A Thesis

entitled

Comparison of Control Strategies for Greenhouse Gas Emissions from Public Transit Buses in Ohio and its Climatic Implications

by

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The transportation sector is one of the largest feeders of greenhouse gas (GHG) emissions in the United States. The GHG emissions are a cause of serious concern because of their effect on human health and their co-inhabitants. Reducing pollution levels for a healthier future is widely debated and is the need of the hour as because each time GHG emission doubles, there is a 5.4°F rise in temperature. For every degree temperature increment, the chances of an extreme weather event occurrence increases. One of the prime strategies that have been put in place to further reduce pollution is switching to public transportation as we move into the future. In years to come, however, the increasing demand and pressure would necessitate the adoption of strategies that would reduce pollution from public transit system. There is immense scope in various possible control strategy options to cut down emission levels from public transit systems such as alternative fuels, land-use management, inspection and maintenance of in-use vehicles, and vehicle scrappage etc. In this thesis, an effort is made to identify strategies and perform modelling operations in freeware to estimate the capacity of the strategies to
curb emissions from public transit buses in the State of Ohio. Projections for ten years (2015-2025) into future emissions from public transit buses in Ohio have been analyzed under three scenarios: the worst case, base case, and the best case. Historical datasets have been used to a large extent during the study to understand and predict future vehicular population. Since, future predictions possess a certain degree of uncertainty; a sensitivity analysis has been performed to check how subtle the output values are with respect to the input parameters. The contribution of predicted emission levels on radiative forcing have been linked to figure out the overall impact on the temperature of the Ohio region in ten years to come.

Computer modelling using software such as GREET, MOVES2014, and mixed-use trip generation model were used primarily to establish the futuristic emission trends for public transit buses. The uncertainty of the datasets obtained is tested using what-if scenario analysis. Of all the strategies discussed, the biodiesel fuel has been found to be the most efficient followed by natural gas and its blends, land-use planning and inspection and maintenance of transit buses, in that order. 80 % reduction in CO₂ emissions can be achieved if the control strategies were to be used as in the best case scenario in Ohio. As a result of reduction in emissions, the reduction in temperature would be 0.005 ºC approximately.
I would like to dedicate this thesis to my parents, Mr. Naba Kumar Kalita & Mrs. Bornali Kalita for their blessings, support, love and encouragement.
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List of Abbreviations

GHG...........................Greenhouse Gas
CO₂..........................Carbon Dioxide
CO₂-e.......................Carbon Dioxide Equivalent
BAU..........................Business as usual
BD.........................Biodiesel
NG...........................Natural Gas
CNG.........................Compressed Natural Gas
LNG........................Liquefied Natural Gas
I/M.........................Inspection and Maintenance
MXD.......................Mixed-use-trip
VMT......................Vehicle miles travelled
Chapter 1
Introduction
1.1 Overview

Climate forcing over the past 1,000 years has led to global warming in the 20th century. Changes in solar irradiance and volcanism during the pre-anthropogenic decade, contributed to about 41 to 64% temperature variations during that time period. However, the later part of the century, especially since the 1950s, warming phenomenon seemed more justifiable and in agreement through greenhouse gas (GHG) forcing (Crowley, 2000). Climatic fluctuations have a profound impact on human health such as cardiovascular mortality and respiratory illnesses due to heat waves, altered transmission of infectious diseases and malnutrition from crop failures. In many worldwide regions, the warming trend over the decades has contributed to increased morbidity and mortality rates. Extreme weather events such as high temperatures, humidity, precipitation etc. predict an excess risk of various health outcomes that would double by the year 2030 (considering 2000 as base year) (Patz, Campbell-Lendrum, Holloway, & Foley, 2005). To avoid such destructive outcomes, the accelerated pace at which global greenhouse gases are emitted needs to be reduced to considerably safer levels for survival of this planet.

The growing GHG emissions are largely due to fossil fuel combustion in the ever-growing energy, industry, and transportation sector. Efforts are being made worldwide to develop, and implement low or no emission engines and identify new energy sources possibly to run the sector. Further technical and behavioral mitigation measures alongside investments in new infrastructure and urban redevelopment can diminish energy demand substantially. One of the strategies of cutting down energy demand is using more and more public transit systems in
the coming years. The primary aim of this thesis is to examine certain control strategies that could reduce the transportation sectors’ emissions. Techniques of cutting down emissions from public transit buses in the State of Ohio have been studied. The percentage reduction in emissions and its correlation with radiative forcing has been used to figure out its impact on the climate.

1.2 Statement of the problem

The control technology options that can possibly be implemented to reduce the emission levels of greenhouse gases (GHG) emitted from public transit buses in Ohio has been examined. The thesis is divided into the following set of objectives described below:

- Estimating the quantity of emissions for a period of ten years for public transit buses considering 2015 as the base year from the point of view of three different control strategy options:
  
  (i) Use of alternative fuels: Examination of pollution emissions levels in terms of carbon dioxide (CO\(_2\)) and the carbon dioxide equivalent (CO\(_2\)-e) using biodiesel. Two forms of natural gas, compressed natural gas (CNG) and liquefied natural gas (LNG) will also be analyzed.
  
  (ii) Land Use Planning: Assessment of the vehicle mile travelled (VMT) reductions as a result of changes in mixed use patterns and its influence on average emission factors have been evaluated.
  
  (iii) Emission Control for in-use vehicles: Examination of inspection and maintenance (I/M) program benefits in terms of their maintenance levels before and after maintenance of public transit buses.

- Measuring the efficacy of the control strategies in terms of three scenarios:
Case i: The Worst Case- No control (no technology used; not even the ones currently in use)

Case ii: The Base Case- Business-as-usual scenario.

Case iii: The Best Case- If all the control technologies were to be applied aggressively for the best possible outcomes.

- Interpretation of the effects of emissions to the temperature of the Ohio region.
  This will serve as an indicator for climate change in Ohio.

1.3 Glimpse of upcoming chapters

As we go further into the thesis, the chapters that we are going to be presented with have been briefly mentioned.

1.3.1 Chapter 2: Literature Review

The chapter on literature review discusses the research conducted on climate change and transportation emissions. Also, several emission control technologies used in different parts of the world, e.g. Beijing, China and Madrid, Spain and in different points in time have been carefully studied. Methods to analyze the pollution levels for future years at a particular location have been planned. The effects of emissions on temperature and climate forcing have been discussed in-depth to figure out the knowledge gaps.

1.3.2 Chapter 3: Methodology and Data Collection

The methodology and data collection chapter, as the name suggests, has the entire plan of the study on how the thesis research work was conducted for the collection of data. It has a step-by-step documentation of the examination of control strategies for GHG reduction against the
backdrop of three scenarios, the worst, the base, and the best case using Ohio public transit buses as the vessel of the analysis.

1.3.3 Chapter 4: Analysis of Results

This chapter on results analysis contains testing the uncertainty level of the data gathered for future years. The overall efficiency of the emissions scenarios are established and plotted.

1.3.4 Chapter 5: Discussion and Conclusions

The final chapter of the thesis correlates the results obtained to temperature data and discusses its climatic implications. Also, the scope of future expansion of this project has been laid out.
Chapter 2

Literature Review

2.1 Background

2.1.1 Climate Change and Greenhouse gas (GHG) emissions

Anthropogenic and natural influences have changed Earth’s climate throughout history. Extreme events, rising global temperatures, rising sea levels, declining Arctic sea ice, warming oceans and decreased snow cover are all compelling evidence of rapid climate change. A majority of these climatic changes could be attributed to rising global temperatures, and the rising temperature of the planet to the ever increasing emissions levels of carbon dioxide (CO₂) and other greenhouse gases (GHG). In the United States, the greenhouse gas (GHG) emissions have risen by approximately 4% and the temperature by 0.14°F in the past decade. Researchers predict that in the United States, by the year 2100, the rise in temperature would be in the range of 2 to 11.5°F. The reason for our enormous debating on this topic is its’ effects on our food supply, water resources, infrastructure, ecosystems and our health, thereby threatening the very existence of human beings and their cohabiters on this planet (‘Global Climate Change: Evidence,” 2008) http://climate.nasa.gov/evidence/).

The models used for temperature trends and climatic change correlations are in close agreement with each other. Through several investigations, a majority of the scientific organizations agree that climate-warming trends over the past century are very likely due to human activities. Models using effects of natural processes to explain recent warming trends fail to do so. However, models predicting GHG emissions through human activities succeeded in explaining such trends. Hence, most of the mid-20th century’s observed increase in global
average temperature is very likely due to the increase in human-generated greenhouse gas concentrations (“Global Greenhouse Gas Emissions Data,” n.d.).

Earth’s temperature is controlled by gases in our atmosphere. Greenhouse gases such as carbon dioxide (CO₂) trap heat and make our planet livable by keeping it warm. This in simple terms is the greenhouse effect. Absorption and emission of thermal radiation by GHG in the atmosphere is the ultimate reason for greenhouse effect. Earth receives the Sun’s energy in the form of incident solar radiation. The incident solar radiation: ultra violet light, visible light, and near infra-red radiation passes through the atmosphere.

Some of the energy from the Sun is directly reflected back to the space or short wavelength energy may be absorbed by the Earth. The absorbed energy is re-emitted at longer wavelengths by the Earth. The continuous spectrum of electromagnetic energy from the thermonuclear fusion at the surface of the Sun emits a large amount of shorter wavelength energy. This energy is intercepted by the Earth’s atmosphere and surface. About 20% of this energy in the form of radiation is scattered and reflected by the clouds, 51% is absorbed by the earth, 4% is reflected by the surface, 19% is absorbed by the atmosphere and the clouds, and 6% is scattered from the atmosphere (“Greenhouse Effect: Background Material,” n.d.).

The part of incoming radiation which is absorbed by oceans and land is converted into heat. This heat warms up the Earth’s surface and the air above it. Some gases behave similarly to a layer of glass greenhouse which inhibits the heat from escaping. (“The Greenhouse Effect,” 2012). This layer of greenhouse gases absorb heat and radiate some of it back to the Earth's surface, causing surface temperatures to be higher than they would otherwise be. The most important naturally occurring GHG is water vapor and it is the largest contributor to the natural greenhouse effect. However, other gases, although they occur in much smaller quantities, also
play a substantial and growing roles in the greenhouse effect. These include carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O).

Most abundant GHGs in the atmosphere of the Earth are: Water vapor (H$_2$O), Carbon dioxide (CO$_2$), Methane(CH$_4$), Nitrous oxide (N$_2$O),Ozone(O$_3$) and Chlorofluorocarbons (CFCs). The GHG absorbs Suns’ infrared radiation and trap the heat in the atmosphere of the Earth. CO$_2$ is the most abundant greenhouse gas and a vast majority of global warming could be attributed to it. Other GHGs are often converted to their CO$_2$ equivalents to normalize their effects. Their decay is relatively slow and a portion of this gas remains in the atmosphere for as long as 2000 years. Natural circulation of carbon occurs among the elements on Earth such as the atmosphere, oceans, soil, plants, and animals. The natural existence of CO$_2$ in the Earth’s carbon cycle makes it important. The carbon cycle is altered due to human impacts which adds CO$_2$ into the atmosphere and sways the ability of natural sinks, like forests, to remove CO$_2$ from the atmosphere. In contrast to other GHGs such as methane (CH$_4$), nitrous oxide (N$_2$O) and fluorinated gases and carbon dioxide (CO$_2$) has a very long life in the climate system. This is why there is an increase in atmospheric concentrations of carbon dioxide that will last thousands of years other emissions.

A World Pollution Atlas data published by a Yale University study in the year 2009, presented in Figure 1.1, shows the pollution levels in terms of CO$_2$ emissions for the whole world. The United States produced 5,425 million tons of CO$_2$ emissions, standing second only to China who produces 7,711 million tons.

Human beings are to be blamed for the fact that enormous quantities of CO$_2$ and other GHG have been released into the atmosphere throughout the past century. Of all the causes of climate change, GHG emissions are considered to be one of the most significant. The primary
GHG, CO\textsubscript{2} accounted for about 82\% of the United States GHG emissions according to the year 2012 USEPA statistics. A diagrammatic representation of the percentage of carbon dioxide (CO\textsubscript{2}) as of 2012 US EPA records have been shown in Fig 2.2.

### 2.1.2 Greenhouse gas (GHG) emissions and the transportation sector

In the United States, 28\% of the greenhouse gas (GHG) emissions comes from transportation sector, which stands second only to electricity generation at 32\% ("Sources of Greenhouse Gas Emissions," n.d.). The figure 2.3 depicts the percentage of carbon dioxide emissions from transportation sector by source as of the year 2012 records. On top of that, if we were to consider the distribution of gases emitted from the transportation sector, it would look somewhat like the visual in figure 2.4.

The vehicular population in the United States is on the increase. The number of registered vehicles from 1990 through 2012 has increased by 28.21\% ("Highway Statistics Series," n.d.). GHG (emissions for the same period rose 18.3\% ("Greenhouse Gas Inventory Data Explorer," n.d.). The transportation sector accounts for the second highest cause of GHG emissions (emitting 28\% of total GHG emissions) only after electricity generation in the United States. While cutting down the emission levels, transportation agencies need to deal with challenges such as: reduced revenue, increased congestion, and growing demand for transportation. Thus, the permutation and combination of various strategies and measures to curb the increasing emission levels needs to be studied to tackle the rising emissions. Some states such as California and New York have each taken initiatives to cut down the emission by 80\% from 1990 levels. Ohio ranks fourth in the United States emissions and first in the Midwest (Larsen et. al., 2007).

Approximately 47\% of all emissions come from the transportation sector (ENVIRONMENT, 2015) .
Figure 2.1: An Atlas of Pollution.
(Source: http://e360.yale.edu/images/digest/carbon_web.pdf)
Figure 2.2: 2012 U.S. GHG Emissions
(Source: http://www.epa.gov/climatechange/ghgemissions/gases.html)
Total Emissions in 2012 = 6,526 Million Metric Tons of CO2 equivalent

Figure 2.3: Carbon dioxide Emissions by source.
(Source: http://www.epa.gov/climatechange/ghgemissions/gases/co2.html)
2.1.3 Transportation: A mobile source of air pollution

Broadly speaking, the sources that pollute the atmospheric air are mobile sources, stationary sources, area sources and natural sources. Mobile sources include cars, buses, planes, trucks, and trains. Stationary sources are units lack mobility such as power plants, oil refineries, industrial facilities, and factories. They pollute from a particular geographic point and hence, are defined as point sources of pollution. Area sources include agricultural areas, cities, and wood burning fireplaces and the natural sources are wind-blown dust, wildfires, and volcanoes (“Sources of Air Pollution,” 2012).

As identified by the EPA, mobile sources hold accountability for more than half of all the air pollution in the United States. EPA classifies mobile sources as shown in the following segment:
A. On-road sources: Those vehicles that are certified for highway use are considered to be on-road sources.

i. Cars

ii. Light Duty and Heavy Duty Trucks

iii. Buses

iv. Motorcycles

B. Non-road sources: The types of equipment that either move under their own power or are capable of being moved from site to site are covered under non-road sources of pollution.

i. Aircraft

ii. Motorboats (Diesel and Gasoline)

iii. Locomotives

iv. Lawn and Garden Equipment

v. Construction Equipment

Of all the mobile sources stated above, the focus of this thesis will be buses. The development of transportation infrastructure all around the United States is focused towards public transit. In the upcoming sub sections of 2.2, we will see how the increased number of public transit is likely to cause lesser emissions in the future. However, increased usage of public transit is not the only key to reach emission cut back goals. The use of public transit in addition to certain new strategies would actually bring down GHG emission levels. This is why the focus would on public transit buses in this thesis.

2.1.4 Emissions from Transit Buses
An effective way to reduce air pollution caused by automobiles is public transportation. Maximization of air quality effects of mass transit have to be achieved by utilizing clean and modern pollution controls for transit buses (“Transit Buses,” n.d.). High concentrations of soot, ozone, and smog in many urban areas are caused by particulate matter, nitrogen oxides, hydrocarbons, and carbon monoxide. Volatile organic compounds and black smoke are difficult to analyze due to a lack of data. 95% of GHG emissions from transportation related sector is contributed by carbon dioxide (CO$_2$). Tailpipe emissions of transit buses are currently monitored in many countries around the world (Lowe et al. 2009 and Cooper et al. 2015).

The rate of pollutant emission from a vehicle is determined from the following factors:

- The type and size of vehicles such as cars, light-duty trucks, heavy-duty trucks, urban and school buses, and motorcycles.
- The vehicle age and accumulated mileage.
- The fuel used such as gasoline, diesel, and others.
- Ambient weather conditions that includes temperature, precipitation, and wind.
- The maintenance condition of the vehicle, driving pattern for example, long cruising at highway speeds, stop-and-go urban congestion, typical urban mixed driving (“Transportation and Air Quality,” n.d.).

Increased use of transit buses for public use substantially yields fuel savings. This commensurate to lesser emission. 89 pounds of CO$_2$ per 100 passenger miles is emitted by a typical passenger car as opposed to 14 pounds of CO$_2$ emitted by a full bus over the same distance. Approximately, 67% of the transit buses in the United States are heavy-duty buses. The seating capacity of a heavy duty bus ranges from 26 to 40. Medium duty
buses have a seating capacity ranging between 16 to 30 seats and that for a small bus is 10 to 22 seats. The average annual growth rate of transit buses in North America within 2017 is 6.1% (considering 2007 as the base year) (Lowe et.al. 2009).

2.2 Prior Studies

2.2.1 Public Transit

The increased by use of more and more public transit is considered one of the major ways to cut back pollution levels enormously. Public transportation includes services that provides mobility to the public in shared vehicles. These shared vehicles can be in the form of vans, local and intercity buses and passenger rail. The figure below shows how public transportation produces lower Greenhouse gas (GHG) emissions than autos (Hodges, 2010). As of the 2010 U.S. DOT records, personal automobiles contributes to higher GHG emissions than any other transportation medium as shown in the figure below ("Public Transportation’s Role in Responding to Climate Change," n.d.).

![Percentage of CO₂ emissions by transportation mode](image)

Figure 2.5: Estimated National CO₂ Emissions per Passenger Mile for Transit and Private Autos.
Improvements in fuel economy, resulting from recently approved changes in Corporate Average Fuel Economy (CAFE) standards are likely to be negated due to the projected increases in vehicle miles of travel. However, if investments and use of public transportation are increased, the negation in improvement in the fuel economy can be mitigated. Experts’ indications have it that there is a need to reduce a total of 60%-80% carbon dioxide emissions of 1990 levels by 2050. A comparative study to figure out the amount of each household’s carbon footprint led to the conclusion that, a potential reduction savings of 30% is possible if one car is eliminated and public transportation is used (Figure 2.7) (Bailey et.al., 2008).

![Figure 2.6: Percentage share of GHG emissions from various transportation media.](http://www.apta.com/resources/reportsandpublications/Documents/land_use.pdf)
2.3 Use of alternative fuels: Biodiesel and Natural Gas

2.3.1 Use of Biodiesel

2.3.1.1 Introduction

Biodiesel is a non-fossil fuel. It can be used as a substitute of diesel fuel. It is renewable and made from natural oils and fats. Any natural oil or fat is chemically combined with an alcohol such as methanol (CH₂O) or ethanol (C₂H₆O) for the production of biodiesel. Rapeseed, soybean, palm, coconut or jatropha oils are used for biodiesel production. Depending on the concentrations of biodiesel present, there are various blends of biodiesel. B100 is pure biodiesel, B20 contains 20% biodiesel and 80% petroleum diesel; B5 contains 5% and biodiesel 95% petroleum diesel; and B2 is a blend of 2% biodiesel and 98% petroleum diesel (“Biodiesel Blends,” n.d.). Starting in 2011, there has been a steep leap in the production and consumption of biodiesel blends (“Biodiesel,” 2015).

Full exploration of biodiesel came about after the years around which vegetable oil was fully explored in the 1980s. Vegetable oil fueled engines dates back to the 1900s and were invented by Rudolf Diesel, a German inventor and mechanical engineer. Through the 1930s and 1940s, vegetable oils were used instead of diesel fuel exclusively in case of emergency situations. However, it was not until the 1980s when studies and discussions regarding increased use of renewable sources of energy came into light due to continuous efforts put into reducing the GHG emissions. This led to the full exploration of vegetable oil at that time (Ma & Hanna, 1999).
Biodiesel not only is a cleaner fuel but it also reduces engine wear, cost, and availability. It does not contain carcinogens, such as poly-aromatic hydrocarbons and nitrous poly-aromatic hydrocarbons. When burned, biodiesel produces pollutants that are less detrimental to human health (Lin and Lin, 2006).

2.3.1.2 Environmental Impacts of Biodiesel

Lower levels of carbon dioxide (CO\textsubscript{2}), sulfur dioxide (SO\textsubscript{2}) emissions and reduction in ozone layer depletion are positive impacts of increased biodiesel usage. The reduction in the carbon dioxide (CO\textsubscript{2}) emissions can be attributed to the fact that the quantity of carbon dioxide (CO\textsubscript{2}) generated due to burning of biodiesel is compensated...
by the amount of carbon dioxide (CO₂) absorbed by the feedstock (biomass/plants) that is grown and consumed for biodiesel production (Sánchez-Arreola et.al., 2014).

As sulfur dioxide (SO₂) emissions are concerned, lower emissions are reasoned by the fact that the sulfur content in biomass is lower. Fossil fuel burnt, however, in the cultivation, harvesting and transportation stages negate the advantages. NOx and SOx are responsible for ozone layer depletion. There is a significant reduction of NOx and SOx emissions as a result of biodiesel usage and hence, the negation of ozone depletion. This thesis focuses on GHG emissions. Therefore, the discussion on other pollutants is beyond the scope of this study (Sánchez-Arreola et.al., 2014).

The use biodiesel can have a negative effect on eutrophication, ozone layer depletion and acidification. The measure of such impacts varies in accordance with various studies. Several studies were performed in different geographic locations such as in Europe, India, Denmark and China. The European study shows that B100 obtained from rapeseed oil yields 59% and 214% increase in acidification and eutrophication respectively, in comparison to petroleum based diesel oil. Danish study also showed proof of land occupation in addition to acidification and eutrophication. Jatropha used for the biodiesel study in India showed that acidification and eutrophication increased by 49% and 430% respectively (Sánchez-Arreola et.al., 2014).

Arable lands are converted into biomass production from food production. This leads to the increase in food market prices. The process of mass production of biodiesel also contributes to significant increase in GHGs (Samper, 2014).
2.3.1.3 Biodiesel Emissions

As per NREL research reports, the carbon dioxide emission reductions through the use of blends B100 and B20 are -78.3% and -15.7% respectively. The percentage of emission reductions for other pollutants has been shown in the following table.

Table 2.1: Harmful Emission Reductions.
(Source: National Renewable Energy Laboratory)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>B100</th>
<th>B20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>-43.2%</td>
<td>-12.6%</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>-56.3%</td>
<td>-11.0%</td>
</tr>
<tr>
<td>Particulates</td>
<td>-55.4%</td>
<td>-18.0%</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>-78.3%</td>
<td>-15.7%</td>
</tr>
<tr>
<td>Nitrogen Oxide (NOx)</td>
<td>+5.8%</td>
<td>+1.2%</td>
</tr>
</tbody>
</table>

Figure 2.7: Average emission impacts of biodiesel for heavy-duty highway engines. (Source: http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf)
The impact of biodiesel emissions on CO$_2$ emissions have been presented in Figure 2.9. The emissions are higher if the BD is blended with a clean base fuel instead of an average base fuel. A single correlation has been used to find out the impact of biodiesel emissions in terms of CO$_2$. The correlation accounts for base fuels, biodiesel source, and engine standards altogether at the same time:

$$\% \text{ change in } \text{CO}_2 = (\text{Radiation}) \times 100\% \hspace{1cm} \text{Equation 2.1}$$

where, where vol% biodiesel = Value from 0 to 100

CLEAN = 1 if the base fuel meets the conditions for "Clean" fuel; otherwise, CLEAN = 0.

ANIMAL = 1 if the biodiesel is produced from animal fat, tallow, or lard; otherwise, ANIMAL = 0. The overall vol% biodiesel term represents all biodiesel ("Air and Radiation,” 2002).

Figure 2.8: Biodiesel impacts on CO$_2$ emissions.
2.3.2 Use of Natural Gas (NG): Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG)

Natural Gas (NG) is a fossil fuel that can be used as Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG). It comprises of a gaseous mixture of hydrocarbons, mostly methane (CH$_4$). About one-tenth of 1% is used as fuel for the transportation sector. CNG is stored under pressure. LNG does not need bulky fuel storage. Waste treatment facilities produce biogas. This biogas can be purified and used as CNG, thus, reducing the waste generation.

Of the NG used in the United States, about 94% is domestically grown. This cuts the costs of importing the gases. The amount of smog produced is considerably lesser as a result of 20% to 45% lesser smog pollutants emitted. The amount of GHG emissions are reduced by 5% to 9%. The threat to environmental hazard is brought down drastically, as the NG dissipates into the atmosphere in the occurrence of an accident instead of spilling and finding a way out to the waterways and wildlife.

One of the major concerns of NG usage is the fewer miles run on a full fuel tank in comparison to conventional fuel. It is less readily available in contrast to diesel and gasoline with limited vehicle fueling infrastructure.

2.4 Land Use Planning

2.4.1 Introduction to Land Use Planning

One of the most essential natural resources we have at our disposal is land. It also is the source of different materials needed for human activities, essential for survival on this planet (Dyer et. al., 2013). There is a strong nexus between our dwelling place, work place, places for entertainment, social activities, education and our transportation
requirements (“Smart Growth & Land Use Planning,” n.d.). The travel behaviors of the population in and around an area are shaped up by the land use patterns. Decisions that affect land use planning and management directly affect the energy consumption and GHG production.

A vast majority of the planning solutions emphasized on separation of urban functions in the process of avoiding health problems. However, this separation of facilities has contributed to set of environmental problems. Integration of land use and traffic planning promotes sustainable development. Car-borne traffic has been on a rapid increase because of the land extensive city structures and traffic demand in relation to human activities. For example, the increased use of private cars for personal commuting convenience. This is the reason for focus on tackling growth of traffic and encouraging public transit. Development of urban form and location alongside well organized public transit, therefore, can significantly impact traffic flows (Heral, 2003).

Land use patterns on its own have tremendous amount of environmental effects. The travel decisions every person makes regarding their mobility is largely shaped by the developmental patterns around them. The developmental pattern, transportation infrastructure, and building location and design make up a build environment which determines the amount of travel needed by people to carry out their day-to-day activities (G.Kramer et. al., 2013).

Land use planning is a process of societal planning where institutional decisions regarding the location and positioning of various socioeconomic activities such as agriculture, housing, industry, recreation, and commerce are taken, within a given territory. The development of well-defined areas is protected from such planning. This is
primarily because of environmental, cultural, historical, or similar reasons, and establishing provisions that control the nature of development activities. In fact, in planning these become the yardsticks or control points for the determination of various features needed for development. For example, plot areas, their land consumption or surface ratio, their intensity or floor-area ratio, their density or units of that activity (or people) per hectare, the technical standards of the infrastructure and buildings that will serve them, and related parking allowances (Samper, 2014).

Land use provisions also include levels of gas emissions, light radiation, noise, water, solid waste discharges, and onsite or pre-disposal treatment of pollutants in areas where it is absolutely necessary. The zoning or land use code states such provisions. A combination of a well maintained system of protected areas and strong land use provisions, results in a less-polluted jurisdiction. Improper land use could lead to people running their private automobiles more often and decrease their reliance on public transit due to inaccessibility (Samper, 2014). More number of vehicles on the roads leads to traffic congestion and hence, increases air pollution.

2.4.2 Impacts of Land-use on transport: Relation between Cities and Climate

Urban areas have long been perceived as being largely responsible for climate change. They produce up to 80 percent of all GHGs that are accountable for climate change. About 70 percent of total energy consumption happens in cities (Newman et al. 2008). Most of the industrial activities takes place around the urban city as it node, thus generating a tremendous amount of GHGs. Additionally, high-density settlements around the city characterize intensive land uses which consume much energy giving rise to the amount of GHG produced. A significant reduction in greenhouse gas GHG emissions are
achieved if the development around the city is compact (Bestill and Bulkeley 2007; Blakely 2007, Frank et al. 2007, and others; & Byahut, 2012).

Major US cities are adopting a range of land use and planning strategies such as smart growth, traffic calming, parking management etc. to protect the climate. Smart growth solutions include urban villages, urban villages, neo-traditional neighborhoods, transit-oriented developments (TODs), access management, job-housing balance (JHB), traditional neighborhood design (TND), mixed-use activity centers and context-sensitive highway designs. The effectiveness of these strategies are significantly enhanced when complimented with measures such as intelligent transportation systems, and transportation pricing measures such as reducing fuel subsidies, parking pricing, congestion pricing, and pay-as-you-drive insurance. The complimentary measures are, however, beyond the scope of this thesis.

There are various interactive effects of transportation planning decisions and land use development. A summary of various land use factors have been derived from a very interesting report by Victoria Transport Policy Institute (VTPI), that affect the transportation planning development that will be discussed in the following section (Litman, 2005).

1. **Regional Accessibility:** The travel distances between regional centers, residences, jobs or services are considerably reduced when locations are accessible in a region. The vehicle mileage per person declines significantly. Residents at urban fringes travel 70-90% more in comparison to central area residents.
2. **Density**: Higher count of people, jobs, or houses per unit area of land in acre, hectare, square mile, or kilometer could reduce travel distances. This factor increases walkable destinations and distances that can be cycled. The efficiency of path and public transit are enhanced by an increase in sidewalks and a decrease in vehicle congestion and parking costs. It also reduces vehicle ownership and travel, and increases use of alternative transportation modes.

3. **Mix**: Different land uses—residential, commercial, and institutional, etc., should be in a closer proximity to one another. This can be identified as jobs/housing balance, which is the ratio of jobs and residents in an area. A mixed pattern of development can considerably reduce travel distances between local destinations. Tends to reduce vehicle travel and increase the use of alternative modes, particularly walking. Mixed-use areas typically have 5-15% less vehicle travel.

4. **Centeredness (centricity)**: Major town centers and central business districts should consist of a portion of jobs, commercial and other activities in major activity centers. This provides agglomeration efficiencies and increases public transit service efficiency. It has been found that typically 30-60% of commuters to major commercial centers use alternative modes compared with 5-15% at dispersed locations.

5. **Connectivity**: The degree to which the roads and paths are connected affects the allowance of direct travel between destinations. Careful planning in this aspect reduces travel distances and hence, reduces congestion delays. Increased roadway connectivity can reduce vehicle travel and improve walkway connectivity increase sing non-motorized travel.
6. **Roadway design and management:** The scale and design of streets in order to control traffic speeds, support different modes, and enhance the street environment. This improves walking, cycling and public transit travel. It may improve local environments so people stay in their neighborhoods more. Multi-modal streets increase the use of alternative modes. Traffic calming reduces VMT and increases non-motorized travel.

7. **Parking supply and management:** The number of parking spaces per building unit or hectare, and the degree to which they are priced and regulated for efficiency affect transit usability. Increased parking supply disperses destinations, reduces walkability, and reduces the costs of driving. This, in turn, tends to reduce vehicle ownership and use, and increase the use of alternative modes. The cost-recovery pricing (users finance parking facilities) typically reduces automobile trips 10-30%.

8. **Active transport conditions:** The quantity and quality of the sidewalks, crosswalks, paths, bike lanes, bike parking, pedestrian security, and amenities is a major factor that can discourage people from using the services due to inconvenience. Improvement of the existing infrastructure can encourage pedestrian and bicycle travel, and, therefore, public transit access. Improved walking and cycling conditions tends to increase non-motorized travel and reduce automobile travel. Residents of more walkable communities typically walk 2-4 times more and drive 5-15% less than those in automobile-dependent areas.

9. **Transit accessibility:** The degree to which destinations are accessible by high quality public transit and improve transit access and support other accessibility improvements. Accessibility improvement increases ridership and reduces automobile trips. Residents of transit oriented developments tend to own 20-60% fewer vehicles,
drive 20-40% fewer miles, and use alternative modes 2-10 times more than in automobile-oriented areas.

10. Site design: The layout and design of buildings and parking facilities improves pedestrian access. More multi-modal site design can reduce automobile trips, particularly if implemented with improvements to other modes.

11. Mobility Management: Various strategies that encourage and improve the use of alternative modes, improves and encourages use of alternative modes. This tends to reduce vehicle ownership and use, and increase the use of alternative modes.

12. Integrated smart growth programs: Travel impacts of integrated programs that include a variety of land use management strategies. It reduces vehicle ownership and use, and increases alternative mode use. Smart growth community residents typically own 10-30% fewer vehicles, drive 20-40% less, and use alternative modes 2-10 times more than in automobile-dependent locations, and larger reductions are possible if integrated with improved regional transit and more efficient transport pricing.

The significant reduction in VMT from various factors can be seen by the mechanisms and their impacts on travel are listed above from (1) through (12) (Litman, 2005).

2.4.3 Reduction of Vehicle Miles Travelled (VMT) Using Smart Growth

Ground transportation is heavily impacted by the modes of travel and number of trips. This causes severe traffic jams and idling of vehicles which increases the amount of vehicular emissions. The average trip per person per day was 3.79 for the year 2009. Personal vehicles were used 83% times. Only 1.9% of travelers used transit, and 11.5% biked or walked (BTS, 2014). Irrespective of the purpose of the trip, average peak rush
hours are around 6:00am-9:00am in the morning and 4:00pm-7:00pm in the evening (“Conditions and Performance,” 2015). There is a minor peak around noon.

Figure 2.10 gives the hourly variation of travel information.

Proper land use can decrease traffic demand, so as to abate the vehicular emissions by reducing vehicle mile-age traveled. It can also improve traffic conditions. Over the past half century, ‘‘urban sprawl’’ was the dominant form of urban growth for mega cities worldwide (Southworth, 2001). Urban land form studies show that there is a distinctive connection between land use to travel connections and travel connections–to-climate change (Ewing & Anderson, 2008).

2.5 Emission Control: Use of I/M programs

For vehicles in-use vehicles, inspection/maintenance (I/M) program is the most effective means for emission reduction. I/M program improves air quality by identifying high-emitting vehicles in need of repair (through visual inspection, emissions testing,
and/or the downloading of fault codes from a vehicle's onboard computer) and causing them to be fixed as a prerequisite to vehicle registration within a given non-attainment area ("Cars and Light Trucks," n.d.). An I/M program without quality assurance wastes money and time (Hao et. al., 2006).

The concept for the I/M program is simple: modern vehicles are dependent on properly functioning components to keep pollution levels low. Minor malfunctions in the air/fuel or spark management systems can increase emissions significantly. Major malfunctions can cause emissions to skyrocket. Government can require that vehicles be tested or “inspected” (the “I” in “I/M”) to determine whether their emissions exceed levels appropriate for that vehicle type. Vehicles that fail the test must undergo repairs or maintenance (the “M” in “I/M”) to bring their emission performance up to par, or they must cease operating, at least within the geographic jurisdiction of the I/M program. Studies suggest that a small fraction of the vehicle fleet typically are responsible for a very large share of total vehicle emissions, so an I/M program that reduces the emissions of these “gross emitters” can bring substantial air quality benefits (Husker, 2004).

There are pilot studies performed in various cities across the United States. Remotely sensed data were collected in Tucson, AZ; El Paso, TX; Ute Pass, CO; Denver, CO; and Chicago, IL. The results of the tests were analyzed by comparing the data sets of those vehicles registered in non-I/M zip codes to the vehicles registered in I/M-required zip codes, leaving out those zip codes that are partially in the I/M program.

The studies performed on in-use vehicles in several places across the United States, disagreed in terms of the actual emission levels versus the computer model generated emission values. Inherently, emissions measurement from in-use vehicles is a
more complete and accurate source of information. The reported emissions from vehicles were found to be considerably higher in case of random roadside surveys where in addition to tail pipe emissions, vehicle tampering was studied (Ashbaugh & Lawson, 1991).

2.6 Temperature Fluctuations and Climate Change

The damage done to the climate due to GHG emissions is a matter of serious concern mostly due to the irreversibility in its nature. Oceans, weather patterns, snow and ice, and plants and animals are all susceptible to changing temperature and, hence, the climate. After emissions stop, CO$_2$ concentration in the atmosphere is irreversible for 1,000 years (Solomon, Plattner, Knutti, & Friedlingstein, 2009).

Rising temperatures are responsible for a series of chain reactions that go on around the world. Air temperature directly affects the people and environment. The upcoming section states the effect of rising global temperature on various elements such as agriculture, air quality, human health etc.

2.6.1 Agriculture

The right temperature and appropriate amount of water are essential for crops that are grown for food. A changing climate could affect crops both positively and negatively. For example, warmer temperatures in the Northern U.S. help certain crops to grow and thrive as it is cooler most parts of the year. In southern areas, however, additional heat could hurt crop growth, as it is already warm.

There could be severe losses of crops as the temperature could make it too hot to grow certain crops. Droughts could reduce the amount of water available for irrigation. Stronger storms and more floods could damage crops. As a result of higher temperatures,
there could be changing rainfall patterns. These phenomenon could help some kinds of weeds and pests to spread to new areas. If the global temperature rises an additional 3.6°F, U.S. corn production is expected to decrease by 10 to 30 percent.

2.6.2 Health

Human health, lives and property are threatened by heat waves, severe storms, air pollution, and diseases. Global temperature will increase these threats. Certain groups of people, especially the poor, very young, elderly, or disabled, or those who live in coastal areas or big cities, are more vulnerable to health problems associated with temperature.

For infants and young children, the elderly, and people who are already sick, extreme temperature events can be especially dangerous. Several illnesses are related to heat such as heat cramps, heat stroke, and even death. In the United States, every year heat waves alone can lead to more deaths than hurricanes, tornadoes, floods, and earthquakes combined. In the year 1995, a heat wave in Chicago caused more than 600 deaths.

2.6.3 Air Pollution

The ozone can be found close to the surface of the Earth, where it is the main ingredient of smog and is harmful for people to breathe. Warmer temperatures aid in the increase of the concentration of ozone through chemical reactions from certain pollutants.

In warmer temperatures, ticks and mosquitoes, that are disease carriers can survive longer throughout the year and expand their ranges, putting higher number of people at risk. Malaria, for example, is a deadly disease spread by mosquitoes in many hot, humid parts of the world.
2.6.4 Energy

Rising temperatures demand much electricity usage, as air conditioning is required by more people to maintain a considerably cooler temperature. Cooler temperatures, however, lead to the consumption of lesser energy as buildings needs to be heated up gently. Cooler climates make it harder to produce certain types of electricity, such as hydropower.

Precipitation patterns shift due to climate change. Some areas that rely on hydropower, such as northern California, might not have enough water to produce electricity in the future. They might have to use other energy sources to make more of the electricity for consumption, and if these sources are fossil fuels like coal, oil, or natural gas, more greenhouse gases will be added to the atmosphere.

2.6.6 Water Supplies

Change in climatic patterns is affecting the quantity of water available for human consumption. Rising temperatures, changing precipitation patterns, and increasing droughts will modify the natural water cycle. The amount of water in lakes, rivers, and streams, as well as the amount that seeps into the ground-sub surface water, replenishes the ground water reserve.

In 2007, a major drought hit the southeastern United States. Lake Lanier, which is the main source of drinking water for the Atlanta area, was reduced to record–low water levels. People had to use less water in their homes and businesses and make other changes, such as not watering their lawns.

Numerous drinking water reservoirs and irrigation reservoirs rely heavily on the lakes, rivers, and streams to keep them full. For example, the Colorado River water feeds
many parts of the western United States. The water in the river is fed by melting snowpack in the Rocky Mountains. Less snowpack and earlier snowmelt will reduce the amount of water flowing into the Colorado and other rivers.

2.6.7 Plants, Animals, and Ecosystems

The habitat of most plants and animals enable them to thrive by providing them suitable climate conditions, such as temperature and precipitation. Therefore, any change in the climate of an area can actually impact their suitable habitat, thus, changing the entire ecosystem. The life cycles of plants and animals are also altered due to climatic variations. For example, as temperatures get warmer, many plants are starting to grow and bloom earlier in the spring and survive longer into the fall. Some animals are waking from hibernation sooner or migrating at different times, too.

2.6.8 Forests

Forests protect water quality, offer opportunities for recreation, and provide wood. They are sensitive to many effects of climate change, including shifting weather patterns, drought, wildfires, and the spread of pests like the mountain pine beetle. Natural vegetation is unable to adapt unlike some animals.

Wildfire occurrences are one of the examples of effects of climate change that happen as the Earth gets warmer and droughts increase. Extremely dry conditions resulting from droughts allow fires to start more easily, spread faster, and burn longer. In fact, with the Earth getting just 3.6°F warmer, wildfires in the western United States can burn four times more land than they do at present temperatures. These fires change the landscape and threaten people's lives and property.
2.6.9 Coastal Areas

Low-lying areas near the coast could be inundated as the sea level rises. Rising sea level destroys many coastal wetlands that protect the shore from flooding. Also, it erodes land away. Heat waves, droughts, and coastline damage as well as warmer temperatures could also affect people's jobs, recreational activities, and hobbies ("Student’s Guide to Global Climate Change," n.d.).

2.7 Climate Forcing

In the previous section, the sensitive relationship between temperature and various elements that are affected by the climate have been observed. This association can be mapped in terms of radiative forcing. The Earth’s surface temperature depends on this balance between incoming and outgoing energy. A shift in the energy balance causes the Earth’s average temperature to become warmer or cooler, leading to a variety of other changes in the lower atmosphere, on land, and in the oceans. A variety of physical and chemical changes can affect the global energy balance and force changes in the Earth’s climate. Some of these changes are natural, while others are influenced by humans. These changes are measured by the amount of warming or cooling they can produce, which is called “radiative forcing.” Changes that have a warming effect are called “positive” forcing, while changes that have a cooling effect are called “negative” forcing. When positive and negative forces are out of balance, the result is a change in the Earth’s average surface temperature ("Climate Change Indicators in the United States," n.d.).

Radiative forcing can be used to estimate a subsequent change in equilibrium surface temperature ($\Delta T_s$) arising from that forcing via the equation:
\[ \Delta T_s = \lambda \Delta F \]  

Equation 2.2

where, \( \lambda \), is the climate sensitivity, usually with units in K/(W/m\(^2\)), and \( \Delta F \) is the radiative forcing (Obasi, 2001). A typical value of \( \lambda \) is 0.8 K/(W/m\(^2\)), which gives a warming of 3K for doubling of CO\(_2\).

Climate sensitivity, \( \lambda \) is the equilibrium temperature change in response to changes of the radiative forcing. Therefore climate sensitivity depends on the initial climate state, but potentially can be accurately inferred from precise palaeoclimate data.

For a greenhouse gas, such as carbon dioxide, radiative transfer codes that examine each spectral line for atmospheric conditions can be used to calculate the change \( \Delta F \) as a function of changing concentration. These calculations can often be simplified into an algebraic formulation that is specific to that gas.

For instance, the simplified first-order approximation expression for carbon dioxide is:

\[ \Delta F = 5.35 \times \ln \frac{C}{C_0} \text{ W m}^{-2} \]  

Equation 2.3

Where, \( C \) is the CO\(_2\) concentration in parts per million by volume and \( C_0 \) is the reference concentration. The relationship between carbon dioxide and radiative forcing is logarithmic and thus increased concentrations have a progressively smaller warming effect (Myhre et. al., 1998).
2.8 Conclusions from Literature Review

Much research work has been performed to cut down pollution from the transportation sector. Major studies have been done to decrease the GHG by a great value. Some of the studies have discussed the comparison of various methods to alleviate vehicular pollution. However, none of the studies have performed a comparative analysis of the control strategies using computer modelling tools for the State of Ohio. Also, literature lacks the certainty test of such futuristic data produced by a model/tool/software. The percentage changes in GHG emissions are quite significant for every percent change in the parameters that computer models use. In this thesis, a scenario analysis, certainty tests are performed on modelled emissions data and it’s related to the future years temperature of the Ohio region.

Chapter 3

Methodology and Data Collection

3.1 Overview of Problem

The analysis GHG emission reduction strategies for public transit buses of a region can be performed in a number of ways such as mathematical modelling, conducting field-cum-laboratory experiments, and using computer modelling techniques. Of all of these approaches, computer modelling was chosen to conduct this thesis research. Several tools/software were used for the generation of future changes that the GHG emission data for the State of Ohio in particular. The strategy outputs from the models were compared to choose the most efficient strategy. The strategies, the plan of study, work flow, and model details are presented though the upcoming sections of this chapter.
3.2 Methodology and Approach

The examination of different control technologies requires future GHG emissions. The approach used to evaluate the future GHG emissions from public transit buses in Ohio is complex as it is not possible to just add the different projected activity rates multiplied by the appropriate emission factor. The emissions have been evaluated for all the scenarios using the Environmental Protection Agency (EPA) software MOVES2014, Argonne National Laboratory GREET 2012 spreadsheet tool and EPA tool mixed-use trip generation model. In this thesis, carbon dioxide (CO$_2$) emissions are used a proxy for GHG emissions. These modeling techniques help in generating data for ten future years in terms of reductions in vehicle miles travelled (VMT) and CO$_2$ emissions from the use of various strategies that reduce pollution. Three different scenarios were used to evaluate the benefits of utilization of emission control strategies for the State of Ohio. The strategies have been discussed in Chapter 2 and a summary is given in Table 3.1.

3.2.1 Study Area and Data Collection Plan

The mid-western State of Ohio is being used for the study. The total area of the state is 44,825 square miles. A county map of the region is shown in figure 3.1. The data collection plan for the region has been stated in Table 3.1.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Control Strategy</th>
<th>Data Used</th>
<th>Tools/Software/Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy I</td>
<td>Alternative</td>
<td>Biodiesel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LNG</td>
<td></td>
</tr>
</tbody>
</table>
### 3.3 An Introduction to Modeling Tools/Software

The data for various technologies have been collected using various tools as listed in Table 3.1. The process of collection of the data required preparation of a huge set of inputs to run the tools/models/software. A detailed anecdote of collection and preparation of inputs strategy wise has been discussed in the sub-sections of section 3.3. The emission data, due to usage of alternative fuels-BD, CNG and LNG, have been collected using GREET 2012. Also, MOVES 2014 was used to collect the data. However, MOVES2014 had the limitation of lesser number of fuel choices that excluded BD and LNG. The reason for still using MOVES2014 when GREET 2012 already solved the purpose was that of inspection and maintenance (I/M) program data. The I/M program data were derived from MOVES2014, and the process of preparation of input was the exact same one. As for emission reduction data, EPA tool mixed-use trip generation model was used. The flowchart of the entire process adopted to perform work in this thesis is shown in figure 3.1.
3.3.1 Tools for Alternative Fuels Data: GREET2012 and MOVES2014

Alternative fuels-BD, CNG and LNG, emissions data have been generated in addition to diesel emissions for the sake of comparison. A brief introduction on the models has been discussed in sections, 3.2.1.1 and 3.2.1.2.

![Flowchart depicting the flow of work for GHG Control Strategy Options for Ohio Public Transit Buses.](image)

**3.3.1.1 GREET Fleet Footprint Calculator**

The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Fleet Footprint Calculator has been developed by the Argonne National Lab and sponsored by the U.S Department of Defense (DOE). For a given combination of vehicle and fuel system, GREET yields GHG emissions. The output is in terms of carbon dioxide equivalent (CO$_2$-e). Primarily, the GREET calculators’ resulting emissions are a cumulative of three different GHGs- carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O).
GREET is a fuel-cycle model in the form of a multidimensional spreadsheet model in Microsoft Excel. It can be used for various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. The basis of the calculation that the fuel-cycle model uses is generation of necessary petroleum use and GHG emission coefficients. These coefficients are specific for key fuel production pathways and combustion fuel types.

The tool essentially utilizes two different methods to yield results. They are-
Method (a) Fleet size, vehicle miles traveled, and fuel economy; and Method (b) Fuel use. The first method, method (a) needs the following data to be prepared and collected by the user:

- The Number of Each Type of Vehicle in On-Road Fleet
- The Average Annual Vehicle Miles Traveled by Each Vehicle Type
- The Average Fuel Economy for Each Vehicle Type in the On-Road Fleet (miles per gasoline gallon equivalent)

To use the second method (b), the Annual Total Fuel Use by On-Road Fleet Vehicles (gallons, cubic feet, or kilowatt-hours) is required (Wang, 2009).

The data for this project was obtained using method (a). The input data for ten future years were gathered, starting year being 2015. The tool had to be run ten times as the data for different years were different.
Figure 3.2: County Map of Ohio showing all 88 counties.

3.3.1.2 MOVES2014 for CNG and Diesel

MOtor Vehicle Emission Simulator (MOVES) yields emissions for mobile sources, including both on-road and non-road sources. A very broad range of pollutants are covered by the simulator. It enables multiple-scale analysis. The simulator is based on analysis of millions of emission test results. MOVES aims at providing emissions
estimate for a wide variety of user-defined combination (“Modeling and Inventories,” n.d.).

Running MOVES2014 requires the preparation of huge dataset in prescribed format in the exemplar templates. The graphical user interface (GUI) requires the operator to define the following information: vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and road types. To obtain data for a smaller scale such as counties of a state, the pre-processing of the county data manager (CDM) is necessary.

Pre-processing of the CDM would mean preparing Microsoft Excel templates populated with required data. The CDM asks for input data such as Vehicle Type VMT, Hoteling, I/M Programs, Retrofit Data, Road Type Distribution, Source Type Pollution, Age Distribution, Average Speed Distribution, Meteorology Data and Fuel data. These templates are uploaded into the interface. This leads to the activation on the execute option which enables us users to run the simulation.

The output needs to be retrieved using standard query language (SQL). Prior to that, output needs to be post-processed to be retrieved in MySQL Workbench. The data obtained has to be decoded, so as to understand the meaning of the numbers produced in the analysis. Emissions for transit buses for ten future years starting 2015 were obtained using MOVES software.

### 3.3.2 Tools for Land-Use Pattern: Mixed-use trip Generation Model

The Mixed-Use Trip Generation Model is a spreadsheet tool that uses regression model. It is developed by a U.S. based firm Fehr & Peers for the EPA. The percentage
reduction in trips is calculated using regression model coefficients. ITE Trip Generation and NCHRP 365 factors are used to calculate "Baseline" project site trips by purpose.

For different planning years results would be different for a particular area. The reason for it being different is the difference in changes in surrounding areas. To account for this fact, some off-site variable is taken into consideration. This analysis essentially involves "existing plus project" and "cumulative plus project" scenarios. The basis of determination of trip reduction used in the tools is the following:

- The percent of trips internally captured.
- The percent of external trips which are made by walking.
- The percent of external trips which are made by transit.

There are a number of inputs required to figure out the VMT reductions. General site information details such as total developed area in the site chosen for analysis, number of intersections, transit accessibility, distance from central business district (CBD) etc. are needed. Housing data under the head “Variable Modeling Parameters”, such as average household size, jobs per square feet are required. Additionally, land use data needs to be inserted. Numbers of single family, multi-family dwelling units, supermarket, banks, restaurant, health clubs etc. are some of the examples of the land use inputs. VMT data-average trip length with the site and traffic analysis zone needs to be used to complete the Input sheet of the model.

The limitation of this analysis lies in the fact that there is a limitation on the size of the area for which the emission needs to be found out. The size limitations have been stated below:

- The site should be between 5 and 2000 acres.
• There should be less than 5000 dwelling units and less than 3 million square feet of commercial use.

3.3.3 Tools for I/M Program of in-use vehicles: MOVES2014

The I/M program used MOVES2014 for the emissions. The details about the model has been already stated in section 3.2.1.2.

3.4 Method of Data Collection

While collecting the data, all the various sets of input required future years projection trends on Estimation of emissions before the base year increase in the number of buses to changes in land-use patterns.

3.4.1 Estimation of emissions before the base year

For all the evaluations in this thesis, 2015 have been considered as the base year. The projection trends are assumed to follow the historical pattern. For the historical pattern, past ten years (that is 2005 to 2015) Bureau of Transportation Statistics published figures have been collected.

3.4.2 Alternative Fuel Data

For GREET 2012 tool, alternative fuel emissions were modeled using a method which required the following input data:

i. The Number of Each Type of Vehicle in On-Road Fleet

ii. The Average Annual Vehicle Miles Traveled by Each Vehicle Type

iii. The Average Fuel Economy for Each Vehicle Type in the On-Road Fleet (miles per gasoline gallon equivalent)
For the number of each types of public transit buses by fuel type are listed in the following format shown in Table 3.2. The boxes marked in green color are filled with projected statistics on the number of buses. The reason for not evaluating emissions from the rest of transit buses with fuels such as Liquefied Petroleum Gas (LPG), Electricity, and Gaseous Hydrogen is the unavailability of the historical statistics and projected percentages.

The input table for average annual vehicle miles traveled by each vehicle type is shown in Table 3.2 and for average fuel economy for each vehicle type in the on-road fleet (miles per gasoline gallon equivalent) in Table 3.3. The cells marked in green correspond to the data for transit buses and are filled out.

3.4.3 Land-use pattern Data

Generation of traffic is dependent on the development of the area, the number and length of trips an individual makes. The number of vehicle trips can be considerably reduced if the neighborhood enables walkable access to transit services. Lesser number of vehicles would mean lesser pollution emitted from the personal vehicles in addition to lesser congestions on the road, hence, lesser idling. These interrelationships have been already discussed in Chapter 2. Quantification of benefits of land-use patterns to emission reduction requires a tool to relate the land use pattern and travel. EPA website endorses a spreadsheet tool that relates mixed-use land to miles travelled by vehicles. These vehicle miles travelled (VMT) can be related to emissions using emission factors for different pollutants.

To comply with the various conditions and limitations of the mixed-use trip generation model described in section 3.2.2, in terms of areal limitation of the site, three
geographic points have been chosen in Ohio. The H+T affordability index has been run to identify the highest GHG emitting points in Ohio. Of the several GHG emitting points, three points were chosen. A screenshot of the index which is used to derive highest GHG emitting points have been shown in figure 3.2.

The H+T affordability index gives the annual GHG per acre. The highest GHG emitting geographic points are often those which generate more than 20 tonnes of GHG per acre. Since, our aim is to reduce emissions from public transit buses, therefore, locations chosen for evaluation are strategically chosen. These locations are well equipped with transportation infrastructure in addition to being higher GHG emitter. The points identified as highest GHG emitter from the index in figure 3.3 are plotted in the map of Ohio in figure 3.4.
Figure 3.3: H+T Affordability Index showing the highest GHG emitting geographic points in Ohio. (Source: http://htaindex.cnt.org/compare-greenhouse-gas/)
Table 3.2: Input table for the Number of Each Type of Vehicle in On-Road Fleet.

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>Diesel HEV</th>
<th>Biodiesel (B20)</th>
<th>Biodiesel (B100)</th>
<th>Ethanol (E85)</th>
<th>Compressed Natural Gas (CNG)</th>
<th>Liquefied Natural Gas (LNG)</th>
<th>Liquefied Petroleum Gas/Propane (LPG)</th>
<th>Electricity</th>
<th>Gaseous Hydrogen (G.H2)</th>
<th>Liquid Hydrogen (L.H2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>School Bus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Shuttle/Paratransit Bus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Waste Hauler</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
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<td>x</td>
</tr>
<tr>
<td>Street Sweeper</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Delivery Step Van</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Medium/Heavy Duty Pickup Truck</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
</tr>
<tr>
<td>Maintenance Utility Vehicle</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Other</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
Table 3.3: Input table for the Average Annual Vehicle Miles Traveled by Each Vehicle Type.

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>HEV</th>
<th>B20</th>
<th>B100</th>
<th>E85</th>
<th>CNG</th>
<th>LNG</th>
<th>LPG</th>
<th>Electricity</th>
<th>G.H2</th>
<th>L.H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>School Bus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Shuttle/Paratransit Bus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Waste Hauler</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
</tr>
<tr>
<td>Street Sweeper</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Delivery Step Van</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Transport/Freight Truck</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Medium/Heavy Duty Pickup Truck</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

58
<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>Diesel</th>
<th>HEV</th>
<th>B20</th>
<th>B100</th>
<th>E85</th>
<th>CNG</th>
<th>LNG</th>
<th>LPG</th>
<th>Electricity</th>
<th>G.H2</th>
<th>L.H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Utility Vehicle</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>Other</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 3.4: Input table for the Average Fuel Economy for Each Vehicle Type in the On-Road Fleet (miles per gasoline gallon equivalent).
A mapping tool is used to locate these high GHG emitting points using the coordinates of the area in question. The three areas chosen are shown in the figures 3.3 through 3.6.

(i) Geographic Area I: Cincinnati in Hamilton County

Area = 37.431 acres

GHG emission = 16.84 tonnes per acre
Figure 3.4: Ohio map showing three of the highest GHG emitting points.
(ii) Geographic Area II: Toledo

Area = 136.084 Acres
GHG emission = 18.34 tonnes per acre

(iii) Geographic Area III: Columbus
Area 3 = 230.683 Acres

GHG emission = 22.37 tonnes per acre

The average household size, jobs per ksf (thousand square feet), number of dwelling units, average trip lengths etc. for the above three geographic points are collected using the housing data. The model yields VMT reduction data as the output. This reduction in VMT is then converted into emissions using calculations that use emission factor of the pollutants. The resultant emission per acre is scaled to the total area of the State of Ohio.

**3.4.4 I/M Data**

The emissions data as result of utilization I/M program for the in-use vehicles, transit buses, in this case, is obtained by running EPA MOVES2014. Figure 3.6 is the graphical user interface of the simulator. The blue-colored panel on the left hand side of the GUI, enables us to choose the scale of the various input characters required. The time span panel enables us to select the years, months, days and hours of the days for bus emissions. The geographic bounds provides the choice of selecting regions within the United States. The types of roads such as rural or urban
area roads can be determined to extract the output. As for the pollutants in this study, only GHGs are picked from the list of various pollutants which includes total gaseous hydrocarbons, CH₄, NOₓ, NO, PM$_{2.5}$ etc. The simulator is ready when the yellow signs turns green for each of the tabs on the left hand side of the interface.

To run the data for a state, Ohio in this case, a tool called county data manager (CDM) has to be prepared. A screenshot of the CDM has been shown in figure 3.7. For each of the CDM tabs, namely, vehicle type VMT through meteorology data has to be filled with input tables in the format of MS Excel templates. The tool is ready for execution only if the inputs are in correct format and units.

3.5 Data Analysis

The data that has been collected using the aforesaid technique have been analyzed for proper understanding of the impacts of emission reduction. Section 3.4.1 comprises of details of the scenario analysis that was performed with the outputs that were collected from the models.

3.5.1 Scenario Analysis

The cases of different scenarios developed for the purpose of comparison of the emission levels and its relationship with the temperature of the region are stated in the following segment.

3.5.1.1 Case i: The Worst Case

The worst case is a hypothetical situation in which the impact of not using any control over the pollution level is checked.
3.5.1.2 Case ii: The Base Case

This case is the business-as-usual (BAU) case wherein the effect of various control strategies are analyzed in such a way that it follows the trend that have been in practice since some time/ages. The models/software used often has preset functions that actually produces the result for this case. Hence, the data collected is in lines with the base case. The remaining cases are derived via statistical operations using different variables.

3.5.1.3 Case iii: The Best Case

This case detail about the consequences in terms of emissions if all the strategies
discussed were to supersede the current trend of vehicle usage, fuel usage and land use pattern.

Figure 3.9: MOVES2014 County Data Manager (CDM)

3.6 Sensitivity Analysis

The certainty of the data was tested by performing a sensitivity analysis. The responses of the percentage change in the emissions were tested with respect to the change in the parameters that affect the calculation procedures used in the models. This is done in order to figure out the level of certainty in the data.

The data obtained from the steps mentioned in sections 3.4 were plotted with respect to each parameter that the models were dependent on. These plots were used to check the dependence of the GHG emissions on different factors such as average fuel consumed, average
fuel economy, total number of vehicles, and load factor etc. These data were studied in relation to the changes in the GHG emissions when each of the parameters are altered. To predict the exact relationship in-between each of the parameters and emission changes, trend line generation technique was used. The equation from the trend line was used to change the values of the parameters. As per the trend line equations, the factors upon which the emissions were significantly dependent are number of vehicles, fuel economy and the load factor. For the sake of convenience and simplicity, the plots illustrated in figures 4.10 through 4.12 of chapter 4, shows the percentage change in emissions in the y-axis and the percentage change of parameters in the x-axis.

The resultant percentage changes in the emissions as a result of fluctuations in the various significant parameters are summarized in table 3.4.

Table 3.4: Parameters influencing certainty of the output data

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Factors</th>
<th>Percentage Fluctuation</th>
<th>Percentage change in the emission levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD</td>
<td>1) Number of vehicles</td>
<td>10-95%</td>
<td>20-87%</td>
</tr>
<tr>
<td>CNG</td>
<td>2) Fuel Economy</td>
<td>70-83%</td>
<td>50-88%</td>
</tr>
<tr>
<td>LNG</td>
<td>3) Load Factor</td>
<td>50-60%</td>
<td>60-65%</td>
</tr>
<tr>
<td>I/M</td>
<td>1) Compliance Factor</td>
<td>0-100%</td>
<td>0-68.2%</td>
</tr>
<tr>
<td></td>
<td>2) I/M Factor</td>
<td>50-75%</td>
<td>49.2-78%</td>
</tr>
<tr>
<td>Land Use</td>
<td>1) Peak Traffic hours</td>
<td>2-96%</td>
<td>5-88%</td>
</tr>
<tr>
<td></td>
<td>2) Linear, Log, Average Equation accuracies in general</td>
<td>10-36%</td>
<td>10-39%</td>
</tr>
</tbody>
</table>
3.7 Greenhouse Gas Emission and the Climate

It has already been mentioned in Chapter 2, that variation in temperature of the Earth fluctuates the climate and the temperature depends on varying GHG emission. To check for the climatic modifications as a result of utilization of the strategies, examined in this thesis, the analyzed emission data is used to calculate the change in temperature of the Ohio region. This step of the analysis indicates the level of temperature variation over a ten year period in relation to emission reduction. However, during the process of simulations, temperature from the past 50 years has been taken into account. This is because the change in temperature is a very slow process. The significance of every degree rise in temperature however is enormous.
Chapter 4

Results and Discussion

4.1 Introduction

The previous chapter on methodology of collection of data has yielded results as against each strategy. Each of the data has been used for an analysis set in the backdrop of three different scenarios. The presentation, analysis, uncertainty testing of data and its effects on the temperature of Ohio region has been explained with graphs all through the upcoming sections.

The historical transit bus statistics for the State of Ohio have been obtained from the Bureau of Transportation Statistics (BTS) website (“United States Department of Transportation,” 2004). The data have been used to plot the graph in figure 4.1 and is the basis of almost all the calculations performed in this study. All the calculations performed require the number of vehicles count, which in this case, is transit bus. The data for the graph in figure 4.1 later than the year 2013 are retrieved through extrapolation technique in MS Excel.

The distribution of transit buses in Ohio by fuel type have been derived from Ohio Department of Transportation website through 2013. The data for later years have been extrapolated for the remaining years using MS Excel trend line generation tool. The distribution of transit buses by fuel type is shown in Figure 4.2. It has been found that the increase in the total number of transit buses in Ohio is approximately 5.98% by the year 2025. The percentage increase in the number of BD transit buses in Ohio is 6.75% approximately and that of NG transit buses is 6.86% approximately, over a ten year period.
Figure 4.1: Number of transit buses in Ohio.

Figure 4.2: Transit buses in Ohio by fuel type.
4.2 Emissions from the Use of Control Strategy Options

As per USEPA study, the percentage rise in the CO$_2$ emissions due to fossil fuel combustion from the transportation sector increased by 1% for a one year period from 2012 to 2013. For any given year, the CO$_2$ generation from fossil fuel combustion is about 95.1% of all the GHG emissions and other GHG emissions represent just a 1%. The emissions data have been collected as per the data collection plan in table 3.1 presented in Chapter 3. To maintain a consistency, in the calculations and results, all the GHG emissions have been presented in terms of carbon dioxide equivalent (CO$_2$-e) in pounds. The GHG pollutants considered in this study are CO$_2$, CH$_4$, and N$_2$O.

4.2.1 Emissions from the Use of Alternative Fuels: BD and NG

Of the total transit buses in Ohio, approximately 65% of the buses run on diesel fuel, 19% run on CNG, LNG and blends, 9% run on biodiesel blends and the remaining 7% run on other fuels. Higher number of buses pertains to higher VMT values and this justifies the higher GHG emissions from the use of diesel fuel as against BD or NG, as depicted in figure 4.3. The graph has been plotted using the data obtained from GREET 2012 spreadsheet model output.

4.2.2 Emissions from the Land Use Planning

The mixed–use trip generation model yields the output in terms of reduction in VMT from land use planning. The reduction in VMT is then converted to GHG emissions using the
emission factors (EFs) of different GHGs and adding up the emissions in CO$_2$-e. The equation used for the conversion is stated in equation 4.1.

$$\text{Average Emissions} = \text{EF}_{\text{pollutant}} \text{ (g/mi)} \times \text{VMT (mi/yr)} \ldots \ldots \ldots \ldots \text{Eqn. 4.1}$$

where, $\text{EF}_{\text{pollutant}}$ is the emission factor of a GHG pollutant in units of gallon per mile (g/mi) and, VMT is vehicle miles travelled in miles per year (mi/yr).

![Figure 4.3: Emissions from the use of alternative fuels.](image)

**Resultant GHG emissions from Diesel, BD and Natural Gas from Ohio Transit Buses**

<table>
<thead>
<tr>
<th>Year</th>
<th>Diesel</th>
<th>Biodiesel Blends</th>
<th>CNG,LNG and Blends</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions in CO$_2$-e in lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>700,000,000</td>
</tr>
<tr>
<td>600,000,000</td>
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<tr>
<td>500,000,000</td>
</tr>
<tr>
<td>400,000,000</td>
</tr>
<tr>
<td>300,000,000</td>
</tr>
<tr>
<td>200,000,000</td>
</tr>
<tr>
<td>100,000,000</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

**4.2.3 Emissions from Inspection and Maintenance Programs**

MOVES2014 simulator has been used to derive the successful running of I/M programs for in-use vehicles. Figure 4.5 is the plot of the CO$_2$-e emissions from the use of I/M program versus the emissions without the I/M programs.
4.3 Data Analysis

The impacts of adopting the three different strategies are analyzed by testing it in the backdrop of three different scenarios that were designed in section 3.4.1 of Chapter 3.

![Emissions from Land Use Planning](chart)

Figure 4.4: Emissions from the use of mixed use trip generation model.

4.3.1 Case I Analysis: The Worst Case

This case is the analysis of a hypothetical situation, wherein the emission levels were measured assuming the use of conventional diesel fuel only. The hypothesis supposed here is that no technologies to improve the quality of the air are in-use or being used. The resultant...
emission is plotted in figure 4.6. The plot in figure 4.6 is the depiction of the worst case against base case results which is the business as usual scenario results using different fuels and technologies that have been in use from years. To achieve the worst case plot, the fraction of vehicles in-use using alternate fuels have been replaced and added to the total number of vehicles using diesel fuels and this information is used to run the models.

![Carbon dioxide Equivalent from I/M Programs](image)

**Figure 4.5: Emissions from the use of I/M program for in-use public transit buses in Ohio.**

As a result of this analysis, it is seen that for almost each year considered starting 2005, the emissions are higher if only diesel fuel are used for public transit buses. The emissions from I/M program were approximately 20%, from mixed-use planning were about 7-9% lower emissions, and the use of alternative fuel (BAU) were 85%-95% lesser than the diesel fuel only emissions for each of the years examined.
4.3.2 Analysis for Case ii: The Base Case

With the BAU case, there is a rise in the GHG emissions each year. It can be attributed to the fact that there will be an increasing number of transit buses in years to come. Diesel fuel run transit buses are found to be the highest emitter of GHGs all over the 20-year span, with the highest 841,822,472 pounds in the year 2025. On an average, the emissions from diesel oil combustion are 5 to 88% higher than the emissions resulting from all other pollution control strategies. If current trends were to be followed, then, BD emissions were found to be the least polluting of all strategies, with the highest emission levels being 68,125,696.24 pounds.

4.3.3 Analysis for Case iii: The Best Case

While performing Case ii scenario analysis, it was observed that the best of strategies that produces lesser emissions are BD, NG and its blends, I/M of in-use vehicles and land use planning. All of these strategies were found to produce lesser GHGs in contrast to diesel oil. Therefore, strategies that yielded more efficient outcomes than the conventional fuels are used instead to illustrate the progress made in percentage emission reduction. For the same number of transit buses travelling over the same distance, the modelling is performed for emission data.

The plot in figure 4.8 is the representation of emission ranges for the same number of transit buses running over the same distances upon the utilization of various strategies. In this case, 100 buses were considered and the BD was the most efficient technology, with approximately 75% higher efficiency than the other technologies.
Figure 4.6: Worst case emission study.

Figure 4.7: Base case emission study.
4.3.4 Summary of Data Analysis

The best case scenario analysis has been found to yield 20% lesser emissions than the base case. Upon comparison with the hypothetical case, it has been found to produce 80% lesser emissions. On an average, the difference in emissions between the BAU and best case is 141,000,000 pounds. The difference in emission levels between BAU and worst case is found to be 414,483,033 pounds and that between worst and base case is observed to be 555,483,033 pounds. These observations have been presented in figure 4.9.

Figure 4.8: Best case emission study.
4.4 Sensitivity Analysis

The collection of data, its study and analysis through modeling, asked for a huge database of information both historical and futuristic. All the input data, which are futuristic, are projections of the best assumptions that could be figured for successful simulations. Now, certain futuristic data such as that of meteorological data for Ohio counties, future annual VMT, fuel economy, and land-use inputs etc. are dealt with, there is a certain degree of uncertainty involved in the process. Emissions displayed in the form of output plot are sensitive to all such input characters. Hence, a sensitivity analysis has been performed to check the percentage change in emissions that results from the modification of different factors that largely influence the output.

One of the major challenges faced while performing the sensitivity analysis was that different tools utilize different set of backhand calculation processes during its simulation. Not all the calculation steps are clearly known. These are essential to understand and list the factors which characterize the behavior of the emission. Such equations have been discovered using trend line equations in MS Excel while plotting the data retrieved from the simulations.

Different strategies are influenced by factors very different from one another. The plots in Figures 4.10 through 4.15 have detailed depictions of emission level fluctuation versus the percentage variation of a factor. Apart from the ones described, there are several other factors
that changes the performance of different strategies. However, mentioning and studying all the factors are beyond the scope of this thesis.

4.5.1 Factors affecting Emissions from Alternate Fuel Use

Alternative fuel use results are derived primarily from GREET model. The parameters which play a major role in the GHG emission production are number of vehicles, load factor and compliance factor. The increase in the number of vehicles use leads to the increase in emissions. The relationship is almost linear and is presented in Figure 4.8. The sensitivity analysis performed for the GREET model showed that the model is sensitive to number of vehicles, load factor and the fuel economy.
The data plot was used to check the dependence of the GHG emissions on different factors such as average fuel consumed, average fuel economy, total number of vehicles, and load factor etc. These data were studied in relation to the changes in the GHG emissions when each of the parameters is altered. To predict the exact relationship in-between each of the parameters and emission changes, trend line generation technique was used. The equation from the trend line was used to change the values of the parameters. As per the trend line equations, the factors upon which the emissions were significantly dependent are number of vehicles, fuel economy and the load factor. For the sake of convenience and simplicity, the plots illustrated in figures 4.10 through 4.12, shows the percentage change in emissions in the y-axis and the percentage change of parameters in the x-axis.

The relation between the fuel consumed and the distance travelled determines the efficiency of the fuel used in an automobile. The GHG emission profile from vehicles, let alone Urban Buses, is way better if the fuel economy is higher. A fuel economy modification by 70-83% can enhance emission profiles by up to 88%.
Figure 4.10: Plot of Percentage of Emission vs. Number of Vehicles.

Figure 4.11: Plot of Percentage of Emission vs. Fuel Economy.
The load factor influence shown is Figure 4.9, is a measure of how crowded a public transit vehicle must be before additional service is added. A load factor of 1.00 means that every seat on the bus is full, 1.25 means that every seat on the bus is full and the number of passengers standing equals 25% of the number of seats on the bus. The industry standard load factor for crowding is 1.25 (Carrese, Gemma, & La Spada, 2013).

![Percentage of Emission vs. Load Factor](image)

Figure 4.12: Percentage of Emission vs. Load Factor

4.5.2 Factors affecting Emissions from I/M Program

Sensitivity analysis of the MOVES2014 model showed that I/M programs are significantly influenced by Compliance Factor and I/M factor. The compliance rate is the percentage of vehicles in the fleet covered by the I/M program that complete the I/M program and receive either a certificate of compliance or a waiver.

It can be figured from the equation:
Compliance Factor = Percent compliance rate x (100 - percent waiver rate) x Regulatory class coverage adjustment…………………………………………………………………..Equation 4.2

When this relationship is used to read the percentage changes in emission, the rate lays within the range of 0-68%.

The IMFactor is the ratio of the mean emission results from two runs. The first run/targeted run, \( E_p \) was a MOBILE6.2 run, where a combination of parameter were used such as

- Pollutant / Process
- Test Frequency
- Test Type
- Test Standard
- Regulatory Class
- Fuel Type
- Model Year Group
- Age Group
- IMFactor

The second set of runs were done describing the reference program, which is \( E_R \). The I/M factor equation can be given as:

\[ R_p = \frac{E_p}{E_R} \]

The emission varies within a 50% to nearly 77% range and is plotted in Figure 4.13.
4.5.3 Factors affecting Emissions from Land-use Planning

A sensitivity analysis of land-use planning model clearly shows the dependence of the trip generator on peak hours of travel and the percentage of errors in the equation that calculates the VMT reductions. Peak hours of travel have a direct influence on emissions as the amount of travel would be higher that time of the day on weekdays. This is because more number of vehicles would be on-road being used than any other time. A stark rise in emissions that shoots up to close to 90% and it is shown in the following plot.

The mixed-use trip uses a combination of general equations which are log, linear and average equations. The degree of error in these equations also modifies the resultant emission rates. All of the sensitivity tests show a Type II sensitivity index. This sensitivity index yields significant change in the output upon slight change in the input parameter percentages.
Figure 4.15: Percentage of Emission variation depending on peak hours of travel.

Figure 4.16: Percentage Emission depending on errors in model equations.
4.5 Temperature Rise

Temperature change is the key indicator to the changes weather and climatic patterns have in store to offer in years to come. The rise in temperature in response to changing emissions for the State of Ohio has been calculated using the principles of radiative forcing. Carbon dioxide concentration in our atmosphere doubles, global temperatures rise by about 3° C (5.4° F) (Scied, 2015). The details of this concept are discussed in Chapter 2 of this thesis. Two temperature readings have been presented as a response to the range of CO$_2$ concentration for all the years listed below. This CO$_2$ concentration, however, is emissions derived from the Ohio transit buses only.

Using equations 2.2 and 2.3, the temperature calculations are performed. For a temperature difference, the historical patterns of temperature for the past 20 years are observed. The rise in temperature for the next ten years is calculated on the basis of the historical values. The reason for choosing the historical emissions to predict the future temperature trend is that the average annual rise in temperature every year is minimal. Still, it needs to be recorded because of the implications every degree’s warmth has on the weather and climatic patterns.

Graphics in figure 4.17 clearly denotes the difference in temperature that can result from the use of the three strategies discussed in this thesis. The temperature variation calculations are shown in Table 4.1 and 4.2. While calculating the climatic sensitivity, the CO$_2$ concentration in parts per million (ppm) is used. All the CO$_2$e data denoted as C’ in tables 4.1 and 4.2 are listed in the figures were in pounds (lbs) which is a mass unit. These C’ values needs to be converted to
their corresponding values in ppm, which is a unit of concentration and it is represented as C. The reference CO₂ concentration, \( C'_0 \) (in pounds) and \( C_0 \) (in ppm) is collected from the 1890s. The radiative forcing units yields temperature data in K (Kelvin). It is then converted into °F (Fahrenheit) using the relation: 

\[ T(\text{°F}) = T(\text{K}) \times \frac{9}{5} - 459.67 \] 

Equation 4.3

When the values obtained from calculations in the tables 4.1 and 4.2 are obtained and plotted in figure 4.16, it has been observed that the lower GHG emission values yields lower temperature values for each of the years depicted in figure 4.16, which is even lower than the temperature set from the BAU scenario. It is observed that the use of control strategies yields approximately 62.8% lesser surface temperature and a BAU case yields 54.28% lesser surface temperature than the higher emission scenarios.
Table 4.1: Temperature Calculation for higher emission ranges

<table>
<thead>
<tr>
<th>Year</th>
<th>$C'_0 * 10^{-26}$</th>
<th>$C' * 10^8$</th>
<th>$(C/C_0) * 10^{19}$</th>
<th>$\ln(C/C_0)$</th>
<th>$\Delta F = 5.35 * \ln(C/C_0)$</th>
<th>$\lambda$</th>
<th>$\Delta T_s = \lambda * F$</th>
<th>$\Delta T_s (K)$</th>
<th>$\Delta T (\degree C)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>1.92</td>
<td>2.82</td>
<td>2.02</td>
<td>44.456</td>
<td>325.161</td>
<td>0.8</td>
<td>273.151</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>1.92</td>
<td>3.50</td>
<td>2.52</td>
<td>44.672</td>
<td>327.521</td>
<td>0.8</td>
<td>273.151</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>1.92</td>
<td>3.56</td>
<td>2.56</td>
<td>44.689</td>
<td>327.596</td>
<td>0.8</td>
<td>273.151</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>1.92</td>
<td>2.72</td>
<td>1.96</td>
<td>44.420</td>
<td>327.652</td>
<td>0.8</td>
<td>262.152</td>
<td>0.002</td>
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</tbody>
</table>
Table 4.2: Temperature Calculation for lower emission ranges.

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ concentration in pounds (mass)</th>
<th>C'*10^8</th>
<th>CO₂ concentration in ppm (concentration)</th>
<th>ln(C/C₀)</th>
<th>ΔF=5.35*ln(C/C₀)</th>
<th>λ</th>
<th>ΔTₛ=λ*F</th>
<th>ΔT_(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C₀'*10⁻¹⁹</td>
<td>(C/C₀)*10²⁷</td>
<td>5.35*ln(C/C₀)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>1.391</td>
<td>8.02</td>
<td>5.75</td>
<td>63.92</td>
<td>341.97</td>
<td>0.8</td>
<td>273.200</td>
<td>0.05</td>
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<tr>
<td>2005</td>
<td>1.391</td>
<td>8.52</td>
<td></td>
<td>63.983</td>
<td>342.307</td>
<td>0.8</td>
<td>273.200</td>
<td>0.05</td>
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<tr>
<td>Year</td>
<td>Value1</td>
<td>Value2</td>
<td>Value3</td>
<td>Value4</td>
<td>Value5</td>
<td>Value6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td></td>
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</tr>
<tr>
<td>2010</td>
<td>1.391</td>
<td>6.13</td>
<td>8.43</td>
<td>6.06</td>
<td>63.972</td>
<td>342.251</td>
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<td>1.391</td>
<td>8.68</td>
<td>6.24</td>
<td>64.001</td>
<td>342.404</td>
<td>0.8</td>
<td>273.201</td>
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</tr>
<tr>
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<td>6.34</td>
<td>64.016</td>
<td>342.488</td>
<td>0.8</td>
<td>273.201</td>
<td>0.05</td>
</tr>
<tr>
<td>2025</td>
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<td>9.10</td>
<td>6.54</td>
<td>64.048</td>
<td>342.658</td>
<td>0.8</td>
<td>273.201</td>
<td>0.05</td>
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</table>
Chapter 5

Conclusions and Future Recommendations

5.1 Conclusions

In this study, three control strategies to reduce GHG emission levels for transit buses in Ohio were evaluated. Three different tools GREET, MOVES2014, and Mixed-use-trip generation model were used to determine the GHG emission trends for future years. These three strategies were compared to analyze the efficiency of the strategies in reducing pollution in the long-term. Many functions and parameters are involved in the input dataset for the tools. The futuristic input data such as meteorological data, vehicle mileage data, biodiesel source data, and equation inaccuracies data etc. significantly changes the emission calculations. Hence, these influential factors are evaluated to justify the percentage change in the emission values and the tradeoffs. The data obtained were also studied through a scenario analysis. The emission levels were used to plot temperature changes of the Ohio state in ten years to come (through 2025).

It was observed that the use of biodiesel (BD) was the most beneficial strategy in the long run, followed by natural gas as an alternative fuel, land-use planning and I/M program for in-use vehicles. The resultant emissions through I/M program were found to be approximately 20% lower, from mixed-use planning were about 7 to 9% lower and the use of alternative fuel were 85% to 95% below the emissions obtained from conventional diesel oil. The emissions from
conventional diesel oil only was found to be pounds and as for the BAU case, it was found to be pounds. On an average, diesel oil produces 564,306,547.9 pounds, I/M produces 841,798,159.1 pounds, mixed-trip use produces 225,115,56.6 pounds, NG produces 169,576,977.4 pounds, and BD produces 649,576,977.4 pounds of GHG emissions in CO₂-e. As a result of these emissions, the temperature of Ohio region is found to be 54.28% lesser on an average, at 0.005°.

5.2 Future Recommendations

A comparative study of the emissions obtained in this thesis through computer modelling tools can be used to study the emissions from mathematical modelling. This can be used to evaluate the accuracy levels of computer models. The efficiency of the data can be increased by developing appropriate functions mathematically.

The economic and environmental feasibility of using biodiesel can be analyzed. An evaluation of cost-effectiveness of the strategies to be used can be estimated. The dependence of the characteristic of an area on the models, its economic and environmental profitability can be performed. The changes in the temperature may be used to future perform a climatic study. It can be a set example of how a fraction of transportation infrastructure can have significant climatic implications.
References


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