicle type and one hybrid vehicle type. The electric vehicle type was created to represent the stretch along Engdahlsgatan and Sven Hultins Gata where the buses operates on electricity due to the zone management system. The hybrid vehicle type was created to represent the stretch along Gibraltargatan, Aschebergsgatan and Läraregatan where no zero-emission zones apply but where 30 % buses operate on electricity and 70 % on HVO diesel, since three buses are fully electric buses.

New vehicle types were created for each bus line that will change fuel characteristic in the other two scenarios. This was done for bus line 16, 19, 158 and 753 to separate them. By having separate vehicle types for each bus line makes it possible to use the same simulation file to model different scenarios in EnViVer.

In order to confirm that the simulation is representative, a traffic inspection was done where the queue at different intersections was analyzed. The validation was done visually based on personal experience and an acquaintance to the area. The queue length close to the most trafficked locations Kapellplatsen, Chalmersplatsen and the intersection at Läraregatan/Gibraltargatan were analyzed and compared to the simulated queue. The result from the traffic inspection at Läraregatan compared to the result from the simulation can be seen in Figure 3.5.

Figure 3.5 The simulated queue length in Vissim to the left compared to the observed queue length at Läraregatan in the middle and to the right (OpenStreetMap, n.d.)

The vehicle recording time was set to one hour after 30 minutes simulation and after a completed simulation, the vehicle recording was saved. By adding vehicle type, name, number, coordinates, speed and gradient as selected attributes for the vehicle recording, the necessary data for further investigations in EnViVer was included.

3.3 EnViVer emission model

The vehicle recording from the simulation, including the velocity-time profiles for all vehicles, was imported in EnViVer. To compose a more representative fleet for the conditions in Sweden, new vehicle emission classes were created in the Custom Vehicle Park editor. These vehicle classes were used to set up the different scenarios that were later modelled. The analyzed scenarios are:

0. The current state
1. Route 55 as fully electric along the entire stretch
2. All public transits within the road network are electric

Beyond scenario 2, where all bus lines are electric, sub-scenarios were created to investigate the emission effects for each bus line being electric individually in a comparative way.

Vehicle classes were created for cars, vans, trucks, trams and buses. Motorbikes were neglected due to their small share and that no default vehicle emission class was dedicated to motorbikes. Depending on the type of vehicle, parameters in EnViVer such as vehicle type, fuel type, vehicle age distribution and emission legislation were defined. For all vehicles, the era was set as 2017 and the road type as urban. Cars and vans were set as light-duty vehicles, trucks and trams were set as heavy-duty vehicles and all types of buses were set as buses.

The fuel distribution was determined for each vehicle class as well as the vehicle age distribution and the emission legislation. Table 3.5 shows the fuel distribution, vehicle age distribution and emission legislation for each vehicle class.

Table 3.5: Fuel distribution, vehicle age distribution and emission legislation

	Car	Van	Truck	Bus	Bus hybrid	Bus electric	Tram
Fuel distribution	56,5 % petrol, 33,7 % diesel, 4,5 % ethanol, rest % electric [1]	89 % diesel, 9 % petrol, rest % electric ethanol gas [2]	89 % diesel, 9 % petrol, rest % electric ethanol gas [2]	45 % RME, 24 % HVO, 17 % biogas, 11 % diesel [3]	30 % electric, 70 % HVO [4]	100 % electric	100 % electric
Newer than 1 year [%]	11,5 [5]	10 [5]	5 [5]	-	-	-	-
Average vehicle age [year]	10 [5]	8,2 [5]	10,9 [5]	-	-	-	-
Average exit age [year]	17 [5]	15 [6]	15 [6]	-	-	-	-
Emission legislation	-	-	-	Euro VI [7]	Euro VI [7]	Euro VI [7]	Euro VI [7]

[1] (SCB, 2018)
[2] (Trafikanalys, 2018)
[3] (Holm, 2017)
[4] (ElectriCity, 2016)
[5] (Trafikanalys, 2016)
[6] (Trafikanalys, 2015)
[7] (Västtrafik, 2018b)

The maximum allowed value of cars newer than 1 year was 8,1 % in EnViVer and was therefore used instead of 11,5 %. For trucks newer than 1 year, 6,7 % was used instead of 5 % since it was the minimum allowed value. Due to the fact that HVO, RME and ethanol are no available fuel type options in EnViVer, the fuels were recalculated into diesel to represent the same environmental effects. This was also done for petrol for buses and heavy-duty vehicles. The emissions from HVO compared to diesel is only 10 % for CO_2 (Biofuel Express, n.d.) and 22,2 % for NO_x, see Figure 2.4. RME results in 35% CO_2 emissions (Johan Biärsjö, 2008) and 110 % NO_x emissions (Nasir El Bassam, 2010) compared to diesel. The emissions from petrol is approximately 60 % for CO_2 (Wentzel, 2001) and 90 % for NO_x (Transport & Environment, 2015). Ethanol compared to diesel results in 57 % CO_2 emissions and 72 % NO_x emissions (Tessum, Marshall, & Hill, 2010).

Separate vehicle classes for each vehicle were created in EnViVer since the fuel distribution varies depending on which pollutant that will be investigated. Furthermore, the vehicle class for buses were divided into separate vehicle classes with the same parameters for the different bus lines 16, 19, 158 and 753 to be able to see the environmental impact from each bus line. The final distribution of fuel, together with all other inputs for each vehicle class in EnViVer, are summarized in Table 8.15 in Appendix 8.6.

Emission maps for all scenarios and pollutants were created and the given tables with emission values were used to create comparative charts. The reduction of emissions, based on different bus lines being electric, was also presented. The maps were set to report the emissions in gram and the cell size was set to 5 times 5 meters. Emission maps were created for both CO_2 and NO_x emissions, but focus was on NO_x emissions due to its local effects on both the environment and human health, see Section 2.3.2.

4 Result

Firstly, the result for scenario 0, current state, is presented in form of emission maps, total emissions and air pollution share distribution between different vehicle classes. Secondly, a comparison between the current state and the two scenarios regarding Route 55 as full electric and if all buses were electric is presented. The different scenarios are compared for both CO_2 and NO_x in total emissions together with a comparison of sub-scenarios to scenario 2, where each bus line is electric separately to see which one has the highest potential.

4.1 EnViVer emission scenarios

Figure 4.1 shows the NO_x emission map for scenario 0, current state. Higher values of NO_x can be seen at Chalmersplatsen, Kapellplatsen and at the intersection Gibraltargatan/Läraregatan. The emissions rates are lower along the streets. Where the bus stops are located at Gibraltargatan the emissions rates are higher than the rest of the street. The lowest emission values can be seen along Engdahlsgatan and Sven Hultins Gata where Route 55 operates on electricity already.

The same result is seen for CO_2 emissions. The emissions are higher at the intersections and lower along the streets Engdahlsgatan and Sven Hultins Gata. The CO_2 emission map are shown in Appendix 8.7, Figure 8.12.

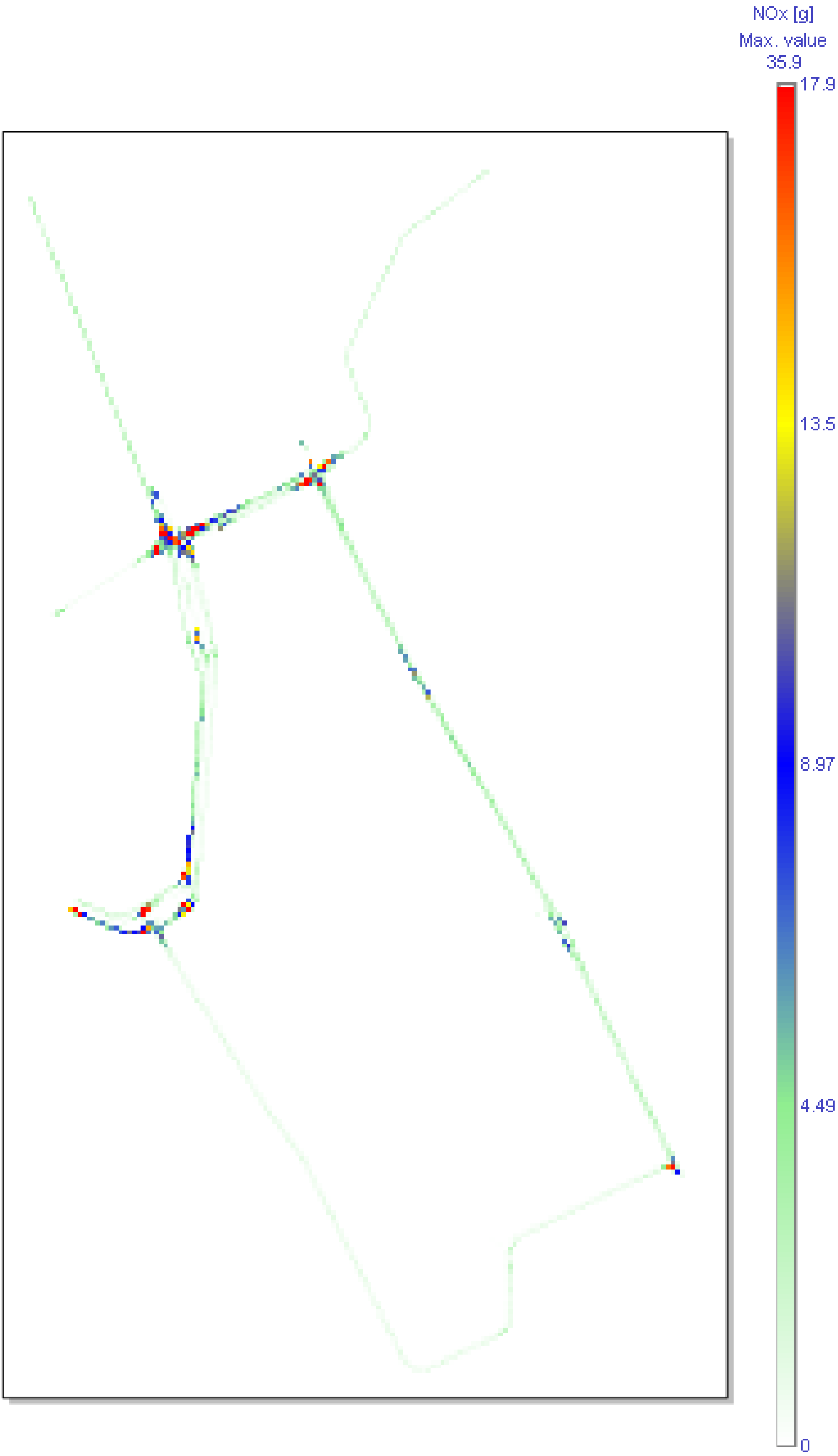

Figure 4.1 Emission map of NO_x scenario 0, current state within the study area.

In total, 688 kg CO_2 emissions and 4396 g NO_x are emitted within the study area during the peak afternoon hour for scenario 0, current state. Table 4.1 shows how much each vehicle class contributes to the total amount of emissions.

Table 4.1 Total amount of CO_2 and NO_x emissions divided between the vehicle classes for scenario 0, current state

Vehicle class	CO_2 [kg]	NO_x [g]
Car	450,226	1612,004
Van	52,333	234,423
Truck	142,612	1539,916
Bus	41,795	975,253
Hybrid Bus	1,151	34,174
Electric Bus	0,000	0,000
Tram	0,000	0,000
Total	688,117	4395,770

The distribution of CO_2 and NO_x emissions are illustrated in Figure 4.2. As can be seen, the main contributor for CO_2 emissions is cars by 65 % while buses only contribute by 6 %. For NO_x emissions, cars and trucks stand for 36 % each while buses contribute by 23 %.

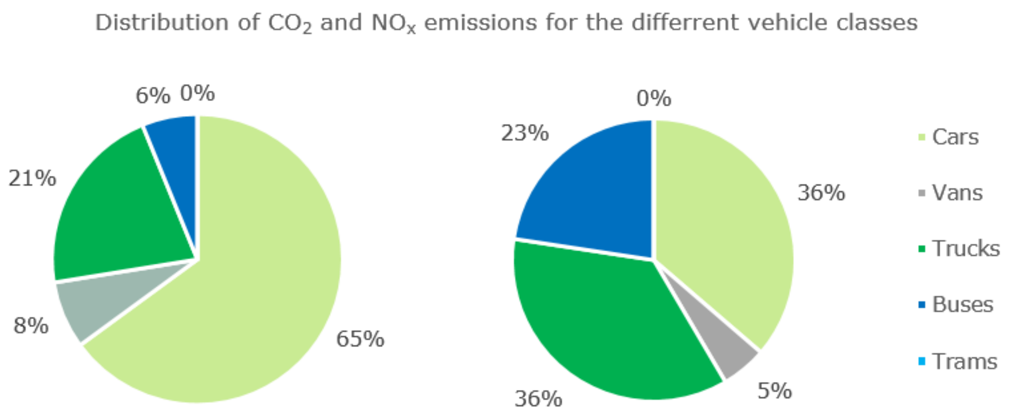

Figure 4.2: Distribution of CO_2 emissions (to the left) and NO_x emissions (to the right) per vehicle class for the current state

4.2 Comparison of scenario 0, scenario 1 and scenario 2

The CO_2 and NO_x emission maps for scenario 1, where Route 55 is fully electric along the stretch, look similar to those for scenario 0. No changes regarding the emission values can be noticed from the emissions maps, see Appendix 8.7, Figure 8.13-8.14. For Scenario 2, slight difference can be noticeable around the intersections of Chalmersplatsen, Kapellplatsen, Läraregatan/Gibraltargatan and the streets Aschebergsgatan and Läraregatan see Figure 8.15-8.16 in Appendix 8.7.

Figure 4.3 shows a comparison of CO_2 emissions depending on the different scenarios. Scenario 1 results in a reduction of 1,1 kg CO_2 emissions compared to scenario 0, which is a reduction of 0,2 %. For scenario 2, if all public transit buses would be electric, it results in a reduction of 38,6 kg CO_2 emissions, which stand for 5,5 % less CO_2 compared to scenario 0.

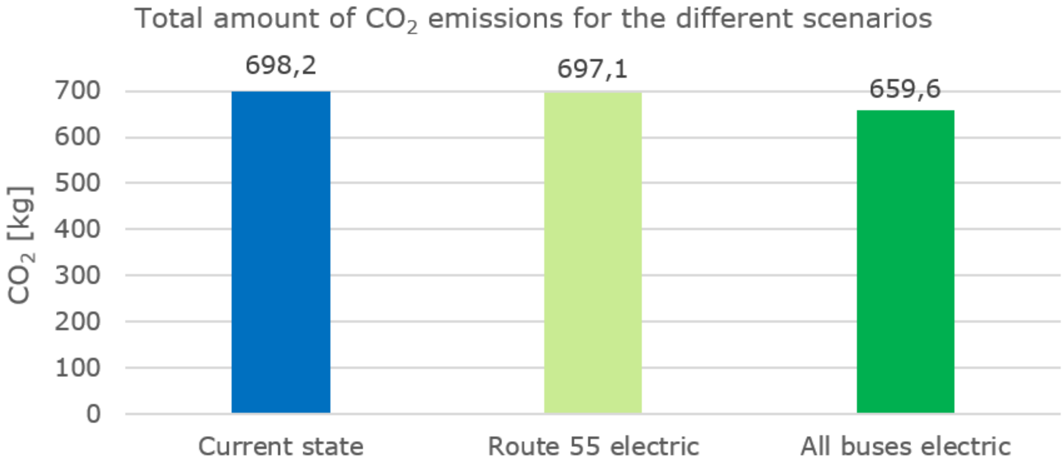

Figure 4.3 Comparison of CO_2 emissions for the different scenarios

The reduction of NO_x emissions is larger than for the CO_2 emissions in percentage. As shown in Figure 4.4, scenario 1 results in 34,6 g less NO_x, while scenario 2 results in 908,3 g less NO_x. This stands for a reduction of 0,8 % and 20,3 % respectively.

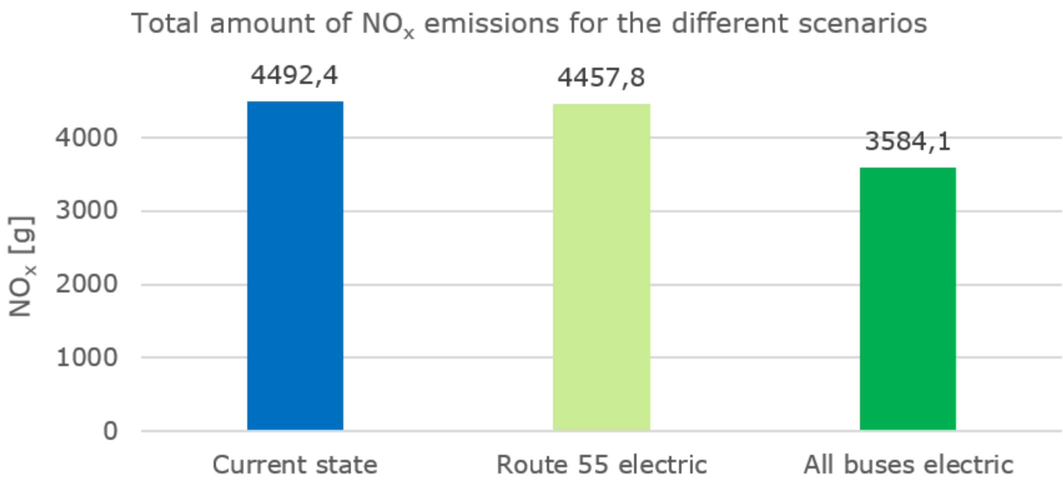

Figure 4.4 Comparison of NO_x emissions for the different scenarios

A comparison of CO_2 emissions for each bus line being electric are shown in Figure 4.5. Bus line 19 has the largest CO_2 reduction with 16,64 kg, followed by bus line 16 with a reduction of 14,4 kg. Bus line 753 can reduce by 3,89 kg, bus line 158 with 2,52 kg and lastly Route 55 with 1,15 kg. If all public transport buses are converted to electric, civil buses in the simulation still account for 4,51 kg CO_2.

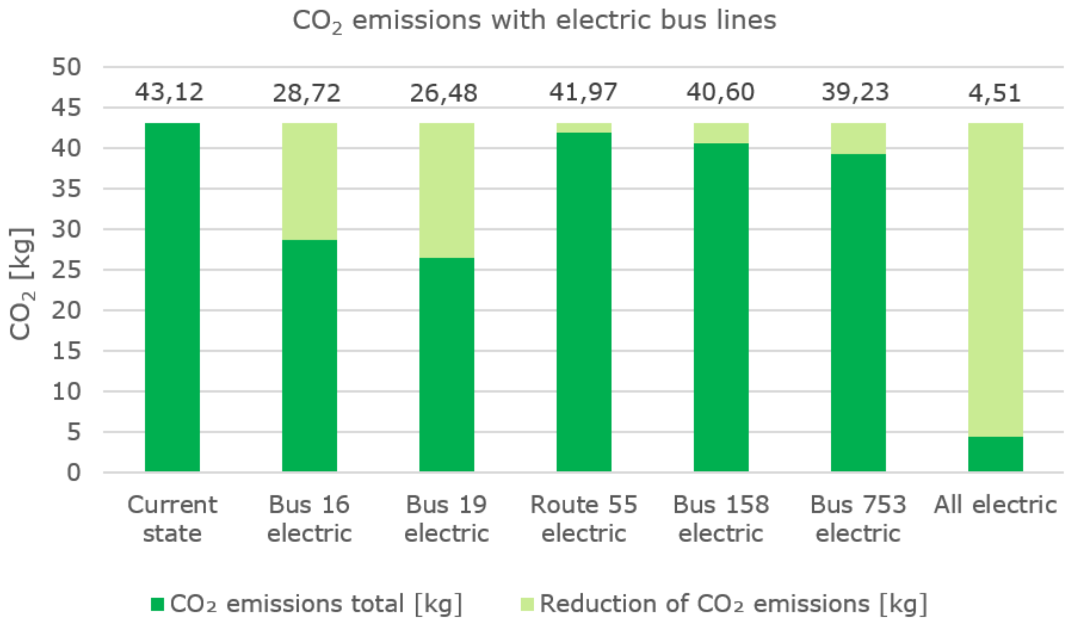

Figure 4.5 Comparison of CO_2 reduction emissions potential with different specific electric bus lines

For NO_x, the comparison between the bus lines look similar to CO_2, as shown in Figure 4.6. Bus line 19 has the largest NO_x reduction with 392 g, followed by bus line 16 with a reduction of 333 g. Bus line 753 can reduce by 89 g, bus line 158 with 59 g and lastly Route 55 with 34 g. If all public transport buses are converted to electric, civil buses in the simulation still account for 107 g NO_x.

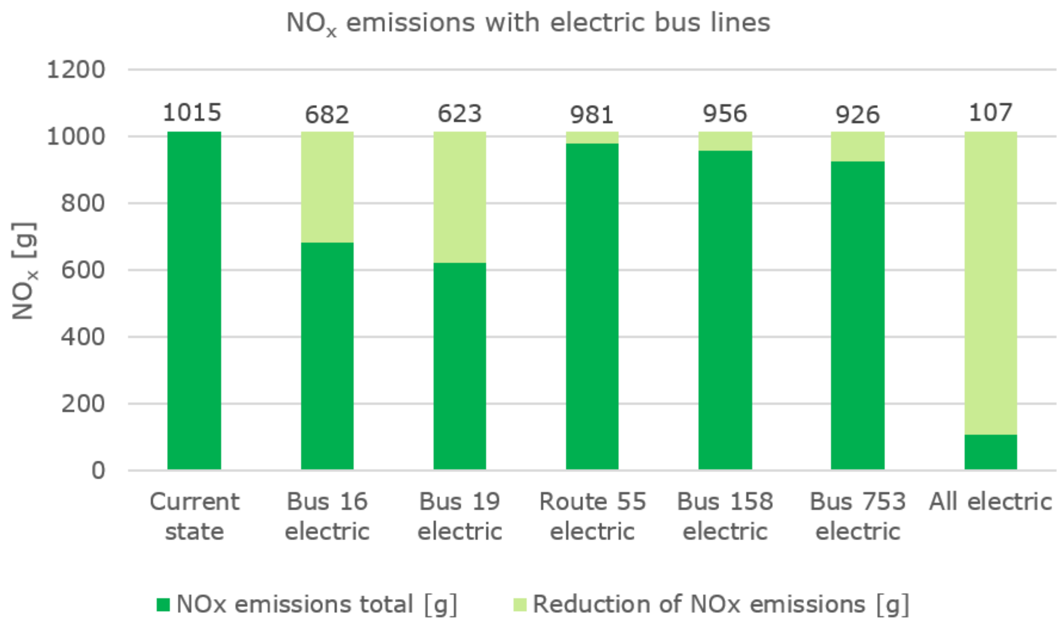

Figure 4.6 Comparison of NO_x reduction emissions potential with different specific electric bus lines

5 Evaluation

The evaluation is divided between the methodology of the study and the results. First, the methodology is discussed in consecutive order as it is presented in Section 3 with simulation area, the traffic simulation in Vissim and the emissions modeling in EnViVer. For the results, the current state scenario 0 is first evaluated, then the plausibility of scenario 1 and 2 together with each individual bus line. Based on the result of the emissions modeling and the bus lines general characteristics, a final suggestion is made regarding which bus line that should be electrified first. Lastly, possible continuing future research within the field is identified.

5.1 Evaluation of Methodology

The simulation area for the project is reasonable to investigate since it is already a part of existing zone management system. Moreover, the area contains characteristics of interest such as high-density urban environment, varying nearby infrastructure and activities, high flow of pedestrians and cyclists, high frequency of public transits buses and varying flow of traffic. The area is also well-known and previous experience further validate the model's accuracy. As shown in Figure 2.9 of measurable NO_X around Johanneberg, values of NO_X close to the Swedish standard limits occur both on Aschebergsgatan, Läraregatan and along Gibraltargatan. This is areas where the zero-emission zones currently are not applied and points toward possible improvements in the zone management system.

The emission model in EnViVer is based on data from the traffic simulation in Vissim and fully rely on its accuracy. As the traffic simulation model was initially created by another research group, unknown simplifications and assumptions made by previous contributors will indirectly affect the results of emissions as well. The vehicles used in Vissim were based on default vehicle types with set engine, body and behavioral characteristics. This might not be representative for all the vehicles moving in the simulation as vehicle models, types and standards in Gothenburg might be the different. Exact behavior and length of vehicles effect queue length and could change the values obtained in the result. The model network was set up with extended branches outside each intersection to include queues created due to its congestion. The branches also create a potential source of error as it allows vehicle emissions outside the intended area of interest to add into the total amount of traffic, possibly creating a scenario worse than reality. The model is however set up for afternoon peak hour during the worst occurring emission situation and is on contrary for most occasions better. As the result is presented in a comparative way, the analysis of differences is still valid when all the scenarios have the same settings. Through a calibration process and observations on site, as seen in Figure 3,5, a traffic model has been created which matches the real traffic situation. Data has both been used from traffic observations together with data from Gothenburg City to obtain a certain accuracy. The network construction and intersection configuration were both gathered from responsible department at Gothenburg City municipality and are known to be correct. By using trustworthy underlying data and from knowing the area by hand, a model has been created where the assumptions and limitations effect the result with low degree.

For the emission results, focus was set on NO_X over CO_2 with reference to their specific local effects, see Section 2.3.1 and 2.3.2. CO_2 has low importance for local circumstances and its effect on global scale is unaffected with regards to changing zone distribution in a zone management system. It is therefore not interesting to base a comparison of different areas and bus lines on their CO_2 emissions, and emphasis is put on NO_X. The EnViVer emission model is based on Versit$_{+\ micro}$, a Dutch database, and default values are set accordingly. Several input values were changed to represent Swedish standards and the Gothenburg region, see Section 3.3, and every vehicle used was redesigned with new characteristics regarding emissions. The new emissions data and vehicle efficiency was validated through the case study of EUTs in Helsinki by Lajunen and Lipman. This study was geographically located not far from Gothenburg and is considered to have a similar environment and climate conditions. Finland and Sweden also share similar fuel standards and the presented values and data should therefore be valid for the case study of Route 55.

Some parameters were however not possible to adjust or model, such as the fuel configuration of HVO and RME diesel. These fuel type efficiencies were recalculated into regular diesel percentages together with electricity. Due to the lack of emission models for specific vehicle configurations, it was not either possible to include other fuel types than diesel, CNG and electricity for heavy vehicles. For both recalculations, average fuel efficiencies have been used in a comparative way which lead to a simplification of the reality and a potential source of error. Besides fuel composition, there is no possible way to dynamically change energy configurations along routes, representing hybrid buses and its zone management. A division of fuel composition is chosen of different energy sources which is valid for the vehicle during the whole route in the simulation, indirectly also for the emission-calculation in EnViVer. For Route 55, it would require a way to switch between electric drive and HVO diesel operation along the route, to create a true scenario of emissions between stretches. As hybrid engines has become a widely used technology, the vehicle database and configuration options should be updated accordingly. In the simulation of hybrid movements around Johanneberg, the route had to be divided into non connected sub-routes which ended where the other started. The next sub-route would then have the same frequency of hybrid vehicles but with a different energy source configuration representing the zone management system. It effects exact arrivals and departures as they might differ and are randomized in the simulation. It does however not affect the total emission calculation as the buses have the same frequency and number of kilometers within the study area. When creating the comparative result based on total amount of NO_X and CO_2, the simplification in Vissim and EnViVer is therefore acceptable.

EnViVer allows emissions calculations in a simplified way without previous knowledge in the field of air pollution, where the only prerequisite is to have a representative Vissim traffic simulation. The calculation formulas used in EnViVer is however not displayed, and ca not be adjusted. Simplifications and faulty unknown parameters could be included in the program, why the exact values from the result should not be in focus and only used in a comparative way.

5.2 Evaluation of results

The scenario 0, current state agrees well with the NO_x emission conditions from Gothenburg municipality, see Figure 2.9 and 4.1, which validates the emission calculation result. The problem areas can be identified to Aschebergsgatan and Läraregatan with focus on the intersections Chalmersplatsen, Kapellplatsen and Läraregatan/Gibraltargatan. For the remaining streets Gibraltargatan, Engdahlsgatan and Sven Hultins Gata, considerably lower amounts were obtained. The emissions rates are most likely higher at intersections and the bus-stops due to frequent and repeated braking, acceleration and formation of queues. If zero-emission zones in a zone-management system was introduced, the first mentioned areas with high air pollution grade should be prioritized for all buses. For scenario 0, a total of 688 kg CO_2 and 4,4 kg NO_x was estimated during an afternoon peak hour where buses stand for 6 % of the emitted CO_2 and 23 % of the emitted NO_x, see Figure 4.2. In combination with the literature study of each pollutant, Section 2.3, it put further emphasis on focusing on NO_x emissions.

For scenario 1, Route 55 full electric, the comparison shows low potential to decrease the air pollution. If Route 55 was made full electric it would decrease 2,7 % of emissions from public transit buses and 0,8 % of the total NO_x emission. Scenario 1 has low potential to improve the current air pollution situation as the hybrid buses on Route 55 are already highly effective by only using HVO diesel besides electricity. When comparing HVO diesel to regular diesel, it has a very low rate of emissions seen to performance. In combination with being 30 % electric powered hybrid buses, and already running 3 out of 10 buses on full electric, Route 55 is a small part of the total as it is. With regards to local air pollution, the current zone management system should be updated. Based on the emission result maps of Scenario 0, current state, and the defined zero-emission zones today, Route 55 should also include the heavily trafficked stretch from Chalmersplatsen to Kapellplatsen. The stretch has the worst NO_x conditions within the area and has also a high presence of pedestrians and cyclists. Due to the opposite reasons, Engdahlsgatan south of Chalmers together with the continuing beginning of Sven Hultins Gata should be excluded from the zero-emission zones. This stretch affects few people, has low contact with offices and residences and has low values of emissions in the current state scenario. The new zero-emission zone would start at the straight along Sven Hultins Gata and continue to Läraregatan, via Chalmersplatsen, Kapellplatsen and exit at intersection Gibraltargatan/Läraregatan.

For Scenario 2, with a full electric public transport bus fleet, the results show a large potential in buses for decreasing the amount of emitted NO_x, being accounted for 20,3 % of the total pollution. To change all the buses in the simulation area would take several years with today's expansion rate of EUVs, but it is a reasonable scenario seen in a long-term perspective. Due to the higher financial cost of implementing pure electric vehicles as described in Section 2.1, implementing hybrid vehicles with a zone management system could be beneficial. Seen to the reasoning and emission-rates of the currently running hybrid vehicles on Route 55, they are suitable for vehicles traveling in both dense urban areas and less crowded suburban areas where local emissions are not a major issue.

Seen to the emissions compilation in Figures 4.5 and 4.6, bus line 19 has the largest potential to decrease public transit emissions in the area. If converted to electric, it will decrease the public transport buses emissions by 38,6 %. Bus line 19 run the longest stretch per trip in the simulation after Route 55, more than twice as long as the rest bus lines, as seen in Table 3.1. Bus 19 enters at the problem area around Kapellplatsen towards Läraregatan and continue along the less polluted street Gibraltargatan. It runs for a majority of the length on Gibraltargatan where a zero-emission zone is not needed. Bus 16 has the second largest potential with the possibility to decrease emission by 33,4 %. Bus line 16 runs the most frequent of all buses for 0,45 km per trip. It runs solely on Aschebergsgatan, entering and leaving at the two areas with the highest air pollution; Chalmersplatsen and Kapellplatsen. The bus lines 158 and 753 run the same stretch as bus line 16, but less frequent. Consequently, they only have the potential to decrease emissions by 9 % and 6 % respectively. The different bus lines vary largely in total length of stretch, from Route 55 with 7,6 km to bus line 753 with 24 km, as seen in Table 3.1. As the electric vehicles currently exist on Route 55, they are not able to operate on all the investigated bus lines. However, with today's new capacity of the Volvo 7900 with 200 kWh battery power compared to 76 kWh, it is technically possible to establish the investigated vehicle on each bus line. As described in the case study of H550 in Helsinki, there are also long-range electric buses with capacity for a full day of operation, possible to use on bus lines similar to the ones in Gothenburg.

The investigated bus lines also have different route environments outside the simulation area. Route 55 goes only in urban environment, similar to bus 16 which runs a majority of its route through central Gothenburg but longer. Bus line 19 also runs a majority through urban environment but less than bus line 16, while bus line 753 and 158 runs through less crowded environments out towards the neighboring municipalities. With above stated, the largest effect can be reached by either electrifying the bus lines 16 and 19 completely or by introducing hybrid vehicles together with a zone management system. Between these two, the bus line 16 should be electrified first as it runs solely on the most polluted areas of simulation. Moreover, it is the most trafficked bus line in Gothenburg region and runs on a majority in urban environment seen to its entire route.

Only a small area in central Gothenburg has been included in this study and more suitable areas for implementing EUT buses might exist. If a larger area was included, other recommendations for zero-emission zones are likely, as when using hybrid vehicles, the electric drive must be allocated with a set capacity. In this study, only emissions have been the decisive factor for reasoning regarding the zone management system. Other factors, as described in Section 2.1.2, should be included for making a full recommendation of the zone distribution beside the emission-based result. The zone management is a relative new technology which has only been in usage since June 2015. A zone management system does not exists for any other project and no studies or scientific reviews has therefore been released. Only data provided from Volvo has been available, however negative effects from it is unlikely. Further development of the zone management system as wells as within battery advancements will only push the implementation forward and make EUTs in form of fully electric or hybrid vehicles more attractive. Providing longer range and cheaper implementation costs will make it possible to apply electric models to more areas and more bus lines.

5.3 Future research

Further research is possible both within the emission calculation programme EnViVer to get a more detailed emission result, together with bringing in a larger area in the simulation. By investigating a larger area or other areas with higher frequency of public transit buses, it is possible to distinguish places where a change to emission-free buses would have a larger effect. Compared to the investigated area around Johanneberg it could then change how a zone management system would be decided as a whole, if its full stretch was included.

When following the Route 55 elongation, several similar areas of interest is identified such as the street Kungsportsavenyn, Brunnsparken or the highly trafficked area around Vasaplatsen. All these urban areas are located in central Gothenburg with high flows of pedestrian and cyclists.

Both Vissim and EnViVer should be improved further regarding hybrid vehicles, as they are becoming a regular fuel configuration. In Vissim it could include developing a dynamic input of fuel configuration for vehicles along a certain stretch, allowing it to switch between energy sources representing a hybrid drive. To increase the usage and expand geographically where it can be applied, EnViVer should include other vehicle and emission standards than the Dutch. This could either be done by developing the database Versit+ or by including other potential databases. It would also be beneficial to be able to adjust the emission calculations and see how it is built up in order to create more extensive analyses.

The zones in Volvo's zone management system is currently not decided with regards to local air pollution measurements. Local concentrations of air pollution also vary during the day as well as the movements of people, consequently changing the importance on emission concentrations between areas. Further research is recommended regarding including local air pollution as a decisive factor when creating zero-emission zones in the zone management system. Together with the possibility for mobile bus measurement along the routes to identify daily variations in concentrations, the possibility with dynamic change of the zero-emission zones should be investigated.

6 Conclusion

During afternoon peak hour, scenario 0 shows a total of 692,2 kg CO_2 and 4,5 kg NO_x emitted for the current condition. Emission maps display higher concentration of both pollutants around Aschebergsgatan and Läraregatan with focus on the intersections Chalmersplatsen and Kapellplatsen. In the simulation, buses stand for 6 % of total CO_2 and 23 % of total NO_x emitted. For Scenario 1, if Route 55 switched to full electric drive, it would emit around 0,2 % CO_2 and 0,8 % NO_x less, while for scenario 2 if all public transit buses switched to fully electric it would emit 5,5 % less CO_2 and 20,3 % less NO_x. Based on emissions, it would be most beneficial to include the stretch Aschebergsgatan between Chalmersplatsen to Kapellplatsen and Läraregatan as zero-emission zones in the zone management system.

In a comparison between each bus line switching to electric drive, bus line 19 and 16 has the largest potential to reduce emissions. Route 55 has the lowest potential due to having already very low emission rates when using modern hybrid buses. Bus line 16 would be most beneficial to include in the zone management system as it runs solely on the identified areas of interest within the simulation while being the most used bus line in Gothenburg region.

The traffic simulation model in Vissim was validated and represents the traffic situation around Johanneberg well. The emission model in EnViVer is based on Dutch standards with limited possibility to change calculation parameters and vehicle characteristics. To make a certified calculation of the emission situation, the programme has to be developed further in order to apply Swedish conditions. The result of the analysis is however based on the difference between the scenarios with measurable changes. The result of the analysis is therefore considered reasonable.

With the current development and investment towards EUVs and EUTs, together with the set goals of Sweden, the Västra Götaland region and Gothenburg City, a future increase of electric vehicles in the public transit fleet is certain. A change will most likely both include fully electric and hybrid vehicles where a zone management system would be beneficial. It is not a question if the involved bus lines will become electrified, but rather in what order and which bus line will be electrified first.

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8 Appendix

8.1 Data collection

Table 8.1 Maximum hour traffic data at Kapellplatsen

	Cars	Vans	Trucks	Trams	Buses	Ebus	Motorbikes	Bikes	Pedestrians
EBL	227	32	18	0	0	0	11	25	1350
EBT	144	25	18	0	7	0	11	0	0
EBR	166	25	18	0	11	0	7	115	252
WBL	47	18	7	0	0	0	4	122	209
WBT	101	18	11	0	0	0	11	0	0
WBR	76	25	4	0	0	0	4	0	166
NBL	108	25	11	0	11	0	7	0	263
NBT	166	29	14	22	29	0	11	0	0
NBR	79	7	4	0	4	0	0	7	22
SBL	97	18	11	0	0	0	7	11	151
SBT	187	36	7	22	29	0	7	0	0
SBR	176	32	7	0	4	7	14	29	1271

Table 8.2 Maximum hour traffic data at the intersection Gibraltargatan/Läraregatan

	Cars	Vans	Trucks	Buses	Ebus
EBL	256	36	11	11	0
EBT	18	0	0	0	0
EBR	259	14	4	0	0
WBL	14	0	4	0	0
WBT	25	0	0	0	0
WBR	14	0	4	0	0
NBL	184	11	4	0	7
NBT	270	36	11	4	0
NBR	32	7	0	0	0
SBL	22	4	0	0	0
SBT	306	50	7	4	18
SBR	180	25	11	11	0

Table 8.3 Maximum hour traffic data at the intersection Gibraltargatan/Engdahlsgatan

	Cars	Vans	Trucks	Buses	Ebus	Motorbike
WBL	47	18	4	0	0	4
WBR	155	22	11	0	0	0
NBL	259	43	11	11	11	4
NBR	32	4	4	0	0	4
SBL	133	22	11	0	0	11
SBT	464	36	18	11	11	14

Table 8.4 Vehicle type ratio at Kapellplatsen

Cars	Vans	Trucks	Motorbikes	Total
75 %	14,0 %	6,0 %	4,0 %	100,0 %

Table 8.5 Vehicle type ratio at the intersection Gibraltargatan/Läraregatan

Cars	Vans	Trucks	Total
87.0 %	10,0 %	3,0 %	100,0 %

Table 8.6 Vehicle type ratio at the intersection Gibraltargatan/Engdahlsgatan

Cars	Vans	Trucks	Motorbikes	Total
82,0 %	11,0 %	4,0 %	3,0 %	100,0 %

Table 8.7 Calculated average vehicle type ratio at Chalmersplatsen where no observations were done

Cars	Vans	Trucks	Motorbikes	Total
80,1 %	11,7 %	4,6 %	3,7 %	100,0 %

Year	Vehicles per day			MAX HOUR (veh/hour)			Speed		
	Total	Heavy	%	Towards centrum	From centrum	Total	Posted	Median	85-percentil
2010	3500	120	3	170	210	380	50	32	39

Figure 8.1 Traffic data for the street Sven Hultins gata (Göteborgs Stad, 2010b)

Year	Vehicles per day			MAX HOUR (veh/hour)			Speed		
	Total	Heavy	%	Towards centrum	From centrum	Total	Posted	Median	85-percentil
2016	11200	600	6	550	410			35	38

Figure 8.2 Traffic data for Aschebergsgatan (Göteborgs Stad, 2016a)

Table 8.8 Calculated vehicle type distribution at Sven Hultins gata

Sven Hultins gata	Cars	Vans	Trucks	Motorbikes	Total
Towards centrum	136	20	8	6	170
From centrum	168	25	10	8	210

Table 8.9 Calculated vehicle type distribution at Aschebergsgatan

Aschebergsgatan	Cars	Vans	Trucks	Motorbikes	Total
Towards centrum	440	64	25	20	550
From centrum	328	48	19	15	410

8.2 Signal phases and intergreen matrix

Table 8.10 Intergreen matrix for Chalmersplatsen

SPÄRRTIDER																								
Utrymmande	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	C18	G19	G20	G21	G22	G23	G24
F1				4,5			6,7	~~6,7~~			0,1					0,1	0,1		0,1					
F2				4,5																				
F3				4,5																				
F4	7,9	7,1	6,3		4,5	5,2																		
F5				4,5		5,4																		
F6				4,5	5,4																			
F7	4,5																							
F8											8,4					10,5	13,2		5,8					
F9										7,5	7,5	8,8	11,6	10,3	9,9	8,6			5,8				12,8	
F10									5,1		5,5	6,5				6,3	8,4			5,6				
F11	0,1							8,9	8,1	8,6								12,4			6,1			12,4
F12									7,6	9,5						8,3	12,0				8,0			
F13									4,5								5,3						7,3	
F14									4,5								4,5					7,6		
F15									4,5							5,6	4,5				8,6			
F16	0,1							4,5	4,9	5,0		6,0			6,4			5,5			8,9			5,5
F17	0,1							5,2		5,0		5,3	7,5	6,2	6,1									
C18											3,5					5,1								
G19	0,1							6,0	6,0															
G20										1,7														
G21											6,1	6,1			4,3	4,1								
G22														1,0										
G23									0,5				2,3											
G24											3,6					6,9								

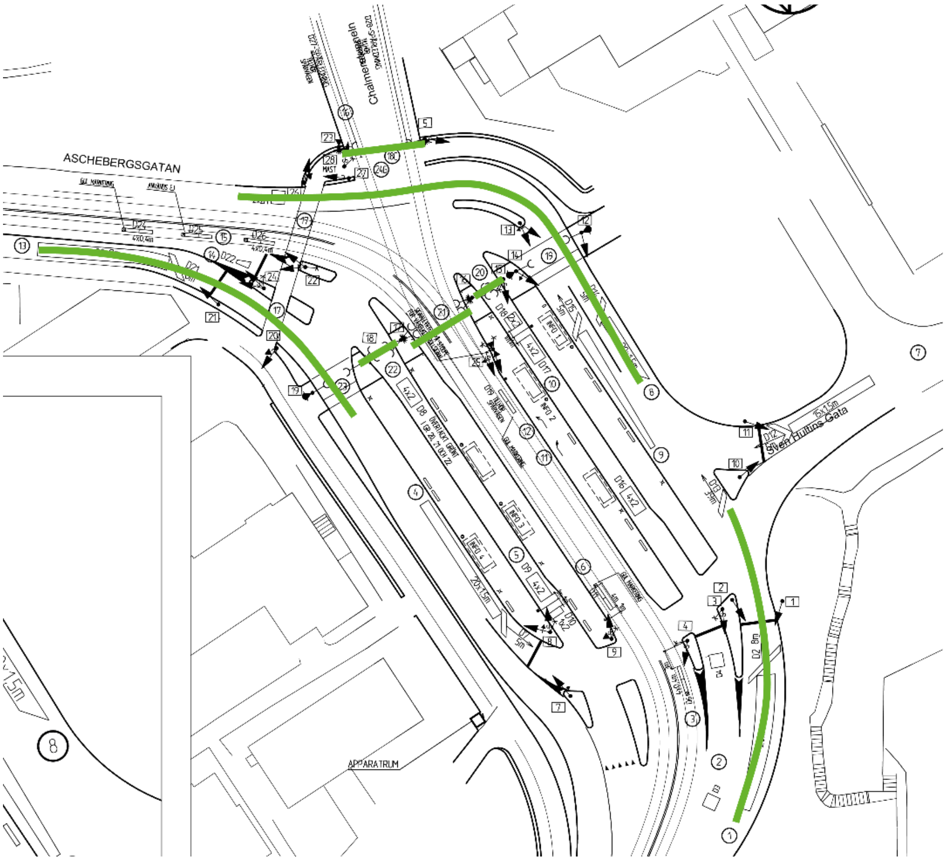

Figure 8.3 Signal phase at Chalmersplatsen, stage 1

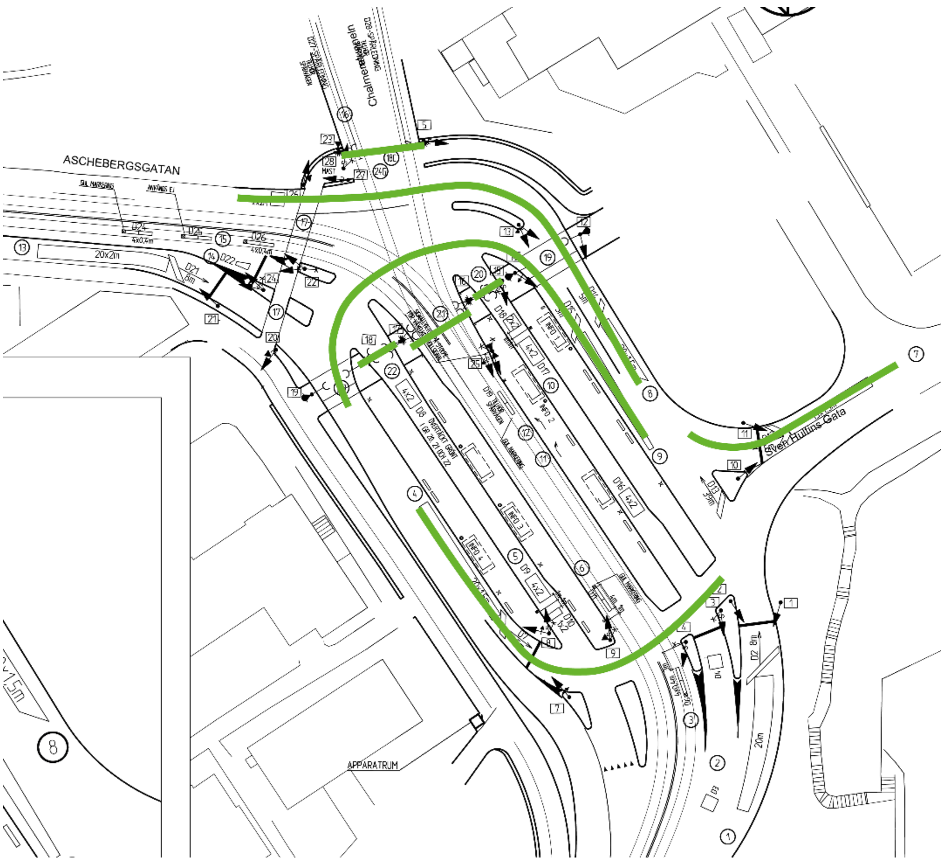

Figure 8.4 Signal phase at Chalmersplatsen, stage 2

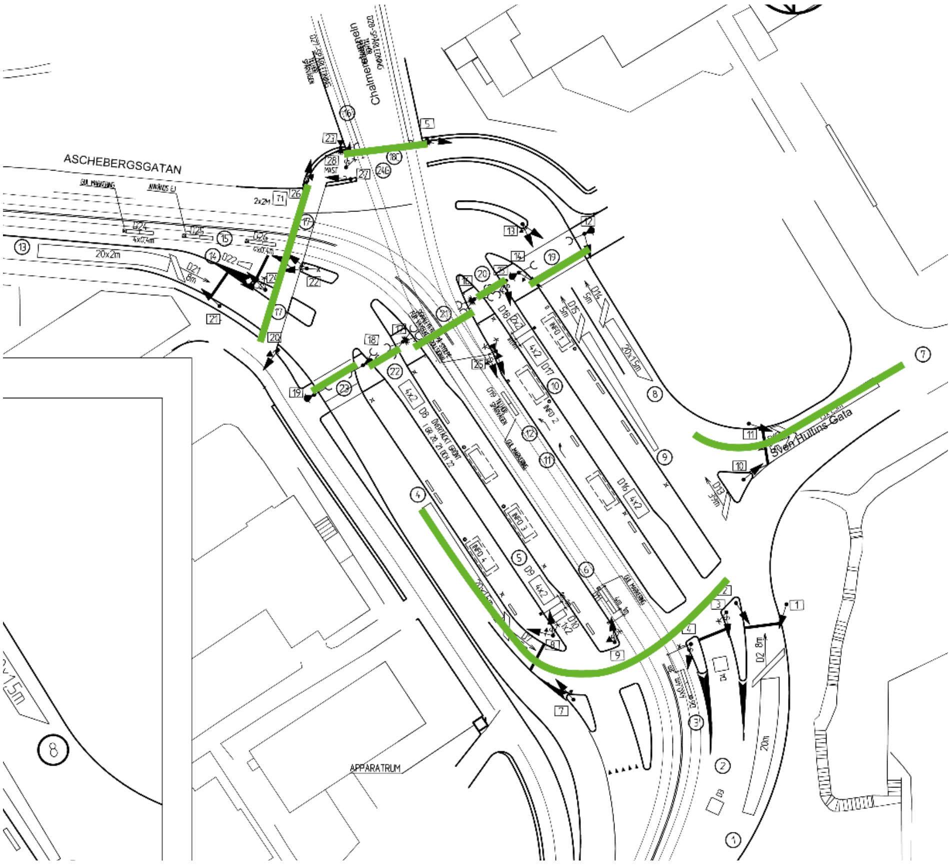

Figure 8.5 Signal phase at Chalmersplatsen, stage 3

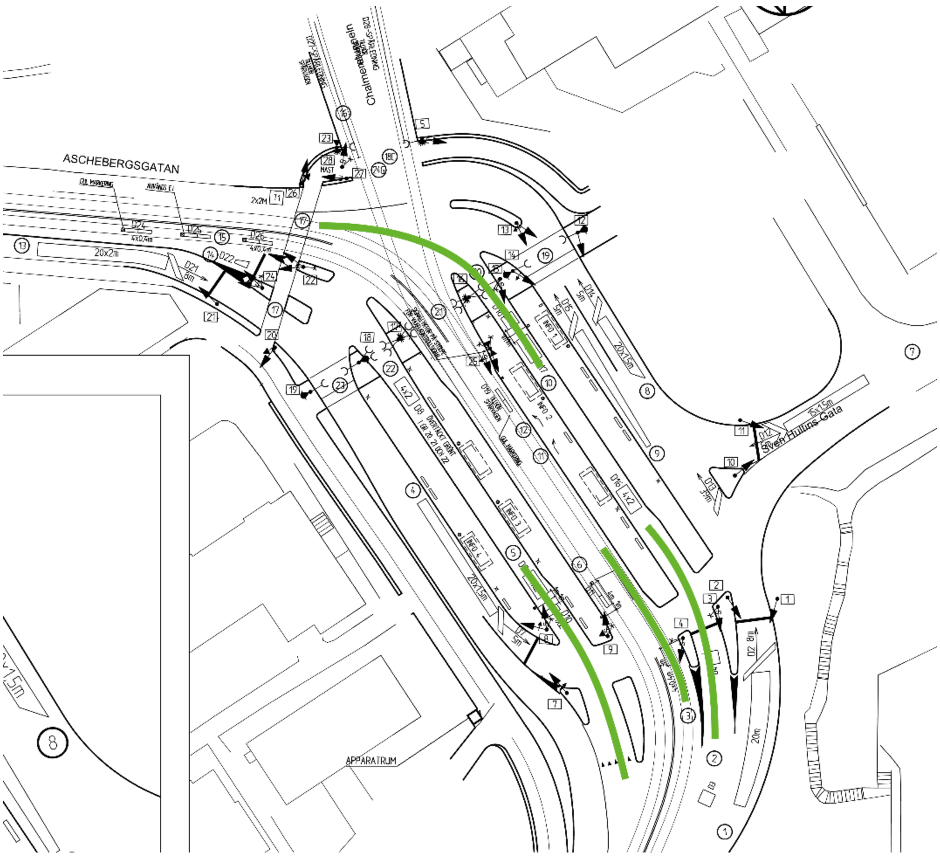

Figure 8.6 Signal phase at Chalmersplatsen, stage 4

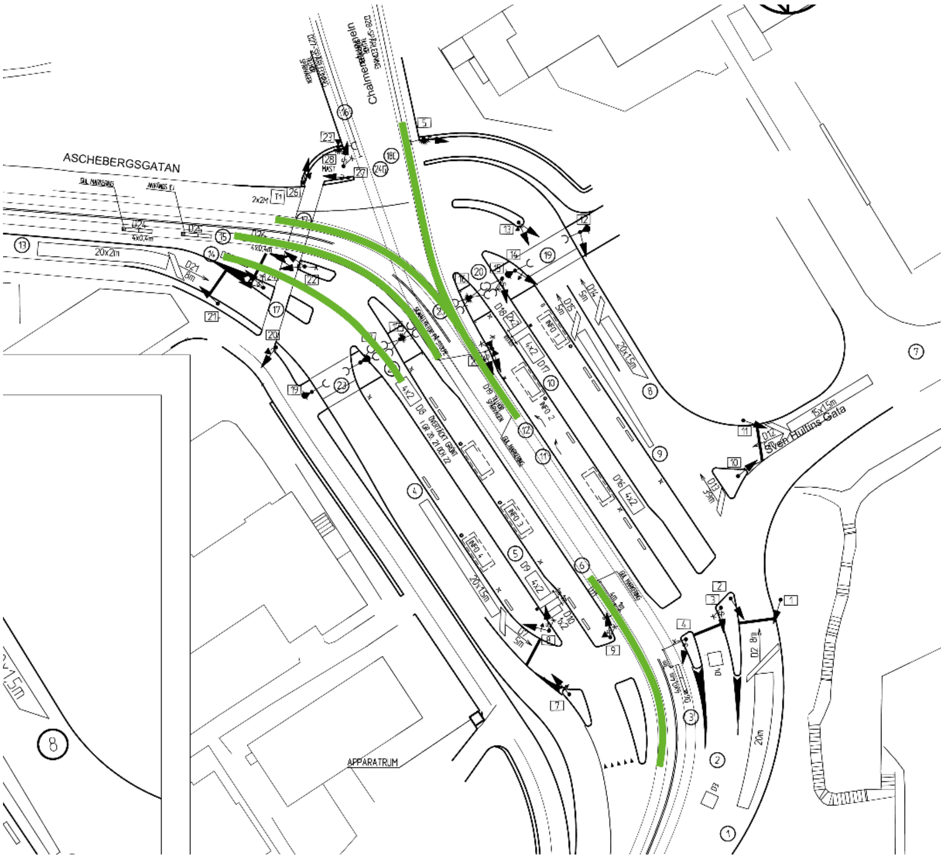

Figure 8.7 Signal phase at Chalmersplatsen, stage 5

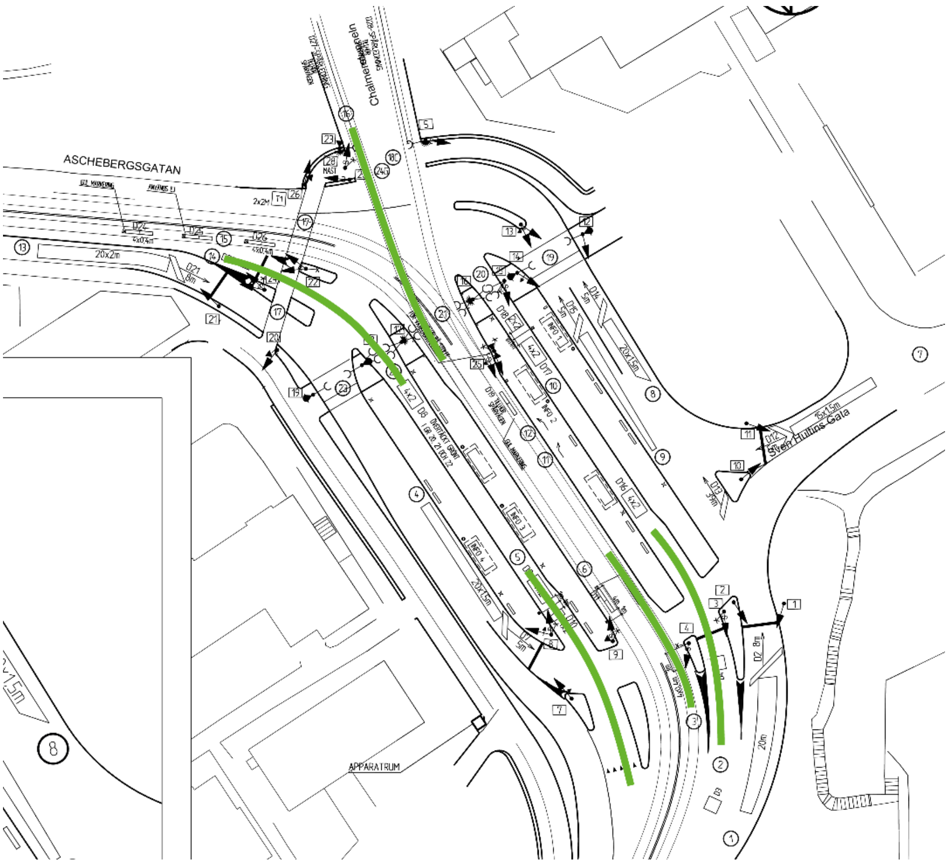

Figure 8.8 Signal phase at Chalmersplatsen, stage 6

8.3 Changes made in Vissim

Table 8.11 Changes made in order to complete the Vissim simulation

	Network Objects	Description	Original	Changes
A.8.3.1	Vehicle types	2D/3D model distribution - Car	Motorbike	Car
		2D/3D model distribution - Tram	Bus	Tram
		Occupancy distribution - Car	Single	2
A.8.3.2	Vehicle input	AmundGrefwegatan - Car	-	255
A.8.3.3	Vehicle routes	From Gibraltargatan turning left into Läraregatan	0,048	0,480
A.8.3.4	Public transport lines	Departure time - Tram to centre [second]	720	267
		Departure time - Tram from centre [second]	720	267
		Departure time - Tram to korsvägen [second]	225	195
		Departure time - Tram from korsvägen [second]	225	195
A.8.3.5	Signal controller - Vissig	Intergreen matrix [second] SG4veh – SG1veh SG17cyc – SG8veh SG19ped – SG9veh SG17cyc – SG13veh SG8veh – SG17cyc SG8veh – SG19ped SG9veh – SG19ped	 5 3 4 4 5 5 5	 8 5 6 8 13 6 6
		Stage assignment Stage 1 SG24 Stage 2 SG24 Stage 3 SG23	 Red Red Red	 Green Green Green
A.8.3.6	Signal controller	Logic file (vap)	Stage 4 has priority	Stage 5 has priority

Table 8.12 Improvements made of the model network in Vissim

	Network Objects	Description	Values
A.8.3.7	Gradient	Gibraltargatan (between Läraregatan and Chalmers tvärgata)	1,79 %
		Gibraltargatan (between Chalmers tvärgata and Engdahlsgatan)	0,71 %
		Engdahlsgatan (between Gibraltargatan and Wallenbergsgatan)	0,62 %
		Sven Hultins gata (between Wallenbergsgatan and Betongvägen)	2,63 %
		Sven Hultins gata (entire stretch along the western side of campus Johanneberg)	0,21 %
		Aschebergsgatan (between Sven Hultins gata and Hugo Grauers gata)	2,13 %
		Läraregatan (between Aschebergsgatan and Gibraltargatan)	0,77 %
A.8.3.8	Vehicle routes	New route from Sven Hultins gata to Engdahlsgatan/Rännvägen for cars and vans	
		New route from Sven Hultins gata to Aschebergsgatan/Guldhedsgatan for cars, vans and trucks	
		New route from Aschebergsgatan to Sven Hultins gatan/Guldhedsgatan for cars, vans and trucks	
		New route from Gibraltargatan to Läraregatan for cars	
		New route from Läraregatan to gibraltargatan for cars	
		New distribution alternative from Rännvägen turning right into Sven Hultins gata for cars was created	
		New distribution alternative from Rännvägen turning left into Engdahlsgatan for cars was created	
A.8.3.9	Speed	New speed at Läraregatan to Kapellplatsen to link-based speed	50 km/h
		New speed at Läraregatan to Gibraltargatan to link-based speed	50 km/h
		New speed at Amund Grefwegatan to Kapellplatsen to link-based speed	50 km/h
A.8.3.10	Blocked vehicles	Guldhedsgatan to Aschebergsgatan/Sven Hultins gata lane 1 blocked for trams, lane 2 blocked for cars, vans, trucks and motorbikes	
		Aschebergsgatan to Sven Hultins gata/Guldhedsgatan lane 1 blocked for trams, lane 2 blocked for cars, vans, trucks and motorbikes	
		Aschebergsgatan to Kapellplatsen lane 1 blocked for trams, lane 2 blocked for cars, vans, trucks and motorbikes	
		PT stop at Chalmersplatsen blocked for cars, vans, trucks and motorbikes	
A.8.3.11	Links	Longer link for trams at Aschebergsgatan into PT stop at Chalmersplatsen	
		Longer link for trams at Guldhedsgatan into PT stop at Chalmersplatsen	

8.4 Vehicle input values

Table 8.13 Vehicle input values for vans

Entry location	Vehicle input from traffic observation	Maximum-hour traffic data from Gothenburg City, vehicle input	Vehicle output from traffic observation	Maximum-hour traffic data from Gothenburg City, vehicle output
Amund Grefwegatan	61	-	50	-
Aschebergsgatan	61	49 [1]	79	41 [2]
Rännvägen	0	-	11	-
Läraregatan	54	21 [3]	64	21 [4]
Gibraltargatan	58	40 [5]	65	40 [5]
Guldhedsgatan	69	54 [6]	46	-

Table 8.14 Vehicle input values for trucks

Entry location	Vehicle input from traffic observation	Maximum-hour traffic data from Gothenburg City, vehicle input	Vehicle output from traffic observation	Maximum-hour traffic data from Gothenburg City, vehicle output
Amund Grefwegatan	22	-	33	-
Aschebergsgatan	29	21 [1]	32	18 [2]
Rännvägen	8	-	0	-
Läraregatan	15	6 [3]	15	6 [4]
Gibraltargatan	29	15 [5]	22	15 [5]
Guldhedsgatan	27	21 [6]	18	-

[1] (Göteborgs Stad, 2010a)
[2] (Göteborgs Stad, 2017)
[3] (Göteborgs Stad, 2014c)
[4] (Göteborgs Stad, 2016c)
[5] (Göteborgs Stad, 2014b)
[6] (Göteborgs Stad, 2016b)

8.5 Distribution of vehicles

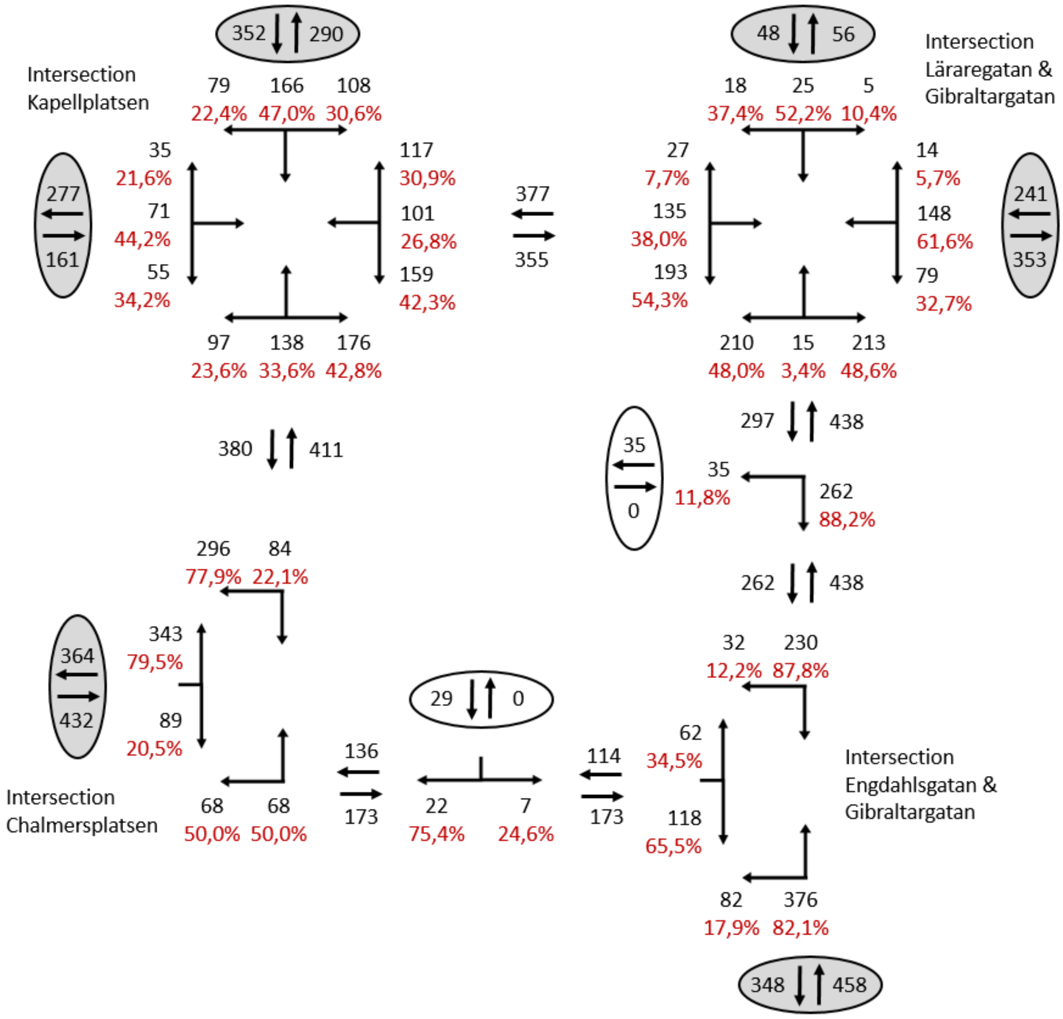

Figure 8.9 Distribution of cars in the road network after the calibration. The grey circles represent the in- and outflow of cars into the network.

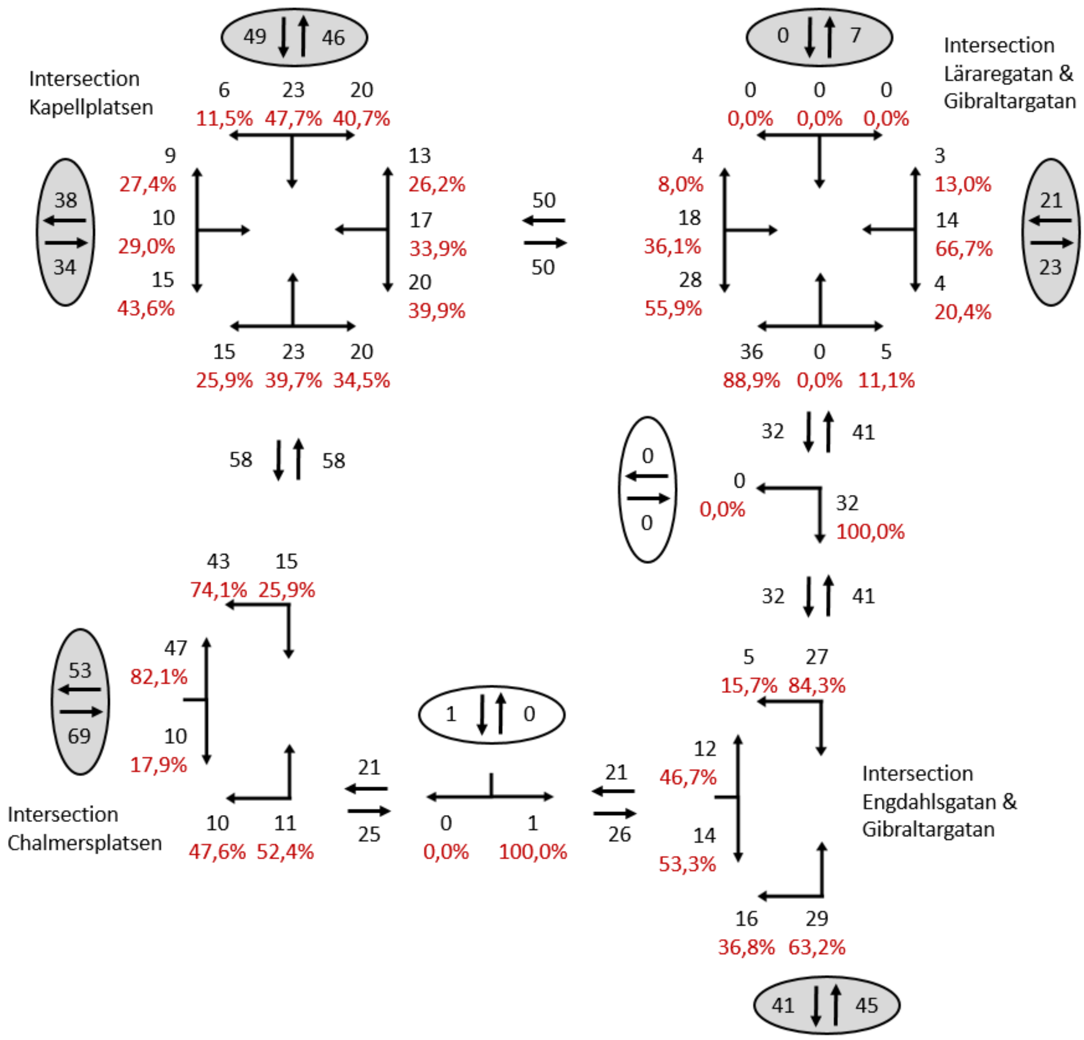

Figure 8.10 Distribution of vans in the road network after the calibration. The grey circles represent the in- and outflow of vans into the network.

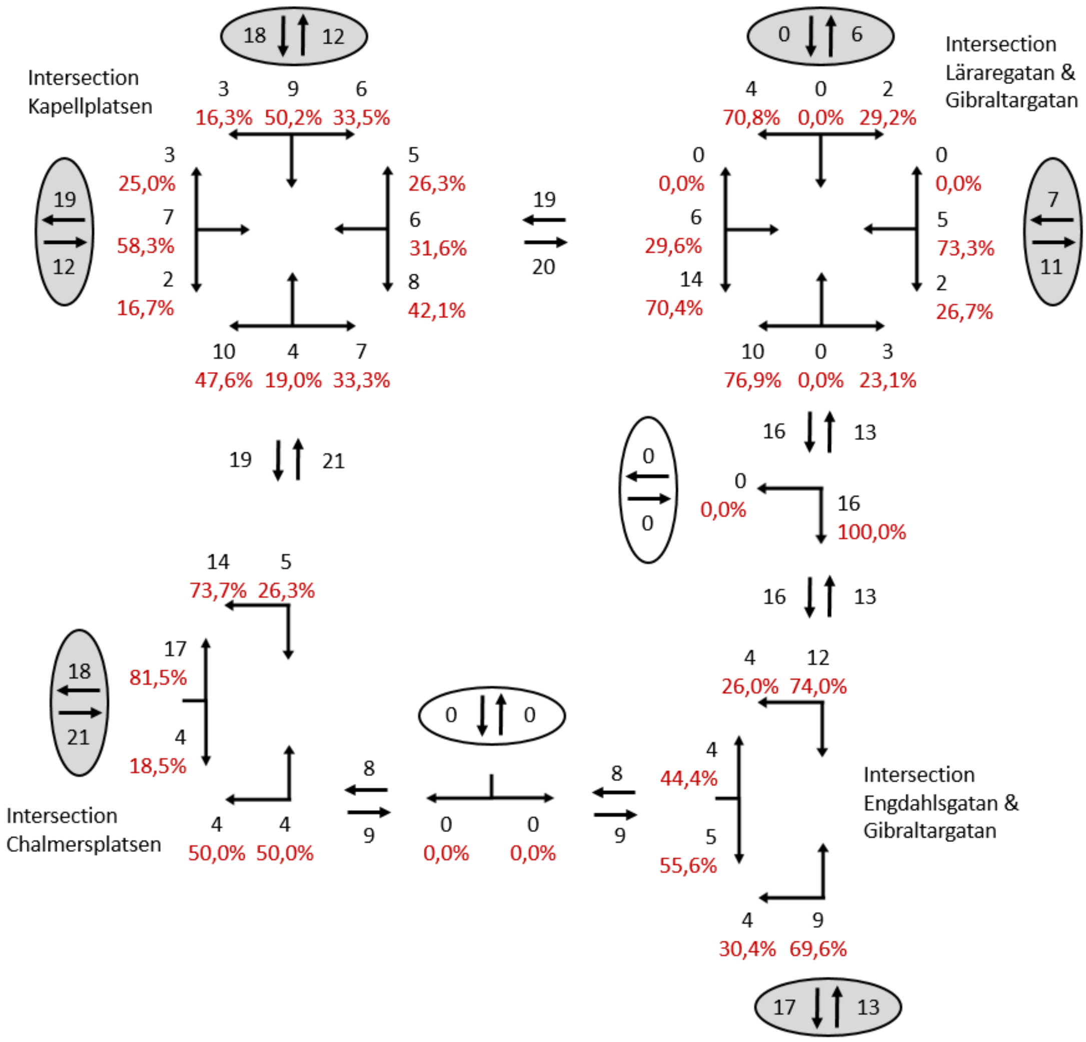

Figure 8.11 Distribution of trucks in the road network after the calibration. The grey circles represent the in- and outflow of trucks into the network.

8.6 Vehicle classes in EnViVer

Table 8.15 Summary of the created vehicle classes in EnViVer

Vehicle	Road type	Vehicle type	Era	Fuel type: Petrol [%]	Diesel [%]	LPG [%]	CNG [%]	Electric [%]	Vehicle age distribution: Newer than 1 year [%]	Average vehicle age [year]	Average exit age [year]	Maximum age [year]	Emission legislation
Car CO_2	Urban	Light-duty	2017	60,8	33,7	0	0	5,5	8,1	10	17	-	Result of age distrib.
Car NO_x	Urban	Light-duty	2017	60,1	33,7	0	0	6,2	8,1	10	17	-	Result of age distrib.
Van CO_2	Urban	Light-duty	2017	9,6	89,0	0	0,7	0,7	10	8,2	15	-	Result of age distrib.
Van NO_x	Urban	Light-duty	2017	9,5	89,0	0	0,7	0,8	10	8,2	15	-	Result of age distrib.
Truck CO_2	Urban	Heavy-duty	2017	0	94,8	0	0,7	4,5	6,7	10,9	15	-	Result of age distrib.
Truck NO_x	Urban	Heavy-duty	2017	0	97,6	0	0,7	1,7	6,7	10,9	15	-	Result of age distrib.
Bus CO_2	Urban	Bus	2017	0	29,2	0	17,0	53,8	-	-	-	-	Euro VI
Bus NO_x	Urban	Bus	2017	0	65,8	0	17,0	17,2	-	-	-	-	Euro VI
Bus hybrid CO_2	Urban	Bus	2017	0	7,0	0	0	93,0	-	-	-	-	Euro VI
Bus hybrid NO_x	Urban	Bus	2017	0	15,5	0	0	84,5	-	-	-	-	Euro VI
Bus electric	Urban	Bus	2017	0	0	0	0	100,0	-	-	-	-	Euro VI
Tram	Urban	Heavy-duty	2017	0	0	0	0	100,0	-	-	-	-	Euro VI

8.7 Emission result maps

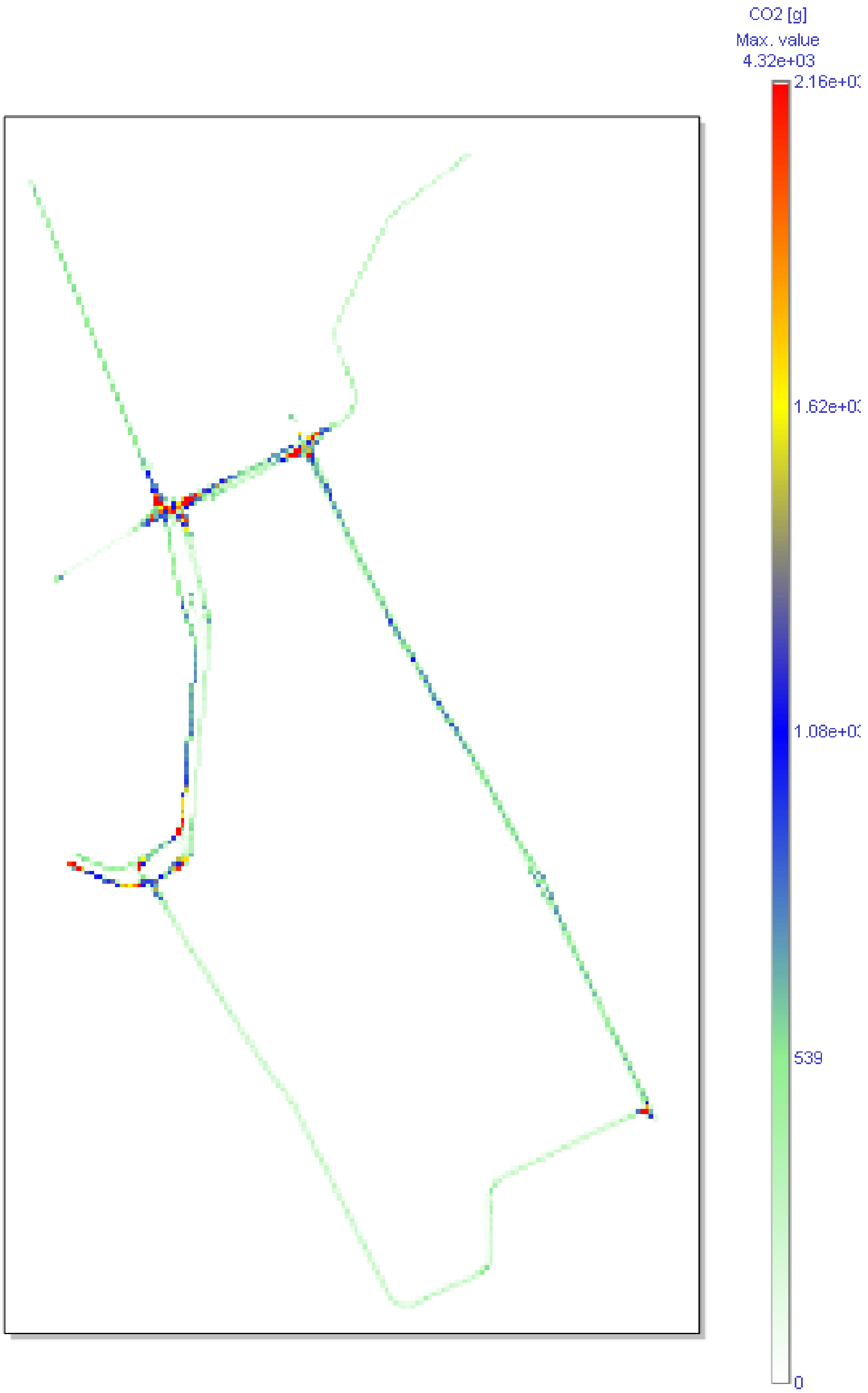

Figure 8.12 Emission map of CO_2 scenario 0, current state within the study area.

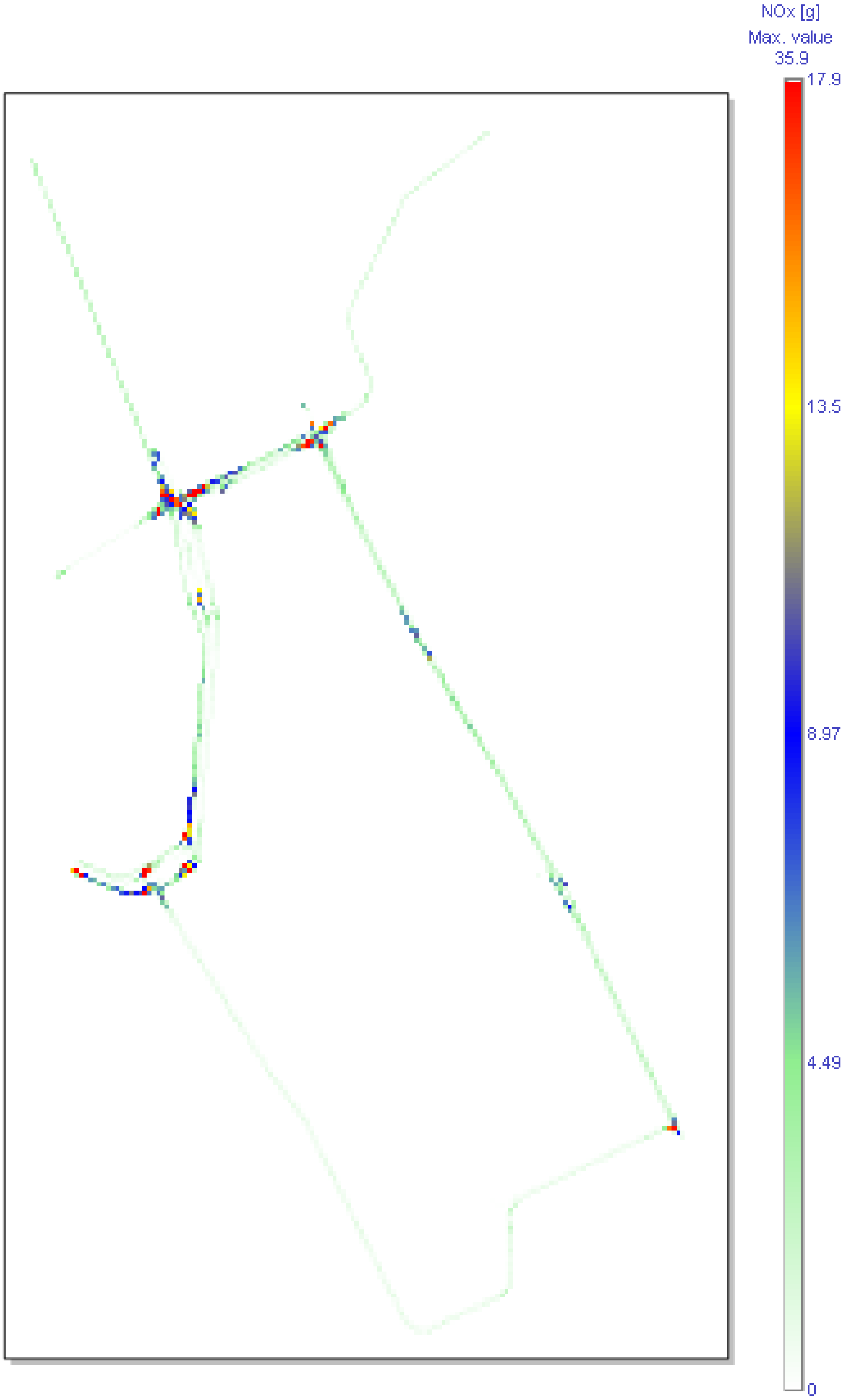

Figure 8.13 Emission map of NO_x scenario 1, electrified 55 within the study area.

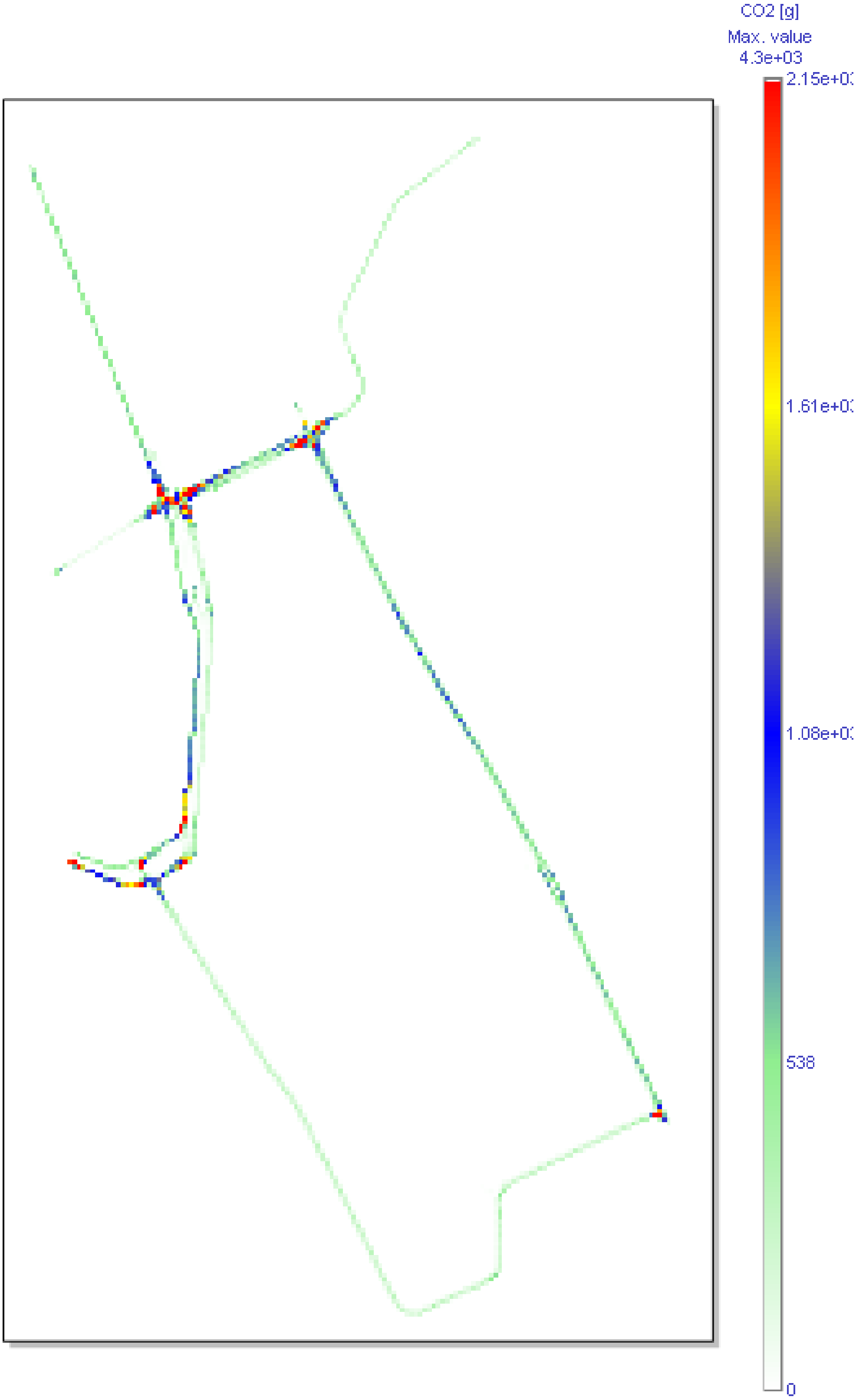

Figure 8.14 Emission map of CO_2 scenario 1, electrified 55 within the study area.

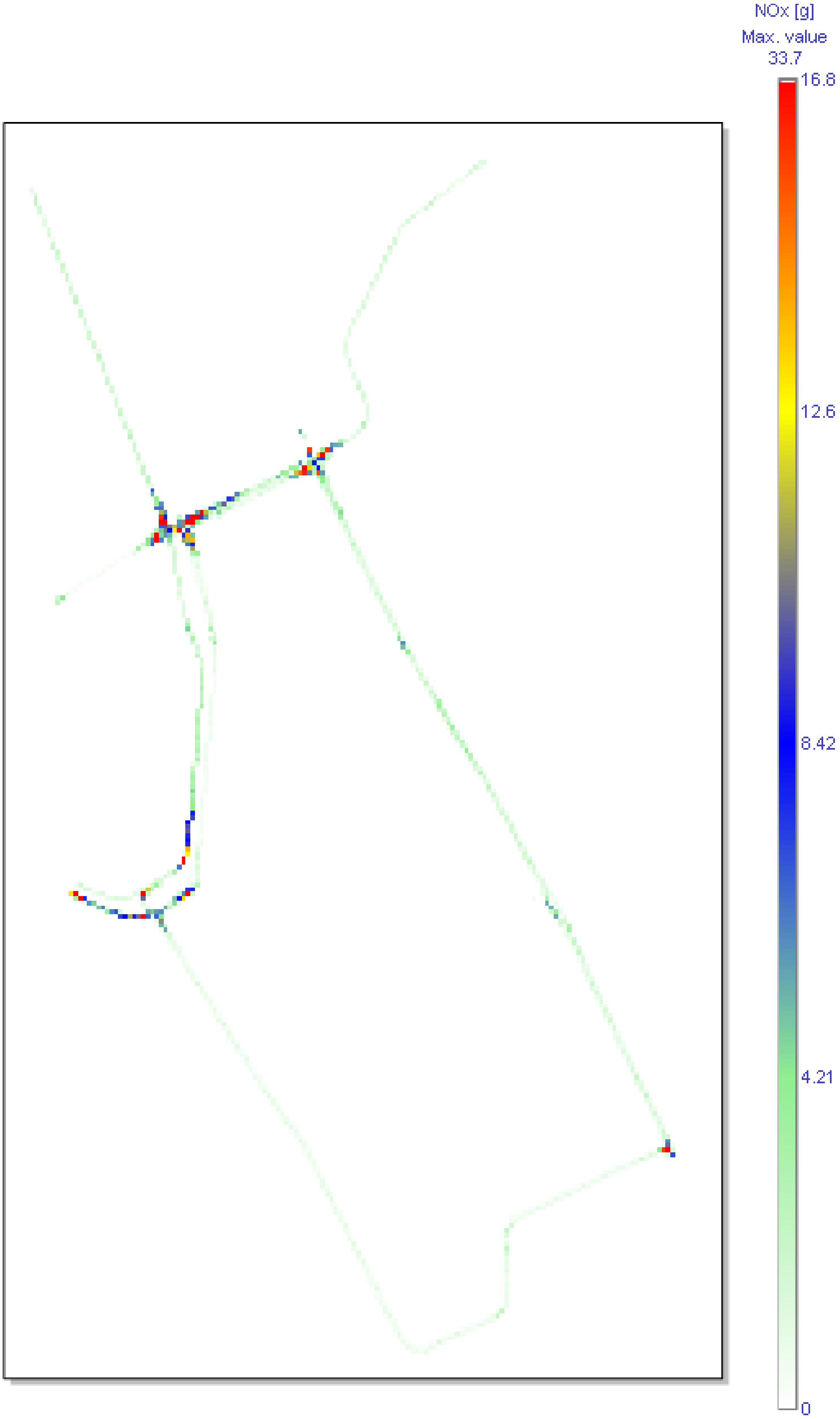

Figure 8.15 Emission map of NO_x scenario 2, all buses electric within the study area

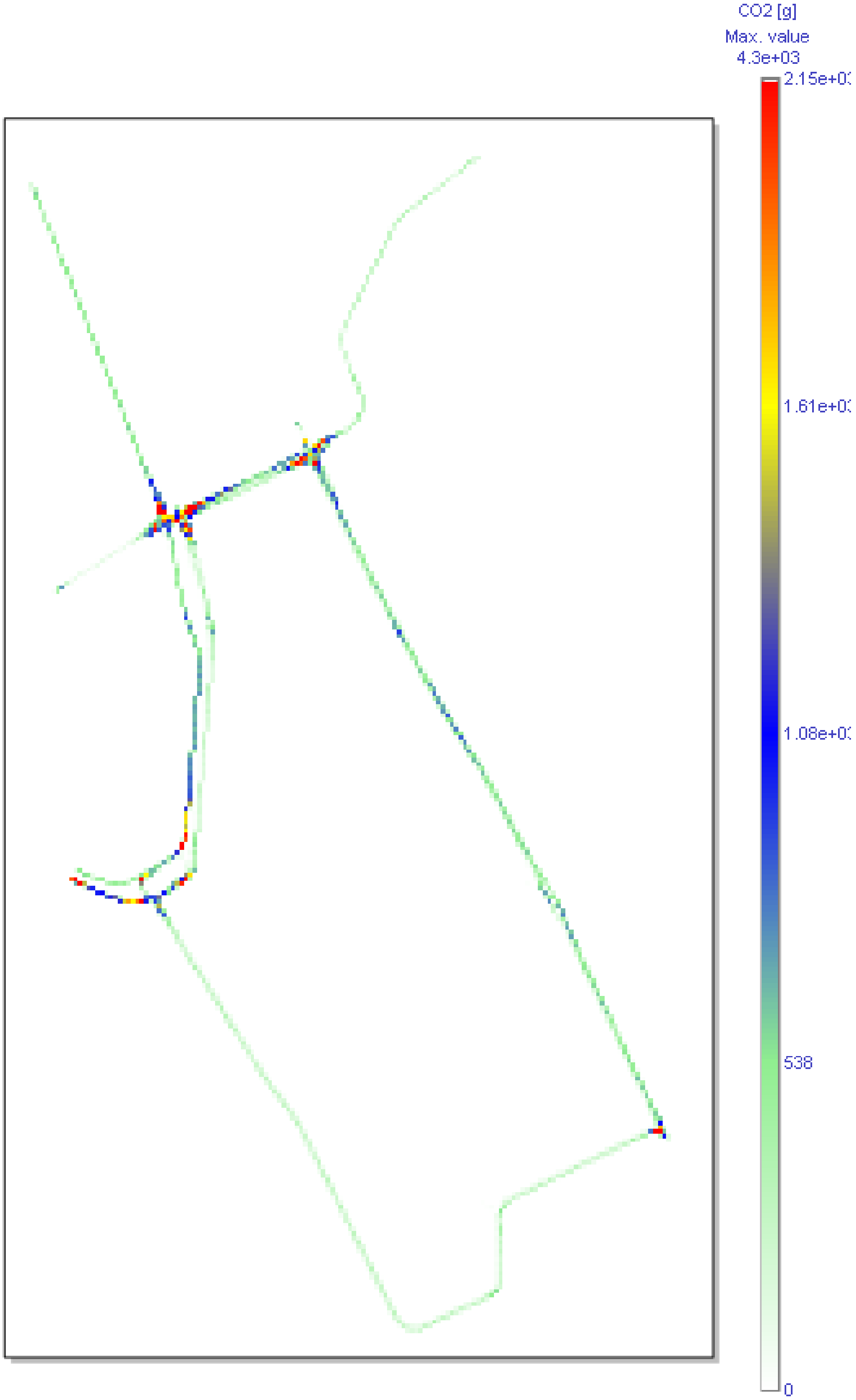

Figure 8.16 Emission map of CO_2 scenario 2, all buses electric within the study area