Developing a City Scale Emissions Inventory and Exploring Electrification of Transportation: A Case Study of the City of Waterloo

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Significant growth in the scale of climate action is witnessed globally as cities, nations and environment agencies implement mitigation strategies and try to meet their ambitious emission reduction goals. As a result, many sectors have experienced significant emission reduction in recent years, except for transportation. Over the past two decades, transportation emissions, primarily driven by the sector's high dependency on fossil fuels, are continuously rising. Cities are the hotspots as they drive the majority of transportation demand. Various policies and local climate action strategies are already in place to mitigate emissions, including but not limited to reducing auto dependency and use of alternative modes and cleaner fuel. However, limited means are available to quantify the effectiveness of these strategies. While various methods and guidelines inform national emission estimation processes, limited tools are available for cities to report their local emission inventory. The purpose of this research, therefore, is to prepare a methodology which can be adopted by local authorities to better report and manage local transport emissions at the municipal and regional scale. The Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES) is customized to develop emissions inventory at the disaggregated level while capturing local transportation characteristics. The model is applied to a case study area selected in the City of Waterloo, and emissions (CO2 equivalent) are estimated from different vehicle types and vehicle activities. The emission results obtained are extrapolated to the city scale, and different scenarios are explored to identify the potential for Electric Vehicles (EVs) to contribute to further emission reduction. Transportation sector emissions for the City of Waterloo are projected for 2031 and 2051 based on increased traffic and commercial vehicle activity share. Research findings suggest that the majority of Waterloo's transportation sector emissions are from light-duty vehicles. Heavy and medium-duty vehicles on the other hand, have a smaller share in total vehicle activity but are significant contributors to emissions, which makes their electrification critical to the City's emission reduction plan. To meet the City's long-term emission reduction goals, an ideal transport emissions profile is created considering the complete and partial electrification of different vehicle types. The research findings suggest that to achieve the City of Waterloo's 2050 emission reduction target, 100% electrification of light and medium duty vehicle and 25% electrification of heavy-duty vehicles would be required. However, this transition to an electric fleet is quite challenging as economic,

policy and infrastructure barriers to market adoption of electric vehicles, especially medium and heavy-duty vehicles need to be addressed.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AAGT	Average Annual Growth Rate
ADT	Average Daily Traffic
BET	Battery Electric Trucks
BEV	Battery Electric Vehicle
CO2Eq	Carbon dioxide Equivalent
COPERT	The Computer Programme to Calculate Emissions from on-road Transport
EC	European Commission
ECCC	Environment and Climate Change Canada
EPA	Environment Protection Agency
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FHWA	Federal Highway Administration
FTR	Freight Transport by Road
GHG	Greenhouse Gas
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicles
HOV	High Occupancy Vehicle
IPCC	Intergovernmental Panel on Climate Change
LDV	Light Duty Vehicle
LULUCF	Land use, land-use change, and forestry
MOBILE	The Mobile Source Emissions
MOVES	Motor Vehicle Emission Simulation
Mt	Megatonnes/ Million tonnes
PCP	The Partners for Climate Protection
PDM	Project Data Manager
PHEV	Plug-in Hybrid Electric Vehicles
SF	Seasonal Factors
SWIFT	Space of Waterloo's Innovation in Future Transportation
VKT	Vehicle Kilometer Travelled
VT-Micro	Virginia Tech Microscopic Energy and Emissions Model
ZEV	Zero Emission Vehicle

1 INTRODUCTION

"There's one issue that will define the contours of this century more dramatically than any other, and that is the urgent threat of a changing climate"….*Barack Obama*

A rapidly changing climate is driving nations across the world to declare a state of emergency. The year 2019 witnessed growth in the scale of climate actions as cities, nations and global environment agencies work towards implementing mitigation strategies and try to maintain net global temperature rise between 1.5 to 2 Degree Celsius (2016, Paris Agreement). Canada, amongst other countries, is committed to not only meet its 2030 target but also to achieve net-zero emissions by 2050 (2020, Progress towards Canada's GHG Emissions Reduction Targets).

However, despite various actions and policy changes adopted at the federal and provincial levels over the last several decades, Canada has missed a series of emission reduction targets – the 1992 Rio target, and 2005 Kyoto target. Also, Canada is likely to miss its 2020 Copenhagen and 2030 Paris targets as the projected emissions in 2020 and 2030 are 16% and 31% over the respective target (Canada's Fourth Biennial Report, 2020). Canada's total GHG emissions in 2017 were 716 Megatonnes of Carbon Dioxide Equivalent (Mt CO2 eq) which represents a 15Mt or 2% decrease from 2005 emissions. However, the Paris agreement, requires Canada to reduce its total emissions by 30% from 2005 levels by 2030 (equivalent to a 305 Mt annual reduction). Furthermore, the Pan-Canada Framework on Clean Growth and Climate Change sets long term national target of 80% reduction by 2050. Meeting Canada's 2030 and 2050 require significant reduction in individual IPCC sectors. The Canadian (national level) GHG emissions and sink estimations are guided by the Intergovernmental Panels on Climate Change (IPCC) and are calculated every year for the six IPCC sectors: Energy; Transport; Energy-Fugitive Sources; Industrial Processes and Product Use; and Agriculture and Waste. The emissions inventory is also estimated for five sectors of the Canadian economy – Electricity, Transportation, Oil & Gas, Buildings, and Industry (Emissions Inventory Canada 1990-2017). Except for the transportation sector ("transportation"), all other sectors have experienced significant emission reduction in recent years. However, over the last two decades, transportation has experienced a steady growth in emissions primarily driven by use of medium and heavy-duty freight vehicles. Due to these reasons, many experts consider transportation to be a key obstacle to meeting Canada's future emission reduction targets (Pollution Probe, 2018).

Of all the IPCC sectors, transportation is one of the most diverse sectors and largest source of GHG in Canada after Energy. The transport sector contributes a quarter of total national GHG, i.e. around 24%, 174 Mt in 2017. As per the Third Biennial Report, transport emissions are projected at 153 Mt in 2030 which is almost a 12% reduction from 2017 levels. However, to meet the 2030 target, a further reduction of 23 Mt is required in the transport sector itself with an additional 77 Mt in future reductions corresponding to clean electricity, green building and the electrification of transportation.

Emission reduction of this scale and pace is unprecedented and requires progressive measures including development of alternative vehicle fuel or zero-emission vehicle strategies. During the 1990s and 2000s, as a measure to reduce emissions, the federal government provided financial support to the proliferation of alternative vehicle fuels (propane, natural gas, CNG and LNG) which was later extended to EV users under the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative. The program's 2019 budget of $130 million is to support zero emission vehicle (ZEV) penetration by achieving sales target of 100% by 2040. Despite decreasing oil prices, auto manufacturers are investing heavily in green energy to meet global pollution standards and EVs would play a major role in decarbonizing the transport sector. Bloomberg 2020 projections also indicate that EVs will make up about 35% of the total vehicle sales worldwide by 2040 as the overall cost of ownership of EVs would significantly decrease over the next few years. Electric mobility is already one of the most common strategies that countries adopt to reduce emissions. In North America, 92% of the transport sector relies on non-renewable energy, which is the major source of tail-pipe emissions. Electric vehicles thus having zero tailpipe emissions is considered an effective way to meet future emission reduction targets (Electrification Coalition, 2020).

Global figures indicate the transport sector alone accounts for almost a quarter of CO2 emissions with the on-road sector contributing about 95% (International Energy Agency Report, 2019). The UNFCCC, an agency with a sole objective to stabilize global GHG levels, was established in 1994, yet ever since that time transport emissions continue to rise even in those regions which have seen a significant decrease in GHGs in other sectors. As per Eurostat data, total GHG emissions in Europe decreased by almost 21% from 1990 to 2017, however, transport emissions increased by 28% in the same period (European Environment Agency 2019). In the case of Canada, the total emissions from all the IPCC sectors have decreased between 2005-2016, however, emissions in the transport sector increased by 4% (National Inventory Report 2005-2016). Reducing emissions in the transport sector is difficult as the sector is heavily dependent on fossil fuel and decarbonizing will require considerable investments in the development and adaptation of clean technologies (Santos, 2017). The transport sector emissions are mainly from fuel combustion in six different sub-sectors - Road Transport, Domestic Aviation, Navigation, Railways, Other Transport (Off-Road), and Pipeline. Road Transport accounts for almost 82.3% of total transport emissions, 154 Mt in 2018 (National Inventory Report, 2020). The emissions primarily occur from passenger and commercial vehicles and trucks, which are either light-duty or heavy-duty. The increased emissions in the Road Transport are mainly due to an increase in vehicle kilometres traveled (VKT) which corresponds to changing lifestyles, vehicle dependency, and increased demand for commercial activities. The total fleet size also increased by 37% since 2005, most significantly increasing for light-duty trucks and heavy-duty vehicles. Light-duty trucks mainly constitute sport utility vehicles (SUVs), pickup trucks and minivans, contributing over 34% to road transport emissions (52.8 million tonnes in 2018). Whereas, heavy-duty vehicles contribute 42% (65.4 million tonnes in 2018) to the total road transport emissions (ECC, National Inventory Report 1990-2018). Emissions from light-duty trucks (LDT) and heavy-duty vehicles (HDV) increased by 27% and 28% respectively from 2005 levels whereas fleet size increased by 78% and 52% respectively. These two vehicle categories combined are the fastest growing and largely formulates the on-road freight vehicle fleet.

A significant segment of transport sector is freight transport by road (FTR) which is the lifeline of Canada's supply chain, logistics and warehouse industry. FTR primarily constitutes light-duty trucks (LDVs), medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs), facilitating the movement of food and high valued manufactured and processed goods within the country and across borders. FTR acts as a bridge between other modes of transportation by providing a viable mode for fast first and last mile deliveries. Almost all businesses in Canada largely depend on trucking to maintain their production system. Increased demand for e-commerce and fast track deliveries have resulted in even further reliance on the trucking industry. In recent years, the FTR sector has experienced a surge in demand due to increased economic activities resulting in more trucks moving on Canadian roads, thus producing more emissions. Transporting goods by road produces three times more emissions than transporting the same goods by an alternative mode (rail). Despite rail being more sustainable, FTR has always been the primary mode choice as it is more economical, flexible and relatively faster. Research suggests that for every kilometer traveled, HDV emit over 200% more GHG emissions than a passenger car (NRC, Fuel Consumption Guide, 2020 & ICCT.2018), which makes FTR a key target for future emission reduction plans.

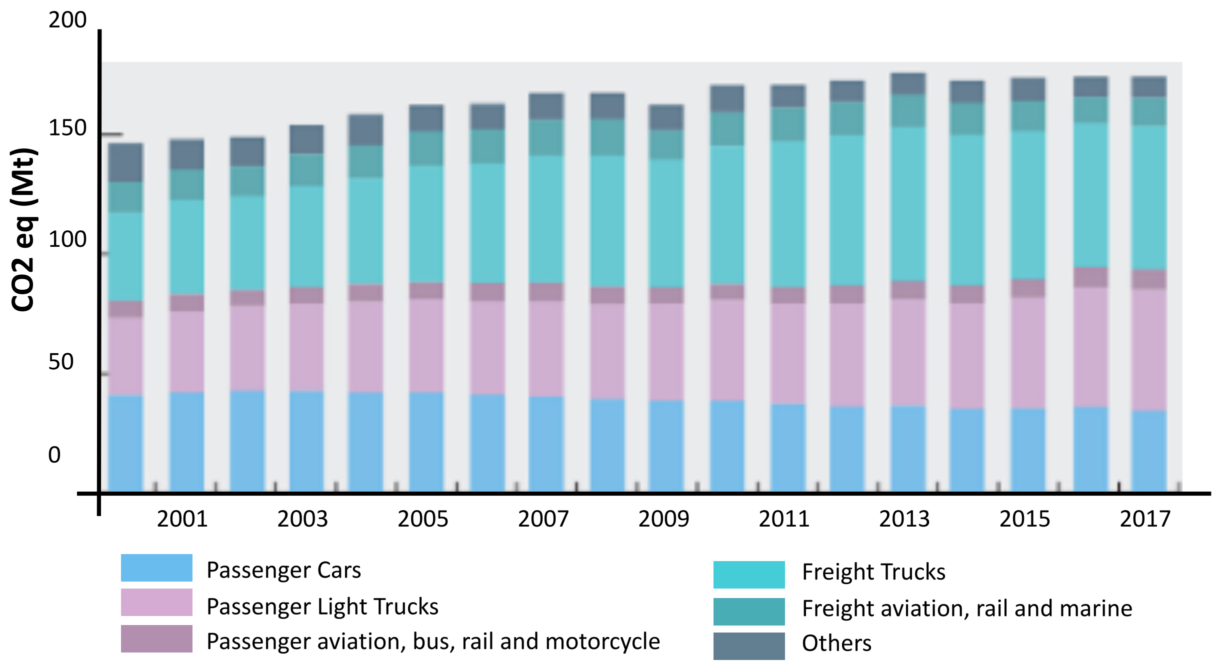

Figure 1-1: Transport Sector GHG Emissions for Canada, 2000-2017

The figure 1-1 shows that emissions from transport sector have increased from 146 Mt in 2000 to 174Mt in 2017, with freight trucks accounting for the largest increase (44%) from 50 Mt in 2000 to 72 Mt in 2017. Freight is a constantly growing segment of the transportation sector and is often overlooked in GHG emission reduction goals as passenger emissions currently represent more than 50% of Canada's total transportation emissions, see figure 1-1 (Canada & Environment and Climate Change Canada, 2018). In addition, there are few viable alternatives to the FTR sector available in the market that can meet performance needs while competing in global markets. Canada's 2nd Biennial Report on Climate Change states that freight emissions will surpass passenger emissions by 2030 if no specific measures are taken in this sector.

Studies suggest that to effectively reduce emissions from any sector, periodically measuring and reporting emission sources and sinks at different levels is necessary (Kholod et al., 2016; Corvalán et al., 2002; Kennedy et al., 2010). While various methods and guidelines inform national emission estimation processes(IPCC 2006), limited tools are available for cities to report their local emission inventory. Cities play a crucial role in climate action and emission reduction strategies as they consume 78% of the world's energy and account for 60% of global emissions (UN, Climate Action 2020). Emission inventory at the urban level not only improves the accuracy of national inventories but also helps decision-makers identify emission-intensive activities and develop targeted policies. For emission reduction strategies to work, local government needs to have a good overview of emission sources and their respective reduction potential (Bader and Bleischwitz, 2009; Hong et at., 2011; Xiao et al., 2017). An appropriate emission inventory method allows municipalities to not only monitor local emissions but also to evaluate and compare the effectiveness of their climate action plans. Different methods exist worldwide to estimate transport emissions at different levels; one of the most common macroscopic methods uses vehicle registries and annual kilometers travelled to estimate vehicle exhaust emissions (Kholod et al., 2016).

Three different approaches cities use to estimate their on-road emissions and the most preferable one is based on local fuel sales data (Kennedy et al., 2010). However, this method can give reasonable results only when the number of vehicle trips outside a city's border is negligible relative to inter-city trips. The Region of Waterloo uses this approach to report its transport emissions. The total energy consumed by all the vehicles operating in the Region is multiplied by the emissions factor of different GHGs. However, the Region uses generalized emission rates across all vehicle classes provided in Canada's National Inventory Report. The second approach estimates fuel consumption from the total vehicle kilometers travelled (VKT) by different types of vehicles within the city. This method provides relatively accurate results compared to the first method as the method allocates VKT according to different vehicle characteristics (commercial and passenger) and fuel types (gasoline and diesel, propane and natural gas) based on local traffic counts, household activity surveys, odometer reporting programs and local transportation models. This method more accurately depicts local transport characteristics and travel behaviors than the fuel sales method. However, data availability at the city scale is always a challenge. The third approach uses fuel sales data from national, provincial or regional levels and then scales these data down to a city level. The scaling factors depend on vehicle registries at regional and local levels, which are difficult to estimate due to data gaps. This approach is least accurate of all as it assumes that average VKT at the city level is the same across the region. All these macroscale methods use data at aggregate levels and ignore cities' complex transportation systems. Accurately estimating emissions requires a an approach that disaggregates transportation characteristics such as vehicle counts, modal split, transport network characteristic and travel behavior – vehicle speed, idling time, and queue length (Muresan. M, 2015).

As stated above, substantial efforts to meet GHG reduction targets are required from public and private corporations. Local governments can play a major role in emission reduction as they directly or indirectly own around 44% of the total GHG emissions in Canada (Federation of Canadian Municipalities, 2009). Local and regional institutions generally have a significant influence on development and land-use decisions and therefore can regulate and shape the pattern of transportation demand. Also, local governments are more engaged with people and therefore can influence communities to change their behavior and adopt sustainable lifestyles. However, the adoption of electric transportation requires progressive measures at all levels of government – federal government in regulating vehicles and setting targets; provincial governments in providing incentive and EV purchase programs; and local municipalities in providing suitable charging infrastructure, changing building codes, creating community awareness and adopting disaggregated level emissions inventory process.

1.1 Research Question and Objectives

Considering the urgent need to reduce transport emissions by accurately accounting and planning at local level, the main objective of this research is to provide a methodology for estimating transport emissions at a local level for urban areas. The methodology can be used by municipalities to more accurately report their transport emissions which can further guide local climate change mitigation plans and policies. The research also evaluates the possible implications of fleet electrification in achieving future emissions reduction targets. The project scale analysis of the EPA's Motor Vehicle Simulation Model (MOVES), is used to estimate the City of Waterloo's transport emissions. The study area is identified within the City of Waterloo for which the model is customized. Different scenarios exploring a shift from the existing fleet to electric are also explored for local emission reduction, with a focus on electrifying the commercial vehicle fleet. This research addresses the following research question:

What are the possible implications of commercial vehicle fleet electrification in reducing emissions at the urban municipal level?

To answer the research question, the following objectives are defined for the research:

1) To establish a methodology for accounting transport emissions at a disaggregated level using project level analysis of MOVES
2) To extrapolate emissions from the study area to the city scale considering the emission rates of different vehicle types;
3) To critically examine the existing municipal emissions accounting and reduction strategies of the City of Waterloo and the Region of Waterloo;
4) Based on the outcome of objective 2, create transport emission scenarios for 2031 and 2051 to assess reduction targets and the role electrification.

1.2 Thesis Structure

This research is structured in five chapters, the first – Chapter 1 – being this introduction to the study. Chapter 2 reviews the existing literature on emission estimation methods (micro and macro) currently used in the transport sector and highlights the challenges with how they are employed at the local level. The literature review also provides an overview of emission reduction strategies used worldwide in the transport sector and specifically in the (FTR) sector. Chapter 3 outlines the research methodology for estimating urban transportation sector emissions using project scale analysis of MOVES. The method is then applied to the study area. The emission estimation model developed is explored to identify the potential for vehicle electrification to achieve the City of Waterloo's long-term emission reduction targets. The research methodology also explains methods used to project the city's transport emissions for 2031 and 2051. The fourth chapter discusses the results of emission model for the study area and City of Waterloo. Different electrification scenarios for 2031 and 2051 are presented for the City considering increased traffic (Average Annual Daily Traffic) and proportions of commercial vehicle activities. The research 's final, fifth chapter highlights the need to adopt more accurate emission estimation models locally and to explore the role of commercial vehicle electrification to achieve long term emission reduction goals.

2 LITERATURE REVIEW

Accounting, reporting and mitigating GHG emissions at various geographic scales is a continuously evolving field of study as there is an urgent need for climate action to maintain the global temperature rise under 2 degrees Celsius (Intergovernmental Panel on Climate Change, IPCC, 2014, Schleussner et al., 2016). Global collaboration on climate change at the 21st United Nations Framework Convention followed by the Paris Agreement 2016, requires all participating countries, including Canada, to combat climate change and to reduce carbon emissions by 40% by 2030 (Jonkeren, Francke, & Visser, 2019). This ambitious target has put additional responsibilities on developed counties to prepare low carbon development strategies across all sectors, as they are net importers of GHG emissions, (Nabernegg, Bednar-Friedl, Muñoz, Titz, & Vogel, 2019). To effectively reduce emissions, periodically measuring and reporting emission sources and sinks at different scales is a must (Kholod et al., 2016; Corvalán et al., 2002; Kennedy et al., 2010). While various methods (IPCC 2006) inform national emission estimation processes, limited tools are available for cities to report their local emission inventory. Emission inventorying not only helps local municipalities plan for carbon neutrality but also supports cost savings, increased organizational efficiencies, and better asset management. For these reasons, accurately estimating emissions is often seen as a foundation to successfully formulate and implement climate action strategies. The literature reviewed in this chapter explores various emission estimation methods (micro and macro) currently used in the transport sector and highlights the challenges with their adoption at local scales. Also reviewed are emission reduction strategies used globally in transport as general and FTR sector.

2.1 Emissions in Transport Sector

The transport sector is one of the major contributors of CO2, the greenhouse gas (GHG) most responsible for global warming. As per international energy agency reports in 2019, more than 97% of global transport sector emissions are from fossil fuel combustion (oil and gas) (International Energy Agency Report, 2019). In 2017, transport accounted for almost a quarter of global CO2 emissions, of which, the on-road sector alone contributed 95%. The UNFCCC came into existence on 1994 and despite all their efforts, transport emissions continue to increase even in regions where GHGs have significantly decreased in other sectors. As per Eurostat data, total GHG emissions in Europe decreased by almost 21% from 1990 to 2017; however, transport emissions increased by 28% (European Environment Agency 2019). In Canada, the total emissions from all the IPCC sectors decreased between 2005-2016, but emissions in the transport sector increased by 4% (refer to figure 2-1 below). Increased emissions are due to more kilometers driven and an overall increase in commercial fleet size of 38% since 2005 (13% increase in cars, 75% light-duty trucks and 47% heavy-duty truck) (ECCC. National Inventory Report.2005-2016).

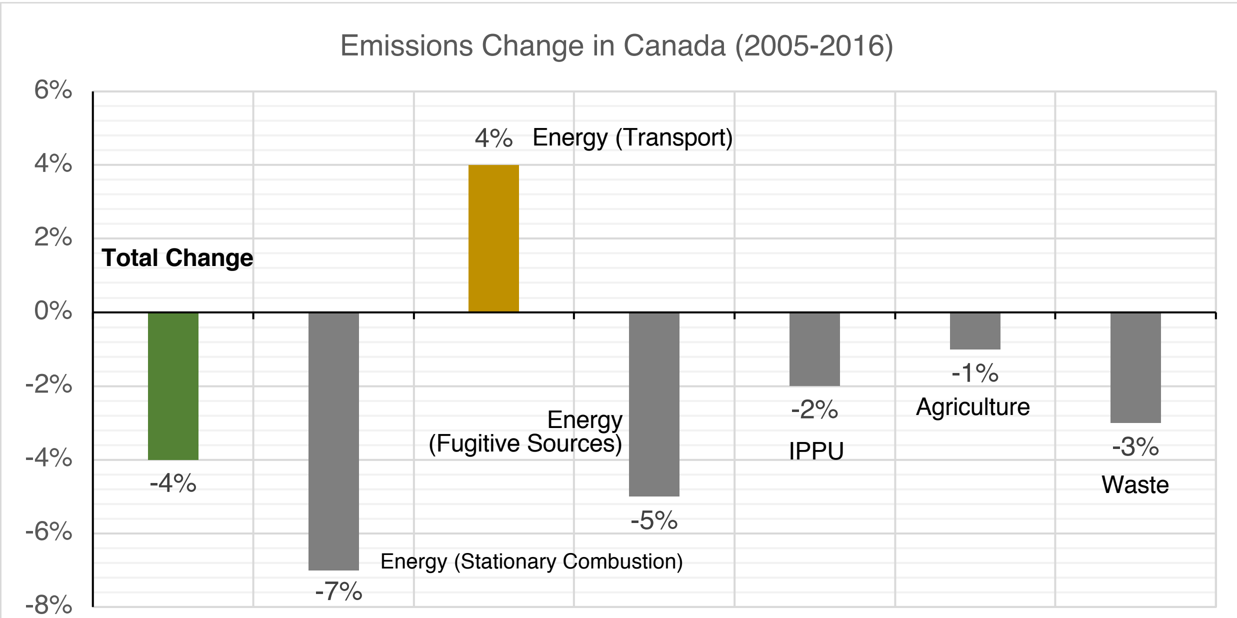

Figure 2-1: Change in Emissions in IPCC sectors, 2005-2016

Source: ECCC. National Inventory Report 2005-2016

The gradual increase in transport emissions is due to many reasons including population growth; increasing travel demand and car-dependency; low-density development, poorly integrated transit networks; and inappropriate policy interventions (Hasan, M.A. et al. 2019). Reducing emissions in the transport sector is even more difficult given heavy dependence on fossil fuels. Decarbonizing will require sizable investments in the development and adaptation of clean technologies (Santos, 2017). Another challenge is accurately accounting and monitoring transport emissions, especially at the city scale. With increasing urban population (about 50% globally and 70% in Canada in 2018), cities are a major driver of GHG emission growth and must play a significant role in tackling global climate change. This starts with accurately accounting for their emissions. The road transport sector is estimated to contribute up to 40% of a city's total GHG but these inventories are highly uncertain because simple and generic methods are used for estimation in most cases (Kennedy et al., 2010).

2.2 Emissions in Freight Transport by Road (FTR)

A significant segment of the transport sector is freight, contributing almost half of Canada's transport emissions. While transport emissions are caused by both passenger and freight (goods movement), most focus has been on passenger transport in emissions mitigation plans. Contributing 4.6% to the Canada's total gross domestic product and employing 905,000 people in 2017, the freight sector is vital to Canada's economy and therefore, very susceptible to climate change (Transport in Canada. 2017). Freight transport is continuously growing and with increases in urbanization, e-commerce, and increasing demand for same day deliveries, more freight vehicles are expected to operate on urban roads. It is estimated that freight emissions will surpass passenger emissions by 2030 (Ewing et al., n.d.).

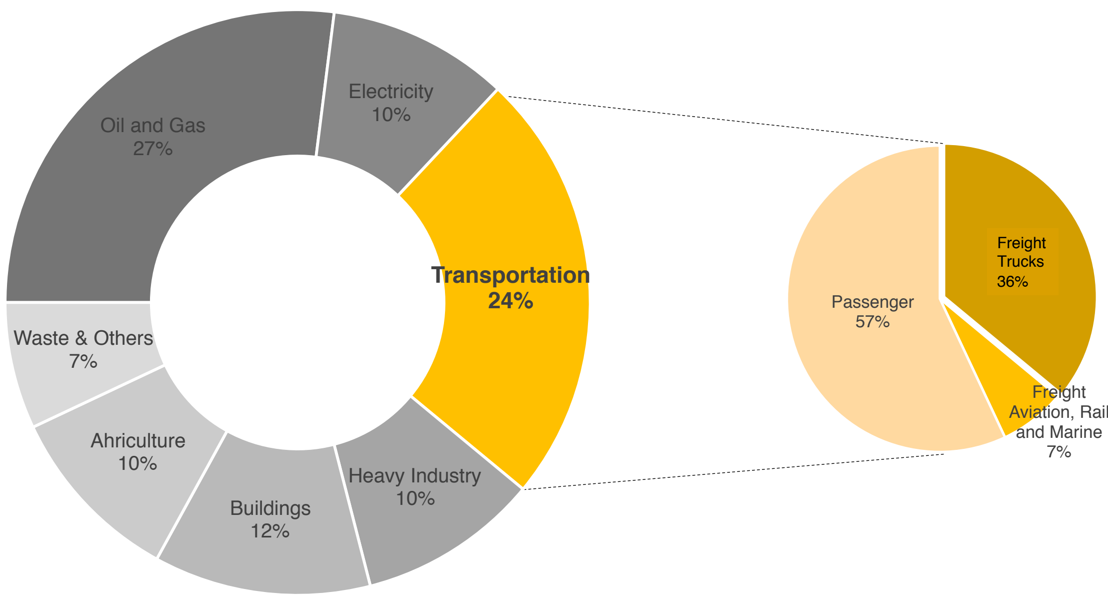

Figure 2-2: Transport Emissions in Canada, 2017, Environment and Climate Change Canada

Freight transport by road (FTR) is a major contributor of GHG and until recently the planning of freight activities have always been focused on profit maximization (Crainic, 2000; Forkenbrock, 2001). Due to increasing environmental concerns worldwide, freight carriers and policy makers are paying attention to negative externalities of FTR sector (Demir, Bektaş, & Laporte, 2014a; Ang-Olson & Schroeer, 2002). Although significant improvements in vehicle technology have reduced tail-pipe pollutants and increased fuel efficiency, emissions are continuously increasing as more vehicle are now moving on roads. For example, in the United States, transport sector emissions are expected to increase more than in any other economic sector, with on-road freight growing more rapidly than passenger (Blank, 2012; Muratori et al. 2017). It is evident that the freight sector is a significant part of North American's economy and has huge climate implications; therefore, serious mitigation measures are required from private and public institutions to address these impending challenges

There are also several challenges to properly account, monitor and mitigate emissions in the freight sector. The freight sector is comprised of local, regional, national and international transport systems which are either governed by public or private agencies at different levels. Due to the complex governance structure, greater effort is required from policy makers and transport planners to achieve a shared vision for the future of the freight sector (Regan, A. et al. 2000). Another key challenge is the rapid evolving nature of the freight sector which makes it difficult for businesses to keep up with changing consumer preferences (online retail and fast-track deliveries), while being environmentally conscious. The sector experiences various technological, political and governance challenges; however, the most significant challenge is data availability as local level freight data is limited and collected either independently by private companies (vehicle tracking data for example) or through limited government programs. Therefore, it difficult for planners to understand the existing realities of the sector and plan for the future, especially at the local scale (Ewing et al., 2020). The limited availability of freight data as compared to passenger data presents challenges for planners and traffic engineers to accurately measure freight emissions as well.

Decarbonizing freight was not given importance until very recently and with concern over climate change increasing worldwide, policymakers, public institutions, freight carriers, and logistics providers have started to pay more attention to mitigating the negative externalities of freight operations. Various studies have been conducted which provide methods to estimate and monitor GHG emissions, to improve operational and technological efficiencies, and to implement emission reduction strategies in the freight transport sector. The following sections provide an overview of these studies.

2.3 Emissions Estimation Methods

Article 4 of the United Nations Framework Convention on Climate Change (UNFCCC) requires all participating countries to periodically record and report their national GHG inventories. The purpose is to report anthropogenic emissions (GHG associated with human activities) from all sources and removal from sinks and to estimate global net GHG balance. Canada's national inventory is prepared every year by Environment and Climate Change Canada (ECCC), the most recent report being submitted in 2019 which summarizes total GHG sources and sinks from 1990 to 2017. The national inventory report estimate emissions at four different levels: (1) National level; (2) Provincial & Territory level; (3) IPCC sectors – Energy, Industrial Process & Product Use, Agriculture, Waste and Land use, Land-use Change and Forestry (LULUCF); and (4) Canadian Economic Sectors – Oil & Gas, Electricity, Transport, Heavy Industries, Buildings, Agriculture, Waste & Others. The transport sector is one of the Canadian economic sectors and emissions in this category are simply a re-allocation of emissions from the IPCC sector. National transport emissions are estimated based on the tier-1, IPCC reference approach (top-down approach) which uses following equation.

$E_{Category,\,G} = FC_{F,R}$ (Activity Data)* $EF_{G.F,R.T}$ (Emissions Factor)

$E_{Category,\,G}$ = GHG emissions by source category
$FC_{F,\,R}$ = Quantity of fuel consumed (in physical units, such as kg, L or m^3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.)
$EF_{G.F,\,R.T}$ = Country / Region specific emissions factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)
sub G = Type of Greenhouse Gas
sub F = Type of Fuel (gasoline, diesel, propane, ethanol, natural gas etc.)
sub R = Region
sub T = Vehicle Technology

Canada's national inventory is guided by IPCC 2006 best practices and uses data such as total fuel and energy consumption to estimate emissions in the transport sector. The principal source of this data is the annual Report on Energy Supply and Demand in Canada (RESD) collected by Statistics Canada 1990-2017. Both top-down (fuel supply and demand) and bottom-up (annual surveys from end users) approaches are used to estimate fuel supply and demand in broad economic sectors including transport sector (Statistics Canada, Table: 25-10-0030-01). While fuel data is available at provincial and sectoral levels, accuracy is low compared to the national data as the data is collected through specific surveys directed to energy suppliers, end users and provincial ministries (National Inventory Report 1990-2017, Part-2). As a result, total emissions estimated at the national scale are more accurate than that at the provincial or sector levels. Apart from national inventory reports, five out of ten provinces (British Columbia, Ontario, Quebec and Alberta and Manitoba) compile their own independent inventories using a range of methods from scaling down national inventories (British Columbia) to collecting independent fuel consumption data from different facilities. Regulations are in place which require these facilities to declare their annual emissions if these exceed a certain threshold. In Quebec and B.C, the threshold is 10,000 tonnes of CO2 whereas in Alberta it is 50,000 tonnes a year, which leaves various sectors out of the province's emission estimation. Oda et al. (2019) highlight various challenges of using national scale inventories to obtain disaggregated subnational emissions as spatial disaggregation of emissions is very different from the approach defined by IPCC, 2006. Another issue specific to national transport GHG inventories is that generic emission factors are used across all vehicle classes. Franco et al. (2013) define emission factors (EFs) as a functional relation that predict the quantity of a pollutant emitted per distance travelled or per unit of fuel consumed. EFs depend on various factors including engine technology, fuel specifications, and vehicle operations; thus, they are crucial for emission estimation. Environment Canada's National Inventory Report 1990-2017 provides a comprehensive list of EFs in the transport sector which are used to create national, provincial and regional inventories. While different EFs are provided for different gases (CO2, CH4, N2O) and fuel types (gasoline and diesel), the same factors are used for light-duty, medium-duty and heavy-duty passenger and commercial vehicles (table provided in Appendix-D).

National and provincial GHG inventories are very important to monitor global climate change and implement climate change mitigation strategies. While various guidelines inform national scale inventorying processes, limited tools are available to accurately report emissions locally. The Partners for Climate Protection (PCP) program sets broad guidelines for the accounting of local emissions. For emission reduction strategies to work, local governments need to a good overview of emission sources and their respective reduction potential (Bader & Bleischwitz, 2009; Hong et at., 2011; Xiao et al., 2017).

Different methods exist worldwide to estimate local transport emissions. One common method uses vehicle registries and annual vehicle kilometer travelled to estimate vehicle exhaust emissions; however, this approach is seldom used at a city level mainly due to the detailed data required and expensive surveys involved (Kholod et al., 2016). The Computer Programme to Calculate Emissions from on-road Transport (COPERT) model, developed by the European Environment Agency (EEA), uses a similar approach and is commonly used in many European, African and Asian countries (Ntziachristos et al., 2009). The model uses activity data inputs such as vehicle distribution by class and fuel type to estimate emissions at a national scale and data inputs such as fleet composition, traffic volume, road type and vehicle kilometer travel to estimate emissions at city scale. Kholod et al., (2016) highlights various shortcomings of the vehicle registry approach including difficulty in gathering detailed data at local level. Also, data from existing vehicle registry programs cannot be used directly in many emissions models as different vehicle classifications are used in transportation and emission estimation models. Vehicle registries also do not reflect the actual traffic distribution on city roads. For example, long-haul commercial fleets registered in one region are often used to perform deliveries in other regions. Therefore, the vehicle registry approach can result in under estimation of exhaust emissions especially when the emissions are estimated within the city boundary.

Kennedy et al. (2010) describe three different approaches cities can use to estimate their on-road emissions. The most preferable one is based on local fuel sales data; however, this method can give reasonable results only when the number of vehicle trips over the city border is negligible as compared to trips made within the city. The Region of Waterloo use this approach to report its transport emissions. The total energy consumed by all the vehicles operating in the Region is multiplied by the emissions factor of different GHGs. However, the Region uses generalized emission rates across all vehicle classes provided in Canada's National Inventory Report. The second approach estimates fuel consumption from total vehicle kilometer travelled (VKT) by different types of vehicles within the city. This method provides relatively accurate results compared to the first method, as the method allocates VKT according to different vehicle characteristics (commercial and passenger) and fuel types (gasoline and diesel, propane and natural gas) based on local traffic counts, household activity surveys, odometer reporting programs and local transportation models. This method more accurately depicts local transport characteristics and travel behaviors than the fuel sales method of emission estimation. However, data availability at the city scale is always a challenge. The third approach uses fuel sales data from a national, provincial or regional level and scales down it to the city level. The scaling factors depend on vehicle registries at regional and local level, which is difficult to estimate due to data gaps. This approach is least accurate of all as it assumes that average vehicle kilometres traveled at the city level is the same as that at a regional or higher level. However, vehicle activity within a city's transport network is complex and requires a focus on disaggregated characteristics including vehicle counts, traffic distribution, modal split, travel behavior, and road network attributes.(Muresan. M, 2015). Unlike macroscale approaches which use EFs to estimate GHG emissions, microscale models use vehicle activity and individual drivers' behavior including travel speed, acceleration and deacceleration rates and network characteristics (Demir et al., 2014). Rakha et al., (2003) classify these models based on their specificity and the uncertainty of the data used to estimate emissions. Generalized activity data are more uncertain and least specific compared to measured activity data, measured fuel consumption data, and directly measured emissions data.

Various microscopic models have been developed to estimate transport emissions including MOBILE, EMFAC, the Virginia Tech Microscopic Energy and Emissions Model (VT-Micro), and the Comprehensive Model Emissions Model (CMEM). These models typically differ in structure, approach and level of data inputs (Rakha et al., 2003), Muresan.M, 2015). Various microscopic models consider up to five major aspects of transportation to estimate fuel consumption including (1) vehicle: weight, shape, engine size/shape/ temperature, transmission, fuel type, oil viscosity; (2) environment: road gradient, pavement type, altitude, wind conditions, other surface conditions; (3) traffic: speed, congestion; (4) driver: idle time, gear selection, aggressiveness; and (5) operations: fleet size & mix, payload, empty kilometers, number of stops. Most models consider only vehicle, traffic, and environment aspects. Aspects related to operations are considered as externalities and the impacts of 'poor driving behavior' are not considered in most simulation models (Demir et al., 2014). The most recent and commonly used model in North America is MOVES2014, which is an upgrade of the US EPA's MOBILE (Muresan.M, 2015; EPA, 2020). Almost all microscopic models require detailed traffic volume counts on each individual road link. Many states in the US and Canada use automatic detection technologies to collect traffic volume data. The data is collected through automatic equipment which records continuous traffic distribution and volumes on different parts of the road network. However, in some cases short duration traffic data programs are also used as they are cost- and time efficient. Some agencies also use short duration traffic volume counts (representing typical traffic on any given road section) to estimate on-road emissions. Other agencies use weeklong traffic data for every hour of the day to get more accurate results (US Department of Transport, 2016).

2.4 About MOVES

MOVES (Motor Vehicle Emissions Simulator) is an emission estimation model prepared by EPA. The model was first released in 2010 as an upgrade to the earlier emission model, MOBILE. The most recent version of MOVES available is MOVES2014. MOVES provides a modeling platform which supports analysis at different scales, including detailed project analysis. The model estimates emissions including GHGs, air pollutants and air toxins for all types of on-road vehicle activities from sources such as tailpipe, fuel evaporation, and brake and tire wear. MOVES2014 can also estimate emissions for non-road mobile sources. The default data in MOVES is set to the US context; however, data inputs such as driving patterns, emissions rates, vehicle class, and road types. can be customized to local contexts. While most macro models multiply emission factors directly with fuel consumption, MOVES estimates emission inventories by multiplying specific emission factors with emission related activity (on-road / off-road activities – free flow, queuing, idling) and by applying various criteria to simulate specific situations. MOVES produces total emissions (mass inventories) and emission rates (g/km) called 'outputs' for different geographic locations and time periods for the following pollutants. (1) HC (THC, NMHC, NMOG, TOG, VOC); (2) CO; (3) NOx (NO, NO2); (4) NH3; (5) SO2; (6) PM10, 2.5 (organic carbon, elemental carbon, sulfate, brake wear, tire wear); (7) Greenhouse Gases CO2, CH4, N2O); and (8) Toxics: Benzene, Ethanol, MTBE, Naphthalene, 1,3- Butadiene, Formaldehyde, Acetaldehyde, Acrolein. The model also produces outputs based on the following parameters:

(1) **Vehicle Class (or source types)** – vehicle class is organized by patterns of vehicle activity. In the default setting, vehicles are classified as: Motorcycle, Passenger Cars, Passenger Trucks, Light Commercial Trucks, Bus (intercity, transit, school), Heavy Trucks (Single Unit/ Combination: Short Haul/Long Haul), Refuse Truck, and Motorhome. Emissions can therefore estimate emissions for all these vehicular classifications.

(2) **Road Type** – road types are defined based on the different driving patterns expected to occur upon them. In the default setting, road types are classified as: urban restricted (freeway), urban unrestricted (non-freeway), rural restricted, and rural unrestricted.

(3) **Emission Processes** – defined by the combinations of how and when emissions are produced such as running, starting, extended idling, evaporating (permeation, vapor venting, liquid leaks), refueling (vapor loss, spillage), Crankcase, Tire Wear, and Brake Wear.

(4) **Fuel Type** – emissions are produced for different engine technologies and current options are limited to gasoline, diesel, CNG, and electric engines.

Emissions can be estimated for different geographies using three scales of analysis – (1) national scale; (2) county/ regional scale; and (3) project scale. National and county level analyses estimate emission inventories for the entire country and individual regions within. Conversely, project scale analysis is best suited for emissions at local level: cities or individual transport projects such as road extensions, parking lots, intersections, transit hubs, etc. The project scale analysis within MOVES allows modeling at individual link levels where driving patterns can be customized to local contexts. Since the level of customizability peaks at the project level, MOVES is more suitable for international (outside U.S) users. Figure 2-3 is a schematic diagram of data flows at different scale in MOVES.

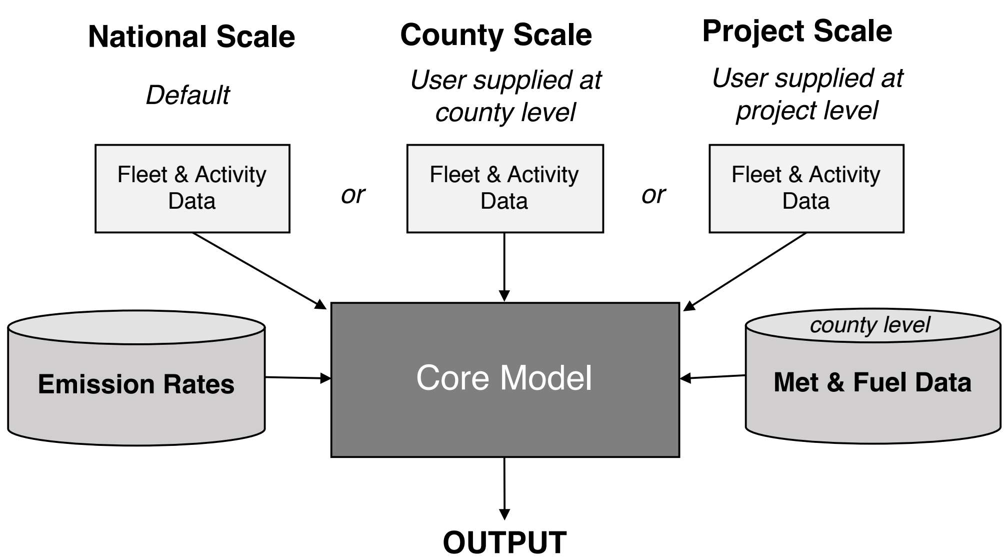

Figure 2-3: Schematic Diagram of data flow at various analysis scale in MOEVS

2.4.1 Level of Customization for International Users

Based on data availability, MOVES can be customized at three levels (1) **1st Tier** – data such as local activity, fleet distribution and fuel parameter are added based on local context. However, the resulting model would use default emission rates, driving patterns, vehicle classes and road types. (2) **2nd Tier** – this tier builds on the 1st tier's by allowing different emission rates based on the mapping of country or region-specific vehicle technologies. The resultant model will use default data for driving patterns, vehicle class and road types. (3) **3rd Tier** – This tier allows for region specific data inputs, such as vehicle class, road types, and driving patterns, to build on data from the 1st and 2nd tier. The resultant model therefore presents the most accurate simulation of the local context. Depending on a particular region's data availability, MOVES can be customized for local analyses with relative ease. In the case of on-road emissions estimations, data inputs such as vehicle population and activity data are the most critical.

2.5 Emissions Reduction Strategies

Transport activities related to cargo distribution and service provision have increased considerably in recent years primarily due to increasing urbanization and consumerism. The freight sector plays a crucial role in cities' commercial activities by facilitating wholesale, distribution, logistics and intermodal operations. While light-duty trucks mainly perform first and last mile deliveries within the urban boundary, medium- and heavy-duty trucks feed local businesses by connecting them to global supply chains. The research of McKinnon et al. (2015) and Muñoz-Villamizar et al. (2017) highlights the environmental impact of freight activities in terms of their GHG emissions contributing to climate change and pollutants impacting public health. To mitigate these impacts, local authorities need to explore technological innovations in the urban freight sector (Björklund, M. 2015). A range of strategies have already been explored by researchers and stakeholders including but not limited to better truck routing, use of smaller and newer trucks, consolidated local delivery systems, alternative modes and fuels, off-peak deliveries, and low emission zones (Dablanc et al. 2013). An extensive literature explores truck routing, network optimization and other related topics; however, most of this work focuses on optimizing regional, not urban freight (Schröder & Cabral, 2019; Ang-Olson & Schroeer, 2002; Chassiakos, A. et al. 2010; Dessouky, M. et al. 2008).

Urban freight is an evolving field of study which investigates city-level logistics to achieve overall operational efficiencies and cost minimization while eliminating environmental externalities (Dablanc, L. 2012). Research into urban freight distribution systems and their externalities concludes that bottlenecks in these systems are more prevalent in areas with high densities (Cidell, J. 2010; Hesse, M. 2008). For these reasons, many cities are now experimenting with different strategies to solve urban freight problems. Dablanc et al. (2013) highlight various strategies to address urban freight problems such as first and last mile pickups and deliveries, environmental impacts and congestion. Last mile strategies are related to efficient local deliveries and pickups to and from residences and local business. Strategies to solve environment problems are based on using alternative fuels, electric vehicles, and new technology to reduce emissions and pollutants.

Wang, et al. contend that last mile logistics are one of the least efficient segments of the freight sector, causing 28% of the total transportation cost. Therefore, stakeholders want to minimize their cost while reducing environmental impact and maintaining services (Wang, Y. et al. 2016). The Urban Freight Research Roadmap (2014) sees new technology shaping the future of freight transportation systems. Studies predict that with the advent of new technology, urban logistics will be dominated by autonomous vehicles and bike courier services with only 20% traditional light-duty vehicles being used for pick-ups and deliveries (Joerss et al. 2016). Another revolutionary concept picking up speed in the freight sector is the use of unmanned aerial vehicles, or drones, for commercial delivery especially in low density urban areas. Studies reveal that the transportation of goods by trucks is four times more carbon intensive than conventional aircraft; since drones are electric powered, use far less energy per package-km than delivery vans or aircrafts, if implemented carefully, drones could contribute significantly to emission reduction in the urban freight sector (Stolaroff et al., 2018; Joerss et al. 2016). Winkenbach (2016) also highlights the potential of new technology, including autonomous and/or EVs, to make urban freight more sustainable and efficient. However, concerns about the viability of some of these new technologies are several, including the prohibitive investments involved in the implementation process.

Jose et at (2018) discuss the role of Off-peak Hour Deliveries (OHD) in reducing urban freight emissions by shifting focus from carriers to receivers. OHD is one of such programs under the vast field of Freight Demand Management (FDM) which allows receivers to change the time of deliveries. Since, receivers have a vested interest in improving their business conditions, making them aware of the impact of their practices and promoting OHD to improve sustainability in urban freight. This approach was tested in New York City, where a one-time financial incentive of $2,000 was given to 400 businesses to accept OHD. The success of this program also prompted other cities including Copenhagen (Denmark), Sao Paulo (Brazil) and Bogota (Colombia) also started testing pilots (Jose et at 2018).

Oliveira et al’s (2017) systematic literature review of the use of sustainable vehicles for last mile deliveries examined economic, environmental and social implications of five different types of vehicles/ equipment: (1) diesel powered; (2) biodiesel; (3) electric; (4) autonomous; (5) bicycle/

tricycle. The study concludes that light commercial vehicles (gross vehicle weight less than 3,500 kg) powered by electricity are the best alternative for last mile delivers Some of the studies examined in the Oliveira, et al. (2017) also concluded the use of autonomous electric vehicles and bicycle, tricycle, motorcycle (all electric) as alternatives for last mile deliveries.

Light commercial vehicles (LCVs) currently dominate the North American logistics industry accounting for 75% of the total market share in 2017 (Commercial Vehicle Market Size, Share & Trend Analysis Report, 2018). Calgary commercial vehicle movement data indicates that 50% of local trips are made by light-duty vehicles such as pickup trucks, vans, and even passenger cars (Stefan et al 2005). Europe has also seen a significant increase in LCVs in the past decade compared to medium and heavy-duty trucks (Schoemaker et al. 2005). This demonstrates that smaller vehicles are more preferred means of logistics when it comes to serving dense urban areas. Adoption of smaller commercial vehicles for last mile delivers occurs in many countries including Brazil and India where bicycles/ tricycles are used by many logistics companies to comply with traffic regulations and avoid congestion. UPS also started testing electric tricycles as an alternative delivery option with the first pilot operation occurring in 2017 in Pittsburgh. While reduction in commercial vehicle size is seen as the most effective strategy to mitigate urban freight's externalities, integrating last mile with other freight operations which primarily include heavy trucks is a challenge. Regardless, LCVs are dominating urban freight sector and their market is uniquely positioned to rapidly transition to electric power (Wyatt, D. 2020). The use of EVs for last mile deliveries is considered the most viable strategy for the future as it has the potential to significantly reduce dependency on fossil fuel thus reducing emissions (Weiss, 2015; Wyatt, 2020).

Other common strategies and policy initiatives adopted worldwide to improve last mile deliveries and reduce the environmental impact of urban freight include (1) Truck fuel efficiency and emission standards (e.g. California)considered one of the most effective tools in reducing emissions in the U.S and mainly encourages heavy-duty vehicles to use cleaner fuels; (2) Low emission zones (e.g. London, Milan) in many European cities restrict high emission vehicles in certain parts of the city; (3) Alternative Modes (e.g. London, Milan, France), for example many European cities have tried shifting truck freight onto regional rail systems; however, financial viability is a key concern; (4) Restrictions on truck idling (e.g. California); (5) Environmental Justice as a community mitigation measure (e.g. Los Angeles, New York, Atlanta), government has started initiative in many U.S cities to consider ‘environmental justice’ a performance measure for any new freight projects (Dablanc, L. 2013).

2.6 Potential of Electrification in Emissions Reduction

Of all the operational and technological solutions available to reduce emissions, electric mobility is considered the most feasible option to reduce tail pipe emissions. Many countries have already established their emission reduction targets in line with the Paris agreement and are implementing decarbonizing strategies in transport sector. The European Union (EU) recently introduced regulations in the transport sector to mitigate emissions and improve quality of life. The agreement signed with car companies across Europe is to achieve a CO2 limit of 94g/km by 2020 (EU Regulations, 2009; 2014). However, with current engine technology available, CO2 levels cannot be reduced below 103 g/km (Ranieri, L 2017). Therefore, adoption of zero emission vehicles/ EVs is seen as the only solution to achieve such ambitious targets especially in urban areas.

Electrification Coalition (EC), a non-for-profit organization facilitating deployment of EVs in the US, states that 92% of the transport sector in North American relies on petroleum fuel, the major source of tail-pipe emission. Since electric vehicles have zero tail-pipe emissions, municipalities and private companies are actively looking to electrify their vehicle fleet in order to achieve their emissions targets (Electrification Coalition, 2020). The European commission has also set an ambitious target of reducing total emissions by 80% (60% in transport sector) by 2050 and adopted low-emission mobility strategy to help meet the target (EC Roadmap 2050). The City of Toronto’s electric mobility strategy - Transform TO - is also optimistically set to significantly reduce transport emissions by 2050 (*City of Toronto Electric Mobility Strategy: Assessment Phase*, n.d.). North Colorado, with the help of EC, prepared an electric mobility strategy - Drive Electric Northern Colorado (DENC) - to successfully adopt EVs (Electrification Coalition, Case Study - DENC). The City of Houston, through its comprehensive strategy for sustainable transport, is also promoting the use of EVs and is currently transforming its municipal fleet of 9,277 cars, vans and trucks into electric vehicles (Electrification Coalition, Case Study – The City of Houston).

Currently there are four types of vehicles available in the market which can facilitate the electric mobility strategy. Depending on the type, these vehicles can provide electric propulsion for a portion of the distance travelled. Different types of vehicle include: Hybrid Electric Vehicles (HEV); Plug-in Hybrid Electric Vehicles (PHEV); Battery Electric Vehicle (BEV); and Fuel Cell Electric

Vehicle (FCEV). HEVs and PHEVs have smaller battery capacities compared to BEVs and FCEVs, therefore they are more suitable for short distance trips of up to 85kms. BEVs can make a trip of up to 540kms on a single charge, making them more suitable for long distance commercial trips. Although, these vehicles have zero tail pipe emissions, there are other sources of emissions associated with the EVs including that from energy sources, manufacturing of batteries, transportation of vehicles and disposing off waste which are also called life cycle emissions.

To date, there is much attention given to transforming light commercial vehicles and passenger fleets mainly because they account for the most transport emissions (more than 50% in Canada). However, with increasing freight demand, equal attention is required on mitigating emissions in the freight sector as well. The State of Freight Report 2017 also realized that decarbonizing freight sector is a way forward to meet future emissions reduction goals (Plumptre, B. 2017). Freight sector growth is directly linked to increasing population and economic growth; however, cutting down freight activity by reducing VKT is not a viable strategy to reduce emissions.

2.7 Role of Municipalities in Decarbonizing Transport Sector

Achieving nationwide emission reduction targets requires a low-carbon transportation sector which in turn requires investments into more effective emissions accounting, monitoring, and policy and infrastructure development. Municipalities can play a major role in facilitating this transition at a local level, firstly by accounting for local transport emissions accurately. The Partners for Climate Protection Program (PCP) under the Federation of Canadian Municipalities, which represents over 350 municipalities across Canada, highlights the importance of accurately accounting and reporting GHG emissions (FCM - PCP Protocol, 2014). PCP provides Canadian municipalities with accounting guidelines for different sectors including transportation; they suggest that emissions data is best collected at a sufficiently disaggregated level for all individual vehicle types to reflect local circumstances and inform effective mitigation measures.

Municipalities play a significant role in preparing and implementing electric mobility strategies by promoting the commercial and personal use of EVs within city boundaries. The International Council on Clean Transportation (ICCT) reports the importance of EVs in reducing transport emissions and that government efforts are required to support the market shift away from traditional fuel combustion vehicles. Based on data collected from 14 major cities in North America, Europe and China, ICCT highlights three major areas where local government can intervene to support the EV market including (1) financial and non-financial incentives for consumers; (2) community engagement and awareness campaigns; and (3) supporting infrastructure, such as designated parking/charging stations for different vehicle types. Consumer incentives are further categorized as purchase incentives, incentives on vehicle operations, parking and High-Occupancy Vehicle (HOV) lane access. Purchase incentives are mainly in form of federal and provincial tax credits and help consumers to overcome the cost difference and convenience barriers with the adaptation of new technology (Jin, Searle, & Lutsey, 2014; Lutsey et al., 2015; Tal & Nicholas, 2016; Vergis & Chen, 2014; Yang et al., 2016; Zhou et al., 2016, 2017). Transport Canada recently announced nationwide a purchase incentive of $2,500-$5,000 for EVs. Provinces like British Columbia and Quebec also have their own rebate programs. Quebec provides a rebate of up to $8,000 on new EV purchases and $600 for purchase of a home charging station. The US federal government provides tax credits of up to $7,500 for the purchase or lease of EVs whereas state tax credits range from $5,000 in Colorado to $1,750 in Pennsylvania. Municipal involvement in purchase incentives are typically minimal; however, some provide rebates and local tax exemptions: the city of Riverside provides up to a $500 rebate in addition to state and federal incentives for all new EV consumers (The City of Riverside, 2020).

Operational incentives are given to consumers once they have purchased the vehicle. These incentives come in the form of complete fee waiver or fee reduction for vehicle registrations, vehicle inspection, licensing, and other administrative processes. However, these incentives are largely administered at the provincial or state level, with a limited role for local municipalities. Municipal governments usually have more control over incentives such as free EV parking or designated parking spots and garages. Some US cities, including cities in Nevada, Hawaii, Cincinnati, and Salt Lake City provide free parking, while San Jose also offers parking garages for BEVs thus providing cost savings of up to $100/month for local users (Slowik. P, Lutsey. N, 2018). Some municipalities in the US also allow single occupancy EVs to use HOV lanes for free thus providing benefit of up to $3,350 in some cases (Slowik & Lutsey, 2018). These benefits relatively small in scale; however, they could scale upwards to benefit local delivery businesses with larger commercial fleets.

To increase the uptake of EVs, municipalities play a key role in developing the required infrastructure. Various studies show that the number of public charging facilities is closely correlated to EV usage (Hall, Cui, & Lutsey, 2017; Slowik & Lutsey, 2017; Zhou et al., 2017).

Local governments can facilitate the development of EV charging infrastructure through, for example, direct installation, financial support, expediting permits, and adopting EV-ready building codes. (Slowik. P, Lutsey. N, 2018). In addition to developing EV support infrastructure, creating consumer awareness and helping people understand new technology is important and local government can very effectively undertake these programs. The City of Boston runs a website, which provide information about types of the EVs available economic and environmental benefits, cost benefits, buying guides, upcoming test drive events, maps of public charging infrastructure, and various rebates and incentives (The City of Boston, 2020). Some municipalities also integrate EVs into their municipal fleet to demonstrate a public commitment to sustainability. Such initiatives are helping cities worldwide to achieve their emissions target, lower pollution levels, and achieve fuel and maintenance cost savings. The City of Columbus, Ohio; transit operators in LA, Seattle, Louisville; and many more such agencies are in the process of electrifying their fleets. (City of Columbus, 2016; Metro, 2019; King County Metro, 2020).

2.8 Research Question and Objective

After reviewing the literature, it is clear that the transport sector's entrenched dependence on fossil fuels in combination with increasing travel activity is behind the continued rise in sectoral emissions. To effectively manage emissions, various studies highlight the need to account transport emissions at a disaggregated city scale that reflects local circumstances. Detailed emissions estimation is necessary to link national and regional emission reduction targets with local targets as well as strategies. However, macro scale emissions estimation methods are currently used in most cities, mainly because of the lack of resources and data required for detailed microscopic analyses. Studies shows that a city's transport network is complex and requires focus on emission estimates to account for disaggregated characteristics including vehicle counts, traffic distribution, modal split, travel behavior, and road network attributes. Accounting emissions for particular vehicle types is vital for targeted approaches to combat emissions in different transport segments. For instance, (FTR), one of the important segments of transport, is rapidly increasing and often overlooked in estimating and mitigating emissions. Various microscopic emissions estimation models are available and are currently being used by various institutions; however, these models are limited when applied at a city scale. Another important finding from the literature is that tail pipe emissions is the largest segment of transport emissions and can be reduced significantly using EVs. Many regional and local municipalities have already set up various programs, such as promoting awareness and use of EVs; providing financial and non-financial benefits (e.g. free parking); and developing support infrastructure (e.g. charging stations). However, studies that quantify the city-wide reduction of GHG emissions if the commercial fleet is electrified have been limited.

Given existing gaps in our understanding and the need to estimate transport emissions at disaggregated levels, this research uses project scale analysis in MOVES to estimate emissions at a local, city level. Using the City of Waterloo as a case study, this research also critically examines the municipality's emissions reduction targets and their relationship to national targets. Different scenarios exploring the emissions impact shifting from the existing fleet to an electric fleet are also presented, with an emphasis on freight activity. Another main objective of this research is to understand the possible implications of fleet electrification in achieving local emissions reduction targets. It is anticipated that electrification will significantly reduce tailpipe emissions; however, this requires additional infrastructure and other user benefits, not only at the local level but also at the regional and provincial levels.

This research addresses the following research question:

What are the possible implications of commercial vehicle fleet electrification in reducing emissions at the urban municipal level?

To answer the research question, the following objectives are defined for this research:

1. To establish a methodology for accounting transport emissions at a disaggregated level using project level analysis of MOVES
2. To extrapolate emissions from the study area to the city scale considering the emission rates of different vehicle types;
3. To critically examine the existing municipal emissions accounting and reduction strategies of the City of Waterloo and the Region of Waterloo;
4. Based on the outcome of objective 2, create transport emission scenarios for 2031 and 2051 to assess reduction targets and the role electrification.

3 METHODS

This chapter elaborates on the methods this research employs to (1) estimate transport emissions at a local level using MOVES; (2) forecast the City of Waterloo's transport emissions for the years 2030 and 2050; and (3) create and explore future scenarios for electrification.

3.1 Study Area

The research focuses on a study area located within the Region of Waterloo, which comprises the three cities of Cambridge, Waterloo and Kitchener, and four townships of North Dumfries, Wellesley, Wilmot, and Woolwich. With a total population of 601,220 in 2018 (Region of Waterloo, Strategic Plan 2019-2023), the Region of Waterloo is one of the fastest-growing regions in Ontario with a population growth rate (37% between 2001 and 2018) higher than the national and provincial average. The region's GDP in 2017 was $27 billion, roughly ~4% of provincial GDP (Region of Waterloo; Ministry of Finance, Ontario). By 2041, the Region is expected to grow by 56% and 77.8% in terms of population and employment, respectively, adding about 299,890 people and 173,780 jobs. (A Place to Grow, 2019). Given this considerable population and economic growth, the region is also experiencing considerably increased GHG emissions. In 2015, the Region emitted 4.3 million tonnes of CO2, i.e., ~7.9 tonnes per capita, a higher rate than in the GTHA (Region of Waterloo Climate Action Strategy, 2015; TAF, 2016). Transport is the most significant contributor to regional emissions, contributing 49% of total emissions in 2015.

The specific study area identified for the research is located in the City of Waterloo and represents contributing 23% of the region's population. The study area forms a portion Waterloo's urban core and is comprised of academic, residential, mix-use, uptown, institutional, employment, and commercial land use. The study area (shown in the Fig-3.1 below) is also part of Space of Waterloo's Innovation in Future Transportation (SWIFT) project, a real-world transportation "Living Lab" (LL) based in and arounds the University of Waterloo campus. The SWIFT-LL, once installed, will collect real-time data including traffic counts, queue length, and travel time on an integrated network of freeways, arterials, local roads, and railway (ION line) facilitating large research projects conducted by the University and local partners.

Figure 3-1: Study Area

The study area represents about 30.24 km of regional and city arterials and major collectors as outlined in Table 3.1. These roads are subjected to commercial vehicle access as per the City's Transportation Master Plan (City of Waterloo, TMP, 2011).

Table 3-1: Study Area – Road Description

Name of Road	Road Type	Length (Km)	No. of Intersections
King Street	Regional Arterial	4.86	28
University Avenue	Regional Arterial	4.98	23
Columbia Street	City Arterial	4.43	7
Westmount Road	Regional Arterial	2.29	8
Erb Street	Regional Arterial	2.63	24
Bridgeport Road	Regional Arterial	1.42	8
Northfield Drive	Regional Arterial	1.46	6
Weber Street	Regional Arterial	4.71	20
Albert Street	Major Collector	1.78	5
Phillip Street	Major Collector	0.62	2
Caroline Street	Major Collector	1.06	10
Total		30.24 Km	

3.2 Methodology Overview

Concepts from the literature are used to develop a technical framework to estimate transport emissions within the study area. MOVES2014, a computer-based model designed by EPA, is the latest version of MOVES, which can estimate motor vehicle emissions at national, county, and project scales. For this research, the project-level analysis of MOVES is used as it allows us to customize the model to the local context. The study is conducted in four stages. In the first stage, on-road GHG emissions from different vehicle classes including passenger cars, light commercial trucks, and heavy-duty vehicles are estimated using disaggregated transport data. The model uses road network characteristics, 2015 traffic volumes, traffic composition, and average vehicular speed as its critical elements. The model's details are provided in the subsequent sections. In the second stage, the transport emissions estimated for the study area are further extrapolated to the city scale using an emissions per vehicle factor. The city's transport emissions could be estimated more accurately using MOVES for the entire city.

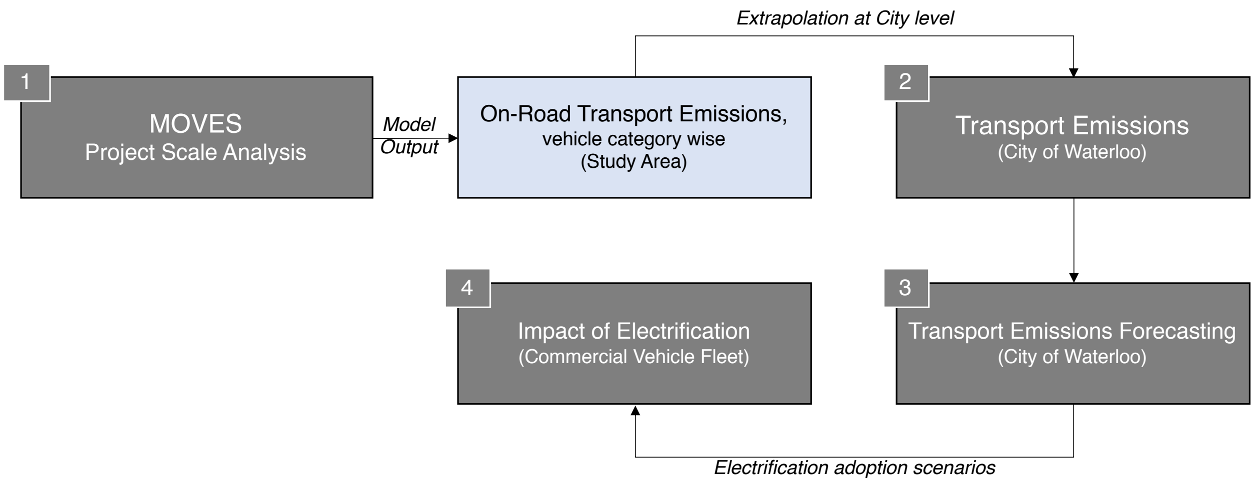

Figure 3-2: Methodology Flow Chart

The third stage of the research forecasts transport emissions for the years 2030 and 2050, considering parameters such as traffic and population growth. Lastly, the potential for the city's emissions to be reduced by adopting a commercial EV fleet for are estimated the two forecast years. The broad overview of the methodology adopted is presented in figure 3-2.

3.3 Setting-up MOVES

Figure 3-3 presents the steps followed to set up and run the MOVES model, details of which are explained below.

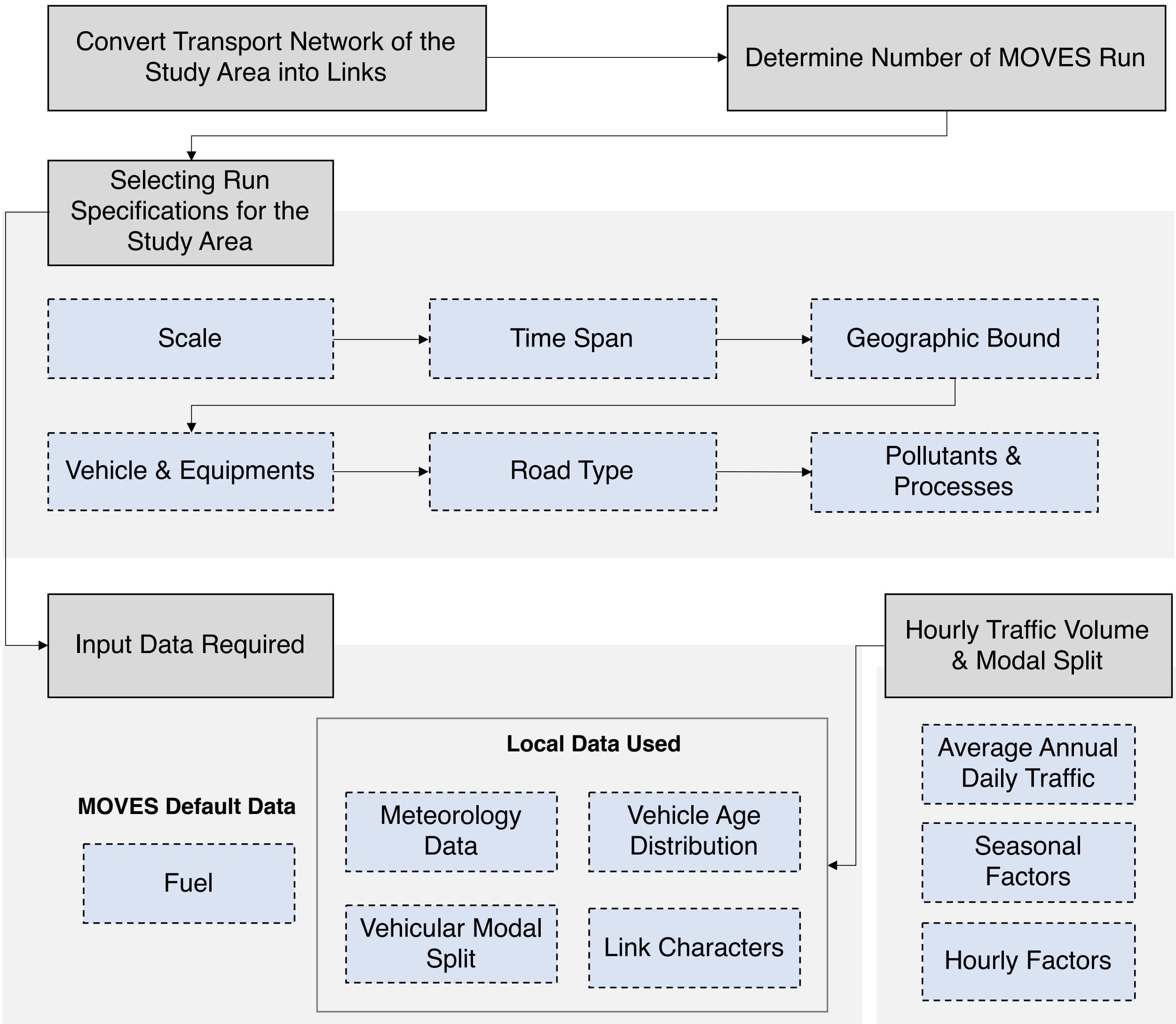

Figure 3-3: Setting up MOVES - Flow Chart

3.3.1 Convert Transport Network into Links

The first, most vital step is to define transport links within the study area to capture where emissions occur. In MOVES, a link represents a segment of road where specific types of vehicular emission generating activity take place, such as acceleration, deceleration, and queuing/ idling. For a defined link, average speed and other characteristics such as elevation and road type remains the same. For example, a stretch of a road between intersections, with free flowing of traffic, can be considered one link. However, at an intersection, different links can be defined depending on traffic flow. MOVES estimates emissions for each link and associated traffic activity identified in the study area. Since the study area comprises different road types and intersections, a total of 846 links are defined, each corresponding to one of three main activities – queueing, approach and departure. The queue link represents vehicle idling at the intersection, whereas the approach and departure link represents a vehicle's deacceleration and acceleration towards and away from the intersection, respectively. Figure 3-4 shows a part of the study area and different identified links; there are a total of 24 links identified for two intersections (eight queues, eight approach, and eight departure links)

Figure 3-4: Links defined in the Study Area

3.3.2 Number of MOVES Run

With the total number and type of links defined, the number of MOVES runs is determined. In MOVES, each run estimates emissions at a specific hour of a weekday or weekend in any given month of the year. For this research, the runs are performed for the four peak hours – morning (7 am to 9 am) and evening (4 pm to 6 pm), representing about 31% of the total daily traffic volume

(24-hour period). The runs are performed for a typical weekday and weekend in the month of June. The month is randomly selected for the analysis and seasonal factors are used to account traffic variations of other months (refer section 3.4.1) in order to estimate annual emissions. Temporal emission variations can also be modelled in MOVES by performing different runs for different seasons and different times of the day. However, due to data limitations such temporal variations are not considered in this research.

3.3.3 MOVES Run Specifications

MOVES runs allow the user to define the place, time, vehicle type, fuel type, road type, and pollutants for analysis. These run specs can be customized by selecting the respective panel provided in the MOVES graphic user interface. For this research, the following run specifications are employed in respect to the study area and desired output:

(1) **Scale** – Project Scale, as it uses data at a disaggregated level to estimate emissions;

(2) **Time** – The run is performed for four peak hours in a typical weekday and weekend during the month of June including 7 am to 8 am, 8 am to 9 am, 4 pm to 5 pm, and 5 pm to 6 pm;

(3) **Geographic Bound** – allows selection of county from different states in the US. MOVES contain default geographic data for each county in the State. Since no such information is available for Canada, Erie County, NY, is selected due to its proximity to Canada.

(4) **Vehicle/Equipment** – This panel is used to choose the type of vehicles for which the analysis is performed. MOVES contain 13 vehicle types, also called “source types" and five fuel categories, from which various combinations can be selected based on the local fleet type. Multiple combinations available in MOVES (represented by ‘X’) and the choices selected (represented by color) for this research are presented in table 3-2 below.

Table 3-2: Vehicle Type selected for the MOVES Run

Fuel Category	MOVES Source Type												
	Motorcycle	Passenger Car	Passenger Truck	Light Commercial Truck	Intercity Buses	Transit Buses	School Buses	Refuse Trucks	Single Unit Short-Haul Trucks	Single Unit Long-Haul Trucks	Motor Homes	Combination Short-Haul Trucks	Combination Long-Haul Trucks
Gasoline	X	X	X	X		X	X	X	X	X	X	X	
Diesel		X	X	X	X	X	X	X	X	X	X	X	X
CNG						X							
E85-Capable		X	X	X									
Electricity		X	X	X									

(5) **Road Type** – Since all the roads within the study area are urban and have unrestricted access, 'Urban Unrestricted Access' type is selected out of 5 different options – rural restricted, rural unrestricted, urban restricted, urban unrestricted and off-network. The selected road type determines the default drive cycle on a link. For example, for unrestricted roads, MOVES assumes a stop-and-go driving cycle with multiple accelerations, de-accelerations, and short periods of idling. In contrast, for restricted road types, higher cruise activity with less time accelerating and idling is assumed.

(6) **Pollutants** & **Processes** – This panel is used to select different pollutants and vehicular emission processes such as running exhaust, start exhaust, and idling exhaust. For this research, all the GHGs and their prerequisites are selected, including Hydrocarbons, Volatile Organic Compounds, Methane (CH4), Nitrous Oxide (N2O), Carbon dioxide (CO2), CO2 Equivalent, and Energy Consumption. All the processes responsible for emitting these gases are also selected for the run, which includes – running exhaust, start exhaust, evaporation permeation, evaporation fuel vapor venting, refueling displacement vapor lost, refueling spillage loss, extended idle exhaust, and auxiliary power exhaust.

Once the run specifications are finalized for the study area, the output panel determines the output's level of detail. For this research, the default setting of each link's hourly emissions is used. Note that other panels, including manage input datasets, strategies, and advance performance, are not used for project-level analysis; therefore, they are ignored here.

3.3.4 Input Data

Once run specifications are selected, the last and most important step is to enter data in the required format. The data tables are entered in the MOVES using Project Data Manager (PDM), an option provided in the pre-processing tab. The PDM comprises various data tables where specific data types can be entered. These include: Meteorology Data, Age Distribution, Fuel, Inspection & Maintenance, Link Source Type, Links, Link Drive Schedule, Operating Mode Distribution, Off-Network, Hotelling, and Retrofit Data. In some cases, locally accurate data must be entered to capture the local context properly to ensure the model reflects the 'real' situation being assessed. For others, conversely, default data already available in MOVES can be used. In this research, the following data was used to obtain results (detailed data tables provided in Appendix-A).

Meteorology Data – Mean temperature of 16.6 degrees Celsius and humidity 73% is used for analysis of Kitchener-Waterloo in June (Kitchener-Waterloo Weather Station, data 2015).

Vehicle Age Distribution – Local/ regional vehicle fractions by age and type of vehicle must be used to get accurate emissions results. However, no such data is available for the Region of Waterloo; therefore, Canada's Vehicle Survey 2009 report was used. The report provides the number of vehicles registered in Ontario by model year (1991 to 2010) and vehicle category (light, medium and heavy vehicles), detailed data tables are provided in Appendix-A (Canada Vehicle Survey: Annual 2009).

Vehicular Modal Split – MOVES' data entry option 'link source type' captures on-road traffic composition or vehicular modal split, which can be the same or different for each link. The traffic composition for the Region of Waterloo's traffic composition was not available. Therefore, traffic data for the comparable Region of Durham, is used to estimate traffic composition factors, details of which are explained in the subsequent section.

Link Characteristics – The data entry option 'link' is one of the most essential used for the analysis as it captures traffic volume, road type, and link characteristics, including link length, average link speed, and link gradient. The following data table format is used for the analysis.

Table 3-3: Link Data Table format for MOVES

Link ID	Region ID	Road Type ID	Link Length (km)	Link Volume	Link Average Speed (km/hr)	Link Description	Link Average Grade
1	001	5			3	Queue	0
2	001	5			28	Approach	0
3	001	5			28	Departure	0

Each defined link is given an ID number (n = 846) consistent in each data table. The Road ID '5' which corresponds to urban unrestricted access road type, is used. The link length is calculated in kilometres for each link using ArcGIS, and queue length of 100 m, corresponding to 15 cars, is assumed at larger intersections. The average Link Grade is considered 'zero' throughout the area, given the relatively flat terrain of the study area. The average link speed of 45 km/hr (28 miles/hr) for approach and departure link and 5 km/hr (3 miles/hr) for queue link is assumed based on the average posted speed limits i.e., 40-50 km/hr. The link volume or the total traffic volume was estimated using Average Annual Daily Traffic (AADT) data available for the Region of Waterloo for the year 2015. The Region calculates total traffic volume on all regional roads and intersections and converts it into AADT. However, MOVES require hourly traffic volume data; due to the lack of such data, AADT is converted to hourly traffic volume using various seasonal factors, details of which are explained in section 3.4.

Fuel –MOVES' fuel data options include Fuel Supply, Fuel Formulation, Fuel Usage, and Alternative Vehicle and Fuel Technology. These define the type and properties of fuel available in the region. The MOVES user guide recommends the use of default data sets; therefore, they are used for this research.

3.4 Traffic Volumes and Modal Split

Traffic volume data is essential to run MOVES. The Region of Waterloo's Average Annual Daily Traffic (AADT) 2015 data is used to estimate hourly traffic volume on each link in the study area. AADT is defined as average traffic on given days of a year at a given location on a road segment. The Region of Waterloo conducts annual surveys to collect traffic volumes along all regional roads to determine AADT, the latest study being held in 2015Various methods are being used to estimate AADT, the average method being the most accurate. The average method takes all the traffic volume passing a road segment in both directions in a year and divides it by the number of days in a year. However, there are operational challenges to this method, given the scale of resources required to conduct surveys. One of the most common and traditional methods used is the American Association of State Highway and Transportation Official's (AASHTO) factor method (Islam, 2016; Keehan,017). This method is used for road segments without permanent count stations. The mathematical formula to estimate AADT using the factor method is:

AADT = ADT X AF X SF X G

ADT - Average Daily Traffic; AF - Correction Factor (if needed); SF - Seasonal Factor; G - Growth Factor (if needed)

As mentioned before, the MOVES project scale analysis uses hourly traffic volumes to estimate hourly emissions for a typical weekday or weekend of a specific month. This research, therefore, uses the above formula to calculate Average Daily Traffic (ADT), which is further used to calculate hourly traffic on each link within the study area. The seasonal and hourly factors from various sources are used to convert the Region of Waterloo's AADT to ADT and hourly traffic, respectively, details of which are provided below.

3.4.1 Seasonal Factors (SF)

The AADT is converted into ADT using the following seasonal adjustment factors, see table 3-4. The factors are defined for weekday and weekend traffic across 12 months. Since, the local data was not available at the time of research, monthly adjustment factors from the City of Toronto's report on congestion trends, 2011-2014 are considered for the analysis. These factors are based on the cross-sectional data from the Ministry of Transportation for the 400 series freeways in the Greater Toronto Hamilton Area (GTHA). Since, the traffic volumes on 400-series freeways largely contribute to the local commercial traffic, therefore the data is used to estimate average weekday and weekend traffic for the study area.

Table 3-4: Seasonal Adjustment Factors

Months	Weekday	Weekend
Jan	0.985	0.780
Feb	1.015	0.810
Mar	1.045	0.840
April	1.040	0.830
May	1.020	0.815
June	1.042	0.835
July	1.040	0.832
Aug	1.060	0.850
Sep	1.068	0.860
Oct	1.062	0.855
Nov	1.075	0.870
Dec	1.030	0.820

3.4.2 Hourly Factors and Modal Split

The hourly factors for the Region of Waterloo's traffic were not available during the research. Therefore, Cordon Count Data from the Data Management Group is used to estimate hourly factors which were further applied to the Region's traffic. The Data Management Group is a custodian of traffic data collected through Transport Tomorrow Survey (TTS) and Cordon Count programs. The cordon count data provides traffic volume and traffic composition at selected points on the regional roads in six GTHA Regions, including Hamilton, Halton, Peel, York, Toronto, and Durham. The Region of Durham is comparable to the Region of Waterloo in terms of population, density (see table 3-5). Therefore, for the analysis, the hourly traffic distribution and traffic composition are assumed to be the same for the two regions.

Table 3-5: Region of Waterloo and Region of Durham

Factors	Region of Waterloo	Region of Durham
Population (2016)	535,154	645,863
Population Density (people/sq km)	390.9	255.9

2016 Cordon Counts for the Region of Durham are used for the analysis. The data provides hourly (6 am to 8 pm) traffic volumes by modes for 448 survey stations across the region. A total of 69 stations are identified for the analysis representing both north and southbound traffic on various arterial roads in the region, which are comparable to that in the study area (Waterloo). Average data from the identified survey stations are used to determine the hourly factors (see figure 3-5 below). Since hourly traffic for the Durham Region is available from 6 AM to 8 PM, the hourly factors are re-adjusted to 24-hour duration to get more accurate results. It is assumed that 85% of the traffic flow is between 6 am to 8 pm based on the Hourly Distribution of Vehicle Trips by Land use data, ITE Trip Generation Manual, 10th Edition.

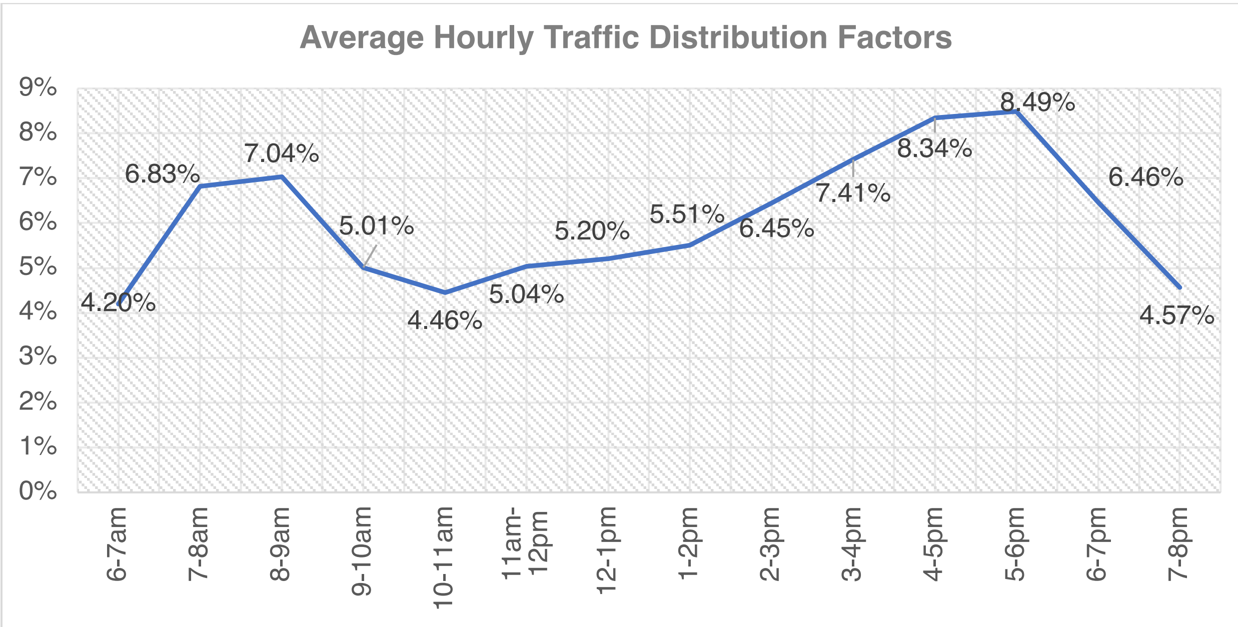

Figure 3-5: Hourly Traffic Factors Assumed for the Study Area

The analysis assumes the fleet composition is the same for the Regions of Waterloo and Durham. The following modal split is estimated for the Region of Durham based on the cordon count data.

Table 3-6: Modal Split for the Region of Durham

Vehicle Type (Durham Region)	Average Modal Split
Autos, Passenger	89.99%
Light Trucks	5.63%
Medium Trucks	1.69%
Heavy Trucks	1.56%
Trailer Combination	0.03%

The vehicle categories provided in the Region of Durham's cordon count data (Table 3-5) are different from those used in MOVES. Categorizing commercial vehicles is always a challenge in freight transportation studies as no standard classification system exists to differentiate between commercial and passenger vehicle activities. Vehicle classification in MOVES is based on the

Federal Highway Administration (FHWA) classification, a standard system used in the USA. Therefore, based on the gross vehicle weight rating (GVWR) provided by FHWA, commercial and passenger vehicles in the study area are categorized (see table 3-6).

Table 3-7: Vehicle Classification for the Study Area

Vehicle Class, Study Area (MOVES)	Durham Region's Vehicle Class	Vehicle Class (FHWA)	GVWR in kg	Example
Passenger Cars	Auto, Passenger	Class 2b Trucks with 2 Axles and 4 Tires	3,855 - 4,535 kg	All Cars with or without one or two axle Trailers
Passenger Trucks	Auto, Passenger	Class 2b Trucks with 2 Axles and at least 6 Tires or Class 3 Trucks	3,855 – 6,350 kg	Pick-ups, Vans with or without one/two axle trailer
Light Commercial Trucks	Light Duty Trucks	Class 4 & 5 Trucks	6,350 - 8618 kg	Two axle trucks
Single Unit Trucks (52)	Medium Duty Trucks	Class 6 & 7 Trucks	8,618 - 14,968 kg	3 or more axle single unit trucks, also includes dump truck
Combination Trucks	Heavy- Duty- Trucks and Trailer	Class 8 and above	>14,968 kg	Multiple axle, multiple combinations, Garbage Truck, Const. Truck

To generate emissions at a disaggregated level, MOVES further classifies passenger vehicles into cars and trucks and medium and heavy commercial trucks into short-haul and long-haul. The level of classification is justified as the different fuel types used in these vehicles generate emissions at different rates. Therefore, the following assumptions are made to determine the modal split (see table 3-7) and sub-categorize passenger and commercial vehicles in the study area

- The ratio of Passenger Cars to Passenger Trucks used is 55:45, based on the 2009 Passenger Vehicle Survey.
- Single Unit Trucks are considered the same as Medium Trucks and Combination Trucks as Heavy and Trailer based on their respective gross weight range(table 3-6).
- The ratio of Single-Unit and Combination trucks short haul to long haul is 98:2 and 80:20, respectively, based on study of commercial vehicle movement in the GTHA (Metrolinx, 2010).

Table 3-8: Modal Split assumed for the Study Area

Vehicle Type (FHWA classification)	MOVES ID	Fractions
Passenger Cars	21	0.4949
Passenger Trucks	31	0.4049
Light Commercial Truck	32	0.0563
Single Unit Short-haul Truck	52	0.0166
Single Unit Long-haul Truck	53	0.0003
Combination Short-haul Truck	61	0.0127
Combination Long-haul Truck	62	0.0032

3.5 Emissions at the City Scale

As reported in the literature, many macro models used by regional and local authorities underestimate urban transport emissions as these models consider aggregated transport data such as fuel consumption, vehicle mile travel, and vehicle registries and emissions rates. However, city-scale emissions estimation at a disaggregated level provides more accurate emissions inventories as it includes different vehicle activities such as free flow approach, free flow departure, idling and queuing. In this research, the city's emissions are estimated by extrapolating emissions derived for the study area. The emissions rates generated from MOVES are used to estimate the city's emissions which include emissions from all three link types – approach link, departure link and queue link. The summation of the City of Waterloo's AADT from all the road sections is used to capture local vehicle activity and emissions are estimated based on following formula:

$$CO_2 \text{ Eq} = \text{R} \sum_{n=0}^{k} (L_n V_n)$$

R = Emissions Rates in g/km

L = Road Section Length in km (average length of 240 m is used)

n = number of links in the City of Waterloo

k = counter for summation over n links

V = Average Annual Daily Traffic on each individual links

The emissions derived using the above formula are the approximate transport emissions of the city for the year 2015, which are then used to estimate future projections and analyze the impact of vehicle electrification.

3.6 Emissions Forecasting

As highlighted in the literature, to meet the Paris agreement, the transport sector in Canada needs to reduce its emissions by at least 25% by 2030, which means an additional reduction of 23 Mt from a projected 153 Mt. Canada also plans to become carbon neutral by 2050. With these ambitious targets already set in motion, there is a need to set local emissions reduction targets and align them with national targets. The 2015 transport emissions for the City of Waterloo are projected, based on an increase in traffic and population. The FWHA uses these factors to project AADT based on the following formula which is used to estimate future emissions for the city of Waterloo to 2031 and 2051.

$$\mathbf{AADT_{future} = AADT_{current}\,(1+ AAGR)^{N}}$$

AADT – Annual Average Daily Traffic; AAGR – Annual Average Growth Rate; N – Projected Year

The AAGR plays a major role in traffic projections at the regional level as it reflects the future growth in traffic activities due to multiple factors not limited to population and employment growth. AAGR is often derived from regional traffic demand models and other inputs provided by regional transport authorities. However, as per the FHWA's AADT projection guidelines, the regional population growth rates can be used in absence of these local traffic models. The Region of Waterloo’s traffic demand model is under review; therefore, regional population growth rates were used to project traffic and emissions for the City (see table 3-9).

Table 3-9: Population Growth Rate

Census Year	Population	Annual Growth Rate
2001	456,100 A	-
2006	497,200 A	1.80%
2011	527,400 A	1.21%
2016	556,600 A	1.11%
2031	742,000 P	2.22%
2036	789,000 P	1.27%
2041	835,000 P	1.17%
2046	879673 P*	1.07%
2051	922338 P*	0.97%

(Place to Grow, 2019); A- Actual; P- Projected; * extrapolated for this research

The emissions profile of the city is directly linked to the increased traffic activity, which in this case is governed by the region's future population growth. It is important to understand the emissions sensitivity to these population growth rates. However, due to the limited scope the analysis is not included in this research but is something important to be considered for future work.

3.7 Electrification Adoption Scenarios

The literature highlights the key role of EVS in decarbonizing the transport sector as they emit zero tailpipe emissions. Canada ranks 5th in the world in terms of commercial vehicle production; however, of the1.4 million vehicles produced in 2018, only 0.4% were electric. To achieve emissions reduction targets, Canada is committed to electrifying its vehicle fleet (Sharpe & Lutsey, 2019). One of the main objectives of this research is to determine the future potential of EVs (commercial and passenger) in reducing local transport emissions. Different electrification scenarios for 2031 and 2051 are explored for the City of Waterloo considering increased AADT and proportions of commercial vehicle activities. The commercial to passenger vehicle activity share for 2031 and 2051 is considered based on the Ontario's new vehicle sales data (2000-2019) which shows an average annual growth of 4% in commercial and -3% in passenger vehicles (Statistics Canada, Table: 20-10-0001-01, data provided in Appendix -I). The sensitivity of emissions with increased share of commercial vehicle activity is also assessed for the five following cases:

1. Base case – proportion of commercial to passenger vehicle activity remain same as 2015 i.e. 10:90
2. Case-1, proportion of commercial vehicle activity increased by 10% i.e. 20:80 by 2051;
3. Case-2, proportion of commercial vehicle activity increased by 20% i.e. 30:70 by 2051;
4. Case-3, proportion of commercial vehicle activity increased by 30% i.e. 40:60 by 2051;
5. Case-4, proportion of commercial vehicle activity increased by 40% i.e. 50:50 by 2051;

Finally, future electrification potential for the City of Waterloo is examined for a realistic case of a 10% increase in commercial vehicle activity by 2031 and 20% by 2051. For the realistic case emissions (tailpipe) profile is created for different electrification scenarios including business as usual case i.e. no measures adopted in decarbonizing transport sector in the future. The emissions are estimated for increased traffic and increased proportions of commercial vehicle activities using the similar approach of extrapolation. An ideal emissions profile for the City of Waterloo meeting an 80% reduction target from 2015 levels by 2051 is proposed. The electrification of different class of passenger and commercial vehicles is explored to meet the city's long-term target. Finally, the level of electrification needed to meet the city's 80% emission reduction goal by 2051 is estimated.

4 ANALYSIS

The methods discussed in the previous chapter are applied to the study area, and transport emissions at the disaggregated level are calculated using MOVES project scale analysis. The emission results obtained for the study area are then extrapolated to the whole city of Waterloo, details of which are provided in this chapter. This chapter also presents the emission reduction due to electrification of commercial vehicles for two future state scenarios.

4.1 Vehicle Activity in Study Area

The study area incorporates the urban core of the City of Waterloo along with major commercial corridors and industrial areas. The major land use categories present include commercial, institutional, residential, recreational and uptown. The total area is about 11 sq.km and is served by 30km of arterial and major collector roads. The study area captures approximately 59% (2.5 million) of the total vehicle activity within the city (4.26 million); a significant area that is critical for emissions estimation. Vehicle activity is defined as total number of vehicles moving on distinct road segments per day performing acceleration, deacceleration, queuing and idling, measured as sum of average annual daily traffic on all the road segments in the study area. A total of 11 arterial and major collector roads (refer table 3-1) are studied for the research which represent about 2.5 million vehicle activities daily. University Avenue and King Street together contributes about 41% of the total vehicle activity in the area on a daily basis. The distribution of total vehicle activity on each individual arterial road is provided in the figure 4-1 below.

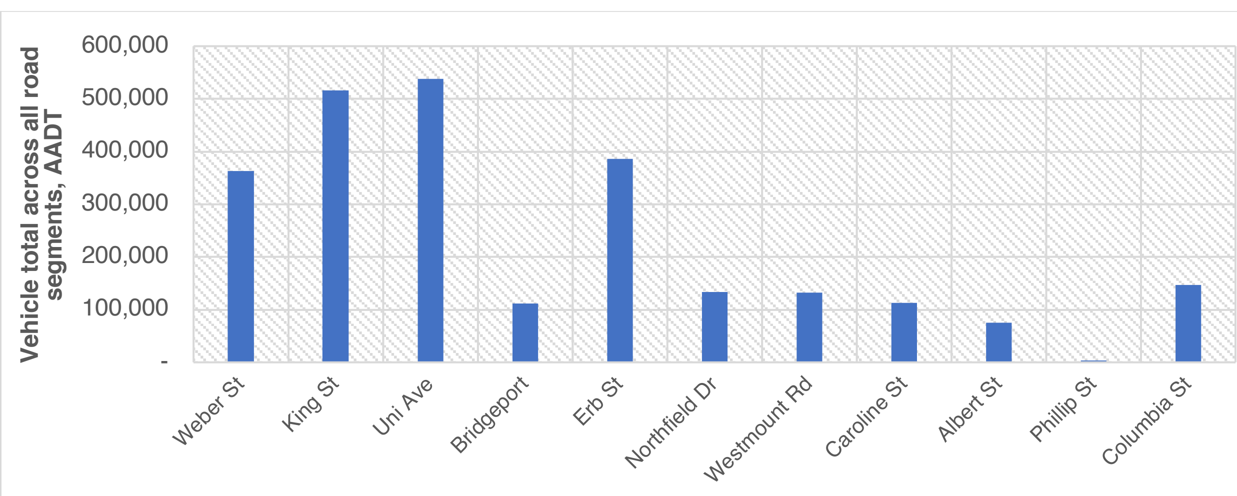

Figure 4-1: Arterial Daily Vehicle Total in Study Area, 2015

The GHG emissions are estimated for different road segments using MOVES project scale analysis. The MOVES take in to account the local transport characteristics including vehicle activity, hourly traffic volumes (estimated from AADT), average speed, vehicle type and local metrological data – temperature and humidity to estimate urban transport emissions at disaggregated level. The emissions are estimated for mainly three type of on-road vehicular movement – approach (deacceleration), departure (acceleration) to and from an intersection and queuing (idling) at the intersection. The emissions are estimated for each road segment in the study area, for which the average annual daily traffic is presented in the figure 4-2.

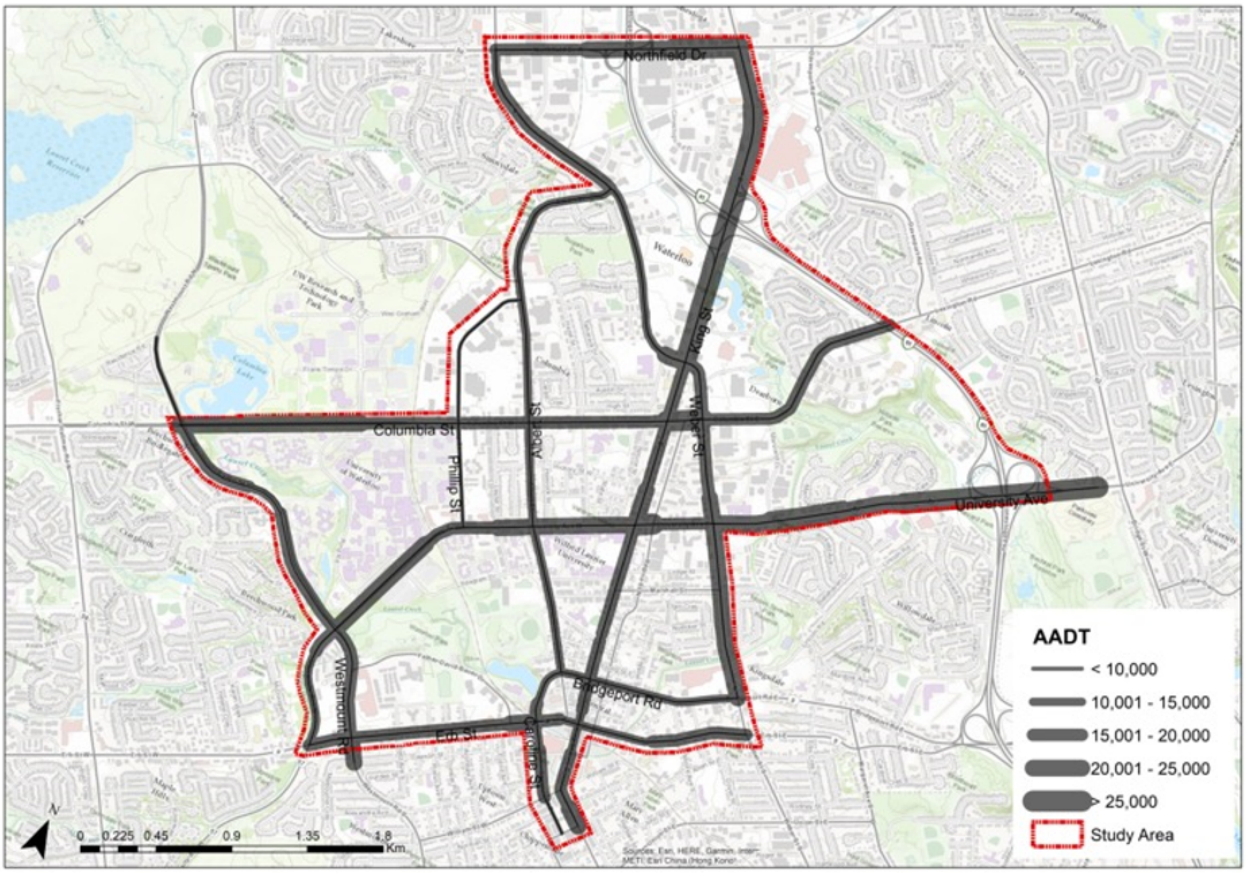

Figure 4-2: Average Annual Daily Traffic in Study Area, 2015

The figure 4-2 shows that the highest traffic per day is recorded on University Avenue and King Street on the segments which are closer to the highway. Using different seasonal and hourly factors provided in the methodology, AADT is converted into hourly traffic volume (data table provided in Appendix-C) and emissions are estimated for different vehicle type during the peak hour of a typical weekday in the month of June. The vehicular modal split for the study area is assumed to be similar to that of the Region of Durham, as per the details provided in section 3.4.2. Of the maximum number of vehicle activities, about 90% are from passenger travel and only 9% are from commercial travel. The distribution of vehicle activities for different vehicle types are provided in the figure 4-3. Five types of vehicle are considered for the analysis including passenger car and passenger trucks, light commercial vehicles, single unit trucks (medium duty vehicles) and combination trucks (heavy duty vehicles and trailers), vehicle classification used for the study area is provided in methods chapter, refer table 3-6.

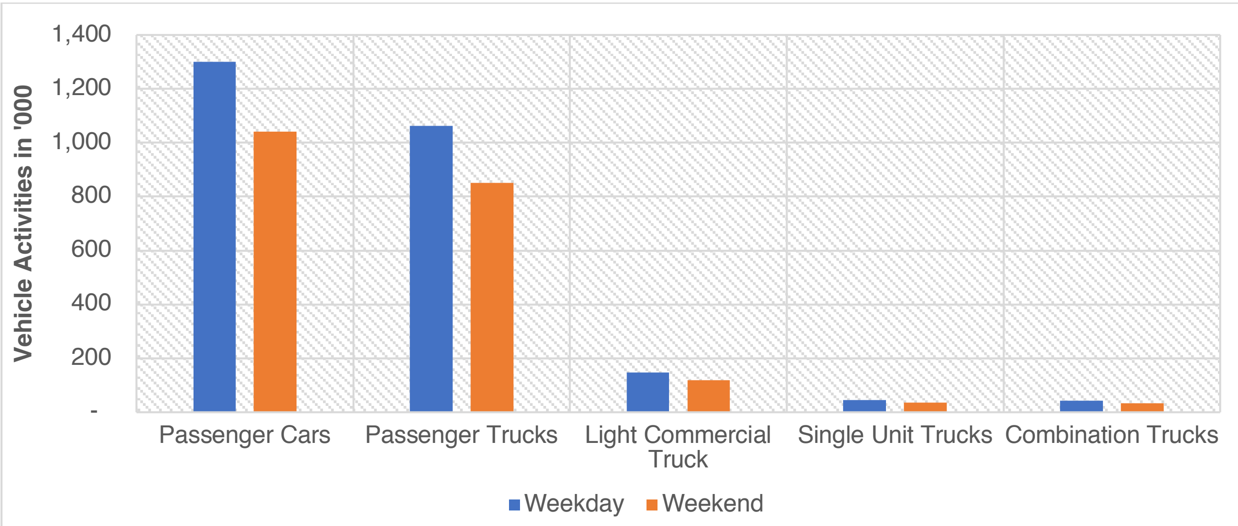

Figure 4-3: Vehicle Activities from different types of vehicles

The vehicle type is critical for the emissions estimation as the emissions rate during free flow and idling differs for different types of vehicles. It is observed that emissions rate is much higher for commercial vehicles, meaning, they emit more GHG per kilometer traveled than a passenger vehicle.

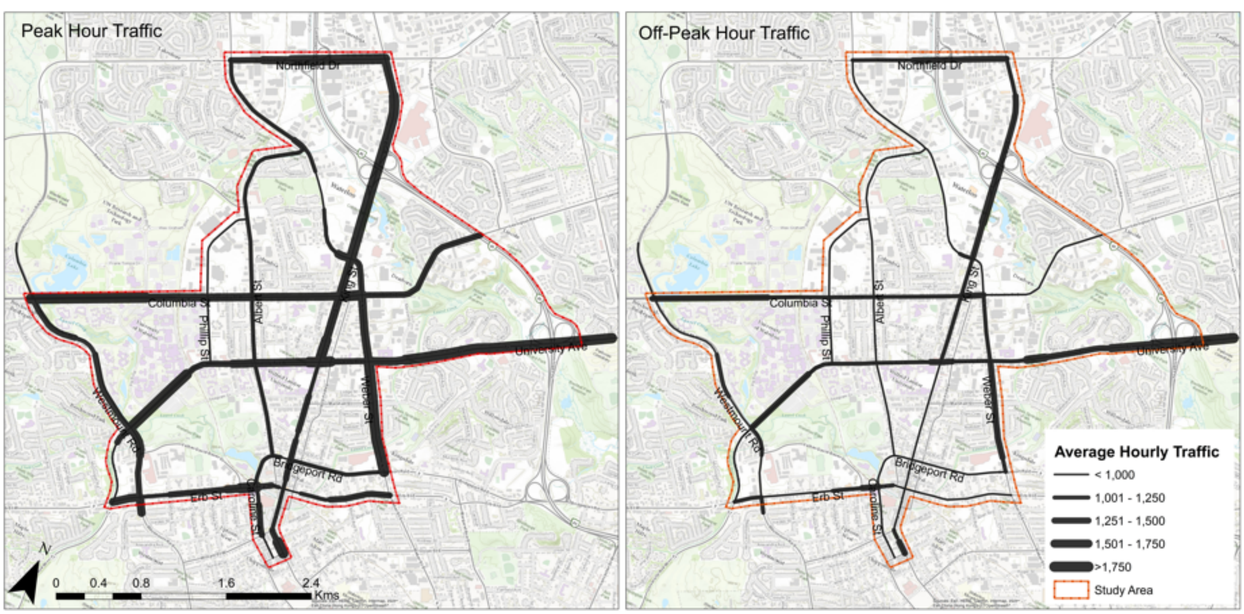

Figure 4-4: Link wise average peak and off-peak hour traffic

The emissions for the study area are estimated for morning and evening peak hours (7am-9am and 4pm-6pm), which comprise 31% of the total daily traffic. The average peak hour traffic is observed to be more than 1,700 vehicles on various segments of Columbia Street, King street, Northfield drive and University Avenue (see figure 4.4)The high level of traffic activities observed on these road segments during the peak hour is linked to the surrounding land use (Academic, Commercial, Uptown and Employment). Significant traffic activities on some road segments closer to Highway-85 on University Ave, King St and Northfield drive is also observed during off-peak hours. The peak and off-peak hour vehicle activities are used to estimate hourly emissions which are further extrapolated to estimate daily, and annual emissions in the study area based on different traffic proportions during the day, details of which are provided in subsequent sections.

4.2 Emissions in the Study Area

The study area, with 184,896 vehicle activities per hour happening on the many segments that make up 33 km of major roads, produces 27.93 tons of carbon dioxide equivalent per hour. The similar amount produced from 112 plane trips from Toronto to Montreal and 10 months of natural gas consumption in an average household. The CO_2 equivalent is produced from five types of vehicles and two type of fuel categories with the distribution provided in figure 4-5.

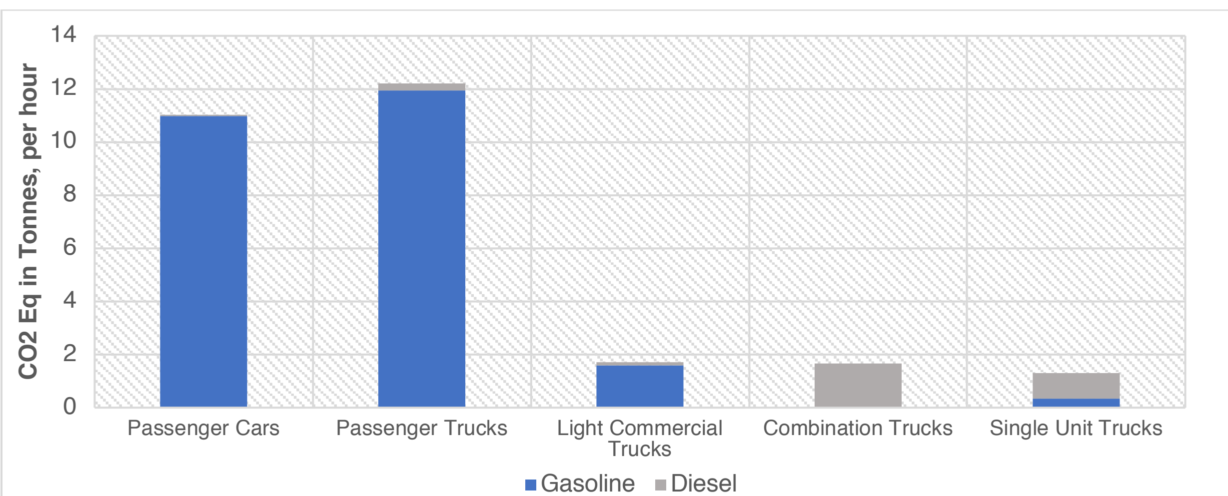

Figure 4-5: CO2 Eq. per hour

Carbon dioxide equivalent is term used to represent different greenhouse gasses including CH_4 and N_2O in a common unit. Since, different gases have different climate impacts, CO_2 equivalents (CO2 Eq) provide an overall impact of all greenhouse gases. It is observed that majority of emissions in the study area, about 82% (22.94 tones per hour of CO2 Eq), are from gasoline powered passenger vehicles, as the majority of the local fleet is comprised of such vehicles. On the other hand, gas and diesel-powered commercial vehicle produce 17% emissions (4.69 tonnes of CO2 eq per hour), however, constitutes only 9% of the total vehicular fleet. It can therefore be inferred that on an average a commercial vehicle produces more CO2 eq per hour than a passenger vehicle. It is observed that, on an average a combination truck, single unit truck and light commercial truck produces 4.7, 3.5 and 1.4 times more emissions than a passenger car respectively.

As per the current scenario, commercial vehicle proportions are much less than that of passenger vehicles, which also reflects from the emissions profile of the study area discussed above. However, literature suggests that freight is a constant growing sand its activities are directly linked to increasing population and economic growth, therefore, cutting down freight activity by reducing VKT may not a viable strategy to mitigate emissions in this sector.

The transport emissions for one of the peak hours (8 to 9am) is estimated for individual road segments and spatially presented in the figure 4-6 below. Such spatial analysis is helpful to identify emission hotspots, which can inform city’s transport and climate mitigation plans.

Figure 4-6: Road Segment wise Emissions (CO2 Eq.) for the Peak Hour (8am to 9am)

Emissions shown above are based on the hourly traffic movement, the considering same vehicle type proportions throughout road segments in the study area. Peak hour emissions are higher on University Ave, King St. and Weber St., which equals to 6.51 (23%), 4.56 (16%) and 4.50 (16%) tonnes of CO_2 Eq per hour respectively. Emissions from these roads segments accounts for 56% (15.57 tonnes of CO_2 Eq) of the total emissions per hour in the study area. The spatial distribution of emissions, using MOVES and Geographic Information System, can help identify pollutant concentrations resulting from high commercial vehicle activity. In addition, emission hotspots can be identified to test and implement new emission reduction strategies as well as play an important role in communicating the impacts of GHG emissions on our community.

4.3 Transport Emissions - City of Waterloo

The City of Waterloo has approximately 180 km of arterial and collector roads serving 139,490 people (2018 Population and Household Estimates for the Region of Waterloo). Spread across 64 sq. km of area, the city's population density is 21.7 people per hectare, which is around five times the overall population density of the Region. The city's land use and built form largely determines transport characteristics and travel behaviors which are very different from that of the region as a whole. According to the city's Transportation Master Plan (TMP, 2018), 74% of the trips made within the city are of length 8km and shorter. Also, the average length of the road segment between intersections is less (~240m) than that in the region (~1.5km). Such variations in the transport network significantly affect the emissions profile within the city boundary as vehicles spend more time idling and queuing at the intersection thus producing more emissions. As of now, the City of Waterloo does not report urban transport emissions, however, the emission inventory is done only at the regional level using fuel consumption-based models, the details of which are explained in section 4.4.

Literature suggests that macro models of emission estimation use data at aggregate level and ignores city's complex transport system. To accurately estimate urban transport emissions, focus is required at disaggregated transport characters such as vehicle counts, modal split, transport network characteristic and travel behavior – vehicle speed, idling time, queue length (Muresan. M, 2015). A comprehensive approach to emissions inventory can help cities to not only support national climate action targets but also to plan for their own reduction strategies especially in the transport sector as it contributes heavily to the overall city's emissions. MOVES project scale analysis provides a micro approach to estimate local on-road and off-road transport emissions at a disaggregated level. For this research the model is applied to the study area, representing 17% of the city's total area and 59% of the total daily vehicle activities. However, the similar methodology can be used to get more accurate emissions for the entire city given the traffic data is available for all the road segments.

For this research, emissions estimated from the study area are extrapolated to the city scale using the vehicle specific emissions rates derived from MOVES study area analysis. The annual average daily traffic for 2015 was available for only 60 km of the arterial and collector roads in the City of Waterloo, representing 4.2 million vehicle activities per day. To extrapolate emissions at the city scale, it is assumed that the transport characteristics in the city including the average speed of vehicles, average road length between intersections, vehicle type distribution are similar to that in the study area. The city's emissions are estimated by multiplying emissions rates (derived from MOVES) with the number of vehicle activities and average trip length, detailed provided in Methods chapter, section 3.5. The results show that total vehicle activity in the city emits 572.66 tonnes of CO2 Eq per day, equivalent to 0.21 million tonnes a year. Daily vehicle specific emissions profile of the city is provided in the figure 4-7 below.

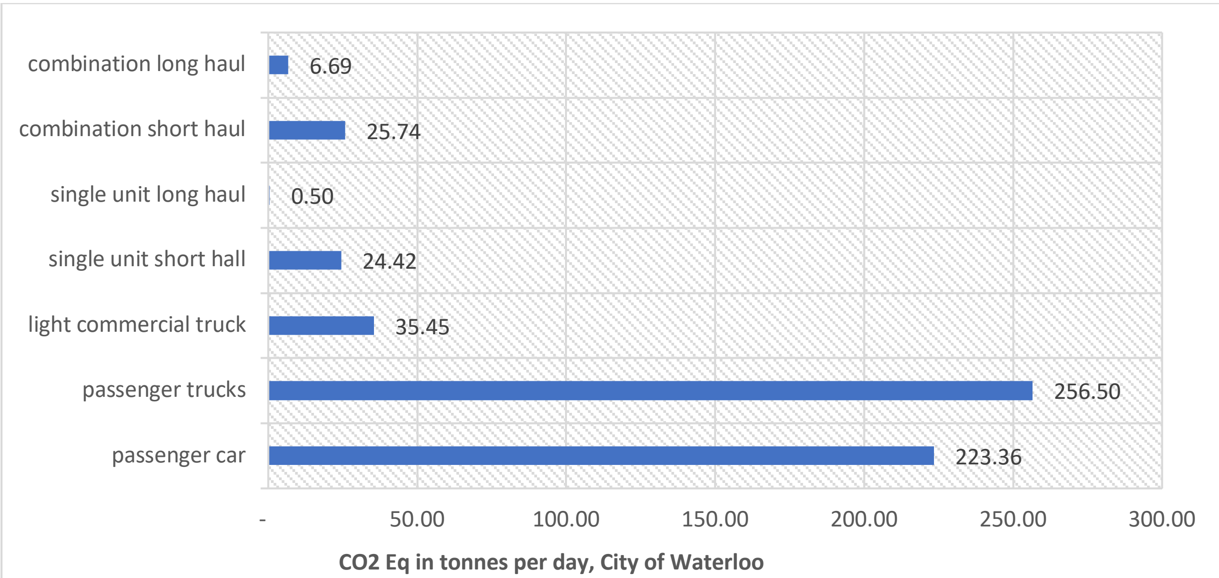

Figure 4-7: Emissions in Tonnes per day, City of Waterloo

The vehicle specific emissions rates for all three type of links – approach link, departure link and queue link are generated for the study area using MOVES (see table 4-1). The same emission rates are also considered while estimating emissions for the city. The emission rate is defined as the amount of CO2 Eq (in grams) produced from a particular type of vehicle running a kilometer of road length and performing different activities – acceleration, de-acceleration, free flow, queuing, idling.

Table 4-1: Emission Rates

Vehicle Type	MOVES Vehicle ID	Emissions Rate of CO2Eq. in gram/km
Passenger car	21	440.99
Passenger trucks	31	618.95
Light Commercial Truck	32	615.69
Single unit short hall	52	1437.29
Single unit long haul	53	1435.55
Combination short haul	61	1979.84
Combination long haul	62	2057.95

The table 4-1 shows that the average emission rate of a combination and single unit truck is almost 4 times that of a passenger car. Although the fraction of these vehicle is very less on city arterials and collector roads (approximately 3%, is assumed), their emission contribution is significant, which is around 57.36 tonnes a day (10% of the city's total daily emissions). Light commercial trucks, on the other hand, have a similar CO2 Eq rate as passenger trucks and contribute around 35.45 tonnes of CO2 Eq per day (6% of the city's total emissions), refer figure 4-7. Currently light commercial trucks only contribute to 3.5% of the total vehicle activity in the City. According to the literature, the fraction of commercial vehicles is anticipated to increase in the future and above analysis suggest that the emission from commercial vehicles will increase at a much higher rate than that from passenger vehicles.

4.4 Comparison with the Regional Estimates

The emissions inventory and reduction strategy for the Region of Waterloo was published in 2013 in "A Climate Action Plan for Waterloo Region in 2020" and updated in "Our Progress, Our Path" Report in 2015. It reports that overall emissions of the Region declined by 5.2% from 4.6 million tonnes of CO2 eq in 2010 to 4.3 million tonnes in 2015. However, the share of transport emissions increased by 5% i.e. 44% (2.0 million tonnes) of total emissions in 2010 to 49% (2.1 million tonnes) in 2015. According to the 2015 inventory, the Region's emissions from transport sector is ~2 million tonnes of CO2eq.

The Region of Waterloo is a part of the PCP (The Partners for Climate Protection) program, a network of Canadian municipalities working together to mitigate the effects of climate change at community level. The PCP provides three different approaches of recording transport emissions at the local scale including (1) fuel sale; (2) vehicle kilometers travelled (VKT); and (3) vehicle registration. The Region of Waterloo uses the fuel sales approach which involves obtaining the total amount of automotive fuel purchased within the community and multiplying it by specific emission rates. This approach is the simplest way to record transport emissions as it requires the minimum resources and data. The total energy (fuel) consumed by all the vehicles operating in the region is multiplied by the emissions factor of different GHGs including CO2, CH4 and N2O and their corresponding global warming potential. The emissions factors for these gases depend on the type of fuel combustion and vehicle technologies. The Region uses emission rates provided by Environment Canada's National Inventory Report (Table provided in Appendix-D). These emissions rates are generalized values for all types of vehicles – light, medium and heavy-duty passenger and commercial vehicles powered by specific type of fuel (gasoline and diesel).

Also, the rates are comparatively low compared to the ones estimated by MOVES for the study area in this research, (see table 4.2).

Table 4-2: Emissions Rates Comparison

Type of Vehicle	Emissions Rate used by the Region g/km*	Emissions Rate from MOVES g/km	Emissions Rate from MOVES (include idling) g/km
Passenger car	230.7	240.57	440.99
Passenger trucks	230.7	355.94	618.95
Light commercial truck	230.7	352.61	615.69
Single unit short hall	230.7	735.91	1437.29
Single unit long haul	230.7	693.48	1435.55
Combination short haul	230.7	1267.44	1979.84
Combination long haul	230.7	1319.08	2057.95

Note: Fuel economy of 10L/100 km is assumed when converting g/L fuel (unit of Region's emission rates) to g/km (unit of MOVES rates).

* Region's emission rates mentioned in the table is for gasoline powered vehicle

**MOVES emission rate is an average for gasoline and diesel power vehicle

MOVES provides different emission rates for different types of vehicles depending on vehicle activity, driving pattern, idling time, vehicle technology, fuel type and model year. However, the Region assumes that the fuel efficiency of different type of vehicles (car, light commercial trucks, combination trucks) is same, therefore uses general emission rate of 230.7 g/km across all vehicle class powered by gasoline. Also, the emission rates used in the Regional emissions inventory does not include emissions from idling or queuing therefore highly underestimates (by almost 50%) the actual emissions from different vehicle activity. This level of discrepancy in the emission rates may not provide accurate emission results especially at city scale with congested roads and more idling and queuing time. Using generalized emission rates for passenger and commercial vehicles may be justified in the current circumstances given that the fraction of passenger vehicles is much higher than commercial (90:10 ratio). However, with increasing demand of commercial activities, emissions from these vehicles would be highly underestimated if a similar approach or standard emissions factors continue to be used. Another disadvantage is that regional emissions inventory is not at a disaggregated level- road segment wise, vehicle type wise, and therefore, it is difficult to quantify the emission reduction potential through various mitigation measures.

The fuel sales approach is based on an assumption that all the vehicle activities in a community are burning and will purchase fuel from that very community. This assumption, however, is not true in many cases, especially for the vehicles making long haul, inter community trips. Emissions from commercial vehicles cannot be accurately estimated using fuel sales methods as their operations are mostly over long distances and cover multiple communities. Therefore, this method may lead to over or under estimation of emissions. The fuel sales approach is typically the simplest for local authorities in terms of data collection. However, PCP points out that the fuel sales collected at the local level may not be comprehensive as fuel delivered to commercial card locks, commercial and industrial operations with fleet fueling stations and small remote fueling stations are often excluded (PCP Protocol, 2014).

Waterloo's Regional Transport Master Plan, (2018) reports an increase in the number of inter-regional trips mainly due to a strong economic and transportation links to the GTHA. The number of trips destined outside the region increased from 50,000 (4.5%) in 2006 to 65,000 (6%) in 2016. The average number of daily trips (inbound and out bound) made to neighboring municipalities in 2016 is presented in the figure 4-8.

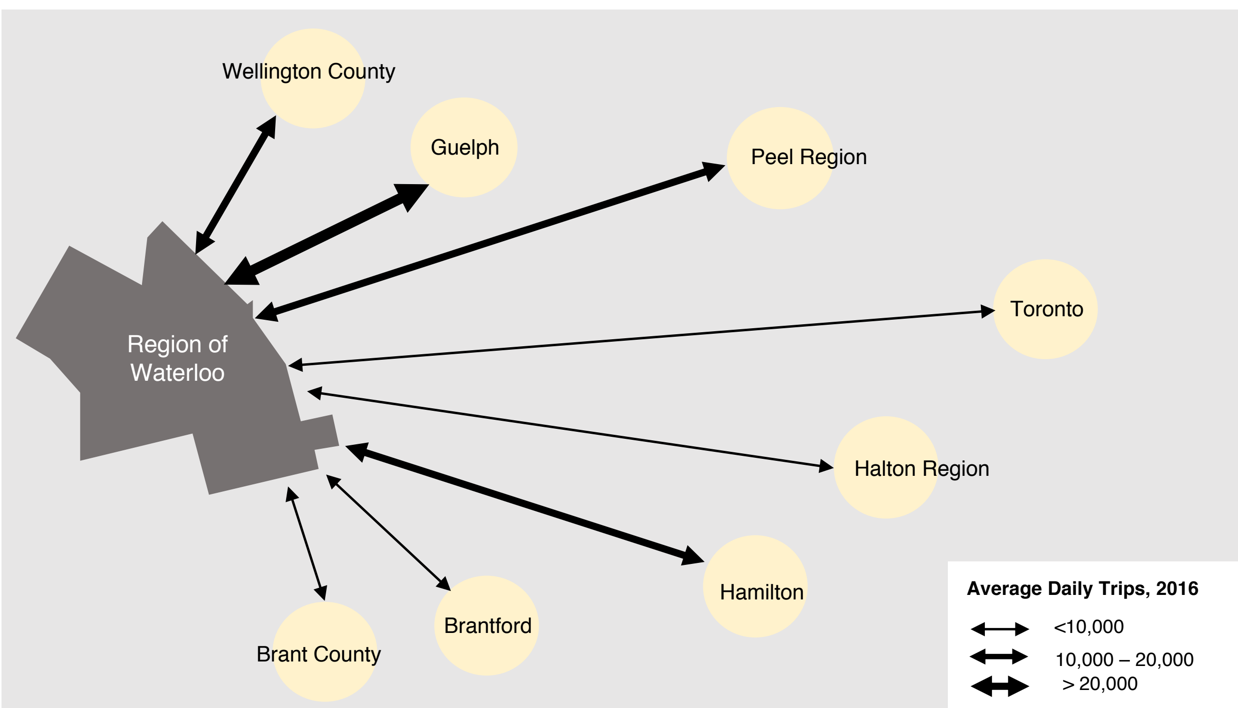

Figure 4-8: Inter Regional Trips (inbound and out bound) per day, 2016

Source: Transportation Master Plan, 2018

As per the TMP, more than 90,000 daily inter-regional trips were made on an average to and from the Region of Waterloo in 2016. Therefore, the significant number of inter-regional trips challenges the accuracy of fuel sales approach currently used by the Region of Waterloo.

The Region of Waterloo comprise of tri cities of Kitchener, Cambridge and Waterloo, which are of different sizes in terms of population, economy and traffic. According to the Regions' AADT data 2015, the city of Waterloo's total vehicle activities recorded per day was 4.2 million as compared to 5.6 million in Cambridge and 8.8 million in Kitchener. Therefore, we would expect that the emissions profile will be different for the three cities. Since, fuel sales data is not available at the local level, the regional approach of emission estimation fails to provide community specific transport emissions.

Based on above arguments, it can be concluded that Regional emission estimates are inaccurate and fail to provide transport emissions profile at disaggregated levels. According to the 2015 emission inventory, the Region of Waterloo produced 2 million tonnes (49% of total Region's emissions) of CO2 eq in the transport sector. This number includes all the direct and indirect transport emissions from the community and corporate operations including emissions from regional transport services, maintenance and construction. The number is estimated using regional fuel sales data and generalized emission rates; therefore, its accuracy is highly doubtful. In addition, following aspects are also missing from the region's estimates:

- The regional transport emission number does not provide proportions from different vehicle types – commercial, passenger; light, medium heavy duty etc.
- Regional transport estimates do not include emission from idling or queuing, which is significant in an urban setting.
- Community specific emissions, important to prepare community action plans, future reduction targets and mitigation strategies, cannot be deduced from the region's inventory.

On the other hand, transport emissions from MOVES are more accurate and available at disaggregated level. The MOVES use hourly traffic volume and vehicle movement pattern (speed during approach, departure and queuing) along with other meteorological and geographical factors. The emission factors generated by the model are based on the time each type of vehicle spends performing different on-road activities. Based on the micro approach used for the study area and extrapolation done at the city scale, it is estimated that city of Waterloo produced 0.21

million tonnes of CO2eq in 2015 as opposed to the regional estimate of 2.11 million tonnes produced in the entire region in the transport sector. The emissions estimated for the city is much lower (almost 1/10th) than the region's estimates. But it is important to note that the city's estimated emission of 0.21 million tonnes of CO2 eq per year is only on-road vehicle activity happening on only 60 km of the city's arterial roads which represents only 1.5% of the total regional road network of 3887 km (arterial and collector road length of 1175km). Also, emissions estimated in this research for the city of Waterloo does not include emissions from construction vehicles, transit buses and off-road activities such as parking. These activities contribute significantly to the city's transport emissions, but due to the data limitations these vehicle activities are not included the analysis.

4.5 Emission Projections and Impact of Electrification

The research's main objective is to assess the future potential of vehicle electrification in reducing urban local emissions. To address this objective transport emissions for the city of Waterloo are projected for 2031 and 2051 and electrification scenarios are created to meet the targeted emissions. The Region of Waterloo's initial target was to reduce 6% emissions below 2010 levels by 2020, however, the new target of 80% reduction by 2050 was adopted by the Region and City of Waterloo, Kitchener and Cambridge in 2018 (Committee Report PDL-CPL-18-26). This new regional target is in line with provincial and federal targets to flight global climate change. Since, almost 50% of the region's emissions comes from the transport sector, reduction in this sector will significantly help meet targets. This section, therefore, demonstrates the level of electrification required in the transport sector to meet the emission reduction target at the city scale.

Emissions estimated for the City of Waterloo are projected for 2031 and 2051 based on the growth of annual average daily traffic and changing proportions of vehicle classes, The base year is 2015 and an average year-on-year growth rate of 1.18% and 1.37% is assumed for 2031 and 2051 vehicle activity projections respectively based on region's population growth rate (see Appendix-E). Figure 4-9 provides projected vehicle activity (the sum of AADT on all road segments in the City of Waterloo).

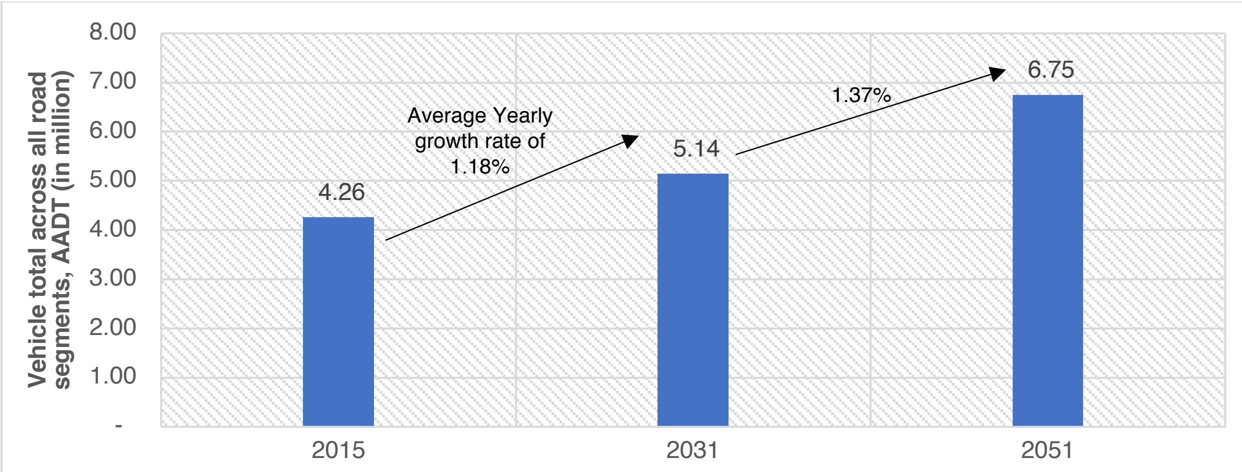

Figure 4-9: Daily Vehicle Activity Total in the City of Waterloo, Projections

For the above vehicle activity projections, emissions are estimated for 2031 and 2051 for the base case, where passenger and commercial vehicle fractions remain the same as 2015 levels (passenger to commercial vehicle activity ratio of 90:10). Four different cases are created each representing a 10% percent change in the commercial vehicle activity. The table 4-3 provide the growth percentages in city's transport emissions (CO2 Eq) from the base case, if commercial vehicle activity share increases.

Table 4-3: Emissions estimation sensitivity to changing commercial vehicle shares

CO2Eq % difference to time frame base case / Vehicle Type	Share of Commercial Vehicle Activity				
	Time frame, Base Case 10%	20%	30%	40%	50%
Passenger	-	-11%	-23%	-34%	-45%
Commercial	-	135%	270%	395%	509%
Total per day	-	12%	25%	36%	44%

Note – Refer Appendix-F, G for absolute emissions for these cases for 2031 and 2051.

The table 4-3 above shows that the estimates of future emissions with higher proportions of commercial vehicles increase base case year estimates overall by ~12% with only a 10% increase in their proportion. For example, in either 2031 or 2051, increasing the proportion of commercial to 10% would see increase from commercial vehicles emissions from the 2031 or 2051 base case (90% passenger 10% commercial) by 135%. The high sensitivity of emissions to commercial vehicle fraction is because emission rates of commercial vehicles are much higher than that of passenger vehicles. Exploring the sensitivity to the proportion of commercial vehicles, it is important to remember that the emissions forecast cases are based on the assumption that all the other parameters including average speed, average link length, and vehicle technology remain the same.

To understand the impact of electrification on emission reduction in the City of Waterloo, a realistic case of 20% share of commercial vehicle (i.e. 10% increase from base case) activity by 2031 and 30% (i.e. 20% increase from base case) by 2051 is assumed. The increase in commercial vehicle activity relative to changes in passenger vehicle activity is assumed based in part on the new vehicle sales in Ontario and correlation analysis which shows that vehicle sales and vehicle activity are highly correlated. The city's total emissions projections are provided in the figure 4-10, with assumed change in proportions of passenger and commercial vehicles provided in Appendix-H.

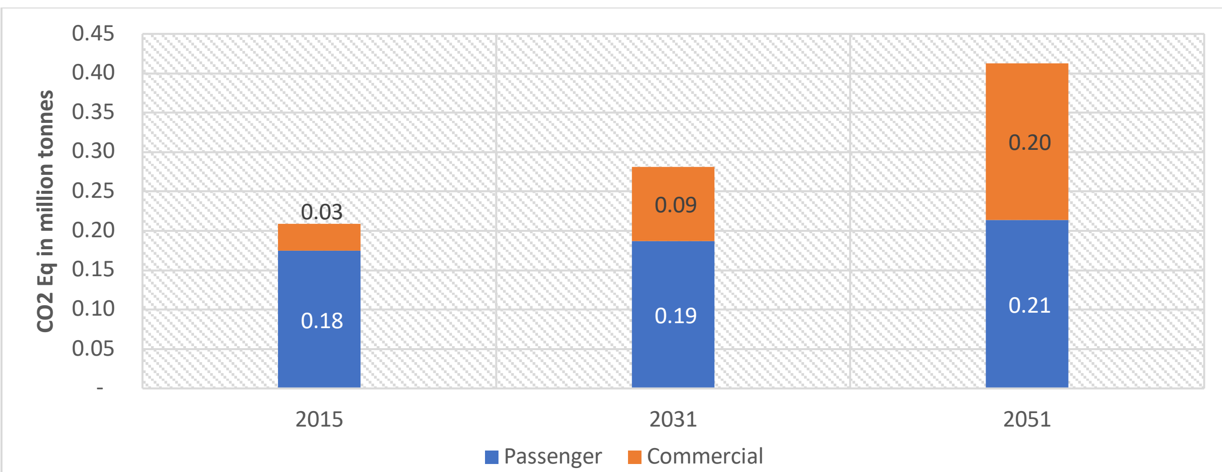

Figure 4-10: Emission Projections 2031 and 2051 - City of Waterloo

Table 4-4: Vehicle specific emission projections 2031 and 2051, City of Waterloo

Vehicle Type	Emissions Projections per year in Million Tonnes		
	2015	2031	2051
Passenger Car	0.082	0.089	0.104
Passenger Truck	0.094	0.098	0.110
Light Commercial Truck	0.013	0.028	0.055
Single Unit short hall	0.009	0.026	0.068
Single Unit long haul	0.000	0.006	0.017
Combination short haul	0.009	0.027	0.047
Combination long haul	0.002	0.009	0.012
Total (million Tonnes)	**0.209**	**0.283**	**0.413**

4.5.1 Impact of Vehicle Electrification on Emission Reduction

As described above, the City of Waterloo's transport emissions are expected to increase from 0.21 million tonnes of CO2eq in 2015 to 0.41 million tonnes in 2051, if business is as usual. The emissions forecast is based on the assumption that commercial to passenger vehicle activity proportions will increase to 20% by 2031 and 30% by 2051 from the base year, while all other parameters remain the same. Based on this assumption and results provided in the section1.5, commercial vehicle contribution will increase to 33% of total transport emissions by 2031 and 48% by 2051 from only 16% in the base year (see Figure 4-10 and Table 4-4).

In line with federal and provincial targets, City of Waterloo's 2050 target is to reduce its emissions by 80% below 2010 levels. Since, the transport sector is the single largest contributor, emissions reduction in this sector will significantly reduce city's total emissions. As mentioned in the literature, one of the most effective strategy to reduce transport emissions (tailpipe) is electrification of vehicular fleet. The Canadian government has also realized the need to decarbonize the transport sector, and therefore has set an ambitious federal target to increase light duty EV sales to 30% by 2030 and 100% by 2040 (Natural Resource Canada, 2019). Under the 'Zero Emissions Vehicle Program, a federal investment of $130 million is allocated to provide localized charging infrastructure across Canada. BloombergNEF, in its 2020 Electric Vehicle Outlook also forecasted an increase in global EV market share to 58% by 2040 from an existing 2.7% (BloombergNEF, 2020). These projections are based on various parameters including falling battery prices, policy pressure to reduce global emissions and emerging technology in the EV models (BloombergNEF, 2020). However, due to Covid-19 pandemic and reduced oil prices, EV adoption rate is expected to be slower but the long-term outlook suggests comparatively higher adoption rate of EVs in some countries like China and Europe (~70% by 2040) as compared to 60% in the US (BloombergNEF, 2020). These projections are based on long-term electrification commitments from auto manufactures across the globe.

Based on these electrification projections and local government targets, the following figure 4-11 is created for the City of Waterloo representing (1) 2051 transport emissions profile if business is as usual; (2) target emissions in the transport sector considering 80% reduction from base year; (3) scenarios of vehicle electrification and their impact on emission reduction.

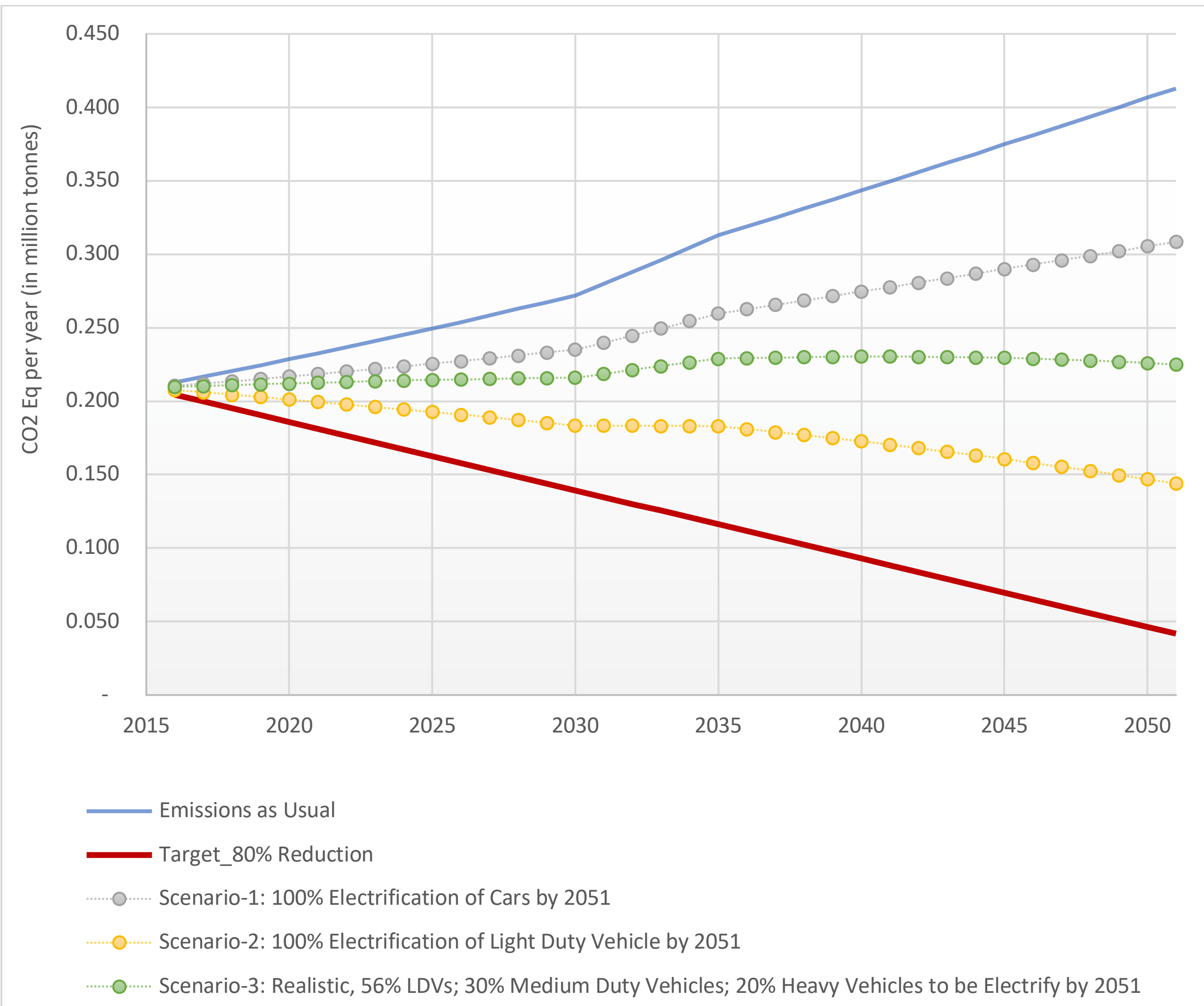

Figure 4-11: Impact of Vehicle Electrification on Transport Emissions, City of Waterloo

Transport emissions in the City of Waterloo are expected to increase by 97% from the base year if business is as usual i.e. limited adoption of EVs across all vehicle categories. However, a reduction of 80% is required to meet regional, provincial and national emission reduction goals. In case of scenario 1, where only passenger cars are electrified by 2051, emissions will reduce by only 25% from the business as usual case. As per the 2013 Climate Action Report and 2015 Progress Report, the Region of Waterloo is planning on electrifying only passenger cars, however, the above analysis shows that this approach is not sufficient to meet the long-term target.

Scenario-2 is based on the federal government's target of electrification of light duty vehicles (LDV) which include passenger cars, passenger trucks and light-duty commercial trucks. The majority of vehicle activities in the city is through LDVs, and therefore the electrification of this category will significantly reduce transport emissions. However, analysis shows that with even 100% electrification of LDVs by 2051, emissions will be reduced by 65% from the usual case as opposed to the 80% required. Government of Canada's target is to shift the LDV sales to 100% electric by 2040, however, 100% fleet replacement is not possible during this time as the market adoption rate of EVs depend on various factors including but not limited to lower capital and operating costs as compare to traditional combustion vehicles and availability of required infrastructure. Therefore, a more realistic Scenario-3 is presented based on global EV market adoption rates forecast by BloombergNEF 2020. This scenario assumes 56% LDVs, 30% Medium Duty Vehicle and 20% Heavy Duty Vehicles to be electrified by 2050 which will reduce city's emissions by 45% from the usual case. The emissions considered in the above analysis are only from tailpipe, however, life cycle emissions of EVs should be factored in for more accurate projections.

The above scenarios, however, are not sufficient to meet the city's long-term emission reduction target. The most optimistic scenario 2, where all light duty vehicles are electrified, will still have emission reduction gap of 15%. To fill this gap, focus must be given to medium and heavy-duty commercial vehicles (see figure 4-12).

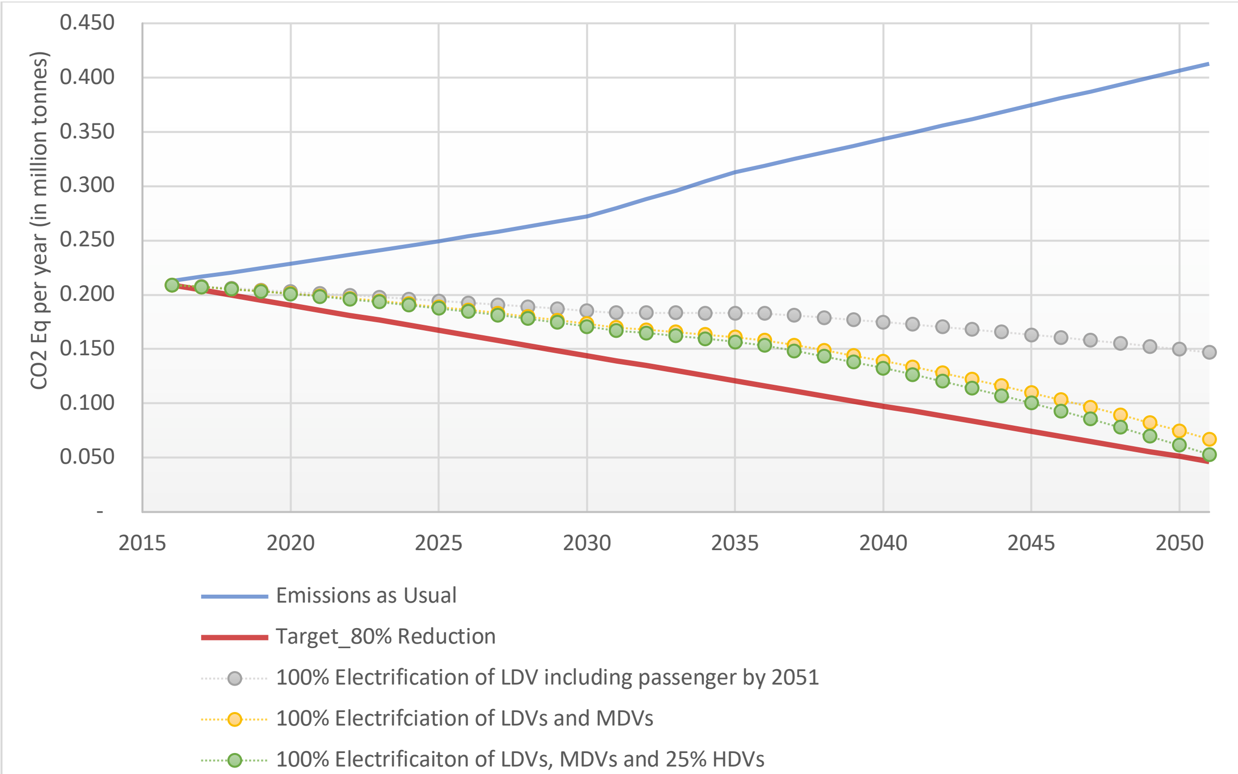

Figure 4-12: Impact of Commercial Vehicle Electrification on Transport Emissions, City of Waterloo

The figure 4-12 shows three different cases of commercial vehicle electrification in addition to passenger and their impact on emission reduction. The first case which is similar to scenario 2, mentioned in the section above, will reduce emissions to only 65% while target is to achieve 80% by 2051. It is possible to meet this target if heavy and medium duty vehicles are electrified as well. As shown in the figure 4-12, 100% electrification of Light Duty Vehicles and Medium Duty Vehicles by 2051 can reduce emissions to 72% and with partial electrification (25%) of heavy-duty vehicles, the city's long-term target of reducing transport emissions to 80% below 2015 levels can be met.

By 2051, medium and heavy commercial vehicles activity in the city of Waterloo is expected to increase to 15% of overall vehicle activities from 3.28% in the base year. Since, these vehicles consume almost 30 times more fuel than average passenger car, electrification will significantly reduce fuel consumption and therefore total emissions. However, it is challenging to achieve the transition as commercial vehicles carry heavy cargo over long distances and operate on low cost and high efficiencies. EVs trucks therefore would require powerful and cost-effective batteries along with sufficient charging infrastructure for businesses to adopt them. As discussed in literature, long-haul electric trucks or BETs available currently in the market cost almost three times more than traditional trucks and their overall cost of ownership is also not currently competitive enough. The lack of charging infrastructure is another major barrier to BET adoption in addition to reluctance of auto manufactures to invest in new technologies. Furthermore, the electricity required to charge a heavy-duty electric truck is enormous, at almost 8 times than a typical light duty vehicle and will put additional demand on the power grids. Also, the weight and cost of batteries that would be required to carry heavy cargo over long distances would be enormous. For example, a typical heavy-duty electric truck with a range of ~956 km would require a battery weight of ~14,000 kg which would cost around $300,000 (Poovanna, P. 2019). Despite these barriers, to meet the emissions target and fight climate change, commercial vehicles electrification is inevitable and underway in many countries such as China, Norway, Germany, USA. Many auto manufacturers and startup are now looking to innovate and decarbonize long-haul trucking industry (Nikola Motors, USA; BYD, China; Daimler Trucks, Germany; Rivian, USA; Volvo and Tesla, USA). Canada also needs to advance its policies and technological innovations, policies to provide required infrastructure and innovations to bring down the effective cost so that commercial trucks can feed the Canadian supply chain sustainably and cost effectively.

5 CONCLUSION

In this research a new approach to estimate urban transport emissions at a disaggregated local level is developed and its utility is explored. Conventional methods of emission estimation use aggregated data including fuel sales, vehicle kilometer travelled and generic emission rates. There have been many studies that argue that these approaches provide inaccurate results if applied at urban local context. The transport sector is one of the major contributors of GHGs and most challenging to decarbonize as it is heavily depended on fossil fuels. Electrification seems to have promising results in terms of reducing tailpipe emissions. However, the market penetration rate of EVs is expected to take a dip with the onset of Covid-19 pandemic and continuously falling oil prices, especially in freight sector as its operations are based on cost minimization.

In the long-term, EVs are expected to have majority sales worldwide as many counties and auto manufactures have shown serious commitments towards transitioning the transport sector to fully electric. As an initiative to fight climate change and reduce transport emissions, Canada too has set a national target to shift all its auto sales of light duty vehicle to 100% electric by 2050. Various policies and local climate action strategies are already in place to mitigate emissions in the transport sector including but not limited use of transit, active transportation, reduce transportation demand, alternative fuel etc. However, there is no means to quantify the effectiveness of these strategies in terms of emission reduction potential. Also, emissions from passenger transport are usually tackled differently than that from commercial. The commercial vehicle activities are linked to economic growth and increased population, thus reducing vehicle kilometer travel and overall commercial transportation demand is not the most viable strategy to reduce emissions in this sector. There is a need to adopt a better way to periodically report and monitor local emissions in the transport sector at disaggregated level. This research uses the Motor Vehicle Emission Simulator (MOVES) model created by the EPA to estimate urban transport emissions at disaggregated level for the Waterloo study area. There are various benefits of using this type of micro simulation model as it uses traffic data and local transport network characteristics and incorporates emissions and energy requirements for individual vehicle classes.

The main objective of this research is to provide a methodology for estimating transport emissions at local urban level. The method can be used by municipalities to report the transport emissions at disaggregated levels which can further guide local climate change mitigation plans and policies. The possible implications of fleet electrification are also analyzed in terms of meeting future emissions reduction goals. A contextualized model (MOVES, project scale) developed during this research is applied to a case study area selected with in the city of Waterloo and an amount of CO2eq produced from different vehicle activity levels per year is estimated. The results obtained are then extrapolated at the city scale and different scenarios of vehicle electrification are analyzed. Estimates from the Waterloo model indicate that, about 83% of emissions are from passenger vehicles including passenger cars and trucks which constitute about 90% of the vehicle activity in the area. According the Waterloo study area model, commercial vehicles on the other hand contribute only 9% of the vehicle activity but are responsible for almost 17% of total emissions. This is because commercial vehicles have much higher emissions rate meaning they produce more CO2eq per km than an average passenger vehicle. The extrapolation of emissions at the city scale is done considering vehicle specific emission rates obtained from MOVES study area analysis.

Based on the extrapolation and MOVES study area results, the City of Waterloo emits 572.66 tonnes of CO2Eq per day, equivalent to ~0.21 million tonnes a year on an average. Currently 90% of the total transport emissions in the city are from light duty vehicles including passenger cars, trucks and light commercial vehicles as these vehicles contribute majorly to the total vehicle activities. The heavy and medium duty vehicle contribute to a smaller vehicle activity share in the city (only 3%), but their emissions are significant (10%) which makes this vehicle class extremely critical for emission reduction. The research's objective is also to assess the future potential of vehicle electrification in reducing urban local emissions, therefore, to address this objective transport emissions for the city of Waterloo are projected for 2031 and 2051 and electrification scenarios are created to meet the targeted emissions. Research findings suggest that by 2051, the vehicle activities in the City of Waterloo will increase by 58% and transport emissions by 95% from that in base year. With the city's new target of 80% reduction in total emissions by 2050, electrification of the transport sector seems to provide promising results as this sector is heavily depended on fossil fuel and is the single largest contributor of GHG. However, the current plans of the city and federal government focuses on electrification of only light duty vehicles, which as per the results is not sufficient to meet the 80% target.

If we move forward with business as usual, and in particular no electrification of the overall fleet, the model estimates that transport emissions in the city will increase by 95% by 2051 considering all the parameters other than vehicle composition remain same. However, in a scenario where all passenger cars (excluding pick-ups) are electrified, a reduction of only 25% is possible. Another scenario analyzed for this research based on federal target of 100% electrification of LDVs (passenger and commercial) by 2051 which will also fail to achieve the 80% target as 15% gap will still be remaining. These results show that commercial vehicles, especially the medium and heavy-duty classes are critical to emission reduction plans and the government needs to shift its focus by initiating policy changes and providing infrastructure to promote BETs (Battery Electric Trucks). For city of Waterloo to achieve its 2051 emission reduction target, 100% of LDVs and MDVs and 25% HDVs need to be electrified by 2051. However, this transitioning is quite challenging as there are economic, policy and infrastructure barriers to market adoption of electric vehicles, especially BETs.

From this research, it can be concluded that there is a real value in adopting micro method to estimate transport emissions which can provide local inventory at disaggregated level. Region of Waterloo's 'Fuel Sales' approach of transport emission estimation uses regional fuel sales data and generalized emission rate across all vehicle class. Emissions from vehicle activities such as idling, and queuing are not considered in this approach. Furthermore, this approach cannot provide community specific emissions which are important to prepare community climate action plans and set reduction targets. On the other hand, MOVES use hourly traffic volume and vehicle movement pattern (speed during approach, departure and queuing) along with other meteorological and geographical factors thus captures local transportation environment in a better way. The emission factors generated by the model are based on the time spend by each vehicle class performing different on-road activities. The model can be used to estimate emissions from off-road vehicle activities including parking, therefore is more suitable to generate emissions inventory at community level.

Another inference that can be derived from this research is that commercial vehicles are critical to local economy and to the environment. To meet emission reduction targets, commercial vehicles especially heavy and medium duty play a significant role. The development of new commercial freight operations and e-commerce, especially during and after the Covid-19 pandemic will significantly increase the demand of commercial vehicles which will further increase their share of total emissions. The results discussed above suggest that electrification has a huge potential to reduce tailpipe emissions in transport sector. However, to be able to meet ambitious targets which are already in place in many Canadian municipalities, commercial vehicle electrification is the best way forward. This research also acknowledges various challenges, municipalities will have to face in decarbonizing the transport sector. To overcome these challenges joint effort from federal and local government is required to provide suitable charging infrastructure, subsidies & incentives to balance the cost difference and investments in research and innovation to ultimately reduce the overall cost of ownership of EVs and BETs.

The results presented in section 4.3, 4.4 and 4.5 are based on various assumptions therefore are subjected to any changes in the exiting circumstances. The annual average daily traffic data for 2015 is used to estimate emissions for the study area and the city of Waterloo. The AADT was available for only 60km out of 180km of city's arterial and collector road network, therefore, the actual transport emissions for the city will be higher than the emissions estimated using extrapolation in section 4.3. Also, the proportion of vehicle classes assumed on the study are roads is based on data available for the Region of Durham. The vehicle class might differ on different type of roads – arterial, collector, local etc., therefore it is recommended to collect real time data to get accurate emission results. In this research, MOVES is applied to the study area and results obtained are extrapolated to the whole city, however, for more accurate results it is recommended to use to the model for the entire city given the availability of traffic data. The emission projections provided in the research are based on population growth factors and assumption that driving behavior and other characteristics such as fuel type, average speed, meteorological data etc. remain the same. However, a certain change in commercial to passenger vehicle activities share is assumed based on Ontario's vehicle sales data. Electrification scenarios analyzed in section 4.5 are based on government targets already in place and existing studies on market adoption of EVs. While analyzing the emission reduction scenarios, the life cycle emissions and emissions from developing additional infrastructure for EVs for example charging stations, increasing the capacity of power grid are not considered. However, MOVES project scale analysis provide total energy requirements by different electric vehicle activities, which can be further used to estimate emissions from additional infrastructure development.

Recommendations for local and regional municipalities arising from this research would be to adopt micro simulation models such as MOVES to accurately monitor and report on urban transport emissions at a local level. The model can be customized to the local context and use average annual daily traffic as a major data input which is already collected at urban level in many municipalities across Canada. Also, there is a need for local authorities to shift their transport focus to commercial vehicle electrification if long term emission reduction targets are to be met. Methodology developed in this research to evaluate urban transport emissions can be used by various municipalities and local authorities to make informed decisions on vehicle electrification.

However, further research is required to understand the temporal variations of emissions especially in areas with high commercial vehicle activity. Such analysis can help local planners to manage truck routes and plan for sustainable urban freight operations including off-peak hour deliveries. Also, additional work is required to incorporate off-road vehicle activities (such as parking) and life-cycle emissions of EVs. The methodology provided in this research can be used to analyze the impact of on-road and off-road vehicle activities especially those from heavy-duty trucks on the surrounding area's air quality. In addition to greenhouse gases, MOVES can also estimate pollutants such as particulate matter, sulfur oxides, nitrogen oxides, ground level ozone, volatile organic compounds and carbon mono-oxide produced from different types of vehicle and activities. The analysis can therefore inform various health studies, transportation and land use plans to better manage passenger and commercial traffic within the urban boundaries.

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APPENDIX

A. Data Tables - Project Data Manager of MOVES, for Study Area

Vehicle Age Distribution Table

Vehicle Age (years)	Fraction		
	Light Duty	Medium Duty	Heavy Duty
25	0.0413	0.0713	0.0773
24	0.0087	0.0109	0.0090
23	0.0126	0.0114	0.0091
22	0.0147	0.0150	0.0116
21	0.0194	0.0184	0.0173
20	0.0257	0.0265	0.0308
19	0.0266	0.0221	0.0229
18	0.0412	0.0324	0.0264
17	0.0497	0.0353	0.0467
16	0.0525	0.0591	0.0602
15	0.0678	0.0545	0.0739
14	0.0635	0.0564	0.0489
13	0.0742	0.0567	0.0391
12	0.0791	0.0705	0.0565
11	0.0668	0.0697	0.0601
10	0.0740	0.0806	0.0964
9	0.0735	0.0900	0.0925
8	0.0799	0.0851	0.1194
7	0.0764	0.0957	0.0465
6	0.0467	0.0354	0.0486
5	0.0057	0.0026	0.0066

Source: Canada Vehicle Survey, 2009: Number of Vehicles on the registration lists by vehicle model year

Metrological Data Table, Region of Waterloo

Month (ID)	Zone ID	Hour (ID)	Temperature	Humidity
June (6)	-	8 am to 9 am (9)	16.6	73%

Link Source Type Table, Mode distribution

linkID	sourceTypeID	sourceTypeHourFraction
1	Passenger Cars (21)	0.4949
1	Passenger Trucks (31)	0.4049
1	Light Commercial Trucks (32)	0.0563
1	Single Unit Short Haul Trucks (52)	0.0166
1	Single Unit Long Haul Trucks (53)	0.0003
1	Combination Trucks Short Haul (61)	0.0127
1	Combination Trucks Long Haul (62)	0.0032

Link Table

linkID	County ID	Zone ID	Road TypeID	Link Length	Link Volume	Link AvgSpeed	Link Description	Link AvgGrade
1	36029	360290	5	0.062137	1097	3	Queue	0.00
2	36029	360290	5	0.062137	1117	3	Queue	0.00
3	36029	360290	5	0.062137	1137	3	Queue	0.00
4	36029	360290	5	0.062137	1157	3	Queue	0.00
5	36029	360290	5	0.000000	923	3	Queue	0.00
6	36029	360290	5	0.062137	943	3	Queue	0.00
7	36029	360290	5	0.062137	846	3	Queue	0.00
8	36029	360290	5	0.062137	948	3	Queue	0.00
9	36029	360290	5	0.062137	1065	3	Queue	0.00
10	36029	360290	5	0.062137	1592	3	Queue	0.00
142	36029	360290	5	0.062137	1097	28	Departure	0.00
143	36029	360290	5	0.062137	1117	28	Departure	0.00
144	36029	360290	5	0.062137	1137	28	Departure	0.00
145	36029	360290	5	0.062137	1157	28	Departure	0.00
146	36029	360290	5	0.000000	923	28	Departure	0.00
147	36029	360290	5	0.062137	943	28	Departure	0.00
148	36029	360290	5	0.062137	846	28	Departure	0.00
149	36029	360290	5	0.062137	948	28	Departure	0.00
150	36029	360290	5	0.062137	1065	28	Departure	0.00
151	36029	360290	5	0.062137	1592	28	Departure	0.00
283	36029	360290	5	0.062137	1097	28	Approach	0.00
284	36029	360290	5	0.062137	1117	28	Approach	0.00
285	36029	360290	5	0.062137	1137	28	Approach	0.00
286	36029	360290	5	0.062137	1157	28	Approach	0.00
287	36029	360290	5	0.000000	923	28	Approach	0.00
288	36029	360290	5	0.062137	943	28	Approach	0.00
289	36029	360290	5	0.062137	846	28	Approach	0.00
290	36029	360290	5	0.062137	948	28	Approach	0.00
291	36029	360290	5	0.062137	1065	28	Approach	0.00
292	36029	360290	5	0.062137	1592	28	Approach	0.00

The above table provide part of links and their characteristics used in MOVES for the study area

B. Summary of Emissions during peak hour (8am to 9 am), Study Area

Source Type ID	Fuel Type	CO2 (grams)	CO2_Equiv (grams)	CH4 (grams)	N2O (grams)	Total Energy (joules)	Distance (km)
21	Gasoline (1)	10,977,219	10,983,438	252	0	152,744,230,912	25337.45
21	Diesel (2)	35,320	35,324	0	0	479,490,816	74.03
21	Ethanol (5)	3,754	3,757	0	0	52,780,200	8.05
31	Gasoline (1)	11,946,156	11,953,480	297	0	166,226,673,664	20448.27
31	Diesel (2)	255,389	255,573	7	0	3,467,080,192	334.74
31	Ethanol (5)	9,577	9,587	0	0	134,636,800	16.09
32	Gasoline (1)	1,592,340	1,593,577	50	0	22,156,867,584	2732.66
32	Diesel (2)	115,068	115,130	2	0	1,562,129,408	154.50
32	Ethanol (5)	1,216	1,217	0	0	17,098,532	1.61
52	Gasoline (1)	344,164	344,539	15	0	4,788,930,560	263.93
52	Diesel (2)	934,047	934,805	30	0	12,680,322,048	589.02
53	Gasoline (1)	2,803	2,808	0	0	39,001,304	1.61
53	Diesel (2)	23,417	23,438	1	0	317,907,296	14.48
61	Gasoline (1)	143	143	0	0	1,985,318	0.00
61	Diesel (2)	1,331,767	1,332,482	29	0	18,079,645,696	651.78
62	Diesel (2)	339,336	339,507	7	0	46,067,10,784	162.54

C. Hourly Traffic Volumes, Study Area, 2015

S. No.	Street Name	Road Segment Name	Link Length (m)	AADT 2015	Monthly Average Daily Traffic		Hourly Traffic Weekday			
					June Weekday	June Weekend	7-8 AM	8-9 AM	4-5 PM	5-6 PM
1	Weber St	Northfield and Glen Forrest	212.11	14946	15574	12480	1063	1097	1300	1323
2	Weber St	Glen Forrest and Parkside Dr	326.56	15228	15868	12716	1084	1117	1325	1348
3	Weber St	Partkside and Dutton	479.61	15492	16143	12936	1102	1137	1347	1371
4	Weber St	Dutton and Albert	124.35	15775	16438	13173	1122	1157	1372	1396
5	Weber St	Albert and Belcan	69.66	12573	13102	10499	895	923	1094	1113
6	Weber St	Belcan and Schaefer St	173.47	12854	13394	10734	915	943	1118	1138
7	Weber St	Schaefer and Blythwood	370.71	11527	12012	9626	820	846	1003	1020
8	Weber St	Blythwood and Milford	168.16	12915	13458	10785	919	948	1123	1143
9	Weber St	Milford and High	289.01	14508	15118	12115	1032	1065	1262	1284
10	Weber St	High and King	128.37	21693	22605	18114	1543	1592	1887	1919
11	Weber St	King and Forwell Creek	147.53	17404	18135	14533	1238	1277	1514	1540
12	Weber St	Forwell Creek and Columbia	238.30	17116	17835	14292	1218	1256	1489	1515
13	Weber St	Columbia and Hickory	472.15	18823	19614	15718	1339	1381	1637	1666
14	Weber St	Hickory and University	151.17	20790	21664	17360	1479	1525	1808	1840
15	Weber St	University and Lodge	286.63	22518	23464	18803	1602	1652	1958	1992
16	Weber St	Lodge and Marshall	112.61	24245	25264	20245	1725	1779	2109	2145
17	Weber St	Marshall and Noecker	194.53	24267	25287	20263	1726	1780	2110	2147
18	Weber St	Noecker and Mackay	159.65	24288	25309	20281	1728	1782	2112	2149
19	Weber St	Mackay and Lincoln	161.85	24310	25332	20299	1729	1783	2114	2151
20	Weber St	Lincoln and Bridgeport	138.09	22065	22992	18425	1570	1619	1919	1952
21	King St	Northfield and Conestoga	369.78	20036	20878	16731	1425	1470	1743	1773
22	King St	Conestoga and Highway 85 NB Ramp	674.93	26410	27520	22053	1879	1937	2297	2337
23	King St	Highway 85 SB Ramp and Manulife & Service	561.34	30646	31934	25590	2180	2248	2665	2711
24	King St	Manulife & Service and Blue Springs	131.60	25940	27030	21660	1845	1903	2256	2295
25	King St	Blue Springs and Weber	219.84	25780	26863	21527	1834	1891	2242	2281

S. No.	Street Name	Road Segment Name	Link Length (m)	AADT 2015	Monthly Average Daily Traffic		Hourly Traffic Weekday			
					June Weekday	June Weekend	7-8 AM	8-9 AM	4-5 PM	5-6 PM
26	King St	Weber and Columbia	364.14	19744	20574	16487	1405	1449	1717	1747
27	King St	Columbia and Hickory	431.63	18814	19605	15710	1339	1380	1636	1665
28	King St	Hickory and University	219.87	22010	22935	18379	1566	1615	1914	1947
29	King St	University and Signals (WLU)	110.36	15537	16190	12974	1105	1140	1351	1375
30	King St	Signals (WLU) and Lodge	181.64	15537	16190	12974	1105	1140	1351	1375
31	King St	Lodge and Bricker	40.39	15036	15668	12556	1070	1103	1308	1331
32	King St	Bricker and Marshall	74.00	16449	17140	13735	1170	1207	1431	1456
33	King St	Marshall and Ezra	26.26	16000	16672	13360	1138	1174	1392	1416
34	King St	Ezra and James	39.68	16051	16726	13403	1142	1178	1396	1420
35	King St	James and Noecker	69.07	16611	17309	13871	1182	1219	1445	1470
36	King St	Noecker and Elgin	132.46	17620	18361	14713	1254	1293	1533	1559
37	King St	Elgin and Central	50.04	14514	15124	12120	1033	1065	1262	1284
38	King St	Central and Spring	45.75	15325	15969	12797	1090	1124	1333	1356
39	King St	Spring and Young	92.54	15869	16536	13251	1129	1164	1380	1404
40	King St	Young and Bridgeport	92.93	17308	18035	14453	1231	1270	1505	1531
41	King St	Bridgeport and Princess	92.84	16947	17659	14151	1206	1243	1474	1500
42	King St	Princess and Dupont	92.68	16069	16744	13418	1143	1179	1398	1422
43	King St	Dupont and Erb	94.52	14939	15567	12475	1063	1096	1299	1322
44	King St	Erb and Willis Way	178.86	13955	14542	11653	993	1024	1214	1235
45	King St	Willis Way and William	221.77	15252	15893	12736	1085	1119	1327	1350
46	King St	William and Kuntz	80.56	18077	18837	15095	1286	1326	1572	1600
47	King St	Kuntz and George	43.43	15331	15975	12802	1091	1125	1333	1357
48	King St	George and Allen	119.02	24112	25125	20134	1715	1769	2097	2133
49	Uni Ave	Erb and Keats Way	580.72	11756	12250	9817	837	863	1023	1040
50	Uni Ave	Keats Way and Westmount	183.40	16502	17196	13780	1174	1211	1435	1460
51	Uni Ave	Westmount and Seagram	539.35	24451	25478	20417	1739	1794	2126	2163
52	Uni Ave	Seagram and E to Signals (Trans Canada Trail)	192.78	22969	23934	19180	1634	1685	1998	2032

S. No.	Street Name	Road Segment Name	Link Length (m)	AADT 2015	Monthly Average Daily Traffic		Hourly Traffic Weekday			
					June Weekday	June Weekend	7-8 AM	8-9 AM	4-5 PM	5-6 PM
53	Uni Ave	W to Signals (Trans Canada Trail) and Phillip	252.21	17880	18631	14930	1272	1312	1555	1582
54	Uni Ave	Phillip and Lester	207.20	18608	19390	15538	1324	1365	1618	1647
55	Uni Ave	Lester and Sunview	105.14	20410	21268	17043	1452	1497	1775	1806
56	Uni Ave	Sunview and Albert	103.00	20068	20911	16757	1428	1472	1745	1776
57	Uni Ave	Albert and Hemlock	97.12	20199	21048	16867	1437	1482	1757	1787
58	Uni Ave	Hemlock and E to Signals (St Michael/WLU)	94.62	20210	21059	16876	1438	1483	1758	1788
59	Uni Ave	W to Signals (St Michael/WLU) and Hazel	136.14	20300	21153	16951	1444	1489	1765	1796
60	Uni Ave	Hazel and Maple	183.53	21176	22066	17682	1507	1554	1842	1874
61	Uni Ave	Maple and King	93.41	22508	23454	18795	1601	1651	1957	1991
62	Uni Ave	King and Regina	110.23	26307	27412	21967	1871	1930	2288	2327
63	Uni Ave	Regina and Weber	357.35	18740	19528	15648	1333	1375	1630	1658
64	Uni Ave	Weber and Marshland	346.49	21614	22522	18048	1538	1586	1880	1912
65	Uni Ave	Marshland and Carter	167.54	26945	28077	22500	1917	1977	2343	2384
66	Uni Ave	Carter and Mayfield	194.47	25115	26170	20972	1787	1842	2184	2222
67	Uni Ave	Mayfield and Glenridge	66.78	25167	26225	21015	1790	1846	2189	2227
68	Uni Ave	Glenridge and Dale/Lincoln	371.02	24910	25957	20800	1772	1827	2166	2204
69	Uni Ave	Dale/Lincoln and Highway 85 SB Ramp	397.69	29038	30258	24247	2066	2130	2525	2569
70	Uni Ave	btw Highway 85 Ramps	597.16	41287	43022	34475	2937	3029	3590	3653
71	Uni Ave	Highway 85 NB Ramp and Braemore	160.09	42044	43810	35107	2991	3084	3656	3720
72	Bridgeport	Albert and Dorset	75.47	12507	13033	10444	890	918	1088	1107
73	Bridgeport	Dorset and King	98.70	12310	12828	10279	876	903	1071	1089
74	Bridgeport	King and Regina	97.67	13966	14553	11662	994	1025	1215	1236
75	Bridgeport	Regina and Peppler	178.16	14513	15123	12119	1033	1065	1262	1284
76	Bridgeport	Peppler and Moore	216.46	14588	15201	12181	1038	1070	1269	1291
77	Bridgeport	Moore and Laurel	75.44	14663	15279	12244	1043	1076	1275	1298
78	Bridgeport	Laurel and Devitt	54.45	14738	15357	12307	1049	1081	1282	1304
79	Bridgeport	Devitt and Weber	276.36	14813	15436	12369	1054	1087	1288	1311

S. No.	Street Name	Road Segment Name	Link Length (m)	AADT 2015	Monthly Average Daily Traffic		Hourly Traffic Weekday			
					June Weekday	June Weekend	7-8 AM	8-9 AM	4-5 PM	5-6 PM
80	Erb St	University and Westmount	255.42	18911	19706	15791	1345	1387	1645	1673
81	Erb St	Westmount and Dietz	284.96	15469	16119	12917	1101	1135	1345	1369
82	Erb St	Dietz and Beverley	100.35	15940	16610	13310	1134	1170	1386	1411
83	Erb St	Beverley and Roslin	89.49	16411	17101	13704	1168	1204	1427	1452
84	Erb St	Roslin and Dunbar	98.81	16881	17591	14096	1201	1239	1468	1494
85	Erb St	Dunbar and Avondale	99.11	17352	18081	14489	1235	1273	1509	1535
86	Erb St	Avondale and Menno	102.55	17822	18571	14882	1268	1308	1550	1577
87	Erb St	Menno and Wells Lane	50.29	18476	19252	15428	1314	1356	1607	1635
88	Erb St	Wells Lane and Euclid	48.98	18952	19748	15825	1348	1390	1648	1677
89	Erb St	Euclid and Father David Bauer	76.58	19426	20242	16221	1382	1425	1689	1719
90	Erb St	Father David Bauer and Caroline	156.80	23690	24685	19782	1685	1738	2060	2096
91	Erb St	Caroline and Albert	136.60	18348	19119	15321	1305	1346	1596	1623
92	Erb St	Albert and Dominion	71.66	14673	15290	12252	1044	1077	1276	1298
93	Erb St	Dominion and King	43.42	12352	12871	10314	879	906	1074	1093
94	Erb St	King and Hughes Lane	49.32	12036	12542	10051	857	883	1047	1065
95	Erb St	Hughes Lane and Regina	47.15	10426	10864	8706	742	765	907	923
96	Erb St	Regina and Gillen	73.53	11876	12375	9917	845	871	1033	1051
97	Erb St	Gillen and Peppler	102.41	12524	13051	10458	891	919	1089	1108
98	Erb St	Peppler and Willow	84.42	13302	13861	11108	947	976	1157	1177
99	Erb St	Willow and Tweed	98.55	13954	14541	11652	993	1024	1214	1235
100	Erb St	Tweed and Moore	169.54	16184	16864	13514	1151	1187	1408	1432
101	Erb St	Moore and Devitt	114.84	16621	17320	13879	1183	1220	1446	1471
102	Erb St	Devitt and Dover	108.18	16864	17573	14082	1200	1237	1467	1492
103	Erb St	Dover and Weber	171.02	17107	17826	14285	1217	1255	1488	1514
104	Northfield Dr	Weber and Parkside Dr	302.02	18357	19128	15329	1306	1347	1597	1624
105	Northfield Dr	Parkside Dr and Highway 85/Kumpf	244.97	19900	20736	16617	1416	1460	1731	1761
106	Northfield Dr	Highway 85 SB Ramp and Kumpf	21.58	21442	22343	17905	1525	1573	1865	1897

S. No.	Street Name	Road Segment Name	Link Length (m)	AADT 2015	Monthly Average Daily Traffic		Hourly Traffic Weekday			
					June Weekday	June Weekend	7-8 AM	8-9 AM	4-5 PM	5-6 PM
107	Northfield Dr	btw Highway 85 Ramps	431.45	22984	23950	19192	1635	1686	1999	2034
108	Northfield Dr	Highway 85 NB Ramp and Colby/Conestoga	61.92	24527	25558	20481	1745	1799	2133	2170
109	Northfield Dr	Colby/Conestoga and King	386.18	26711	27833	22304	1900	1959	2323	2363
110	Westmount Rd	Residence and Columbia	555.79	9249	9638	7723	658	679	805	819
111	Westmount Rd	Columbia and Old Post Rd	563.92	15772	16435	13170	1122	1157	1372	1396
112	Westmount Rd	Old Post and Lion's Gate	256.21	14982	15612	12510	1066	1099	1303	1326
113	Westmount Rd	Lion's Gate and Longfellow	416.44	18026	18784	15052	1283	1323	1568	1595
114	Westmount Rd	Longfellow and University	363.53	17562	18300	14665	1249	1289	1527	1554
115	Westmount Rd	University and Father David Bauer/ Westcourt	283.50	19492	20311	16276	1387	1430	1695	1725
116	Westmount Rd	Father David Bauer/ Westcourt and Erb	394.47	16928	17639	14135	1204	1242	1472	1498
117	Westmount Rd	Erb and Dawson St	147.83	20861	21738	17419	1484	1530	1814	1846
118	Caroline St	Allen and Freemont	81.66	4678	4875	3907	333	344	407	414
119	Caroline St	Freemont and Norman	67.61	4834	5038	4037	344	355	421	428
120	Caroline St	Norman and Fullerton	40.58	4992	5202	4169	356	367	435	442
121	Caroline St	Fullerton and William	46.62	5149	5366	4300	367	378	448	456
122	Caroline St	William and Alexandra	89.05	16166	16845	13499	1150	1186	1406	1430
123	Caroline St	Alexandra and Willis	160.58	16117	16794	13458	1147	1183	1402	1426
124	Caroline St	Willis and Father David Bauer	38.14	16958	17671	14160	1207	1244	1475	1501
125	Caroline St	Father David Bauer and Erb	168.51	14768	15389	12332	1051	1084	1285	1307
126	Caroline St	Erb and Dupont	109.09	15001	15632	12526	1067	1101	1305	1327
127	Caroline St	Dupont and Albert	251.12	14049	14640	11731	1000	1031	1222	1243
128	Albert St	Weber and Hazel/ Bearinger	904.31	15000	15630	12525	1067	1101	1305	1327
129	Albert St	Hazel and Phillip	118.42	15000	15630	12525	1067	1101	1305	1327

S. No.	Street Name	Road Segment Name	Link Length (m)	AADT 2015	Monthly Average Daily Traffic		Hourly Traffic Weekday			
					June Weekday	June Weekend	7-8 AM	8-9 AM	4-5 PM	5-6 PM
130	Albert St	Phillip and Columbia	734.52	15000	15630	12525	1067	1101	1305	1327
131	Albert St	Columbia and University	620.30	15000	15630	12525	1067	1101	1305	1327
132	Albert St	University and Bridgeport	885.16	15000	15630	12525	1067	1101	1305	1327
133	Phillip St	Albert and Columbia	937.73	1500	1563	1253	107	111	131	133
134	Phillip St	Columbia and University	624.33	1500	1563	1253	107	111	131	133
135	Columbia St	Westmount and Hagey	1,084.17	24017	25026	20055	1709	1762	2089	2125
136	Columbia St	Hagey and Phillip	577.27	20000	20840	16700	1423	1467	1739	1770
137	Columbia St	Phillip and Albert	421.26	20000	20840	16700	1423	1467	1739	1770
138	Columbia St	Albert and Hazel	320.21	20000	20840	16700	1423	1467	1739	1770
139	Columbia St	Hazel and King	501.44	20000	20840	16700	1423	1467	1739	1770
140	Columbia St	King and Weber	210.26	25662	26740	21428	1826	1883	2232	2270
141	Columbia St	Weber and Highway 85	1,368.33	17721	18466	14798	1261	1300	1541	1568

D. Emission Rates used by the Region of Waterloo

Table A6–13 **Emission Factors for Energy Mobile Combustion Sources**

	Emission Factor (g/L fuel)		
Mode†	CO_2	CH_4	N_2O
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 2	2 307 [1]	0.14 [3]	0.022 [4]
Tier 1	2 307 [1]	0.23 [5]	0.47 [5]
Tier 0	2 307 [1]	0.32 [6]	0.66 [7]
Oxidation Catalyst	2 307 [1]	0.52 [8]	0.20 [6]
Non-catalytic Controlled	2 307 [1]	0.46 [8]	0.028 [6]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 307 [1]	0.14 [3]	0.022 [4]
Tier 1	2 307 [1]	0.24 [5]	0.58 [5]
Tier 0	2 307 [1]	0.21 [8]	0.66 [7]
Oxidation Catalyst	2 307 [1]	0.43 [8]	0.20 [6]
Non-catalytic Controlled	2 307 [1]	0.56 [6]	0.028 [6]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 307 [1]	0.068 [8]	0.20 [8]
Non-catalytic Controlled	2 307 [1]	0.29 [6]	0.047 [6]
Uncontrolled	2 307 [1]	0.49 [6]	0.084 [6]
Motorcycles			
Non-catalytic Controlled	2 307 [1]	0.77 [3]	0.041 [3]
Uncontrolled	2 307 [1]	2.3 [6]	0.048 [6]

Source: Environment Canada's National Inventory Report 1990-2017: Greenhouse Gas Sources and Sinks in Canada, Part 2, Table A6-13 (p. 226).

E. Traffic Projections, City of Waterloo

Year	Annual Growth Rate	Average Annual Daily Traffic Total
2016	1.11%	4,311,483
2017	1.11%	4,359,341
2018	1.11%	4,407,729
2019	1.11%	4,456,655
2020	1.11%	4,506,124
2021	1.11%	4,556,142
2022	1.11%	4,606,715
2023	1.11%	4,657,850
2024	1.11%	4,709,552
2025	1.11%	4,761,828
2026	1.11%	4,814,684
2027	1.11%	4,868,127
2028	1.11%	4,922,163
2029	1.11%	4,976,799
2030	1.11%	5,032,042
2031	2.22%	5,143,753
2032	2.22%	5,257,944
2033	2.22%	5,374,671
2034	2.22%	5,493,988
2035	2.22%	5,615,955
2036	1.27%	5,687,278
2037	1.27%	5,759,506
2038	1.27%	5,832,652
2039	1.27%	5,906,726
2040	1.27%	5,981,742
2041	1.17%	6,051,728
2042	1.17%	6,122,533
2043	1.17%	6,194,167
2044	1.17%	6,266,639
2045	1.17%	6,339,958
2046	1.07%	6,407,796
2047	1.07%	6,476,359
2048	1.07%	6,545,657
2049	1.07%	6,615,695
2050	1.07%	6,686,483
2051	0.97%	6,751,342

F. Emissions with respect to increasing commercial vehicle activity for year 2031, City of Waterloo

I. Base case scenario for 2031, passenger to commercial vehicle activity share of 90:10

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	49%	2,545,736.32	0.24	0.27
passenger trucks	618.95	40%	2,082,875.17	0.24	0.31
light commercial truck	615.69	6%	289,392.91	0.24	0.04
single unit short hall	1437.29	2%	85,406.78	0.24	0.03
single unit long haul	1435.55	0%	1,743.00	0.24	0.00
combination short haul	1979.84	1%	65,357.76	0.24	0.03
combination long haul	2057.95	0%	16,339.44	0.24	0.01

II. Scenario-1: Commercial vehicle activity share of 20%

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	45.00%	2,314,688.86	0.24	0.24
passenger trucks	618.95	35.00%	1,800,313.56	0.24	0.27
light commercial truck	615.69	10.00%	514,375.30	0.24	0.08
single unit short hall	1437.29	4.00%	205,750.12	0.24	0.07
single unit long haul	1435.55	1.00%	51,437.53	0.24	0.02
combination short haul	1979.84	3.00%	154,312.59	0.24	0.07
combination long haul	2057.95	1.00%	51,437.53	0.24	0.03

III. Scenario-2: Commercial vehicle activity share of 30%.

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	34.00%	2,057,501.21	0.24	0.22
passenger trucks	618.95	26.00%	1,543,125.91	0.24	0.23
light commercial truck	615.69	20.00%	771,562.95	0.24	0.11
single unit short hall	1437.29	10.00%	411,500.24	0.24	0.14
single unit long haul	1435.55	3.00%	102,875.06	0.24	0.04
combination short haul	1979.84	6.00%	205,750.12	0.24	0.10
combination long haul	2057.95	1.00%	51,437.53	0.24	0.03

IV. Scenario-3: Commercial vehicle activity share of 40%.

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	34.00%	1,748,876.03	0.24	0.19
passenger trucks	618.95	26.00%	1,337,375.79	0.24	0.20
light commercial truck	615.69	20.00%	1,028,750.60	0.24	0.15
single unit short hall	1437.29	10.00%	514,375.30	0.24	0.18
single unit long haul	1435.55	3.00%	154,312.59	0.24	0.05
combination short haul	1979.84	6.00%	308,625.18	0.24	0.15
combination long haul	2057.95	1.00%	51,437.53	0.24	0.03

V. Scenario-4: Commercial vehicle activity share of 50%.

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	30.00%	1,543,125.91	0.24	0.16
passenger trucks	618.95	20.00%	1,028,750.60	0.24	0.15
light commercial truck	615.69	25.00%	1,285,938.26	0.24	0.19
single unit short hall	1437.29	15.00%	771,562.95	0.24	0.27
single unit long haul	1435.55	3.00%	154,312.59	0.24	0.05
combination short haul	1979.84	6.00%	308,625.18	0.24	0.15
combination long haul	2057.95	1.00%	51,437.53	0.24	0.03

G. Emissions with respect to increasing commercial vehicle activity for year 2051, City of Waterloo

I. Base case scenario for 2051, passenger to commercial vehicle activity share of 90:10

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	49%	3,341,361.09	0.24	0.35
passenger trucks	618.95	40%	2,733,840.89	0.24	0.41
light commercial truck	615.69	6%	379,837.54	0.24	0.06
single unit short hall	1437.29	2%	112,099.15	0.24	0.04
single unit long haul	1435.55	0%	2,287.74	0.24	0.00
combination short haul	1979.84	1%	85,784.17	0.24	0.04
combination long haul	2057.95	0%	21,446.04	0.24	0.01

II. Scenario-1: Commercial vehicle activity share of 20%

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	45.00%	3,038,103.83	0.24	0.32
passenger trucks	618.95	35.00%	2,362,969.65	0.24	0.35
light commercial truck	615.69	10.00%	675,134.19	0.24	0.10
single unit short hall	1437.29	4.00%	270,053.67	0.24	0.09
single unit long haul	1435.55	1.00%	67,513.42	0.24	0.02
combination short haul	1979.84	3.00%	202,540.26	0.24	0.10
combination long haul	2057.95	1.00%	67,513.42	0.24	0.03

III. Scenario-2: Commercial vehicle activity share of 30%

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	34.00%	2,700,536.74	0.24	0.29
passenger trucks	618.95	26.00%	2,025,402.56	0.24	0.30
light commercial truck	615.69	20.00%	1,012,701.28	0.24	0.15
single unit short hall	1437.29	10.00%	540,107.35	0.24	0.19
single unit long haul	1435.55	3.00%	135,026.84	0.24	0.05
combination short haul	1979.84	6.00%	270,053.67	0.24	0.13
combination long haul	2057.95	1.00%	67,513.42	0.24	0.03

IV. Scenario-3: Commercial vehicle activity share of 40%

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	34.00%	2,295,456.23	0.24	0.24
passenger trucks	618.95	26.00%	1,755,348.88	0.24	0.26
light commercial truck	615.69	20.00%	1,350,268.37	0.24	0.20
single unit short hall	1437.29	10.00%	675,134.19	0.24	0.23
single unit long haul	1435.55	3.00%	202,540.26	0.24	0.07
combination short haul	1979.84	6.00%	405,080.51	0.24	0.19
combination long haul	2057.95	1.00%	67,513.42	0.24	0.03

V. Scenario-4: Commercial vehicle activity share of 50%

Vehicle Type	CO2 Eq (g/km)	Vehicle Fraction	Vehicle Activity	Link Length (km)	Emissions, 000 tones/day
passenger car	440.99	30.00%	2,025,402.56	0.24	0.21
passenger trucks	618.95	20.00%	1,350,268.37	0.24	0.20
light commercial truck	615.69	25.00%	1,687,835.46	0.24	0.25
single unit short hall	1437.29	15.00%	1,012,701.28	0.24	0.35
single unit long haul	1435.55	3.00%	202,540.26	0.24	0.07
combination short haul	1979.84	6.00%	405,080.51	0.24	0.19
combination long haul	2057.95	1.00%	67,513.42	0.24	0.03

H. Future Change in Commercial and Passenger Vehicle Activity Assumed for City of Waterloo

For future electrification potential scenario analysis, it is assumed that commercial vehicle activity share in the city of Waterloo would be 20% by 2031, and 30% by 2051. The proportions of different vehicle class assumed across all years is provided in the table below.

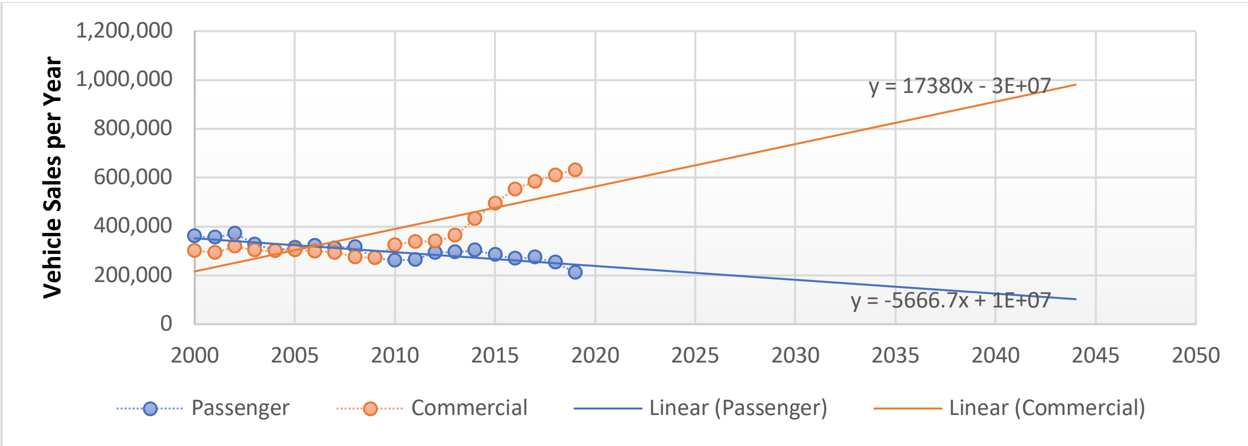
Year	Passenger car	Passenger trucks	Light Commercial Truck	Single Unit short hall	Single Unit long haul	Combination short haul	Combination long haul	Commercial to Passenger share
2015	49.49%	40.49%	5.63%	1.66%	0.03%	1.27%	0.32%	8.91%
2016	49.23%	40.20%	5.89%	1.84%	0.09%	1.35%	0.34%	9.49%
2017	48.96%	39.91%	6.15%	2.01%	0.14%	1.42%	0.36%	10.08%
2018	48.70%	39.62%	6.41%	2.19%	0.20%	1.50%	0.37%	10.67%
2019	48.44%	39.33%	6.67%	2.36%	0.25%	1.57%	0.39%	11.25%
2020	48.17%	39.04%	6.93%	2.54%	0.31%	1.65%	0.41%	11.84%
2021	47.91%	38.74%	7.19%	2.72%	0.36%	1.73%	0.43%	12.42%
2022	47.65%	38.45%	7.45%	2.89%	0.42%	1.80%	0.45%	13.01%
2023	47.38%	38.16%	7.71%	3.07%	0.47%	1.88%	0.47%	13.60%
2024	47.12%	37.87%	7.97%	3.25%	0.53%	1.95%	0.49%	14.18%
2025	46.86%	37.58%	8.23%	3.42%	0.58%	2.03%	0.51%	14.77%
2026	46.59%	37.29%	8.49%	3.60%	0.63%	2.10%	0.53%	15.35%
2027	46.33%	37.00%	8.75%	3.77%	0.69%	2.18%	0.55%	15.94%
2028	46.06%	36.70%	9.01%	3.95%	0.74%	2.26%	0.56%	16.52%
2029	45.80%	36.41%	9.27%	4.13%	0.80%	2.33%	0.58%	17.11%

Year	Passenger car	Passenger trucks	Light Commercial Truck	Single Unit short hall	Single Unit long haul	Combination short haul	Combination long haul	Commercial to Passenger share
2030	45.54%	36.12%	9.53%	4.30%	0.85%	2.41%	0.60%	17.70%
2031	45.27%	35.83%	9.79%	4.48%	0.91%	2.48%	0.62%	18.28%
2032	45.01%	35.54%	10.05%	4.65%	0.96%	2.56%	0.64%	18.87%
2033	44.75%	35.25%	10.31%	4.83%	1.02%	2.64%	0.66%	19.45%
2034	44.48%	34.96%	10.57%	5.01%	1.07%	2.71%	0.68%	20.04%
2035	44.22%	34.66%	10.83%	5.18%	1.13%	2.79%	0.70%	20.63%
2036	43.95%	34.37%	11.09%	5.36%	1.18%	2.86%	0.72%	21.21%
2037	43.69%	34.08%	11.35%	5.53%	1.24%	2.94%	0.73%	21.80%
2038	43.43%	33.79%	11.61%	5.71%	1.29%	3.01%	0.75%	22.38%
2039	43.16%	33.50%	11.88%	5.89%	1.34%	3.09%	0.77%	22.97%
2040	42.90%	33.21%	12.14%	6.06%	1.40%	3.17%	0.79%	23.56%
2041	42.64%	32.91%	12.40%	6.24%	1.45%	3.24%	0.81%	24.14%
2042	42.37%	32.62%	12.66%	6.42%	1.51%	3.32%	0.83%	24.73%
2043	42.11%	32.33%	12.92%	6.59%	1.56%	3.39%	0.85%	25.31%
2044	41.85%	32.04%	13.18%	6.77%	1.62%	3.47%	0.87%	25.90%
2045	41.58%	31.75%	13.44%	6.94%	1.67%	3.55%	0.89%	26.48%
2046	41.32%	31.46%	13.70%	7.12%	1.73%	3.62%	0.91%	27.07%
2047	41.05%	31.17%	13.96%	7.30%	1.78%	3.70%	0.92%	27.66%
2048	40.79%	30.87%	14.22%	7.47%	1.84%	3.77%	0.94%	28.24%
2049	40.53%	30.58%	14.48%	7.65%	1.89%	3.85%	0.96%	28.83%
2050	40.26%	30.29%	14.74%	7.82%	1.95%	3.92%	0.98%	29.41%
2051	40.00%	30.00%	15.00%	8.00%	2.00%	4.00%	1.00%	30.00%

Annual Average Growth Rates (AAGR) of passenger and commercial vehicle assumed for the City of Waterloo, 2015-2051

AAGR- Passenger	-0.43%
AAGR -Commercial	5.06%

I. New Vehicle Sales Data, Ontario and linear projection till 2051



Statistics Canada, Table: 20-10-0001-01 (formerly CANSIM 079-0003)

Note: Commercial vehicles in this table also include pick-up trucks which might be used for passenger activities.