ANKARA YILDIRIM BEYAZIT UNIVERSITY

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INVESTIGATION OF GREENHOUSE GAS EMISSIONS ORIGINATED FROM PUBLIC TRANSPORTATION: THE CASE OF ANKARA

M.Sc. Thesis by

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INVESTIGATION OF GREENHOUSE GAS EMISSIONS ORIGINATED FROM PUBLIC TRANSPORTATION: THE CASE OF ANKARA

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M.Sc. THESIS EXAMINATION RESULT FORM

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2018, 12 July **Fatma Büşra KORKUTATA**

INVESTIGATION OF GREENHOUSE GAS EMISSIONS ORIGINATED FROM PUBLIC TRANSPORTATION: THE CASE OF ANKARA

ABSTRACT

Human induced activities have been increasing the atmospheric abundance of greenhouse gases at an alarming level since pre-industrial times, eventuating in global warming by means of increasing the heat-trapping abilities of the greenhouse gases. Advanced climate models project that global temperature change will exceed 1.5 degrees Celsius at the end of the 21th Century, whereafter the adverse effects of the global warming will be unavoidable. Hence, reducing the atmospheric abundance of the greenhouse gases is of vital importance.

Transportation sector is the second largest contributor of the Turkish anthropogenic greenhouse gases with its dominant source being road transportation. In Turkey, road transportation is heavily dependent on individually-owned automobiles. Greater use of public transportation will reduce excessive automobile dependency and greenhouse gas emissions, also providing economic and social benefits.

Incidental to both international and domestic regulations, the annual national greenhouse gas inventory covering the Turkish anthropogenic greenhouse gases are being reported adopting the IPCC methodology. The national inventory utilizes fuel sold method in emission calculations from transportation sector.

In this thesis, direct greenhouse gas emissions originated from the EGO public transport buses are analyzed with both the highest and the current tier approaches used in the national inventory adapting the IPCC methodology. It is observed that, current approach used estimated emissions in carbon dioxide equivalent ninety five percent less than the highest tier approaches utilized in this thesis.

Altering the fuel use habits and vehicle fleet expansion compared to the current trend, hundred and thirty one kilotons of emissions in carbon dioxide equivalent will be avoided and 88,843,822 TL will be saved in a period of next ten years.

Keywords: Direct greenhouse gas emissions, IPCC methodology, tier approaches, emission factors.

INVESTIGATION OF GREENHOUSE GAS EMISSIONS ORIGINATED FROM PUBLIC TRANSPORTATION: THE CASE OF ANKARA

ÖZ

İnsan kaynaklı aktiviteler sera gazlarının atmosferdeki bolluğunu sanayileşme öncesi zamandan bu yana endişe verici bir seviyede arttırmakta, ısı tutma kabiliyetlerini arttırmak suretiyle küresel ısınmaya neden olmaktadır. Gelişmiş iklim modelleri, 21. Yüzyılın sonunda küresel sıcaklık değişiminin 1.5 santigrat dereceyi aşacağını ve küresel ısınmanın olumsuz etkilerinin önlenemez olacağını öngörmüştür. Dolayısı ile, sera gazlarının atmosferik bolluğunun azaltılması hayati önem taşımaktadır.

Baskın kaynağı karayolu taşımacılığı olmakla birlikte, Türk antropojenik sera gazlarına ulaştırma sektörü ikinci en büyük katkıyı sağlamaktadır. Türkiye'de karayolu taşımacılığı bireysel otomobillere bağımlı durumdadır. Toplu taşımanın daha fazla kullanılması, aşırı otomobil bağımlılığını ve sera gazı emisyonlarını azaltmanın yanında ekonomik ve sosyal faydalar sağlayacaktır.

Uluslararası ve yurtiçi düzenlemelerin bir sonucu olarak Türk antropojenik sera gazlarını kapsayan, IPCC metodolojisini benimseyen ulusal sera gazı envanteri yıllık olarak raporlanmaktadır. Envanterde, ulaştırma sektörü emisyonlarının hesaplanmasında "satılan yakıt" yöntemi kullanılmaktadır.

Bu tezde, IPCC metodolojisi benimsenerek EGO toplu taşıma otobüslerinden kaynaklanan doğrudan sera gazı emisyonları, ulusal envanterde kullanılan mevcut tier yaklaşımı ile en yüksek tier yaklaşımları kullanılarak incelenmiştir. Mevcut tier yaklaşımının en yüksek tier yaklaşımlarına göre emisyonları, karbondioksit eşdeğeri cinsinden yüzde doksan beş daha az hesapladığı gözlemlenmiştir.

Yakıt kullanım alışkanlıklarının ve araç filosu genişlemesinin değiştirilmesiyle mevcut trend ile karşılaştırıldığında, on yıllık süre içinde yüz otuz bir kiloton karbondioksit eşdeğeri cinsinden emisyonun önleneceği ve 88,843,822 TL tasarruf edileceği ortaya koyulmuştur.

Anahtar Kelimeler: Doğrudan sera gazı emisyonları, IPCC metodolojisi, tier yaklaşımları, emisyon faktörleri.

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NOMENCLATURE

Acronyms

AR	Assessment Report
CCCC	Climate Change Coordination Committee
CFCs	Chlorofluorocarbons
CNG	Compressed Natural Gas
COE	Certification of Entitlement
COP	Conference of Parties
EF	Emission Factor
EU	European Union
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hyrofluorocarbons
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
NCAAP	National Climate Change Action Plan
NCV	Net Calorific Value
NGOs	Non-governmental Organizations
NMCHs	Non-methane Hydrocarbons
OH	Hydroxyl Radical
PBAPs	Primary Biological Aerosol Particles
PFC	Perfluorocarbons
SPO	State Planning Organization
TL	Turkish Lira
TURKSTAT	Turkish Statistical Institute
UCTEA	Union Chambers of Turkish Engineers and Architects
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
VKT	Vehicle Kilometers Travelled
VOCs	Volatile Organic Compounds
WMO	World Meteorological Organization

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CHAPTER 1

INTRODUCTION

Throughout its 4.54 billion year geological history, Earth is known to have been subjected to dramatic climatic changes. Paleoclimate archives and researches indicate that climate has shifted between icehouse conditions and hothouse conditions several times due to natural occurrences in a period of two billion years.

Until 19th Century, concentrations of greenhouse gases have not shown a significant alteration for a thousand years. With industrial revolution playing a large role in the 19th Century, increase in population, technological advancements, competition in industrialization, enhancements in the quality of life created a hunger for energy. Invention of the steam engine paved the way for the combustion of vast quantities of fossil fuels.

Concentrations of greenhouse gases in the atmosphere have shown a dramatic increase. Greenhouse gas concentrations recorded before (1750 to 1800) and after industrial revolution (1990) show that carbon dioxide, methane, and nitrous oxide concentrations increased 26%, 115%, and 8%, respectively. In hundred years from 1800, global surface air temperature non-uniformly increased by 0.3℃ to 0.6℃, compared to what it would be normally [1]. These drastic changes have brought attention to the relationship between human induced activities and the warming of the globe.

Today, the term global warming has become a popular topic of discussion throughout the world. Scientific communities of the world is no longer approaching the matter with skepticism. It is now considered as a fact that human induced activities such as deforestation, urbanization, industrial growth, land use changes, alterations in agriculture and livestock, waste management, along with the combustion of fossil fuels, have negative influences on the climate. Contrary to popular belief, global warming is not a new phenomenon. First claim of a relationship between a human

induced activity that is combustion of fossil fuels with global warming dates back to late 1800s.

Svante Arrhenius, a Swedish scientist, published a scientific paper in 1896, pointing out that Earth surface temperatures were higher than it would otherwise be, and temperatures were not uniform over the globe. He attributed this to the alteration of the atmospheric carbon dioxide levels as a result of the modern industry. He estimated that increases in carbon dioxide levels would rise the Earth surface temperature, causing global warming [2].

A century later, today, we experience the consequences of the human-made climate change more than ever. As a result of ever-increasing greenhouse gases with fossil fuel combustion being the dominant source, the atmosphere and the ocean have been warmed like never before. Glaciers have melted, sea levels have risen. Between 1880 and 2012, global average temperatures increased 0.85ºC. Concentrations of carbon dioxide, methane, and nitrous oxide have increased by 40%, 150%, and 30%, respectively, becoming the highest since industrial revolution. Increasing carbon dioxide concentrations caused ocean acidification. Advanced climate models predict that global surface temperature change will exceed 1.5°C at the end of the 21th Century. This warming will not be regionally uniform. Rather more alarming prediction is that even if the cumulative carbon dioxide emissions, which is the primary regulator of global mean surface warming, are stopped by the end of the 21th Century, most of the climate change effects will continue. [3]

Calculating the mentioned predictions, it can be deduced that every country on the Earth will be negatively affected by the consequences of climate change. Non-uniform warming will cause drought in some regions, while other regions face severe cases of flood. Turkey is a plausible example to the countries which will experience drought. Rising sea levels will pose a danger to the island countries. Increasing emissions will reduce the quality of air. Loss of biodiversity will be experienced. Vegetation and animal species will diminish drastically. It is evident that minimizing the greenhouse emissions is of vital importance. This can only be accomplished by the collective efforts of the countries of the world, and the citizens of the Earth.

Energy sector is the largest contributor of Turkish human-made (anthropogenic) greenhouse gas emissions, constituting 83% of the total greenhouse gas emissions. Much as energy sector is liable for the biggest contribution, emissions originated from transportation sector is linked to the types of energy use. The transportation sector has the second largest share in this total of energy sector emissions. Dominant source of transportation emissions is road transportation. It is responsible for the 91.44% of the emissions originated from transportation [4].

In Turkey, transportation is dominantly dependent on individually-owned automobiles. Thanks to today's improved welfare, while almost every household owns an automobile, some owns more than one. Ankara takes the first place in having the most automobiles per capita with as much as 252 automobiles per thousand people [5, 6]. The increasing numbers of automobile ownership is accompanied by a high incidence of greenhouse gas emissions, environmental, social, and safety problems. This necessitates fundamental changes in the transportation sector. The effective utilization of public transportation will serve as a solution to these problems. In addition to its economic and social benefits, by cutting down a great number of automobiles on the road, public transportation will reduce greenhouse gas emissions by a considerable amount, therefore alleviating the environmental problems.

Although remaining behind, the Turkish Government adopts an attitude towards reducing greenhouse gas emissions with both international legislative regulations and domestic policies. In April 22, 2016, Turkey became a party to the Paris Agreement which aims to keep global temperature rise below 2ºC, requiring a gradual reduction in fossil fuel usage, as a developing country.

The purpose of this thesis is to investigate the greenhouse gas emission reductions originated from EGO (Ankara Electricity, Gas and Bus Operations) public transport vehicles by the introduction of electric buses along with altering the fuel use trend and fleet planning. The assessment of the obligations that municipalities must fulfil in the context of the National Climate Change Action Plan has made this thesis important. In this thesis, as recommended by the IPCC (Intergovernmental Panel on Climate Change), CO_2, CH_4, and N_2O emissions, which are the largest contributors to the climate change, are calculated adopting IPCC methodologies. Country-specific

emission factors for diesel oil and natural gas are determined. In calculations, for CO_2 Tier 2 approach, for CH_4, and N_2O Tier 3 approach is employed, tier approaches being the highest for each category.

1.1 Sectoral Contributions to the Total Greenhouse Gas Emissions

Energy, industrial processes and product use, agriculture, land use, land use changes and forestry and waste sectors are the contributors of the greenhouse gas emissions. Expressed in *Figure 1.1*, among these sectors, energy sector contributes to Turkish anthropogenic greenhouse gas emissions the most.

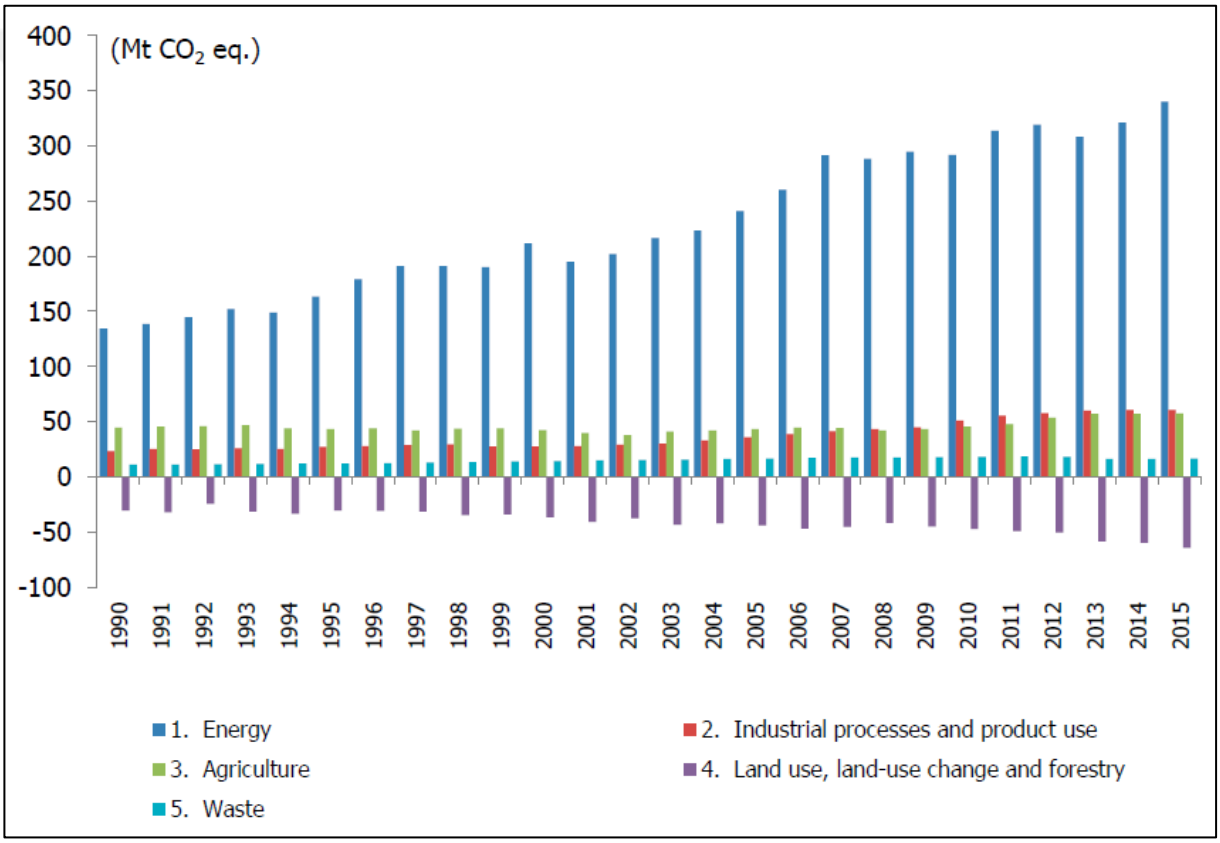

Figure 1.1 Greenhouse gas emission trend by sectors, 1990-2015 [4]

Figure 1.1 displays that emissions from all sectors show an increasing trend since industrial revolution. In this period, industrial processes and product use sector showed 156% increase. It is followed by energy sector with 153% increase, land use, land use change and forestry sector with 112% increase, waste sector with 52% and agriculture sector with 28%.

In *Figure 1.1*, it can be clearly seen that the share of the energy sector in total greenhouse gas emissions is by far the largest, with 83%. It is followed by Industrial processes and product use sector 15%, agriculture sector with 14%, waste sector with 4% and land use, land use changes and forestry sector with -16%.

Major cause of the increase in greenhouse gas emissions from energy sector is the rise in the fossil fuel combustion. Also, in parallel with growing economy and increase in population, increase in demand for energy is liable for the emission increases in each sector.

Decreases in emissions are the product of economical recessions in years 1994, 1999, 2001, and 2008. Increases in emission removals from land use change and forestry sector in years 2009 through 2011 also contributed to this decrease in cumulative emissions (see *Figure 1.1*).

Total emissions are decreased by 1.5% in 2013 compared to 2012. This decrease in emission is however not related to the economic recession. It is attributed to the change of energy use patterns for electricity generation. *Figure 1.2* shows the changes in energy sources used for electricity generation between 2012 and 2015.

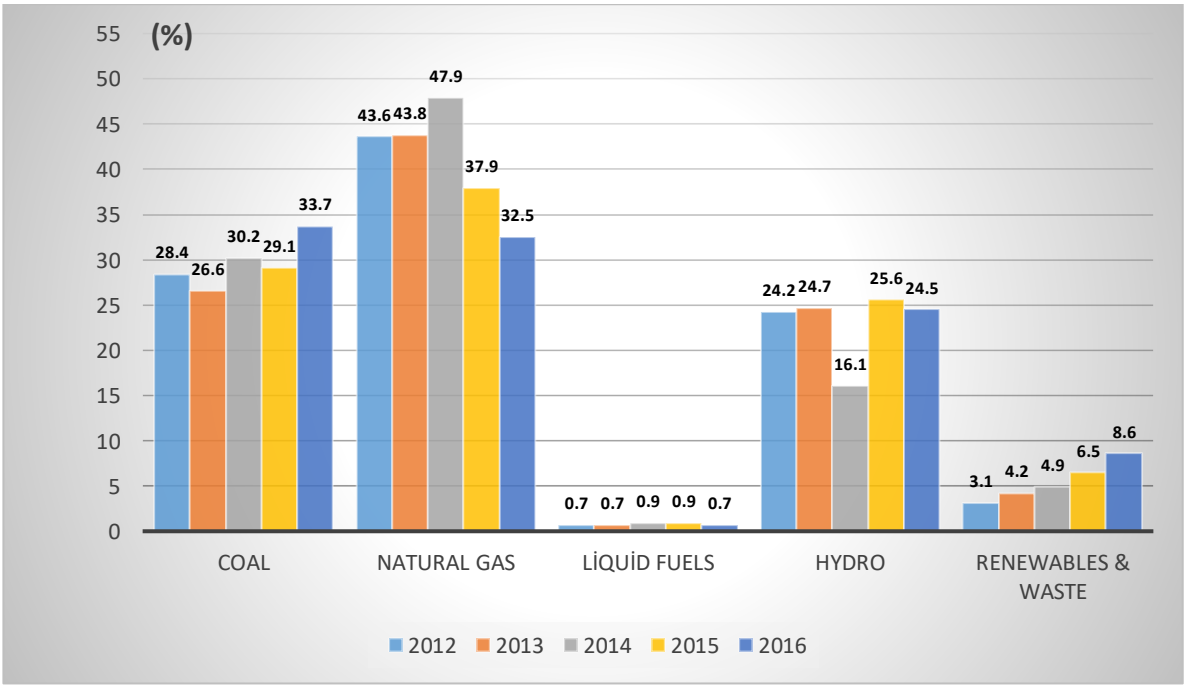

Figure 1.2 Electricity generation by energy sources, 2012-2015 [7]

Displayed in *Figure 1.2*, energy source utilized in electric generation is slightly diverted from the use of coal to the use of renewable sources in 2013 when compared to 2012. Utilization of the renewable sources is at the highest point in 2016, but so is the utilization of the coal, hence the rise in emissions continues. In order to reduce emissions, the use of fossil fuels must be avoided.

Primary contributor of the greenhouse gas emissions, combustion of fossil fuels, is accounted by the energy sector. The energy sector consists of subcategories of energy industries, manufacturing industries and construction, transportation and other sectors. Indicated in *Figure 1.3*, transportation sector is the second largest contributor of greenhouse gas emissions.

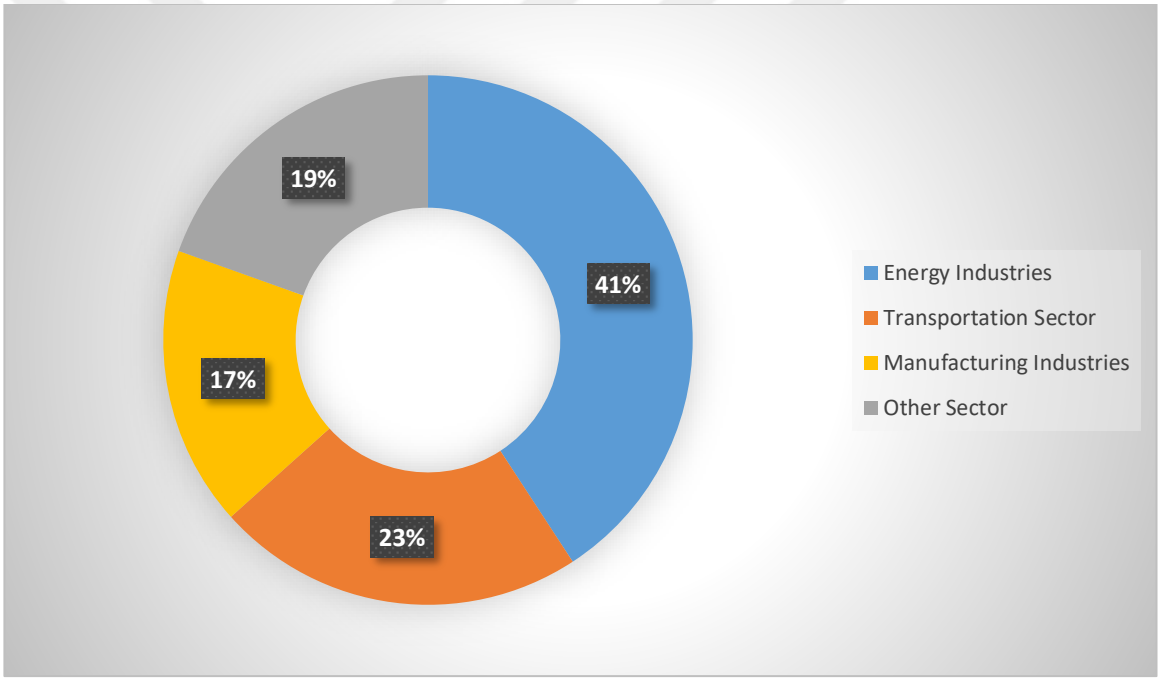

Figure 1.3 Emissions originated from the energy sector by source, 2015 [4]

In the total represented in *Figure 1.3*, road transportation is the dominant source of the transportation sector emissions. It is responsible for the 91.44% of the emissions originated from transportation, followed by domestic aviation with 5.5% and domestic navigation with 1.5%.

Sectoral contributions are identified based on CO_2 equivalents of each greenhouse gas; however, each greenhouse gas is more dominant in different sectors. CO_2 gas is

dominantly emitted from energy sector, as the fossil fuel combustion is the primary source of CO_2. CH_4 is primarily emitted from the agriculture and waste sector. Enteric fermentation and solid waste disposal is the main cause of this greenhouse gas. Major contributor of N_2O emissions is agriculture sector. Industrial processes and product use sector is the only sector that is responsible for the fluorinated gases. Refrigeration and the use of consumer products are the main cause for the fluorinated gases [4].

1.2 The Role of the Private Automobile in Total Emissions

Industrial revolution paved the way for an increase in purchasing power. In parallel with the improved welfare, number of vehicles owned by a household increased throughout the world. In Turkey alone, between the years 1990 and 2017, the total number of vehicles have increased from 3,750,678 to 22,218,945, showing a total of 492% increase with an annual average increase of 7%. Out of these totals, the number of automobiles of 1,649,879 in 1990, climbed to 12,035,978 in 2017. *Figure 1.4* indicates the increases in number of automobiles, number of vehicles, and automobile ownership rate in Turkey between 1990 and 2017.

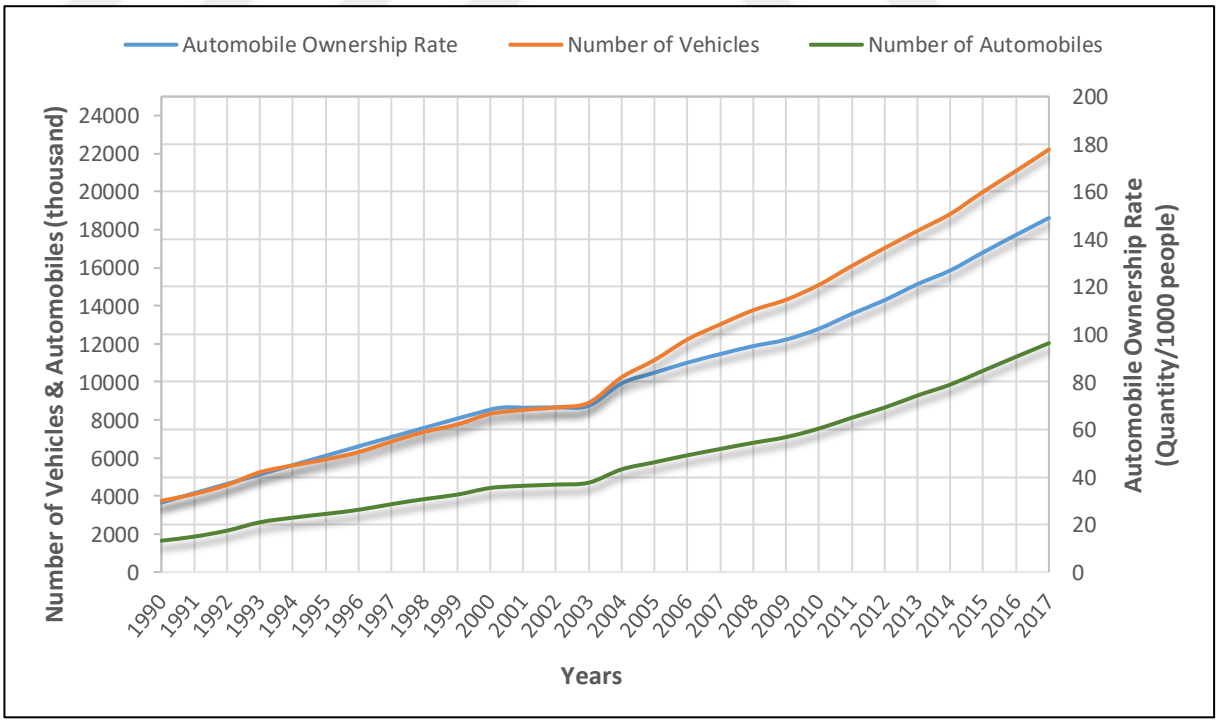

Figure 1.4 Quantities of vehicle, automobile and automobile ownership, 1990-2017 [5, 6]

The number of automobiles per thousand people increased from 68 (2000) to 148 (2017). Exhibited in *Figure 1.4*, years 2001-2002 show a slowdown in the total number of vehicles. This slowdown is related to the economic recession.

Although Istanbul has the biggest number of automobiles with 2,813,027, Ankara is the second with 1,376,928 automobiles followed by Izmir, which is the third biggest with 739,809 automobiles. Ankara takes the first place in having the most automobiles per capita with as much as 252 automobiles per thousand people. Ankara is followed by Mugla with 213 automobiles and Burdur with 206 automobiles per thousand people [5, 6].

Ever-increasing numbers of automobiles accompany a large amount of greenhouse gas emissions through combustion of fossil fuels. Exhibited in *Figure 1.5*, cumulative emissions show a 147% increase in parallel with increasing number of automobiles since 1994. Decreases in emissions are the product of economical recessions in respective years. Increases in emission removals from land use change and forestry sector in years 2009 through 2011 also contributed to this decrease in cumulative emissions (see *Figure 1.1*)

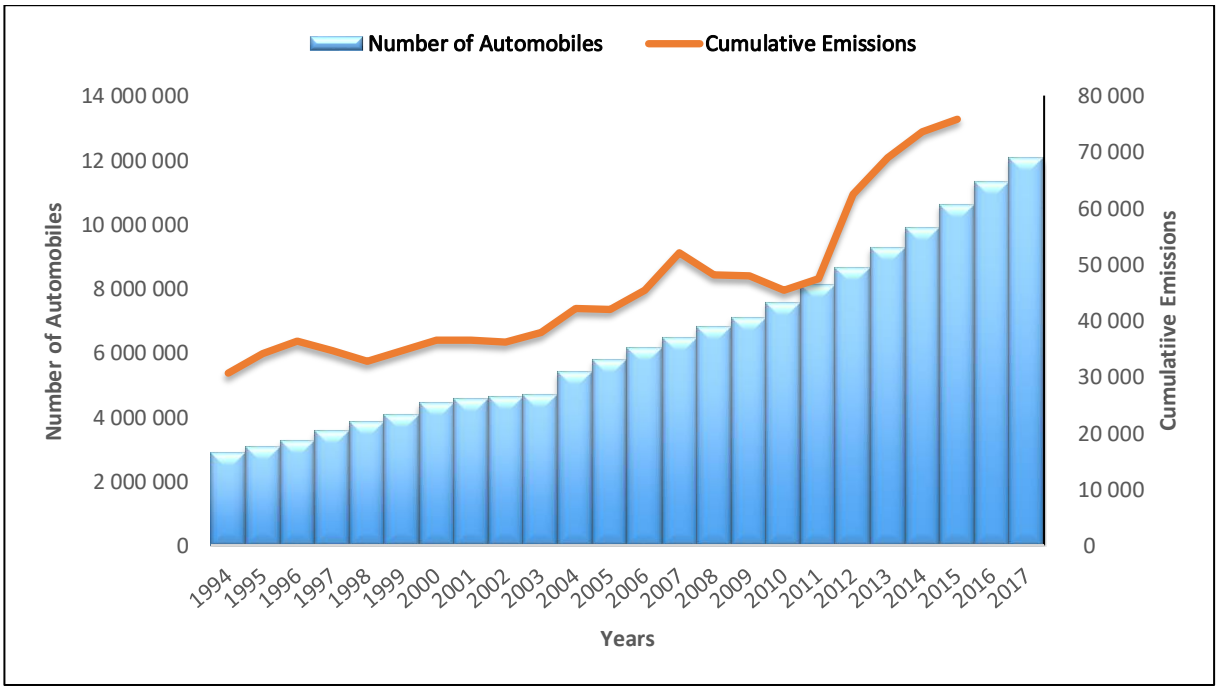

Figure 1.5 Emission changes with the increase in number of automobiles

As the statistics indicate, emissions and automobile dependency form a vicious circle. Adding more and more automobiles every year will bring even more greenhouse gas emissions with it. In order to break this circle and stop the human-made climate change before it is too late, fossil fuel usage must be reduced significantly.

Problems private automobile brings are not confined to environmental issues only. Primary problems and the dissatisfaction that overdependence on private automobile causes can be defined as; traffic congestion and uncomfortable transportation conditions it creates, traffic accidents, high-cost infrastructure investments, air pollution along with climate change. Automobile dependency in transportation harbors great environmental, economic and social problems.

Choosing public transportation over private automobile will serve as a solution to these problems. Beyond its many benefits, public transportation will reduce emissions and therefore air pollution by cutting down a great number of automobiles on the road. It will ease the traffic congestion and the problems it brings created by the intensive automobile use. Employing energy efficient vehicles, public transportation will provide a better fuel economy. Also it serves a function in a healthy economy.

1.3 Benefits of Public Transportation

Urban areas are positioned to be the centers of business, entertainment, science, culture, social and economic advancements. Continuous access to the activities carried out in urban areas is one of the basic necessities. In this regard, public transportation satisfies the need of the inhabitants for movement in order to perform activities such as work, education and entertainment.

Public transportation delivers means of mobility for people from all social strata, providing easy access to significant locations and services on daily basis. Public transportation embodies elements of reliability, cost effectiveness, comfort and safety. It is regarded as an instrument of ensuring social and economic equality. Public transportation pays regard to supporting the utilization of energy efficient resources. Hence, increases energy savings and as a result of which, reduces foreign dependency on energy.

Public transportation contributes to an increase in life quality by ensuring safe, economical and efficient means of mobility. It is also an important factor of a healthy economy. Public transportation being an integral part of the global economy, both influences economic developments and is directly affected by these developments. It supports the economy, directly by creating and sustaining employment and indirectly by enabling regional development.

Public transportation annihilates the increasing traffic congestion which progressively impairs the quality of life as a consequence of the automobile dependency. Public transportation provides environmental, economic, and social benefits not only to its customers but also to the society as a whole.

1.3.1 Environmental Benefits of Public Transportation

In a transportation system that is predicated on individual automobiles, environmental problems such as greenhouse gas emissions and air pollution emerge. Due to the ever increasing number of private automobiles, consumption of fossil fuels in transportation increases continuously and accompanies greenhouse gas emissions in a great abundance.

Greenhouse gas emissions from road transportation is the largest contributor of transportation sector emissions. *Table 1.1* displays the changes in greenhouse gas emissions between the years 1990 and 2015. Exhibited in *Table 1.1*, road transportation contributed 69.3 megatons of CO_2 equivalent in 2015. CO_2, CH_4 and N_2O emissions climbed to 67.9 megatons, 14.4 kilotons and 3.6 kilotons, respectively [4].

Table 1.1 Greenhouse gas emissions from road transportation, 1990-2015 [4]

Year	CO_2 (kt)	CH_4 (kt)	N_2O (kt)	CO_2 eq. (kt)	TJ
1990	24,143	3.9	1.804	24,777	335,589
1991	22,686	3.7	1.712	23,288	315,543
1992	23,232	4	1.804	23,871	323,808
1993	28,403	4.9	2.192	29,178	395,708
1994	26,672	4.8	2.105	27,419	372,206
1995	28,942	5.3	2.301	29,760	404,093
1996	30,753	5.7	2.458	31,628	429,564
1997	28,993	6.9	2.329	29,858	408,624
1998	27,033	7.3	2.233	27,881	383,300
1999	29,346	7.6	2.287	30,219	415,241
2000	30,988	8.8	2.158	31,850	439,986
2001	30,694	8.3	2.05	31,512	434,724
2002	31,264	7.7	2.106	32,084	441,038
2003	32,517	7.9	2.119	33,347	458,427
2004	34,230	8.2	2.203	35,090	482,069
2005	34,668	8.4	2.195	35,532	488,494
2006	37,463	9	2.289	38,370	527,725
2007	42,689	10.2	2.447	43,674	601,495
2008	39,630	10.3	2.253	40,559	562,707
2009	39,289	10.7	2.17	40,204	556,696
2010	39,033	11.2	2.106	39,941	554,362
2011	39,995	11.2	2.093	40,899	567,688
2012	55,142	12.4	2.882	56,310	775,067
2013	61,607	12.8	3.224	62,889	864,602
2014	65,608	13.4	3.434	66,967	921,018
2015	67,889	14.3	3.561	69,309	955,968
Total Change since 1990 (%)	**181**	**266.7**	**100**	**180**	**185**

As an energy source gasoline, diesel oil, natural gas and liquefied petroleum gas (LPG) were used in road transportation. Shown in *Figure 1.6*, diesel oil is liable for the largest

share of CO_2 emissions originated from road transportation with 77%. LPG follows diesel oil contributing 13% of the road transportation emissions. On the other hand, together with biofuel, natural gas contributes the least amount of emissions with as low as 1%.

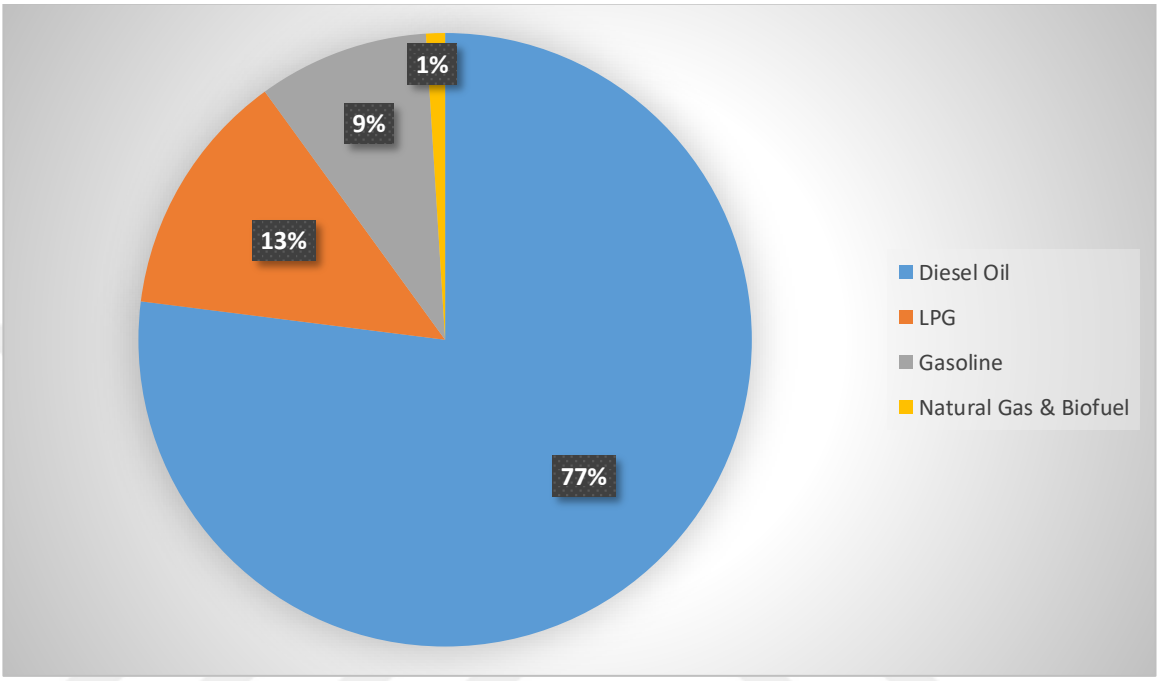

Figure 1.6 Contributions of different fuel types to CO_2 emissions [4]

Along with the increase in greenhouse gas emissions, fossil fuel combustion from automobiles is associated with air pollution. Air pollution report of the year 2017 reveals that Istanbul, Ankara, Adana, Amasya, Manisa, Bursa are leading in the list of most polluted cities. Artvin, Bitlis, Eskisehir, Yozgat, Kirsehir, and Kirikkale are on the short list of six clean cities, throughout Turkey [8]. When PM_{10} concentrations are analyzed, the air inhaled in these cities is harmful to human health. In order to avoid these adverse effects, the reduction of the combustion of fossil fuels is vital.

Preferring public transportation over automobiles will reduce a considerable amount of greenhouse gas emissions by cutting down a great number of automobiles on the road. If 42% of the automobile drivers choose public transportation over individual automobiles, it will eventuate in an almost 40% decrease in CO_2 emissions and 30% decrease in PM_{10} emissions from transportation sector [9]. Hence, greater use of public

transportation will reduce greenhouse effect, enhance the quality of air, therefore reducing the damaging impacts on public health.

1.3.2 Economic Benefits of Public Transportation

Public transportation is cost-efficient. For instance, choosing to perform daily routines with a bus will cost much less than that of an automobile. *Figure 1.7* shows the types of fuel used by road motor vehicles in 2017.

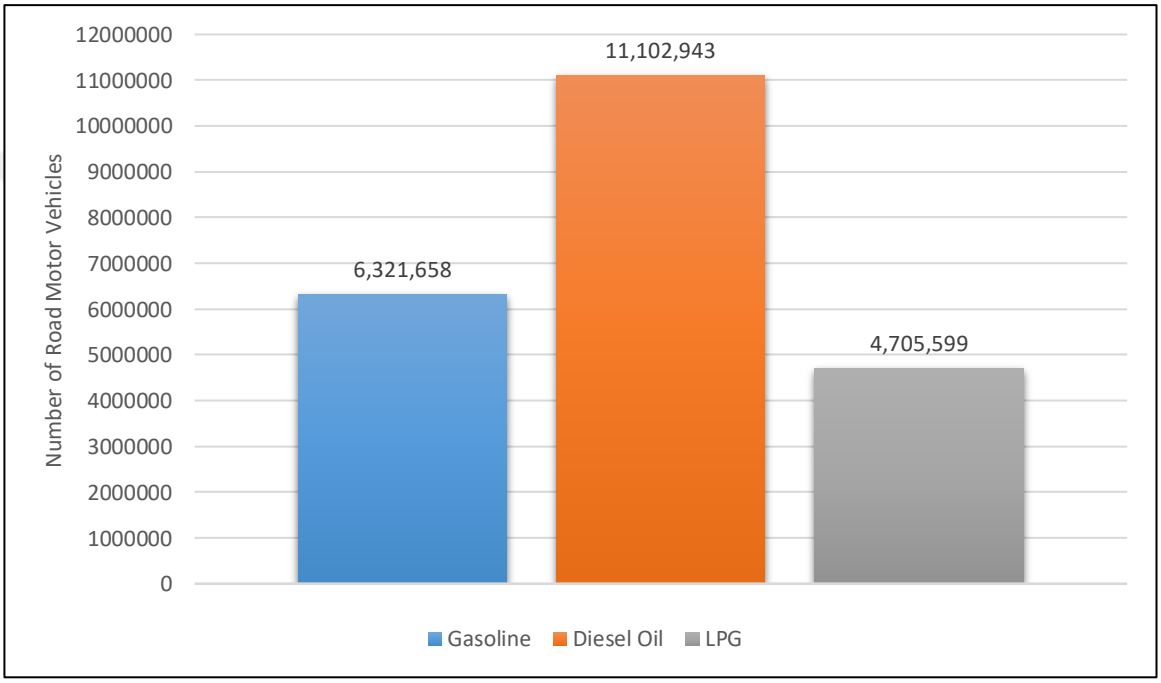

Figure 1.7 Number of road motor vehicles by the type of fuel used [4]

Half of the vehicles on the road use diesel oil as an energy source, while the 28.5% use gasoline and 21.2% use LPG. Turkey is among countries which use the most expensive gasoline, diesel oil and LPG. *Table 1.2* denotes the prices of the fuels in both U.S. dollars and Turkish liras and their respective places in the world ranking.

Table 1.2 Fuel prices in Turkey, 2018 [10]

Fuel Type	Price (liter, US Dollar &TL)	Global Rank
Gasoline	1.37$ or 6.26₺	55th most expensive
Diesel Oil	1.25$ or 5.71₺	52th most expensive
LPG	0.76$ or 3.47₺	14th most expensive
Notes: * Prices are last updated on Jun,25 2018 * Exchange rate of dollar is last updated on Jun,29 2018		

Taking into account that developing countries mostly import auto spare parts and energy sources, automobile dependent transportation imposes a significant burden on the national economy. Public transportation sector utilizes energy efficient vehicles, hence they provide better fuel economy. Turkey is an energy-import dependent country. Savings in energy consumption will result in a reduction in energy imports, therefore contributing to economic welfare of the country as well as that of the individuals.

In a different perspective, greater use of public transportation will serve a relatively effortless method of reducing greenhouse gas emissions, increasing air quality while contributing to the economy without enforcing new government regulations, through reducing the amount of fuel consumed.

1.3.3 Social Benefits of Public Transportation

Public transportation plays an important role especially in urban areas in terms of providing access to its residents to satisfy their needs of education, work, entertainment and many others. The need of people to access other people, place or goods and services are of capital importance from the point of economic welfare as well as social welfare. Beyond allowing people to integrate with the city, the greater use of public transportation will help build strong communities that are safer and more productive. Public transportation is also of great importance in terms of senior mobility.

Public transportation will relieve the traffic congestion, a consequence of overdependence on automobiles, which constitutes a significant problem in urban areas like Istanbul and Ankara. Private automobile is an inefficient method of transportation in terms of overcrowding the roadway. Therefore, especially in developing countries investments in urban road networks show an increase as time progresses.

Much as investing in new roads seems like a solution to the traffic problem in urban areas, in the long term it will end up augmenting the traffic congestion even more. New roads built accompany new settlements and turn into centers of attraction over time, thereby increasing the traffic intensity by creating additional transportation demands.

Although a bus occupies more space on the road then an automobile, an average bus carries 80 people where an automobile carries only five. Hence, greater use of public transportation will ease the traffic congestion to a large extent.

1.4 Review of the Previous Studies

There are number of studies available on total greenhouse gas emissions of Turkey in literature. Among these, Can (2006) prepared CO_2 emission inventory for the years 1990 through 2003. In this study, CO_2 emission inventory for the years between 2004 and 2010 was determined making projections. The inventories were prepared based on fuel consumption data from industrial, residential, traffic sources and thermal power plants at province and district levels. Based on provinces and districts, CO_2 uptake rate of the forests were determined and ground level CO_2 concentrations were estimated [11].

Lu (2017) explored the variables of energy consumption, greenhouse gas emissions and economic growth in Asia. The study revealed that there is a long-run co-integration relationship between energy consumption, greenhouse gas emissions and economic growth in Asia [12].

Pekin (2006) prepared greenhouse gas emissions inventory covering gases that are required to be regulated by Kyoto Protocol, originated from transportation sector

between the years 1990 and 2004. Estimating greenhouse gas emissions, Tier 1 and Tier 2 approaches of IPCC guidelines were adopted. The study indicated that 84% of the transportation sector emissions in 2004 were from road transportation. The importance of reducing the number of individually-owned automobiles and increasing the use of alternative fuels such as LPG and natural gas in order to reduce greenhouse gas emissions were expressed [13].

Sorusbay (2007) addressed the impacts of CO_2 emissions from road transportation to the environment. The study discussed the measures to be taken in order to reduce greenhouse gas emissions originated from road transportation. The study revealed that the control of CO_2 emissions from road transportation vehicles is directly linked to the adoption of measures in production and use stages of road vehicles. It is projected that financial policies and incentives to be applied towards reducing the use of road vehicles will encourage the use of appropriate vehicles for the environment [14].

The study carried out in both United Kingdom and India (2009) estimated the health effects of urban road transportation utilizing different scenarios. The study revealed that reduction of CO_2 emissions through lesser use of private motor vehicles had significant benefits on health than the increase in the use of low emission motor vehicles. It is indicated that the combination of both would have even largest health benefits. The study argues that in order to provide larger health effects, policies to be applied should not focus only on the use of low emission vehicles, but they should discourage the use of private motor vehicles [15].

To the author's knowledge, there aren't any studies available on country-specific emission factors for road transportation for Turkey.

1.5 Aim of the Thesis

The purpose of this thesis is to investigate the reductions of greenhouse gas emissions from EGO public transport buses by altering the fuel use patterns and fleet planning. The first step in accomplishing this purpose is to prepare an adequate greenhouse gas emissions inventory for public transport buses. Current published inventories reveal that fuel sold method is utilized when calculating the emissions from transportation

sector. Although it's a good method of choice for the CO_2 emissions, for CH_4 and N_2O emissions it's not quite reflective of the actual values. Another calculation method, that is vehicle kilometers travelled (VKT) method, accounts for vehicle type and technology, fuel economy, emission control technology used and operating conditions. Hence, VKT method is the appropriate method of choice for the calculations of CH_4 and N_2O emissions originated from buses.

Emission factors have an important role in emission calculations. There are default emission factors determined in guidelines prepared by IPCC. However, it is highly recommended to use country-specific emission factors. There has not been calculated country-specific emission factors for Turkey due to the lack of registered data. Calculations of the emissions and emission factors will be further discussed in later chapters.

1.5.1 Objectives of the Thesis

In order to achieve the aim, in this thesis;

- Emission inventory for the direct greenhouse gas emissions of the EGO public buses for the year 2017 will be prepared.
- Direct greenhouse gas emissions in the inventory will be calculated using both fuel sold and VKT methods. The difference in calculated emission values between methods will be investigated.
- Country-specific emission factors will be determined in detail to the extent permitted by the data available.
- From 2018 to 2027, direct greenhouse gas emissions will be estimated in two projections. Projection-I will exhibit the direct greenhouse gas emissions of 2018 to 2027 in consequence of the current trend in vehicle expansion and fuel use whereas Projection-II will examine the reduction in direct greenhouse gas emissions of 2018 to 2027 through altering the fleet expansion and fuel use patterns. Differences between the two projections are investigated.

1.6 Structure of the Thesis

This thesis is comprised of six chapters structured on four key objectives detailed as follows:

Chapter 1 presents an overview of the thesis. In this chapter, the relationship between the changes in atmospheric concentrations of greenhouse gases and the increase in individually-owned automobiles is addressed. Climate change and its current and future impacts are examined. Particular emphasis is placed on the benefits of choosing public transportation over private automobiles. A review on the previous studies are included. The chapter introduces the aim and objectives of the thesis as well as the structure of the thesis.

Chapter 2 describes greenhouse effect, climate change and their anthropogenic and natural drivers. Greenhouse gases, their sources of abundance and their influences on climate change are introduced in this chapter. The difference between the impacts of direct and indirect greenhouse gases is addressed while drawing attention to the immediate need of minimizing the concentrations of the greenhouse gases in the atmosphere to avoid adverse climate change effects before reaching to the point of no return.

Chapter 3, examines the international and domestic regulations. Actions taken by a selection of developing and developed countries towards encouraging public transportation, reducing automobile dependency and reducing greenhouse gas emissions are observed. Information on the current transportation trends in Ankara is provided.

Chapter 4 introduces the methodology used in calculations. Global Warming Potential, tier approaches and emission factors are defined including the primary factors that increase the uncertainties in the emission factors. The importance of choosing the appropriate tier approach and emission factor is addressed. To what extend utilizing VKT method instead of fuel sold method influences the calculated amount of emissions is expressed.

Chapter 5 comprises the emission calculations. Direct greenhouse gas inventory of the EGO buses for 2017 is prepared. Country-specific emission factors for diesel oil and CNG are calculated. Both the lowest and the highest tiers are used in current direct greenhouse gas calculations. Direct greenhouse gas emissions of the next ten years are estimated by means of two projections.

Chapter 6 is the final chapter of this thesis. This chapter includes discussion and conclusion.

CHAPTER 2

CLIMATE CHANGE AND THE GREENHOUSE GASES

2.0 Overview

In this chapter, climate change phenomenon and its natural and anthropogenic drivers are explained. Terms natural and enhanced greenhouse effect are defined. Greenhouse gases and how they form, along with the source of their abundance in the atmosphere are identified. Their contribution to the climate change phenomenon are examined.

This chapter addresses that greenhouse gases show an increasing trend since pre-industrial times substantially due to anthropogenic activities.

2.1 Climate Change Phenomenon

Climate is regarded as the statistical average of observed weather patterns for a given area, generally for over 30 years. Precipitation patterns, surface temperatures, weather extremes are the influencing factors of the climate. Composed of five coordinated constituents, climate system designates the Earth surface climate. These five constituents are atmosphere, oceans, terrestrial and marine biospheres, cryosphere, and the land surface. Climate system balances itself by reflecting the solar energy that strikes the Earth's atmosphere back to space by the emission of infrared energy.

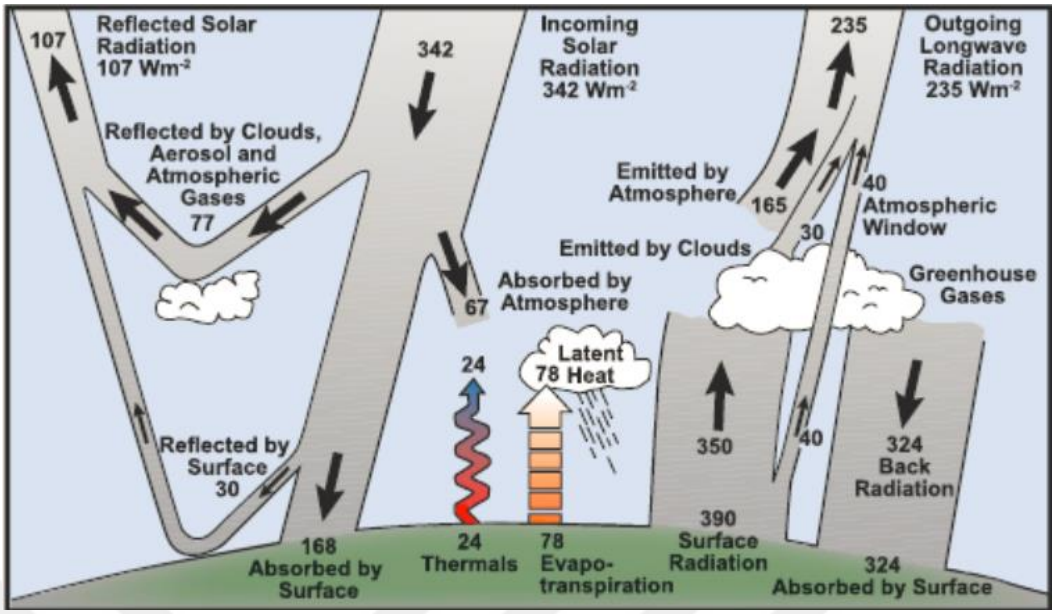

Figure 2.1 Global energy balance [16]

Figure 2.1 shows that while almost 20% of the incoming solar radiation is absorbed by the atmosphere and 50% of it is absorbed by the Earth's surface, the remaining is reflected back to the space. The energy absorbed by the surface is transferred back to the atmosphere by evapotranspiration, by longwave radiation absorbed by clouds and greenhouse gases, warming the air through interaction with the thermals. The outgoing longwave radiation is radiated back to the Earth, and to the space. This process brings the climate into a balance. The natural balance can be altered by changing the greenhouse gas concentrations in the atmosphere.

Existence of the greenhouse gases is what makes the Earth habitable. Greenhouse gases keep the Earth warmer (at about 14ºC) by trapping some of the longwave radiation emitted from the Earth's surface, known as the natural greenhouse effect. Human induced activities such as fossil fuel combustion and deforestation have constantly added to the concentrations of the greenhouse gases in the atmosphere. Between 1880 and 2012, concentrations of carbon dioxide, methane, and nitrous oxide have increased by 40%, 150%, and 30%, respectively, becoming the highest since industrial revolution. Increasing concentrations of the naturally occurring greenhouse gases lead to an increase in the amount of the outgoing longwave radiation trapped therefore making the Earth warmer than it would be otherwise, called the enhanced

greenhouse effect. Naturally occurring greenhouse gases are water vapor, carbon dioxide, ozone, methane and nitrous oxide.

Sulfate aerosols from sulfur dioxide emissions can have a cooling effect on climate by reflecting and absorbing solar radiation; however, when compared to other greenhouse gases their life span is much shorter (days to weeks).

The constant additions to the greenhouse gas compositions disrupt the natural course of the Earth, causing climate change. Global average temperatures increased 0.85ºC since the industrial revolution, and is predicted to exceed 1.5°C at the end of the 21th Century. From then on, even if the emissions are stopped, climate change effects will be unavoidable [16].

2.2 Greenhouse Gases

It's clear that driving force of the climate change is the increasing compositions of the greenhouse gases as a result of human activities. Some of the greenhouse gases occur in the atmosphere naturally, ensuring the life on Earth by keeping it warm. However, substantial increases in their compositions in the atmosphere enhanced their heat-trapping abilities, disturbing the natural balance of the climate. Carbon dioxide, methane, and nitrous oxide are examples to the naturally occurring greenhouse gases. These gases have a very long lifespan in the atmosphere (decades to centuries).

Some of the greenhouse gases occur entirely due to human activities. These gases are collectively called "the halocarbons". Halocarbons contain bromine, chlorine and fluorine. Examples include; Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs).

Carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and tropospheric ozone (O_3) are called tropospheric gases. These gases have short lifespan and are air pollutants. Tropospheric ozone is formed by CO, NO_x and non-methane hydrocarbons (NMHCs). Alterations in the compositions of tropospheric ozone is associated with the air quality, and climate change.

Although water vapor is an important greenhouse gas for its contributions to the greenhouse effect, due to its concentrations in the atmosphere depending primarily on air temperature rather than human-made emissions it is regarded as a feedback agent. Therefore, the contribution of water vapor emissions resulting from human activities to the climate change is neglected [16].

Aerosols (exceedingly small particles) are derived mainly from emissions of primary particulate matter (SO_2, NO_x, volatile organic compounds (VOCs)) and forming of secondary particulate matter (sulfuric acid, nitric acid, ammonia). Aerosols are composed of black carbon, organic and inorganic species (sulfate, nitrate, ammonium, sea salt), mineral species (desert dust), and primary biological aerosol particles (PBAPs). Aerosols can be naturally occurring or anthropogenic.

The rising air hosts the formation of clouds through expanding and cooling which enables the transfer of the aerosols into droplets and ice crystals in supersaturated air. Via this process, aerosols contribute to biogeochemical cycles in the Earth system. Transferring nutrients to ocean ecosystems is an example. Anthropogenic aerosols play a role in climate change through this transfer with clouds.

Aerosols disperse and absorb solar radiation. While dispersing of aerosols have a cooling effect on climate, making the Earth more reflective; absorption of aerosols have a warming effect on climate. Although the understanding of the aerosols is not yet comprehensive, common view is that anthropogenic aerosols have a cooling effect on climate. Aerosols have short lifespan [3].

Regulation of six greenhouse gases is required by Kyoto Protocol. These gases are; carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride.

2.2.1 Water Vapor

Atmosphere is rich in water vapor. Water vapor is an important greenhouse gas for its contributions to the greenhouse effect. Compared to carbon dioxide, contribution of water vapor to the natural greenhouse effect is reputed to be two to three times larger. Much like other greenhouse gases, concentrations of water vapor in the atmosphere

increased due to human activities. For instance, increasing evaporations from irrigated crops contribute substantially to the increase in water vapor concentrations, whereas the contribution of the combustion of fossil fuels is very little. Lifespan of the water vapor in the atmosphere is ten days.

Abundance of water vapor in the atmosphere depends primarily on air temperature rather than anthropogenic emissions. Also, due to its short lifespan, it doesn't have a notable contribution to the long term greenhouse effect. Hence, the contribution of water vapor emissions resulting from human activities to the climate change is neglected. Instead, water vapor is regarded as a feedback agent.

With every addition of 1ºC to the air temperature, atmosphere can hold approximately 7% more water vapor. The increase in the concentration results in more warming. This process is called water vapor feed-back.

Increasing concentrations of other greenhouse gases affect water vapor concentration in the atmosphere. If other greenhouse gases didn't exist, the substantial reduction in the temperature would result in a tremendous drop in the water vapor concentration, fail to provide the necessary temperature to prevent the Earth from freezing. Other greenhouse gases provide the temperature necessary to maintain current atmospheric water vapor concentrations. Though it is not regarded as a direct contributor to the climate change, water vapor enhances the effects of the increasing anthropogenic emissions by a factor of two to three [3].

2.2.2 Carbon Dioxide (CO_2)

Carbon dioxide is an important greenhouse gas that has a significant impact on global warming. It transmits most of the shortwave radiation coming directly from the Sun but traps the outgoing longwave radiation from the Earth surface.

CO_2 participates in various cycles between atmospheric, oceanic, land biotic, marine biotic and mineral reservoirs. Between atmosphere and ocean surface, also between atmosphere and terrestrial biota are where the largest fluxes take place. The carbon in the atmosphere is present in its oxidized form, which is CO_2. Carbon dioxide in the

atmosphere is part of this global cycle and is directly associated with geochemical and biological processes [17].

Primary sources of the amount of CO_2 in the atmosphere are fossil fuel combustion and land use change. CO_2 concentration increased from its pre-industrial revolution level of 278 parts per million (ppm) (1750) to 390.5 ppm in 2011. Since industrial revolution till 2011, the average global annual increase in CO_2 was 1.7 ppm. The increase rate of CO_2 varied from year to year due to small changes in the balance between photosynthesis and respiration on land [3].

2.2.3 Methane (CH_4)

Methane is one of the naturally occurring greenhouse gases that has a very long lifespan in the atmosphere. Concentrations of methane in the atmosphere have been increasing since pre-industrial times due to anthropogenic activities.

Methane has the second largest radiative forcing after carbon dioxide. Radiative forcing is the measure of changes in the energy balance of the Earth-atmosphere system. Positive radiative forcing warms the Earth surface, when negative forcing has a cooling effect on the Earth surface.

Methane is produced from biogenic and non-biogenic sources. Non-biogenic sources of methane production are; biomass burning, waste treatment, mining and combustion of fossil fuels such as natural gas, petroleum and coal. Biogenic sources include livestock, rice agriculture, forests, landfills, wetlands, oceans and termites.

Also, methane sources can be categorized as natural and anthropogenic. Natural sources include emissions from oceans, termites, forests, wetlands, termites, fire and geological sources. Anthropogenic methane is emitted from livestock, rice agriculture, landfills and waste treatment along with fossil fuel combustion [16].

Methane concentration in the atmosphere has increased by a factor of 2.5 since pre-industrial era. The concentration rose from its 1750 level of 722 parts per billion (ppb) to 1803 ppb in 2011. This increase in methane concentration is attributed to anthropogenic activities. Major anthropogenic sources that contribute to this increase

in methane concentration are emissions from mining and combustion of fossil fuels, rice paddy agriculture expansion and the emissions from waste and landfills. Anthropogenic emissions are liable for 50 to 65% of the total emissions [3].

2.2.4 Nitrous Oxide (N_2O)

Nitrous oxide has the third largest radiative forcing after methane. Nitrous oxide concentration in the atmosphere has increased by a factor of 1.2 since pre-industrial era. Dominant anthropogenic source contributing to this increase is emissions from soil treatment using organic (manure) and synthetic nitrogen fertilizer from soil. Alterations in the nitrogen cycle along with interactions between CO_2 sources affect N_2O emissions from the ocean and on land [3].

2.2.5 Halocarbons, Perfluorocarbons and Sulfur Hexafluoride (SF_6)

Halocarbons having indirect and direct radiative forcing effects, occur entirely due to human activities. Halocarbons containing bromine (halons) and chlorine (CFCs and HFCs) are the cause of ozone depletion. Emissions of these halocarbons are regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer. HFCs have lifespans in the range of 1.4 to 270 years. [16, 17]

Increases in the concentration of HFCs and CFCs contributed to direct radiative forcing about +0.25 W/m^2 since pre-industrial times till 1995. Halocarbons contribute to negative radiative forcing as well by means of depleting the stratospheric ozone [3].

Perfluorocarbons (PFCs) and SF_6 absorb infrared radiation quite effectively. Hence, even in small amounts, they have substantial radiative forcing effects. PFCs and SF_6 have lifespans of 1000 to 50,000 years. Although their contribution to radiative forcing is small, due to their lifespan in the atmosphere their existence will influence the climate for thousands of years. Therefore their contribution to radiative forcing is almost permanent. PFCs are emitted primarily from aluminum production. Dominant sources of SF_6 emissions are electricity distribution systems and magnesium production. [16]

2.2.6 Carbon Monoxide (CO)

CO is a toxic gas and a product of incomplete combustion of fossil fuels. It oxidizes to CO_2 in the atmosphere as a result of natural processes. Carbon monoxide is not regarded as an important greenhouse gas due to its lack of direct radiative forcing effect on climate and short lifespan in the atmosphere; however, it has an indirect radiative forcing effect through enhancing the concentrations of CH_4 and tropospheric ozone.

Reacting with it, CO reduces the concentration of hydroxyl radical (OH), an atmospheric constituent that helps to annihilate CH_4 and tropospheric ozone. Reducing the concentrations of OH, CO prevents it from diminishing these greenhouse gases. Meaning, increases in CO levels lead to enhanced concentrations of CH_4 and tropospheric ozone in the atmosphere [17].

CO has damaging effects on human health. Merging with the hemoglobin, CO decreases the oxygen-carrying capacity of the blood. While low concentrations of CO cause heart diseases, high concentrations result in death [8].

2.2.7 Nitrogen Oxides (NO_x)

Nitrogen oxides have indirect radiative forcing effects on climate as a result of forming tropospheric ozone, combining with CO and NMHCs. Nitrogen oxides have short lifespans in the atmosphere. Emissions of nitrogen oxides are emitted from microbial activity in soil, lightning, fossil fuel combustion, natural and anthropogenic fires [13].

Even in small concentrations, NO_x is extremely poisonous. Exposure to NO_x results in respiratory and eye diseases [8].

2.2.8 Non-methane Volatile Organic Compounds (NMVOCs)

Non-methane volatile organic compounds comprise of compounds like ethane, butane and propane. They have short lifespans of hours to months in the atmosphere. Much as nitrogen oxides, NMVOCs take part in tropospheric ozone formation, therefore contributing to the indirect radiative forcing effect on climate. Emissions from

NMVOCs are dominantly emitted from fossil fuel combustion, industrial processes, biomass burning and non-industrial consumption of organic solvents [17].

2.3 Conclusion

This chapter explained the terms climate change, greenhouse effect and enhanced greenhouse effect. Long lived and short lived greenhouse gases, how they originate and to what extent they contribute to climate change are addressed.

Chapter exhibited that climate change and its disastrous consequences are not simply caused by the presence of the greenhouse gases. Instead it is caused by the excessive amounts of greenhouse gases in the atmosphere as a result of anthropogenic activities. Their abundance in the atmosphere is primarily due to land use changes, waste management, industrial processes, and agriculture along with the unconscious use of fossil fuels such as coal and petroleum.

This chapter revealed that some of the greenhouse gases are more effective on climate change than others. The chapter emphasized that the existence of the long lived greenhouse gases influences the climate for a very long period of time due to their lifespan in the atmosphere. Therefore reducing the concentrations of these greenhouse gases is of great importance. However, the chapter revealed that the atmospheric concentrations of greenhouse gases continued to increase significantly since pre-industrial times.

CHAPTER 3

REGULATIONS AND IMPLEMENTATIONS

3.0 Overview

This chapter comprises a review of both international and domestic actions taken towards reducing greenhouse gas emissions. Chapter also investigates successfully implemented policies implemented to reduce greenhouse gases and to reduce automobile dependency in selected countries. Current situation of the public transportation in Ankara is also examined in this chapter.

This chapter reveals that Turkey has fallen behind -yet showing progress- in meeting the needs of climate protection in both international and domestic levels. On the other hand, the situation of the world does not appear to have been promising so far either. The ever-increasing greenhouse gas emissions reveal that countries of the world fail to actualize the targets set so far.

3.1 International Legislative Regulations

It is evident that increasing greenhouse gas emissions accompany environmental problems that have consequences affecting all countries of the world. Hence, minimizing the greenhouse gas emissions is of vital importance. This can only be accomplished by the collective efforts of the countries of the world. Turkey have adopted various international legislative regulations on environment, with the intent of doing its part on environment protection.

3.1.1 United Nations Framework Convention on Climate Change (UNFCCC)

Following the findings of Svante Arrhenius, the Swedish scientist who revealed that increasing carbon dioxide compositions in the atmosphere as a result of the modern industry is directly associated with the warming of the Earth, it took almost a century for the humanity to take preventative action.

In 1988, the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) jointly assembled the Intergovernmental Panel on Climate Change (IPCC). Scientist representing numerous countries gathered to evaluate all existing scientific information of the time regarding the impacts of the climate change on social, environmental and economical levels with the aim to strategize convenient responses.

In 1990, IPCC has published its first report commissioned by United Nations General Assembly (UNGA), containing a scientific assessment, an impact assessment and response strategies. Examining the assessment, UNGA initiated to lay the foundations of the Framework Convention on Climate Change (FCCC) [18]. As a product, UNFCC, which is regarded as the first significant international action against climate change, is signed by 196 countries including the European Union at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992.

UNFCCC aims to keep the greenhouse gas emissions at a certain level with the cooperation of the party countries on the basis of "common but differentiated responsibilities and respective capabilities". Turkey became a party to UNFCCC twelve years later in May 24, 2004, as a developing country being the only country in Annex-1 (historical responsibilities) with special circumstances, without an obligation to reduce greenhouse gas emissions.

In 2001, Climate Change Coordination Committee (CCCC) is established in Turkey to determine policies to be pursued and measures to be taken regarding climate change. In 2004, CCCC is reconstituted following Turkey's participation to the UNFCCC to ensure the coordination between public and private institutions and organizations and to determine appropriate domestic and foreign policies regarding Turkey's special circumstances. Eleven technical working groups have been formed, one of them being Greenhouse Gases Emission Inventory Technical Working Group undertaken by Turkish Statistical Institute [19].

In 2007, Turkey published the First National Communication on Climate Change, which includes greenhouse gas inventories between 1990 and 2004, projections, measures to be taken, financial assessment and climate change impacts on Turkey [20].

3.1.2 Kyoto Protocol

Kyoto Protocol regulates legal obligations within the scope of United Nations Framework Convention on Climate Change (UNFCCC), and sets binding targets for countries to reduce greenhouse gases 5% below 1990 levels. Kyoto Protocol entered into force in 2005. Four years later in 2009, Turkey became a party to the Kyoto Protocol.

Objective of the Kyoto Protocol for the party countries in Annex-I is to reduce the amount of anthropogenic greenhouse gases in CO_2 equivalents specified in Annex-A to at least 5% below the 1990 levels. In line with this objective, quantified emission limitations or reduction commitments between the years 2008 and 2012 for Annex-I countries were included in Annex-B. Kyoto Protocol targets that the party countries make provable progress in achieving these limitations or commitments by 2005.

To achieve this overall objective, party countries have undertaken obligations to reduce or limit greenhouse gas emissions at different rates as a result of the negotiations. However, Turkey has not taken on an obligation to limit or reduce the greenhouse gas emissions despite being an Annex-I country. This is attributed to the fact that Turkey was not a party to Kyoto Protocol when the negotiations were carried out [21].

3.1.3 Paris Agreement

In April 22, 2016, Turkey became a party to the Paris Agreement as a developing country. Paris Agreement aims to keep the global temperature rise below 2ºC, with the contributions of all of the party countries.

The distinctive feature of the Paris Agreement is that it doesn't pay regard to "common but differentiated responsibilities and respective capabilities" basis of UNFCC. Agreement anticipates developed countries to provide required funding and technology transfer to the least developed countries and developing countries in order to enhance their capability to reduce greenhouse gas emissions.

With the declaration of “Intended Nationally Determined Contribution” (INDC), Turkey announced that greenhouse gas emissions will be reduced from its 21% rise at the time by 2030 [22].

3.2 National Approaches to Emission Reductions from Public Transportation

Alongside international policies, Turkey adopts a number of domestic policies in order to fulfill the greenhouse gas emission reduction targets.

3.2.1 Development Plans

Development Plans are generally five-year plans that include economic, social, cultural and environmental policies. Currently, there are ten Development Plans that are published.

3.2.1.1 Environmental Policies

As industrialization and economic development continued rapidly, after entering the period of planned development environmental problems were not addressed and specific policies were not established in the first (1963-1967) and second development plans (1968-1972). Only, the development of the environmental health conditions has been mentioned in the general sense.

After 1963-1972 period, development plans started to draw attention to the environmental problems, indicating the current situation and measures to be taken emphasizing that the evaluation of the problem within an integrated planning is essential.

Third Development Plan (1973-1977) calls attention to certain environmental problems such as water, air and coast. In this Plan, existing environmental problems were identified. Establishment of environmental policies that don’t hinder industrialization and economic development was referred. Although economic development was primarily aimed in this Plan, raising the awareness of public

regarding the environmental problems was listed among the principles to be adopted. The first step in environmental protection was taken in this Plan.

Fourth Development Plan (1979-1983) addresses preventing environmental problems before they occur by implementing preventative environmental policies. Primary principle of the fourth Development Plan on environment is that environmental problems should be taken into account in industrialization, modernization of agriculture, urbanization process. Hence, rationality in utilization and conservation of nature and natural resources will be ensured and long-term irreversible environmental problems will be avoided. Plan also draws attention to the air pollution in Ankara. It is noted that projects that will serve as a solution to this problem will be put into practice during the period of this Plan. In this Plan, it has been brought to agenda that the associations and foundations that work on environment related issues will be supported and encouraged.

Thus far, Development Plans have included environmental policies; however, they did not mention administrative structuring and legislative work. Therefore, these policies are merely an indicative of an increase in the importance of environmental issues. As stated in the Seventh Development Plan (1996-2000), coordination and division of work among institutions responsible for environmental management have not been established and the required information infrastructure and environmental data have not been constituted. Legal arrangements have not been able to reach a level that would provide an effective environmental management.

Greenhouse gas emissions were first mentioned in the Eighth Development Plan (2001-2005). Eighth Development Plan includes policies to be developed towards reducing greenhouse gases. The Plan addresses that greenhouse gas emission inventories of all sectors will be prepared and that country-specific emission factors will be determined in efforts to prevent the air pollution. It is indicated that regulations will be made to increase efficiency and savings in order to control and reduce greenhouse gases originated from transportation, energy, industry and housing. The first real progress in environmental protection was made in this period by being a party to UNFCCC in May 24, 2004. Turkey's official greenhouse gas inventory was submitted to UNFCCC Secretariat for the first time in 2006.

Ninth Development Plan (2007-2013) acknowledges that the need to improve the monitoring, inspecting and reporting system infrastructures and the necessity of sharing and flow of information between related institutions with an integrated system is still continuing. Turkey has become a party to the Kyoto Protocol in the period of this Plan. In the Plan, principles of "sustainable development" and "common but differentiated responsibilities" were brought to attention in order to meet international obligations. Plan stated that a National Action Plan adopting these principles will be prepared exhibiting the policies and measures to be taken in order to reduce greenhouse gases [23].

Tenth Development Plan (2014-2018) covering the present period includes utilizing "green growth" method in order to achieve sustainable development targets. The plan repeats that the ambiguities in duties, authorities and responsibilities regarding environmental management need to be resolved. The Plan addresses that the role of local governments and non-governmental organizations (NGOs) will be increased [24].

In status analysis section, Tenth Development Plan states that a significant process has been made particularly in emission control, expansion of protected areas, protection of biodiversity, along with prevention of environmental pollution and sustainable management of natural resources. It is indicated that with the preventive measures taken against global climate change, cumulatively 1.4 billion tons of emissions were avoided in the period between 1990 and 2007. In 2007-2012 period, 50% reduction in the amount of SO_2 and 36% reduction in particulate matter were obtained [25].

3.2.1.2 Urban Public Transportation Policies

Development Plans address problems of infrastructure, institutionalization and legislation regarding urban transportation and propose policies in order to improve and encourage public transportation.

Until the Fourth Development Plan, the lack of detailed policies on urban transportation stands out. The first three Development Plans lay emphasis on the necessity of preparing an infrastructure regarding urban transportation.

In the period of the Fourth Development Plan, the importance of public transportation in urban transportation is pointed out. The Fourth Development Plan addresses that transportation modes such as buses, subways and suburban systems should be established and that city development plans and transportation plans should be evaluated together.

The Sixth Development Plan notes that road transportation which has relatively lesser unit transportation cost dominates the domestic passenger transport with 95% and is expected to remain about the same. The Plan emphasizes the necessity of taking legal measures against the effects of toxic gases released from road vehicles on environment and human health.

The Seventh Development Plan reveals that public transportation system is not yet at satisfactory conditions due to the rapid increase in the number of individually-owned automobiles. In this Plan, the bottlenecks in the urban road infrastructure in recent years are attributed to the increasing numbers of private automobiles.

The Eighth Development Plan proposes policies that improve traffic safety, raise public transportation quality and increase the mobility by means of walking and cycling.

In the Ninth Development Plan, it is determined that public transportation has not developed sufficiently and, in parallel with this, traffic accidents, excessive fuel consumption and environmental pollution have emerged. In order to overcome these problems, the Plan suggests collaborative, sustainable, environmentally conscious policies that prioritize mobility by means of walking and cycling, reducing the private automobile dependency.

In the Tenth Development Plan, it is stated that bicycle and pedestrian paths will be put into practice. The integration of public transportation systems and the importance of smart transportations systems are emphasized. It is indicated that transportation systems that provide energy efficiency, fuel efficiency and is environmentally friendly will be prioritized [26].

3.2.2 National Climate Change Action Plan

Preparation and adoption of a national action program on climate change was recommended in the report prepared by the Specialized Commission on Climate Change, which was established within the State Planning Organization (SPO) for the preparation of the Eighth Development Plan. Thereupon, Turkey has taken steps in order to prepare the Climate Change Action Plan (NCCAP). Climate Change Action Plan (2011-2023) was concluded and published in July 2011 by the Ministry of Environment and Urbanism. The NCCAP does not contain a digitized greenhouse gas reduction target due to its position on the international legislations of the time. The NCCAP consists of a total of 541 actions to achieve 107 targets on energy, transportation, building, industry, waste, agriculture, land use and forestry sectors along with crosscutting issues among sectors and adaptation to climate change.

In NCCAP, it is specified that Turkey's main target is to do its part on the global combat against climate change without having to compromise its sustainable development efforts adapting the principle of "common but differentiated responsibilities" regarding Turkey's special circumstances. *Table 3.1* exhibits the number of purposes and objectives set in different sectors, crosscutting issues and adaptation to climate change.

Table 3.1 Number of purposes and objectives in NCAAP [27]

Sectors	Purposes	Objectives
Energy	4	9
Building	3	7
Industry	3	5
Transportation	5	10
Waste	1	6
Agriculture	3	5
Land Use and Forestry	4	9
Crosscutting Issues	9	12
Adaptation to Climate Change	17	44
Total	**49**	**107**

Purposes and objectives for energy and transportation sectors are exhibited *in Table 3.2* and *Table 3.3*, respectively.

Table 3.2 Purposes and Objectives for energy sector [27]

Purpose	Objective
Reducing energy intensity	Reduce primary energy intensity by 10% compared to 2008 by 2015 as a result of implemented and planned policies
	Develop the capacity for energy efficiency by 2015
	Support R&D activities on energy efficiency
	Increase the amount of incentives given by MENR for energy efficiency applications by 100% until 2015
Increase the share of clean energy in energy production and use	Ensure that the share of renewable energy in electricity production is increased
	Develop capacity by 2015 so as to increase utilization of renewable energy resources
	Ensure technological development by 2020 for energy production from renewable energy sources
Limit GHG emissions originating from the use of coal in electricity production, by using clean coal technologies and taking efficiency-increasing measures	Increase the average cycle efficiencies of existing coal-fired thermal power plants until 2023
Reduce losses and illicit use in electricity distribution	Reduce nationwide electricity distribution losses to 8% by 2023

Table 3.3 Purposes and Objectives for transportation sector [27]

Purpose	Objective
Developing an intermodal transport system and ensuring balanced utilization of transport modes in freight and passenger transport	Increasing the share of railroads in freight transportation (which was 5% in 2009) to 15% and in passenger transportation (which was 2% in 2009) to 10% by 2023
	Increasing the share of seaways in cabotage freight transportation (which was 2.66% in ton-km in 2009) to 10%, and in passenger transportation (which was 0.37% in passenger-km in 2009) to 4% as of 2023
	Decreasing the share of highways in freight transportation (which was 80.63% in ton-km in 2009) below 60% and in passenger transport (which was 89.59% in passenger-km in 2009) to 72% as of 2023
	Preparing and putting in practice the “Transportation Master Plan” until 2023

Table 3.3 (continued) Purposes and Objectives for transportation sector [27]

Purpose	Objective
Restructuring urban transportation in line with sustainable transport principles	Limiting emission increase rate of individual vehicles in intracity transport
	Developing the necessary legislation, institutional structure and guidance documents until the end of 2023 for implementation of sustainable transport planning in cities
Dissemination of the use of alternative fuels and clean vehicle technologies in the transport sector	Making legal arrangements and building capacity to increase use of alternative fuels and clean vehicles until 2023
	Taking local measures to encourage use of alternative fuel and clean vehicles in urban transport until 2023
Increasing efficiency in energy consumption of transportation sector	Limiting the energy consumption in transport until 2023
Developing the information infrastructure in the transport sector	Building a well-organized, reliable and sustainable information infrastructure with transport and travel data including GHG emission data, until the end of 2016

Analyzing actions for reducing or limiting greenhouse gas emissions regarding energy sector, it is seen that they are pertinent to capacity enhancements for carbon-conscious growth and energy efficiency. In order for the capacity enhancement to be achieved, NCCAP features the following actions; the analysis of the technology needs to control greenhouse gas emissions, preparation and enforcement of the energy efficiency action plan, identification of economic instruments to increase energy efficiency and reduce greenhouse gas emissions, increasing the share of renewable energy in production and use, limiting the greenhouse gases from coal use in electric generation by utilizing clean coal technologies and supporting NGOs and local governments for the development of projects.

Actions in transportation sector include development of railway infrastructure and superstructure, increasing its activity in passenger and freight transportation, establishment of the Main Traffic Management System Center to reduce time lost in traffic and traffic accidents, integration of the purposes and objectives for the low-carbon economy into the Transportation Master Plan, establishment of combined and intermodal transportation infrastructure and constituting interchange terminals between modes.

Actions towards limiting the increase in emissions due to the use of individually-owned automobiles in urban transportation include making investments and

arrangements for road, railway and navigation transportation, integration of public transportation systems with each other and with other modes of urban transportation, establishing pedestrian ways and areas free from automobiles in urban centers, encouraging the concept of "Slowcity", and establishing cycling road networks throughout cities.

In increasing the use of alternative fuels and clean vehicles, actions that stand out include; integration of European Union's (EU) 443/2009/EC, directive on reducing CO_2 emissions from passenger cars and 2009/33/EC, directive on promotion of clean and energy efficient road transport vehicles when purchasing public transportation vehicles into national legislation, initiation of regulations on taxation system in order to reduce greenhouse gas emissions in motor vehicles, carrying low emission strategy for the buses and minibuses into execution and establishment of filling stations for electric cars in cities.

The purposes and objectives in the NCAAP are to be achieved by 2023 [27].

3.3 Urban Transportation Policies in Selected Countries

3.3.1 Developing Countries

3.3.1.1 Brazil

Brazil is the world's fifth largest country in terms of population and area. Brazil has a population of over 208 million and is the eighth largest economy in the world. Being one of the most populated countries in the world, problems regarding transportation arise in crowded cities of Brazil. Similar to other developing countries, fundamental problems such as traffic congestion, air and visual pollution and greenhouse gas emissions as a product of inadequate alternative transportation systems and automobile-based transportation investments are common in the cities of Brazil.

In Brazil, metrobuses running in segregated bus lanes are quite common. About 10 million passengers use this system with over 100 corridors every day. In the Federal Constitution, prepared in 1998, the concept of mobility in urban transportation was mentioned for the first time. Also, it is stated that the municipalities were given the

responsibility of the public transportation systems. With the enforcement of the City Statute in 2001, the cities with a population of over 500,000 have been required to prepare “Integrated Transportation Plans” in accordance with “Urban Master Plans”. However, Integrated Transportation Plans were replaced by “Transportation and Mobility Master Plans” in 2005. In this Plan, participation is emphasized with a different and appropriate approach to solve social problems.

Sao Paulo is one of the most economically and politically important state of Brazil. The state is experiencing significant problems such as traffic congestion and air pollution, especially due to the rapid increase in the number of automobiles. The city where these problems are most intensely experienced is Sao Paulo. The average traffic flow at 25 km/h in 1970s, declined to 20 km/h in 1990 and to 17 km/h in 1998. Also, the length of traffic congestion during the rush hours have reached from 39 km to 122 km between 1992 and 1996. Under these circumstances, the total economic value of the time lost in traffic and over fuel consumption was estimated to be $21 billion (10% of the urban economy). In order to overcome these problems, transportation investments are emphasized; however, these investments cannot catch up with the economic development.

The biggest metro system of Brazil is located in Sao Paulo. The system which has 64 stations operated on five lines, transports 4.5 million passengers a day. In addition to the Metro system, there are bus corridors that are similar to metrobuses. Approximately 2.1 million passengers are transported every day with this system which has a total length of 122 km in ten corridors. In this system transportation fee is collected in the bus and not in the station. Therefore, this system is not entirely regarded as a metrobus system.

Increasing the use of bicycles is also among the policies that are implemented in Sao Paulo. Correspondingly, Sao Paulo practices “car free Sunday” every week between 7am and 2pm.

Curitiba, is the eighth most crowded city of Brazil with the population of 1.8 million. Curitiba has a significant importance in terms of urban transportation. Jaime Lerner, who served as the mayor of Curitiba from 1971 to 1974, carried out fundamental

projects on urban public transportation, one of them being the Curitiba metrobus system. The Curitiba metrobus system was commissioned in 1974 and is considered as the first metrobus system to operate.

The system transports over 500,000 passengers every day. Over the past twenty years, the number of passengers using the metrobus system have increased 50 times more than twenty years ago. A survey conducted among the passengers who use the metrobus system revealed that 28% of the respondents stated they were previously using private automobiles. It is seen that the Curitiba metrobus system is very useful in terms of access to urban transportation systems [26].

3.3.1.2 Colombia

Colombia is a country located in South America with a population of 49 million. The capital of Colombia is Bogota. With the election of Enrique Penalosa as the mayor of Bogota in 1997, applications that set an example for the world have been executed. In the context of sustainable urban transportation policies, Bogota serves as a model for developing countries.

Especially after 1998, utilizing policies to reduce the use of private automobiles, roads and parking areas have been reduced, sidewalks have been expanded, and double-lane bicycle roads have been established, therefore promoting walking and enabling the widespread use of bicycles. As a result, the rate of cycling have increased from 0.58% (1996) to 5% in 2010.

$178 million investment was made for the construction and maintenance of the bicycle roads along with the training activities in a period of ten years. Through the reduction in the use of private automobile, savings from the cost of road investments, traffic congestion and greenhouse gas emissions were estimated to be $492 million in this period of ten years. Also, savings from road safety and operating expenses of automobiles and buses were estimated to be $643 million and $167 million, respectively. That is, with the investment of $178 million in bicycle roads, a total of $1.3 billion worth of economic benefit was achieved in this period of ten years.

Measures taken to reduce automobile dependency in Bogota include license plate restriction system. License plate restriction system restricts automobiles with license plates ending with specific four digits which are determined every working day of the week, between 6pm and 8pm. Adopting this system, 40% of the automobiles are removed from traffic every day.

Also, every Sunday between 7am and 2pm, more than 110 km of road is closed to automobile traffic and is left only to pedestrians and bicycles. Likewise, one day every year, automobiles and motorcycles are not allowed on the streets during 6.30am to 7.30pm. In this day, only public transportation vehicles, pedestrians and bicycles are allowed on roads. It is known as “car free day”.

Bogota does not have a subway, its main public transportation system is the TransMilenio Metrobus System. The planning and the infrastructure of the system was carried out by the state and the operation of the system was assumed by the private companies. The TransMilenio Metrobus Sytem carries 540 million passenger every year. The share of the system in public transportation is about 60%. The system is among the world’s highest passenger capacity metrobus systems by means of normal and express lines. Analyses revealed that the system provides 32% reduction in travel time, 75% reduction in accidental injuries, 92% reduction in deaths, 43% reduction in SO_2 emissions and 12% reduction in particulate matter emissions [26].

3.3.2 Developed Countries

3.3.2.1 Sweden

Stockholm is the capital of Sweden with a population of about 2,110,120. In Stockholm, it has been decided to implement a congestion charging system in order to ease the traffic congestion, increase accessibility and reduce greenhouse gas emissions in the city. The congestion charging system was put into practice in January 2006 in accordance with the act of the Swedish Parliament in 2004. The system was put into trial for six months. The trial was followed by a referendum. Referendum was held in fifteen municipalities and only Stockholm voted in favor of the charges with 53%. As a result, congestion charging system was put into force permanently in August 2007.

Before the system was tested, about 200 additional buses were purchased to increase the service frequency. In addition, 2800 new park-and-ride facilities were established, resulting in a total of 13,800 vehicles. As a product, the number of passengers using public transportation increased by about 40,000 people (6%). Approximately 66% of this increase is estimated to be the result of congestion charging system. Rush hour traffic in the city center was targeted to be reduced by 10-15%; however, after the utilization of the system, it was reduced by 22%. CO_2 emissions were decreased by 14%. It is estimated that an approximate total of $120 million economic benefit was achieved through travel time, road safety, and environment and health issues.

The congestion fee is charged automatically to the driver through license plate recognition. The system is effective between 6.30am and 5.30pm. According to the 2009 data, congestion charging system generated a net revenue of $74 million [26].

3.3.2.2 Singapore

Singapore is a sovereign city-state and island country with a population of 5.6 million. Singapore is considered as one of the world's leading countries in urban transportation policies. In Singapore, people-oriented urban transportation policies are being implemented, in which the number of motor vehicles and their use are controlled, rail systems and bus systems are coordinated. Policies emphasize the pedestrian access and road safety.

"Vehicle Quota System" has been implemented since 1990 in order to prevent the excessive use of private automobiles and to control traffic congestion. With this system, the number of motor vehicles registered to the traffic is determined by the central authority.

Those who want to own an automobile must obtain a Certificate of Entitlement (COE). With this certificate which is valid for ten years, drivers obtain the right to own and drive automobiles. At the end of ten years, drivers must renew their certificates. In order to obtain COE, drivers have to be willing to pay high prices. When the taxes are added, the cost of an automobile can be three times the market price of the automobile.

By this means, purchasing of the automobiles is discouraged and a revenue is generated for infrastructure investments.

To control automobile usage, "Electronic Road Pricing" system is also used in Singapore. With this system, drivers are charged automatically with the electronic identification system located on roads and the equipment placed inside the automobiles. Utilizing this system, traffic intensity is reduced by 10 to 15%.

In Singapore, public transportation consists of rail systems and buses. Passengers benefit from extensive, reliable and comfortable service provided by the public transportation systems. Metro system with 99 stations and over 4000 buses operated on 340 lines are offered as an alternative means of mobility. A rule on public transportation is that the distance of each individual's work or home to the metro or bus station cannot be more than 400 meters.

According to 2008 data, 56% of the daily trips are made using public transportation and 44% using automobiles. Rail systems constitute approximately 60% of the public transportation systems and buses constitute the remaining 40%.

In Singapore, environmental sensitivity is taken into account when taxes are calculated. Taxes vary according to the fuel used by the automobile. Taxes are considerably less for automobiles that use clean fuel [26].

3.4 Current Situation of Public Transportation in Ankara

Ankara is the capital of Turkey with a population of 5.4 million. Ankara takes the first place in having the most automobiles per capita with as much as 252 automobiles per thousand people [5, 6]. Electricity, Gas and Bus Operations (EGO) executes the public transportation systems in the name of Ankara Municipality.

Exhibited in *Table 3.4*, about 56.5% of the passengers choose to travel using public transportation while 43.5% choose private transportation in Ankara every day. 37.5% of those who choose private transportation travel with automobiles. Minibus is the most preferred public transportation type with 31.3%. It is followed by shuttle with 23.2%, EGO buses with 21.2%, metro with 9%, non-municipal public buses with 7%,

Ankaray and suburban train with 3.85%, private public vehicles and shuttles with 4.3% and cable car with 0.3% [28].

Table 3.4 Distribution of transportation types in a business day in Ankara, 2017 [28]

Transportation Type	Number of Passengers	Passenger Total- Public Transportation (%)	Passenger Total- Overall (%)
EGO buses	728,400	21.2	12
Ankaray	130,300	3.8	2.1
Metro	307,800	9	5.1
Cable car	8,970	0.3	0.1
Suburban train	1,700	0,05	0.03
Minibus	1,075,000	31.3	17.7
Shuttle	798,000	23.2	13.1
Non-municipal public buses	240,000	7	3.9
Private public transpt. vehicle	74,000	2.2	1.2
Private district p. transpt. vehicle	30,000	0.9	0.5
Private company shuttle	42,000	1.2	0.7
Total public transportation	**3,436,170**	**100**	**56.5**
Taxi	370,000		6.1
Automobile	2,280,065		37.5
Total private transportation	**2,650,065**		**43.5**
Total	**6,086,235**		**100**

EGO has a fleet of 1690 vehicles. There are 1646 EGO public transportation buses that are currently in service. EGO public transportation buses are fueled with CNG and diesel oil [29]. Distribution of the public transportation buses by the type of fuel used is displayed in *Figure 3.1*.

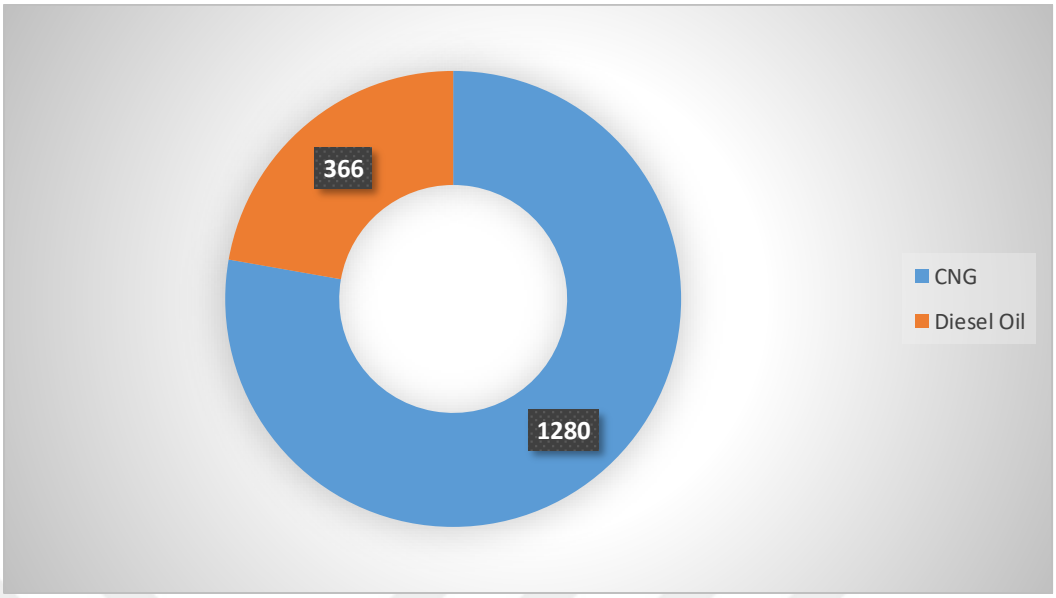

Figure 3.1 Distribution of EGO buses that are currently in service by fuel [29]

EGO bus fleet is comprised of MAN and Mercedes buses. Table 3.5 exhibits the distribution of EGO buses that are currently in service by year, model and fuel used.

Table 3.5 Distribution of EGO buses by model, brand and fuel [29]

Year	Model	Fuel	Quantity
1999	Mercedes Solo	Diesel oil	77
1999	Mercedes Articulated	Diesel oil	60
2006	MAN Solo	Diesel oil	49
2012	Mercedes Articulated	Diesel oil	124
2013	Mercedes Articulated	Diesel oil	56
2007	MAN Solo	CNG	394
2008	MAN Solo	CNG	89
2009	MAN Solo	CNG	347
2010	MAN Solo	CNG	209
2011	MAN Solo	CNG	40
2012	MAN Articulated	CNG	125
2013	MAN Articulated	CNG	76

EGO buses operate on 319 lines with 46 departure points transporting an average of 16,807,766 passengers each month. Table 3.6 shows the number of passengers transported with EGO buses annually, distributed by month.

Table 3.6 Number of passengers transported by month, 2017 [29]

Month	Number of Passengers	Month	Number of Passengers
January	16,814,198	**July**	13,772,991
February	16,416,514	**August**	13,986,745
March	19,592,057	**September**	14,504,560
April	17,457,996	**October**	19,319,970
May	18,102,365	**November**	19,221,455
June	13,297,249	**December**	19,207,086
Average	**16,807,766**		
Total	**201,693,186**		

3.5 Conclusion

In this chapter, international and domestic actions taken towards reducing greenhouse gas emissions by Turkey are investigated. It is observed that Turkey has been pursuing more visible policies in recent years. Turkey has adopted various policies on environmental issues and improving public transportation. However, the chapter displays that, although a significant amount of greenhouse gas emissions are avoided, Turkish anthropogenic greenhouse gas emissions continue to increase through the years and public transportation systems are not yet at a level that constitutes as an alternative to automobiles.

The chapter examined successfully implemented policies to reduce greenhouse gases and to reduce automobile dependency in both developing countries and developed countries. Projects that are carried out and policies implemented on climate protection and urban public transportation in these countries serve as a plausible example to the developing countries such as Turkey.

As it is displayed in this chapter, integrated public transportation systems visibly reduce the excessive automobile dependency through offering alternatives to automobiles. In this chapter, it is emphasized that the effective implementation of

policies regarding environmental protection and public transportation provide great economic, social and environmental benefits.

Also, the current situation of the public transportation in Ankara is examined in this chapter. Most preferred types of transportation in Ankara are displayed. The fleet of EGO buses are investigated by means of fuel, model and quantity.

CHAPTER 4

METHODOLOGY

4.0 Overview

The aim of this chapter is to introduce the methodology of the thesis in order to achieve the objectives of the thesis. First, IPCC methodology which is used in greenhouse gas emission calculations is identified.

In this chapter, tier approaches are explained. The importance of selecting the appropriate tier approach for each direct greenhouse gas is discussed. Emission factors are identified. Elements that increase the uncertainties in the emission factors are addressed.

The chapter emphasizes the importance of using VKT method instead of fuel sold method. The term Global Warming Potential is explained in this chapter and the Global Warming Potential values of direct greenhouse gases are indicated.

4.1 IPCC Methodology

Following the international legislative regulations mentioned in Chapter 3, IPCC Guidelines were prepared within the scope of UNFCCC to ensure that the national greenhouse gas inventories prepared by the party countries are comparable between each other and don't include double counting or negligence on calculations. Guidelines were prepared by the IPCC for the party countries to use as a guide when estimating greenhouse gas inventories to report to the UNFCCC. Guidelines provide methodologies that are internationally agreed.

The IPCC Guidelines were first published in 1995. UNFCCC Conference of the Parties (COP) held in Kyoto approved the use of Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" in calculation of binding targets [30].

The 2006 IPCC Guidelines were prepared to update the Revised 1996 Guidelines, taking the relevant work into account under the Kyoto Protocol and are the most up-to-date guidelines for estimating anthropogenic greenhouse gas emissions.

National greenhouse gas inventories contain standard tables covering all relevant greenhouse gases in respective categories and years, including a report covering the data and the methodology used in calculations. 2006 IPCC Guidelines offer standard reporting tables. The content of the tables varies depending on the obligations to the UNFCCC.

2006 IPCC Guidelines are comprised of five volumes. Volume 1 presents general guidance in estimating the greenhouse gas emissions and removals. Volume 1 also includes the step by step description of data collection, the evaluation of the collected data and reporting to build a national inventory. Volumes 2 through 5 exhibit methodological guidance for emission and removal estimated in different economy sectors. Namely; energy (Volume 2), industrial processes and product use (Volume3), agriculture, forestry and other land use (Volume 4) and waste (Volume 5).

2006 IPCC Guidelines offer guidance on insuring quality on all stages of the inventory development. Guidelines list transparency, completeness, consistency, comparability and accuracy as the indicators of the quality of the inventory. These indicators can be identified as:

- **Transparency:** There should be an adequate and clear documentation so that individuals other than the inventory compliers can understand how the inventory was build.
- **Completeness:** Estimates should be reported for the respective categories of gases, sources and sinks. In case a constituent is missing, it should be clearly documented and the reason should be included.
- **Consistency:** Estimates for different gases, years and categories should reflect the real differences and not the differences arising from the use of different methodologies. Inventories should be developed using the same data sources and method in all years.

- **Comparability:** A national greenhouse gas inventory should be reported such that they can be compared between other countries.
- **Accuracy:** A national greenhouse gas inventory should not be composed of over or under estimates.

Guidelines offer methodology for estimating greenhouse gas emissions at three levels of detail, varying from Tier 1 to Tier 3. Tier 1 is the default method and Tier 3 is the most detailed method. Accuracy and precision improve from Tier 1 to Tier 3. The most important categories in the sense of total greenhouse gas emissions are called key categories. Depending on the availability of the required data, IPCC Guidelines encourage the utilization of the higher tiers [31].

In this thesis, the Mobile Combustion Chapter of the Energy Volume of the 2006 IPCC Guidelines is employed calculating the greenhouse gas emissions from public transportation buses. Energy sector emissions split into categories of emissions from combustion of fossil fuels and fugitive emissions. Greenhouse gases from mobile combustion are estimated by major transportation activities such as road, off-road, railways, air and water-borne navigation. *Table 4.1* shows the sub-sectors of the transportation sector.

Table 4.1 Sub-sectors of transportation sector [32]

Code	**Name**			
1 A 3	Transport			
1 A 3	a	Civil Aviation		
1 A 3	a	*i*		International Aviation
1 A 3	a	*ii*		Domestic Aviation
1 A 3	b	Road Transportation		
1 A 3	b	*i*		Cars
1 A 3	b	*i*	1	Passenger cars with 3-way catalysts
1 A 3	b	*i*	2	Passenger cars without 3-way catalysts
1 A 3	b	*ii*		Light Duty Trucks
1 A 3	b	*ii*	1	Light duty trucks with 3-way catalysts
1 A 3	b	*ii*	2	Light duty trucks without 3- way catalysts
1 A 3	b	*iii*		Heavy Duty Trucks and Buses
1 A 3	b	*iv*		Motorcycles
1 A 3	b	*v*		Evaporative Emissions from Vehicles
1 A 3	b	*vi*		Urea-Based Catalysts
1 A 3	c	Railways		

Table 4.1 (continued) Sub-sectors of transportation sector [32]

Code	**Name**		
1 A 3	d	Water-borne Navigation	
1 A 3	d	*i*	İnternational Water-borne Navigation
1 A 3	d	*ii*	Domestic Water-borne Navigation
1 A 3	e	Other Transportation	
1 A 3	e	*i*	Pipeline Transport
1 A 3	e	*ii*	Off-Road

Emissions originated from EGO buses are included in the category 1 A 3b*iii* Heavy Trucks and Buses sub-sector. Gases to be assessed in each category are listed in *Table 4.2*.

Table 4.2 Suggested aggregation level of analysis [33]

Category Code	**Category Title**	**Gases to be Assessed**
1 A 3a	Fuel Combustion Activities- Transport-Civil Aviation	CO_2, N_2O, CH_4
1 A 3b	Fuel Combustion Activities- Transport-Road Transportation	CO_2, N_2O, CH_4
1 A 3c	Fuel Combustion Activities- Transport-Railways	CO_2, N_2O, CH_4
1 A 3d	Fuel Combustion Activities- Transport-Water-borne Navigation	CO_2, N_2O, CH_4
1 A 3 e	Fuel Combustion Activities- Transport-Other Transportation	CO_2, N_2O, CH_4

EGO buses fall into the category 1 A 3b. Hence, it is suggested by the Guidelines to assess CO_2, N_2O and CH_4 greenhouse gases. These are called direct greenhouse gas emissions. Fuel combustion activities also produce indirect greenhouse gas emissions such as CO, NMVOCs, SO_2, PM and NO_x. These gases have short lifespans in the atmosphere and only contribute to local or regional air pollution.

Greenhouse gas emissions can be calculated using either fuel sold (fuel consumed) data or the distance travelled data. Fuel sold method is appropriate for the calculation of CO_2 emissions and the distance travelled method is appropriate for the calculation of CH_4 and N_2O emissions. Unlike the calculation of CO_2 emissions, the calculation of CH_4 and N_2O emissions requires further information such as vehicle type and technology, fuel economy, operating conditions and emission control technology used. Hence, selection of the tier levels is an important part of the emission calculations [32].

4.2 Tier Approaches

Methods of calculating greenhouse gas emissions are examined in three levels which are expressed as tiers. Tier 1 is a default method that requires the minimum data to make emission calculations while higher tiers require more detailed information. From Tier1 to Tier 3 accuracy and precision improve.

4.2.1 Tier 1

In Tier 1 approach fuel sold method is utilized. Emissions of all the greenhouse gases are calculated through the amount of fuel consumed and average emission factors, not paying regard to the combustion conditions.

The fuel sold method is appropriate for CO_2 emissions calculation since emission factors for CO_2 emissions depend on the carbon content of the fuel consumed. Tier 1 approach takes accounts of the total amount of fuels consumed and averaged carbon content of the fuels.

However, for the calculation of the CH_4 and N_2O emissions, applying average emission factors to the amount of fuel consumed basis of the Tier 1 approach is not as accurate. Because in practice, emission factors for CH_4 and N_2O depend on operating conditions, combustion technology, emission control technology, vehicle technology. Therefore using average emission factors calculating the emissions of CH_4 and N_2O will result in large uncertainties. Yet, for the countries where such detailed data are not available, Tier 1 approach will give an approximate estimate for these emissions [34].

4.2.2 Tier 2

Tier 2 approach is similar to Tier 1 approach in terms of using the amount of fuel consumed in emission calculations. However, in Tier 2 approach, country-specific emission factors are used instead of the default average emission factors of the Tier 1 approach.

Therefore the difference between Tier 1 approach and Tier 2 approach is that Tier 1 approach pays no regard to the combustion conditions whereas Tier 2 approach does by means of country-specific emission factors.

Country-specific emission factors account for the country-specific carbon content of the fuels consumed. Country-specific emission factors differ for different fuels and combustion technologies. Deriving country-specific emission factors from more detailed information on combustion conditions and detailed data on carbon contents of different fuels decreases the uncertainties in emission calculations.

Tier 2 is the highest tier approach for the CO_2 emission calculations. CO_2 emissions are best calculated based on fuel consumed data and the carbon content [34].

4.2.3 Tier 3

Contrary to Tier 1 and Tier 2 approaches which use the amount of fuel consumed data, Tier 3 approach uses the vehicle kilometers travelled data (VKT) in emission calculations.

Tier 3 is the most detailed and accurate approach for the emission calculations. Tier 3 approach accounts for vehicle type and technology, fuel economy, road conditions, emission control technology used and operating conditions through emission factors.

Emission control technology, vehicle technology and operating conditions significantly affect CH_4 and N_2O emissions. Hence, Tier 3 approach is appropriate for the calculations of CH_4 and N_2O emissions. Based on the data availability, 2006 IPCC Guidelines encourage the utilization of the higher tiers [34].

In this thesis, direct greenhouse gas emissions inventory for the category 1 A 3b *iii* which includes the emissions originated from EGO buses will be prepared adapting 2006 IPCC Guidelines. CO_2 emissions from the EGO buses will be calculated using Tier 2 approach. CH_4 and N_2O emissions from the EGO buses will be calculated using Tier 3 approach.

4.3 Emission Factors

Emission factors are coefficients that quantify the pollutant released to the atmosphere per unit activity that is associated with the release of the pollutant. For instance, for energy sector, fuel combustion would be the activity and the mass of CO_2 emitted per unit of fuel combusted would be the emission factor [36].

4.3.1 CO_2 Emission Factors

In transportation sector combustion processes which take place in vehicles are optimized to provide the maximum amount of energy per unit fuel consumed. The aim is to oxidize the maximum amount of carbon existing in the fuel to CO_2. Hence, for fuel combustion activities, CO_2 emission factors are not influenced by the combustion process itself. Instead, CO_2 emission factors depend on the carbon content of the fuels.

Tier 1 approach offers default emission factors for all direct greenhouse gases. The carbon content varies among different fuels. The uncertainty in default emission factors due to the variability in the carbon content of different fuels is reduced through converting to energy units. These default emission factors are suggested to be used only if country-specific emission factors are unavailable [34].

4.3.2 CH_4 and N_2O Emission Factors

In contradistinction to CO_2 emissions, CH_4 and N_2O emission factors are primarily dependent on the combustion technology and the emission control technology used in the vehicles. Therefore, using default emission factors that are fuel based and don't indicate vehicle technology increase the uncertainties significantly. Emission factors vary as the technologies applied vary. Hence, it is highly encouraged by the 2006 IPCC Guidelines to use higher tiered emission factors.

It is stressed in the 2006 IPCC Guidelines that VKT method should be used in emission calculations instead of fuel sold method, even if national data are not available. It is advised to calculate the distance travelled data of the vehicle by multiplying an assumed fuel economy value with the road transportation fuel consumed data.

It is encouraged to calculate emission factors for each vehicle type (e.g. buses) and fuel type based on installed emission control technologies. Emission factors can be further detailed to the extent permitted by the data available (e.g. driving speeds, temperatures, altitude, road conditions) [32].

4.4 Global Warming Potential

Each greenhouse gas has a different heat trapping ability and atmospheric lifetime. Global Warming Potential (GWP) is a means of comparing the global warming effects of the greenhouse gases. GWP is defined as the quantified measure of the globally averaged radiative forcing effects of a specific greenhouse gas relative to a reference greenhouse gas. CO_2 is often chosen as the reference greenhouse gas.

Short lived greenhouse gases such as CO, SO_2 and NO_x do not have respective GWPs. Because short lived gases contribute only to regional changes and do not stay in the atmosphere long enough to be distributed throughout the atmosphere; therefore, they do not have global concentrations.

The GWPs of different greenhouse gases can be compared to estimate the future radiative forcing impacts of the gases. GWP value of a specific greenhouse gas can change over time due to the concentration changes of other greenhouse gases [3]. Radiative efficiencies (the change in radiative forcing for a change in the atmospheric abundance) of the greenhouse gases are not constant over time. Their heat trapping abilities are linked to their abundance in the atmosphere; therefore, their radiative efficiencies may change over time based on changes in their concentrations [36].

GWPs have time periods of 20, 100 and 500 years. The Kyoto Protocol and UNFCCC use 100 year time period in reports and accounting to quantify greenhouse gas emissions in CO_2 equivalents. Hence, 100 year time period is usually used for GWPs [37]. Regardless of the time period CO_2 has GWP value of 1, since it's used as the reference. *Table 4.3* includes 100 year time period GWP values of direct greenhouse gases relative to CO_2 from second (SAR), fourth (AR4) and fifth assessment reports (AR5) published by IPCC.

Table 4.3 Global Warming Potential (GWP) values for 100 year time period [38]

Name	Chemical Formula	GWPs for 100 year time period		
		SAR	AR4	AR5
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28
Nitrous oxide	N_2O	310	298	265

The relation that gives the CO_2 equivalent of a greenhouse gas is expressed as follows [47]:

$$Tg\ CO_2\ eq. = (Gg\ of\ greenhouse\ gas) \times (GWP) \times \left(\frac{Tg}{1000\ Gg}\right) \quad (4.1)$$

Where,

Tg CO_2 eq. = Teragrams of CO_2 equivalents

Gg of greenhouse gas = amount of greenhouse gas in gigagrams

GWP = Global Warming Potential

Tg = Teragrams

4.5 Conclusion

In this chapter, the method used in direct greenhouse gas emission calculations and the must-haves of building a national greenhouse gas inventory are identified. Categories and greenhouse gases that need to be assessed in a national inventory are listed. Which tier approach to utilize in which conditions are addressed. The importance of country-specific emission factors is emphasized.

An inventory of quality must reflect transparency, completeness, consistency, comparability and accuracy. A national inventory cannot be composed of over or under estimates of greenhouse gas emissions. Turkish national inventories are observed to lack accuracy. For transportation sector, Turkish inventory utilizes Tier 2 approach for CO_2 emissions from natural gas and diesel vehicles. For the rest of the vehicles of different fuel type and all of the CH_4 and N_2O emissions, fuel based Tier 1 approach

is utilized using default emission factors, which is not quite reflective of the actual values [4].

The chapter is then concluded with the presentation of Global Warming Potentials of the direct greenhouse gases, why they may change over time and which values to use.

CHAPTER 5

CALCULATIONS, PROJECTIONS AND EVALUATIONS

5.0 Overview

In this chapter, direct greenhouse gas inventory of the EGO buses for the year 2017 is prepared using both the lowest and the highest tiers. Country-specific emission factors for diesel oil and CNG are calculated to the extent permitted by the data available.

Resulting direct greenhouse gas emissions from two projections are also included in this chapter. Projected emissions are calculated using the highest tiers. Projection-I investigates the emissions of the next ten years following the pattern of EGO's fleet expansion. Projection-II reveals the reductions in greenhouse gas emissions covering the period of ten years through addition of electric buses and fleet planning. Later in the chapter, Current and projected greenhouse gas emissions are calculated in CO_2 equivalents. This chapter presents the calculation process utilizing the method introduced in Chapter 4.

The results of the calculations are evaluated and how the aim and objectives of the thesis were achieved are exhibited in this chapter.

5.1 Direct Greenhouse Gas Inventory of Public Transportation Buses

5.1.1 CO_2 Emissions

The 2006 IPCC Guidelines offer two approaches to calculate CO_2 emissions originated from road transportation. Tier 1 approach calculates CO_2 emissions using default averaged emission factors ignoring the carbon content of the fuels. Tier 2 approach calculates the CO_2 emissions using country-specific emission factors accounting for the actual carbon content of the fuels [32].

5.1.1.1 Tier 1

Tier 1 approach utilizes fuel sold method. Emissions of all the greenhouse gases are estimated without paying regard to the combustion conditions. Employing Tier 1 approach, CO_2 emissions are calculated by multiplying the default CO_2 emission factor with the amount of fuel consumed [32].

CO_2 emissions calculation using Tier 1 approach is expressed as:

$$Emission = \sum_a (Fuel_a \cdot EF_a) \quad (5.1)$$

Where,

Emission = Emission in kg

EF_a = Emission factor (kg/TJ)

$Fuel_a$ = Fuel sold (TJ)

a = Fuel type

Steps of Tier 1 CO_2 emission calculation are as follows:

Step 1: Estimate the amount of fuel consumed by fuel type. Fuel consumed is considered equal to the amount of fuel sold.

Step 2: Convert the fuel sold data for each fuel to energy units using net calorific values (NCV) of the fuels displayed in *Table 5.1*.

Step 3: Choose the appropriate default emission factor expressed in *Table 5.2* for each fuel.

Step 4: Multiply the fuel sold with the default emission factor for each fuel.

Table 5.1 Default NCVs of fuels [32]

Fuel Type	NCV (TJ/Gg)	Lower	Upper
Motor Gasoline	44.3	42.5	44.8
Gas/ Diesel Oil	43.0	41.4	43.3
LPG	47.3	44.8	52.2
Jet Kerosene	44.1	42.0	45.0
Lubricants	40.2	33.5	42.3
Natural Gas	48.0	46.5	50.4

Table 5.2 Default CO_2 emission factors for road transportation [32]

Fuel Type	Default (kg/TJ)	Lower	Upper
Motor Gasoline	69,300	67,500	73,000
Gas/ Diesel Oil	74,100	72,600	74,800
LPG	63,100	61,600	65,600
Lubricants	73,300	71,900	75,200
CNG	56,100	54,300	58,300
LNG	56,100	54,300	58,300

In EGO buses, CNG and diesel oil are used as fuel. The amount of fuel consumed by EGO buses distributed by fuel type is indicated in *Figure 5.1*.

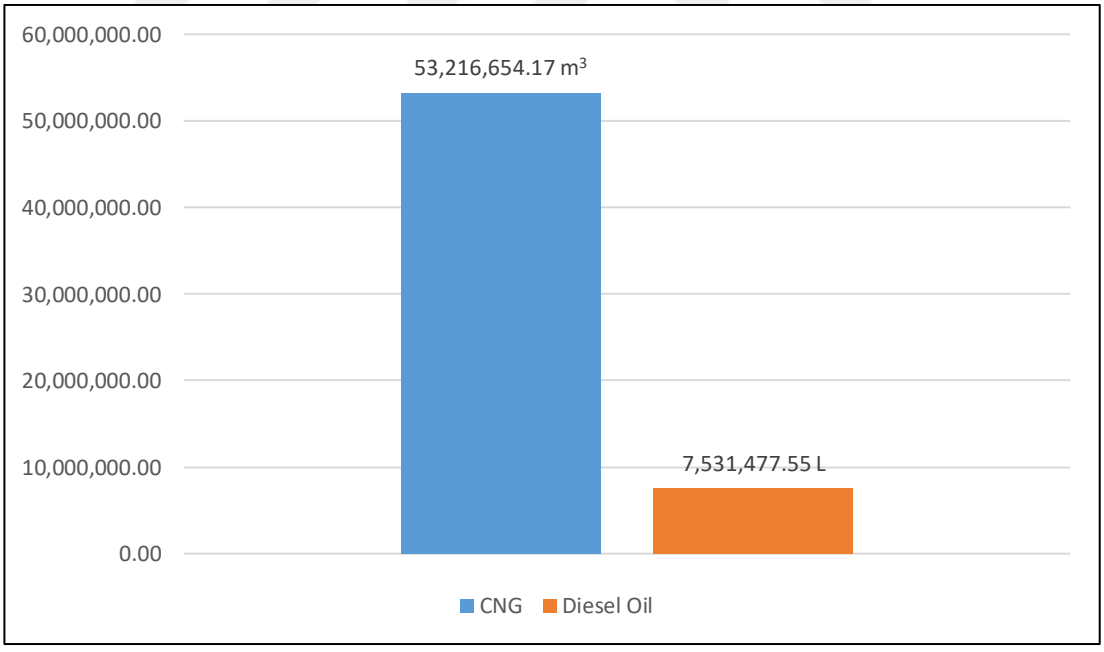

Figure 5.1 Total amount of fuel consumed by EGO buses distributed by type

Fuel consumed values in *Figure 5.1* are obtained by multiplying the fuel economy and total kilometers travelled data of each model and year of the EGO buses. For total kilometers travelled and fuel economy values, see *Table 5.4* and *Table 5.5*.

For buses using CNG:

$$Emission = 1824.57101\ TJ \cdot 56{,}100\ \frac{kg}{TJ} = \ 102{,}358{,}433.7\ kg\ CO_2 \quad (5.2)$$

For buses using diesel oil:

$$Emission = 265.55983\ TJ \cdot 74{,}100\ \frac{kg}{TJ} = \ 19{,}677{,}983.4\ kg\ CO_2 \quad (5.3)$$

A detailed Tier 1 CO_2 emissions calculation is included in Appendix A.

5.1.1.2 Tier 2

Tier 2 is the highest tier approach for the CO_2 emission calculations. Distinction between Tier 1 approach and Tier 2 approach is that Tier 2 approach uses the actual carbon content of the fuels consumed through country-specific emission factors. Tier 2 approach uses the same formula as Tier 1 approach with country-specific emission factors instead of default ones [32]. Employing Tier 2 approach, CO_2 emissions are calculated by;

$$Emission = \sum_a (\ Fuel_a \cdot\ EF_a) \quad (5.4)$$

Where,

Emission = Emission in kg

EF_a = Country-specific emission factor (kg/TJ)

$Fuel_a$ = Fuel sold (TJ)

a = Fuel type

Steps of Tier 2 CO_2 emission calculation are as follows:

Step 1: Estimate the amount of fuel consumed by fuel type.

Step 2: Convert the fuel sold data for each fuel to energy units using net calorific values (NCV) of the fuels.

Step 3: Estimate the carbon content of each fuel.

Step 4: Calculate the country-specific emission factor for each fuel.

Step 5: Multiply the fuel sold with the country-specific emission factor for each fuel.

Country-specific emission factor is calculated using the following relation:

$$EF = Carbon\ content\ of\ fuel \times Carbon\ oxidation\ factor \times \frac{44}{12} \quad (5.5)$$

Where,

EF = CO_2 Emission factor in kg/TJ

Carbon oxidation factor = Percentage of the carbon oxidized

In CO_2 emission factor calculation, the factor (44/12) converts carbon which has a molecular mass of 12 g/mol to CO_2 having a molecular mass of 44 g/mol [40]. Carbon content of the fuel is assumed to be fully oxidized (100%). Net calorific value of 49.085 MJ/kg is used for unit conversion purposes. Detailed information on fuel statistics, emission factor and Tier 2 CO_2 emission calculation are included in Appendix B.

For buses using CNG:

$$EF = \frac{0.7398}{49.085\ MJ/kg} \times 1 \times \frac{44}{12} \times \frac{10^6 MJ}{TJ} = 55263.31873\ \frac{kg}{TJ} \quad (5.6)$$

$$Emission = 2056.27619\ \ TJ\ NG \cdot \left(55263.31873\,\frac{kg}{TJ}\right)$$

$$= 113{,}636{,}646.5\ kg\ CO_2 \quad (5.7)$$

For buses using diesel oil:

$$EF = \frac{0.86261}{0.0428435\ GJ/kg} \times 1 \times \frac{44}{12} \times \frac{GJ}{10^{-3}\ TJ} = 73824.5786\ \frac{kg}{TJ} \quad (5.8)$$

$$Emission = 267.62653\ TJ\ diesel\ oil \cdot \left(73824.5786\ \frac{kg}{TJ}\right)$$

$$= 19{,}757{,}415.8\ kg\ CO_2 \quad (5.9)$$

5.1.2 CH_4 and N_2O Emissions

The 2006 IPCC Guidelines offer three approaches to calculate CH_4 and N_2O emissions originated from road transportation. Tier 1 and Tier 2 approaches utilize fuel sold method while Tier 3 approach utilizes VKT method. CH_4 and N_2O emissions primarily depend on operating conditions, combustion technology, emission control technology and vehicle technology. Tier 1 approach ignores these conditions using default emission factors whereas Tier 3 approach accounts for all of them [32].

5.1.2.1 Tier 1

Tier 1 approach utilizes fuel sold method. Emissions of all the greenhouse gases are estimated without paying regard to operating conditions and technology. Employing Tier 1 approach, CH_4 and N_2O emissions are calculated by multiplying the default CH_4 and N_2O emission factors with the amount of fuel consumed [32].

CH_4 and N_2O emissions calculation using Tier 1 approach is expressed as:

$$Emission = \sum_a (Fuel_a \cdot EF_a) \quad (5.8)$$

Where,

Emission = Emission of CH_4 or N_2O in kg

EF_a = Emission factor (kg/TJ)

$Fuel_a$ = Fuel sold (TJ)

a = Fuel type

Steps of Tier 1 CH_4 and N_2O emission calculation are as follows:

Step 1: Estimate the amount of fuel consumed by fuel type.

Step 2: Convert the fuel sold data for each fuel to energy units using net calorific values (NCV) of the fuels displayed in *Table 5.1*.

Step 3: Choose the appropriate default emission factors expressed in *Table 5.3* for each fuel.

Step 4: Multiply the fuel sold with the default emission factor for each fuel.

Table 5.3 Default CH_4 and N_2O emission factors for road transportation [32]

Fuel Type	CH_4 (kg/TJ)			N_2O (kg/TJ)		
	Default	Lower	Upper	Default	Lower	Upper
Motor Gasoline- Uncontrolled	33	9.6	110	3.2	0.96	11
Motor Gasoline- Oxidation Catalyst	25	7.5	86	8.0	2.6	24
Motor Gasoline- Low mileage Light Duty Vehicle Vintage 1995 or Later	3.8	1.1	13	5.7	1.9	17
Gas/ Diesel Oil	3.9	1.6	9.5	3.9	1.3	12
Natural Gas	92	50	1540	3	1	77
LPG	62	na	na	0.2	na	na

For buses using CNG:

$$Emission = 1824.57101\ TJ \cdot 92\ \frac{kg}{TJ} = 167{,}860.5329\ kg\ CH_4 \quad (5.9)$$

$$Emission = 1824.57101\ TJ \cdot 3\ \frac{kg}{TJ} = 5473.71303\ kg\ N_2O \quad (5.10)$$

For buses using diesel oil:

$$Emission = 265.5599\ TJ \cdot 3.9\ \frac{kg}{TJ} = 1035.68361\ kg\ CH_4 \quad (5.11)$$

$$Emission = 265.5599\ TJ \cdot 3.9\ \frac{kg}{TJ} = 1035.68361\ kg\ N_2O \quad (5.12)$$

For detailed Tier 1 CH4 and N2O emission calculations, see Appendix C.

5.1.2.2 Tier 3

Tier 3 approach uses the vehicle kilometers travelled data (VKT) accounting for vehicle type and technology, road conditions, emission control technology used and operating conditions [32]. Utilizing Tier 3 approach, CH_4 and N_2O emissions are calculated by:

$$Emission = \sum_{a,b,c,d}\left(Distance_{a,b,c,d} \cdot EF_{a,b,c,d}\right) + \sum_{a,b,c,d} C_{a,b,c,d} \quad (5.13)$$

Where,

Emission = Emission of CH_4 or N_2O in kg

$EF_{a,b,c,d}$ = Emission factor (kg/km)

$Distance_{a,b,c,d}$ = Vehicle kilometers travelled (km)

$C_{a,b,c,d}$ = Cold start emissions (kg)

a = Fuel type

b = vehicle type

c = emission control technology

d = operating conditions (urban or rural road type, climate etc.)

Steps of Tier 3 CH_4 and N_2O emission calculation are as follows:

Step 1: Estimate the VKT.

Step 2: Make sure that the VKT data is split into the required vehicle and fuel categories.

Step 3: Multiply the VKT data for each type of control technology or vehicle type with the emission factor for that technology or type.

Step 4: Estimate cold start emissions.

Step 5: Sum the emissions of all vehicle types and fuel types containing the emission control technologies.

Information of the number of starts is required calculating the cold start emissions. Due to the lack of this data, cold start emissions are ignored calculating CH_4 and N_2O emissions. Kilometers travelled by the buses using CNG as fuel split into the categories of control technology, model and year are displayed in *Table 5.4*.

Table 5.4 VKT distributed by model, year, control technology [39]

Number of Vehicles	Model	Year	Fuel Type	Emission Standard	Total Km Travelled
77	Mercedes Solo	1999	Diesel Oil	Euro 2	159,038
60	Mercedes Articulated	1999	Diesel Oil	Euro 2	874,849
49	MAN Solo	2006	Diesel Oil	Euro 3	304,671
124	Mercedes Articulated	2012	Diesel Oil	Euro 5	7,102,982
56	Mercedes Articulated	2013	Diesel Oil	Euro 5	3,723,872
394	MAN Solo	2007	CNG	EEV	13,805,972
89	MAN Solo	2008	CNG	EEV	3,700,865
347	MAN Solo	2009	CNG	EEV	22,913,075
209	MAN Solo	2010	CNG	EEV	14,587,782
40	MAN Solo	2011	CNG	EEV	3,037,712
125	MAN Articulated	2012	CNG	EEV	7,083,518
76	MAN Articulated	2013	CNG	EEV	4,941,705

Estimated average fuel economy values of EGO buses distributed by model and year are exhibited in *Table 5.5*.

Table 5.5 Fuel economy values of EGO buses [39]

Year	Model	Fuel Economy
1999	Mercedes Solo	0.49 L/km
1999	Mercedes Articulated	0.80 L/km
2006	MAN Solo	0.49 L/km
2012	Mercedes Articulated	0.61 L/km
2013	Mercedes Articulated	0.61 L/km
2007	MAN Solo	0.72 m^3/km
2008	MAN Solo	0.72 m^3/km
2009	MAN Solo	0.72 m^3/km
2010	MAN Solo	0.72 m^3/km
2011	MAN Solo	0.72 m^3/km
2012	MAN Articulated	0.95 m^3/km
2013	MAN Articulated	0.95 m^3/km

For buses using CNG:

CH_4 and N_2O emission factors for CNG buses are displayed in *Table 5.6*. Further details on CH_4 and N_2O emission factor calculations are included in Appendix D.

Table 5.6 Tier 3 CH_4 and N_2O emission factors for CNG buses

Year	Model	Emission Factor (mg/km)	
		N_2O	CH_4
2007	MAN Solo	654.47948	49993.16001
2008	MAN Solo	654.47948	49993.16001
2009	MAN Solo	654.47948	49993.16001
2010	MAN Solo	654.47948	49993.16001
2011	MAN Solo	654.47948	49993.16001
2012	MAN Articulated	863.5513	65963.34895
2013	MAN Articulated	863.5513	65963.34895

For 2007 MAN Solo:

$$Emission_{CH_4} = 13{,}805{,}972\ km \cdot \left(49993.16001 \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 690{,}204.1673\ kg\ CH_4 \quad (5.14)$$

$$Emission_{N_2O} = 13{,}805{,}972\ km \cdot \left(654.47948 \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 9035.72538\ kg\ N_2O \quad (5.15)$$

CH_4 and N_2O emissions for all models and years can be calculated repeating the same steps. CH_4 and N_2O emissions originated from EGO buses using CNG are presented in *Table 5.7*. A detailed Tier 3 CH_4 and N_2O emission calculation is included in Appendix D.

Table 5.7 Tier 3 CH_4 and N_2O emissions from CNG EGO buses

Year	Model	CH4 Emission (kg)	N2O Emission (kg)
2007	MAN Solo	690204.1673	9035.72538
2008	MAN Solo	185018.0841	2422.142125
2009	MAN Solo	1145497.941	14996.14933
2010	MAN Solo	729289.9031	9547.411563
2011	MAN Solo	151864.9436	1988.12175
2012	MAN Articulated	467251.8687	6116.971969
2013	MAN Articulated	325970.9223	4267.409353
Total		**3,695,097.83**	**48,373.93147**

For buses using diesel oil:

CH_4 and N_2O emission factors for buses using diesel oil are displayed in *Table 5.8*. Further details on CH_4 and N_2O emission factor calculations are included in Appendix D.

Table 5.8 Tier 3 CH_4 and N_2O emission factors for diesel buses

Year	Model	Emission Factor (mg/km)	
		N_2O	CH_4
1999	Mercedes Solo	73.49987	428.74923
1999	Mercedes Articulated	120	700
2006	MAN Solo	73.49987	428.74923
2012	Mercedes Articulated	91.50024	533.75139
2013	Mercedes Articulated	91.50024	533.75139

For 2012 Mercedes Articulated:

$$Emission_{CH_4} = 7{,}102{,}982\ km \cdot \left(533.75139\ \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 3{,}791.2265\ kg\ CH_4 \quad (5.16)$$

$$Emission_{N_2O} = 7{,}102{,}982\ km \cdot \left(91.50024\ \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 649.9246\ kg\ N_2O \quad (5.17)$$

CH_4 and N_2O emissions for all models and years can be calculated repeating the same calculations substituting the respective values. CH_4 and N_2O emissions originated from EGO buses using diesel oil are presented in *Table 5.9*. Further details on Tier 3 CH_4 and N_2O emission calculation is provided in Appendix D.

Table 5.9 Tier 3 CH_4 and N_2O emissions from diesel buses

Year	Model	CH4 Emission (kg)	N2O Emission (kg)
1999	Mercedes Solo	68.1875425	11.689293
1999	Mercedes Articulated	612.3943	104.98188
2006	MAN Solo	130.6276913	22.3933185
2012	Mercedes Articulated	3791.2265	649.9246
2013	Mercedes Articulated	1987.61668	340.734288
Total		**6590.05271**	**1129.72998**

5.2 Projections

Two projections are designed for estimating the greenhouse gas emissions from public transportation for the period of next ten years. The projections are made utilizing number of assumptions. Assumptions are made by taking account of passenger capacity of each bus, the annual increase in the length of lines and the increase in population. Passenger capacities of the public transportation buses with the addition of the SILEO E-12 Electric bus are listed in *Table 5.10*. The population of Ankara from 2008 to 2017 is exhibited in *Table 5.11*.

Table 5.10 Passenger capacities of EGO buses [40]

Year & Model	Passenger Capacity
1999 Mercedes Solo	100
1999 Mercedes Articulated	157
2006 MAN Solo	82
2012 Mercedes Articulated	152
2013 Mercedes Articulated	151
2007 MAN Solo	82
2008 MAN Solo	82
2009 MAN Solo	80
2010 MAN Solo	80
2011 MAN Solo	80
2012 MAN Articulated	151
2013 MAN Articulated	152
SILEO S-12 Electric Bus	90

Table 5.11 Population increase in Ankara, 2008-2017 [40]

Year	Population	Annual Increase (%)
2008	4,548,939	
2009	4,650,802	2.23926
2010	4,771,716	2.59985
2011	4,890,893	2.49757
2012	4,965,542	1.52628
2013	5,045,083	1.60185
2014	5,150,072	2.08101
2015	5,270,575	2.33983
2016	5,346,518	1.44088
2017	5,445,026	1.84247

As expressed in *Table 5.11*, the population has increased by an average of 2% every year. To account for the 2% increase in urban population, EGO has expanded its vehicle fleet by 3% in 2017.

Annual Reports indicate that new lines are added and some of the existing lines are shut annually. In years 2010, 2011 and 2012, total kilometers driven by the buses increased 4%, 5% and 0.5 % respectively, while in 2013 and 2014 decreased by 0.4%

and 0.7%. Total line length in 2017 rose from 13,635 kilometers to 15,202 kilometers, showing an increase of 11% compared to 2016 and total kilometers driven by the buses increased 6%. It is safe to assume that total line length will increase every year with the new roads, attraction centers, schools, workplaces [40].

Therefore in both projections, the passenger capacity is increased to accommodate for the annual 2% increase in the population. Total kilometers travelled is assumed to increase by 3% every year.

5.2.1 Projection-I

Projection-I estimates the direct greenhouse gas emissions for the period of ten years following the fleet expansion patterns of EGO from 2008 to 2017. Direct greenhouse gas emissions are calculated increasing the number of vehicles of each year and model by 2.5 % to meet the 2% increase in the passenger capacity. The number of vehicles are rounded to the nearest whole number. Total kilometers driven is assumed to increase by 3% every year. The change in the number of vehicles and the number of total kilometers driven are displayed in *Table 5.12* and *Table 5.13*, respectively.

Table 5.12 Number of buses by year and model through years, 2017-2027

Year & Model	2017	2018	2019	2020	2021
1999 Mercedes Solo	77	79	81	83	85
1999 Mercedes Articulated	60	62	63	65	66
2006 MAN Solo	49	50	51	53	54
2012 Mercedes Articulated	124	127	130	134	137
2013 Mercedes Articulated	56	57	59	60	62
2007 MAN Solo	394	404	414	424	435
2008 MAN Solo	89	91	94	96	98
2009 MAN Solo	347	356	365	374	383
2010 MAN Solo	209	214	220	225	231
2011 MAN Solo	40	41	42	43	44
2012 MAN Articulated	125	128	131	135	138
2013 MAN Articulated	76	78	80	82	84
Total	**1646**	**1687**	**1730**	**1774**	**1817**

Table 5.12 (continued) Number of buses by year and model through years, 2017-2027

Year & Model	2022	2023	2024	2025	2026	2027
1999 Mercedes Solo	87	89	92	94	96	99
1999 Mercedes Articulated	68	70	71	73	75	77
2006 MAN Solo	55	57	58	60	61	63
2012 Mercedes Articulated	140	144	147	151	155	159
2013 Mercedes Articulated	63	65	67	68	70	72
2007 MAN Solo	446	457	468	480	492	504
2008 MAN Solo	101	103	106	108	111	114
2009 MAN Solo	393	402	412	423	433	444
2010 MAN Solo	236	242	248	255	261	268
2011 MAN Solo	45	46	48	49	50	51
2012 MAN Articulated	141	145	149	152	156	160
2013 MAN Articulated	86	88	90	93	95	97
Total	**1861**	**1908**	**1956**	**2006**	**2055**	**2108**

Table 5.13 Total kilometers driven by each bus through years, 2017-2027

Year & Model	2017	2018	2019	2020
1999 Mercedes Solo	159038	199534.3822	232587.7411	275486.6881
1999 Mercedes Articulated	874849	940376.1584	983545.3714	1051925.074
2006 MAN Solo	304671	347254.3006	382201.2422	434345.566
2012 Mercedes Articulated	7102982	7311193.864	7511901.086	7780192.544
2013 Mercedes Articulated	3723872	3826735.239	3989008.507	4093774.86
2007 MAN Solo	13805972	14192743.28	14572050.66	14961188.6
2008 MAN Solo	3700865	3820396.031	3974345.008	4096061.58
2009 MAN Solo	22913075	23543727.77	24166936.23	24799989.33
2010 MAN Solo	14587782	14973137.53	15420946.97	15808579.08
2011 MAN Solo	3037712	3150020.325	3254851.945	3369504.459
2012 MAN Articulated	7083518	7289887.957	7488746.562	7754566.619
2013 MAN Articulated	4941705	5108115.394	5267094.567	5435927.971
Total	**82236041**	**84703122.23**	**87244215.9**	**89861542.37**

Table 5.13 (continued) Total kilometers driven by each bus through years, 2017-2027

Year & Model	2021	2022	2023
1999 Mercedes Solo	322048.8351	376461.4997	424757.4747
1999 Mercedes Articulated	1108032.45	1188444.236	1263040.166
2006 MAN Solo	482464.6789	538234.2549	597448.0973
2012 Mercedes Articulated	7994299.873	8216192.579	8490582.626
2013 Mercedes Articulated	4270157.936	4385866.496	4564742.041
2007 MAN Solo	15389256.56	15825245.22	16255195.65
2008 MAN Solo	4221320.11	4397379.24	4524097.744
2009 MAN Solo	25436704.43	26147683.19	26786126.78
2010 MAN Solo	16270065.1	16669066.06	17132497.56
2011 MAN Solo	3487788.942	3613891.917	3733842.314
2012 MAN Articulated	7966814.235	8186840.893	8458733.387
2013 MAN Articulated	5608435.493	5788804.717	5963069.77
Total	**92557388.65**	**95334110.3**	**98194133.61**

Table 5.13 (continued) Total kilometers driven by each bus through years, 2017-2027

Year & Model	2024	2025	2026	2027
1999 Mercedes Solo	475767.1417	523430.2598	582183.0216	641620.0318
1999 Mercedes Articulated	1317775.596	1392216.389	1477975.252	1558631.716
2006 MAN Solo	644621.6422	704170.3288	763522.4487	829799.7624
2012 Mercedes Articulated	8704161.764	8978330.057	9263782.562	9544091.71
2013 Mercedes Articulated	4741887.641	4849982.438	5040244.928	5225495.716
2007 MAN Solo	16683150.56	17148244.01	17624566.05	18095677.31
2008 MAN Solo	4692559.581	4818418.795	4999879.709	5176255.384
2009 MAN Solo	27489140.35	28260394.06	28976104.43	29753461.73
2010 MAN Solo	17593962.23	18127886.36	18602040.81	19142189.91
2011 MAN Solo	3932875.284	4052130.539	4182443.029	4307335.68
2012 MAN Articulated	8728769.755	8941837.151	9224764.603	9502540.82
2013 MAN Articulated	6135286.082	6377115.972	6561874.199	6741262.71
Total	**101139957.6**	**104174156.4**	**107299381**	**110518362.5**

Direct greenhouse gas emissions are then calculated by multiplying the fuel sold data and the kilometers travelled data with the respective emission factors. Fuel sold can be calculated repeating the steps explained in *Chapter 5.1*. For emission factors, see *equations 5.6, 5.8* and *Tables 5.6* and *5.8*.

CO_2 emissions are estimated utilizing Tier 2 approach and CH_4 and N_2O emissions are estimated utilizing Tier 3 approach. The amount of estimated fuel consumption by type and the projected direct greenhouse gas emissions as a result of the increase in the current vehicle fleet for the period of ten years are illustrated in *Table 5.14* and *Table 5.15*, respectively.

Table 5.14 Estimated fuel consumption by type for Projection-I, 2017-2027

Year	Diesel Oil	CNG
2017	7531477.55	53216654.17
2018	7814364.134	54747721.14
2019	8103637.751	56318223.26
2020	8432477.98	57916402.46
2021	8761956.845	59556184.55
2022	9086212.344	61267214.58
2023	9475060.91	62971580.24
2024	9805301.118	64802868.41
2025	10150568.02	66686098.57
2026	10567232.65	68554531.36
2027	10977349.4	70493555.76

Table 5.15 Estimated direct greenhouse gas emissions of Projection-I through years, 2017-2027

Year	CO_2	CH_4	N_2O
2017	133392315.4	3701688.425	49503.66027
2018	137403742.2	3808245.586	50937.83313
2019	141516131	3917546.515	52408.81061
2020	145791414.9	4028803.823	53910.88153
2021	150157210	4142950.386	55450.86528
2022	154661440.1	4262039.48	57054.82991
2023	159320887.3	4380722.352	58662.42557
2024	164097607.5	4508166.806	60376.60255
2025	169024660.4	4639231.001	62140.2488
2026	174107414.7	4769330.214	63901.1539
2027	179323727.9	4904325.225	65725.24459

5.2.2 Projection-II

In the same manner with Projection-I, direct greenhouse gas emissions of the next ten years are calculated to account for 2% increase in the passenger capacity. Total kilometers driven is assumed to increase by 3% annually.

Projection-II is designed to reveal the decrease in direct greenhouse gas emissions with the introduction of electric buses to the current vehicle fleet. In an attempt to identify which buses to expand the fleet with and which ones to decommission, cases where current total kilometers are driven only by buses using diesel oil and only by buses using CNG are examined.

For the case where only diesel buses are put in service, kilometers driven by CNG buses are transferred to diesel buses based upon the passenger capacity of the buses. For example, both 2007 MAN Solo CNG buses and 2008 MAN Solo CNG buses have the same passenger capacity with the 2006 MAN diesel buses (see *Table 5.10*). Thus, both the number of vehicles and the kilometers travelled by the CNG buses are transferred to those of 2006 MAN Solo diesel buses. Passenger capacities of 2009-2010-2011 MAN Solo CNG buses don't match with any of the diesel buses. These buses have a total quantity of 596. Paying regard to the passenger capacities, 596 of these buses correspond to 290 of 2012 Mercedes Articulated buses and 36 of 1999 Mercedes Solo buses.

Kilometers travelled by each model and direct greenhouse gas emissions emitted if only the buses using diesel oil covered the total distance driven in 2017 are expressed in *Table 5.16* and *Table 5.17*, respectively.

Table 5.16 Kilometers travelled by year and model

Year	Model	Quantity	Kilometers Travelled
1999	Mercedes Solo	113	5226359.124
1999	Mercedes Articulated	60	874849
2006	MAN Solo	532	17811508
2012	Mercedes Articulated	490	47515934.88
2013	Mercedes Articulated	181	10807390

Table 5.17 Emissions if only diesel buses are put in service vs current emissions

	CO_2	CH_4	N_2O
Current	133392315.4	3701688.425	49503.66027
Diesel buses only	124779573.8	41619.95448	7134.84934

Direct greenhouse gas emissions for the case where total kilometers are only driven by CNG buses are calculated following the same principles of the case where only diesel buses are put in service. Table 5.18 displays the resulting direct greenhouse gas emissions.

Table 5.18 Emissions if only CNG buses are put in service vs current emissions

	CO_2	CH_4	N_2O
Current	133392315.4	3701688.425	49503.66027
CNG buses only	137655763.9	4476191.657	58599.52785

Figure 5.2 compares the CO_2 emissions and *Figure 5.3* compares CH_4 and N_2O emissions of the both cases to current CO_2, CH_4 and N_2O emissions.

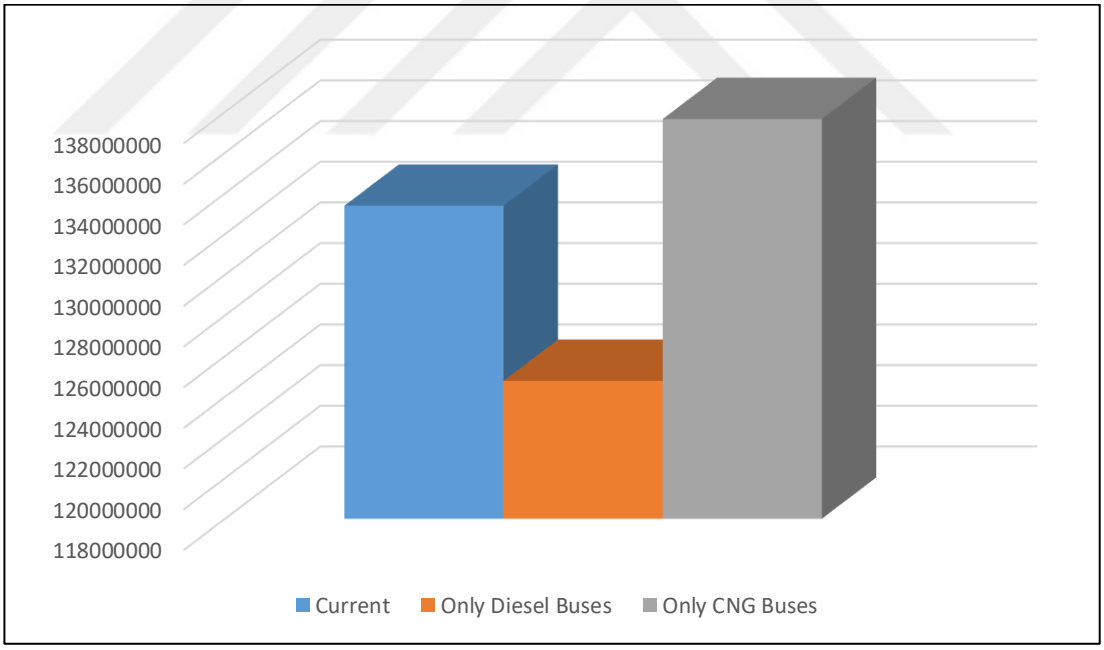

Figure 5.2 CO_2 emissions of both cases compared to the current CO_2 emission

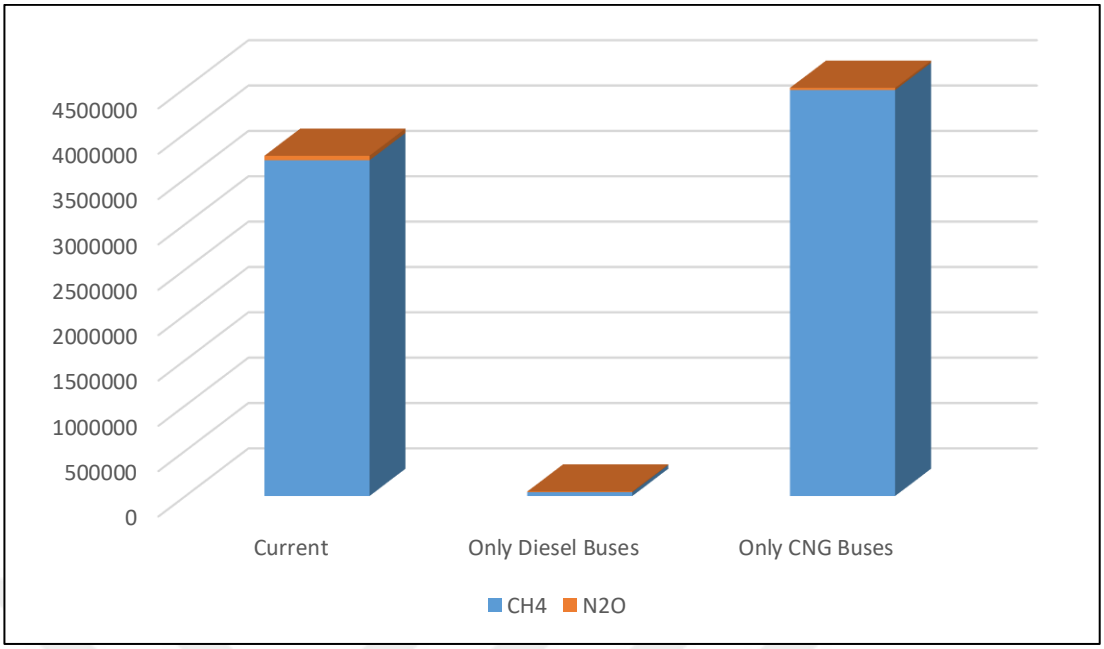

Figure 5.3 CH_4 and N_2O emissions of both cases compared to the current CH_4 and N_2O emissions

Figure 5.2 and *Figure 5.3* reveal that if total kilometers were driven by buses using diesel oil in 2017, CO_2, CH_4 and N_2O emissions would be much lower than both current direct greenhouse gas emissions and the fleet that is only comprised of CNG buses.

CH_4 and N_2O emission factors are higher for CNG buses than the diesel buses. Hence, it explains why CH_4 and N_2O emissions are higher for the case where there are only CNG buses in the vehicle fleet. However, CO_2 emission factors are lower for CNG buses than the diesel buses (*see Tables 5.8 and 5.9* and *equations 5.6* and *5.8*). CO_2 emissions therefore should have been higher for the fleet of diesel buses.

The root cause of the fact that CO_2 emissions are lower when the fleet is comprised of only diesel buses is the indirect influence of the fuel economy values on CO_2 emission calculations. Having looked at the fuel economy values of both diesel and CNG buses (see Table 5.5), CNG buses consume much more fuel than diesel buses. Meaning, diesel buses cover the same distance as CNG buses combusting less fuel, hence the difference in emissions.

Resulting emissions in both cases reveal that in order to reduce the emissions, CNG buses with high fuel combustion rates should be decommissioned and the fleet should be expanded with diesel buses that consume less fuel.

For Projection-II, in 2018, electric buses are introduced in the amount that corresponds to 3% of the current vehicle fleet. Then, 30 electric buses are added to the fleet every year. The adjustments made on the vehicle fleet to reduce direct greenhouse gas emissions are shown in *Table 5.19*.

Table 5.19 Adjustments made on the EGO vehicle fleet

Year & Model	'18	'19	'20	'21	'22	'23	'24	'25	'26	'27
1999 Mercedes S.	NC	NC	NC	NC	NC	NC	-4%	-6%	-8%	-10%
1999 Mercedes A.	NC	NC	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%
2006 MAN S.	NC	+35 %	+35 %	+35 %	+35 %	+35 %	+35 %	+35 %	+35 %	+35 %
2012 Mercedes A.	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2013 Mercedes A.	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2007 MAN S.	NC	NC	NC	NC	NC	NC	NC	-5%	NC	-25%
2008 MAN S:	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2009 MAN S.	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2010 MAN S.	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2011 MAN S.	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2012 MAN A.	-1%	-2%	-3%	-5%	-8%	-12%	-17%	-23%	-30%	-38%
2013 MAN A.	-1%	-2%	-3%	-5%	-8%	-12%	-17%	-23%	-30%	-38%
SILEO S-12	50	+30	+30	+30	+30	+30	+30	+30	+30	+30

NOTES:
* '+' denotes adding more vehicles to the fleet in mentioned percentage than the previous year
* '-' denotes decommissioning of the vehicles in mentioned percentage than the previous year
* NC = No Change

2012 and 2013 MAN Articulated buses were reduced in number owing to the fact that they consume the most amount of fuel in the fleet. 1999 Mercedes Articulated buses consume the second most amount of fuel, hence they are also reduced in quantity. Expansion of the fleet is done through increasing the number of 2006 MAN Solo buses and adding SILEO S-12 electric buses. This is because 2006 MAN Solo buses consume the least amount of fuel and electric buses emit no emissions whatsoever.

1999 Mercedes Solo buses have the same fuel economy as 2006 MAN Solo buses. However, 1999 Mercedes Solo buses are contingent upon Euro 2 emission standard whereas 2006 MAN Solo buses have Euro 3 emission technology. Euro emission standards regulate and restrict the amount of CO, $NO_{x,}$ PM, HC emissions released from the vehicles. Euro 3 standard enforces further reductions in these emissions than Euro 2 emissions. Although 1999 Mercedes Solo buses will emit relatively less direct greenhouse gas emissions than CNG buses covering the same distance, the amount of CO, $NO_{x,}$ PM, HC emissions emitted will be higher. Hence, a number of 1999 Mercedes Solo buses are decommissioned starting from 2024 to 2027. Adjusted vehicle fleet through years is presented in *Table 5.20*.

Table 5.20 Adjusted EGO vehicle fleet through years

Year & Model	2017	2018	2019	2020	2021
1999 Mercedes Solo	77	77	77	77	77
1999 Mercedes Articulated	60	60	60	59	58
2006 MAN Solo	49	49	66	89	121
2012 Mercedes Articulated	124	124	124	124	124
2013 Mercedes Articulated	56	56	56	56	56
2007 MAN Solo	394	394	394	394	394
2008 MAN Solo	89	89	89	89	89
2009 MAN Solo	347	347	347	347	347
2010 MAN Solo	209	209	209	209	209
2011 MAN Solo	40	40	40	40	40
2012 MAN Articulated	125	124	121	118	112
2013 MAN Articulated	76	75	74	72	68
SILEO S-12	0	50	80	110	140
Total	**1646**	**1694**	**1737**	**1784**	**1835**

Table 5.20 (continued) Adjusted EGO vehicle fleet through years

Year & Model	2022	2023	2024	2025	2026	2027
1999 Mercedes Solo	77	77	74	69	64	58
1999 Mercedes Articulated	56	54	51	48	45	41
2006 MAN Solo	163	220	297	400	541	730
2012 Mercedes Articulated	124	124	124	124	124	124
2013 Mercedes Articulated	56	56	56	56	56	56
2007 MAN Solo	394	394	394	374	374	281
2008 MAN Solo	89	89	89	89	89	89
2009 MAN Solo	347	347	347	347	347	347
2010 MAN Solo	209	209	209	209	209	209
2011 MAN Solo	40	40	40	40	40	40
2012 MAN Articulated	103	90	75	58	40	25
2013 MAN Articulated	63	55	46	35	25	15
SILEO S-12	170	200	230	260	290	320
Total	**1891**	**1955**	**2032**	**2109**	**2244**	**2335**

Calculating emissions, the additional kilometers in total kilometers driven are assumed to be driven by the electric buses. The new total of kilometers driven by 2006 MAN Solo buses are accounted as if one more bus is added to the same line covering the same distance. For instance, there are 21 currently operating 2006 MAN Solo buses in Cankaya district [40]. In 2019, say 8 more 2006 MAN Solo buses will be put in service in this district, each of them covering the same amount of distance. Hence, the distance travelled by a single 2006 MAN Solo bus will be the same. The difference in total kilometers travelled is resulted from the increase in quantity.

The amount of estimated fuel consumption by type and the projected direct greenhouse gas emissions as a result of the expansion of the current vehicle fleet for the period of ten years are illustrated in *Table 5.21* and *Table 5.22*, respectively.

Table 5.21 Estimated fuel consumption by type for Projection-II, 2017-2027

Year	CNG	Diesel Oil
2017	53216654.17	7531477.55
2018	53101048.38	7531477.55
2019	52877772.86	7583271.62
2020	52592726.03	7641681.297
2021	52022632.36	7727511.363
2022	51229263.16	7832143.877
2023	50035241.08	7982477.04
2024	48671778.22	8179043.57
2025	46572519.49	8452800.44
2026	44985781.11	8842332.29
2027	41214232.44	9365429.507

Table 5.22 Estimated direct greenhouse gas emissions of Projection-II through years, 2017-2027

Year	CO_2	CH_4	N_2O
2017	133392315.4	3701688.425	49503.66027
2018	133145459.4	3693661.337	49398.57461
2019	132804565.4	3678203.521	49203.38627
2020	132349124.3	3658462.403	48953.04015
2021	131356947.6	3618953.05	48447.69952
2022	129937329.5	3563957.014	47742.2218
2023	127782074.1	3481181.632	46679.4057
2024	125386291.9	3386681.584	45469.50294
2025	121621840	3241159.091	43602.34029
2026	119255500	3131324.752	42218.42487
2027	112574261.7	2869904.98	38868.55171

5.3 Global Warming Potential

Global Warming Potential is used to compare the greenhouse effect that the greenhouse gas emissions may impose over a time period. In this section, the current direct greenhouse gases of the year 2017 and the estimated greenhouse gas emissions of the projections in the previous section will be calculated in CO_2 equivalents. AR5 GWP values are used in calculations.

5.3.1 GWPs of the Current and Projected Greenhouse Gas Emissions

CO_2 eq. is calculated by multiplying the amount of direct greenhouse gas with the GWP values of those gases (see *equation 4.1)*. Current direct greenhouse gases in CO_2 equivalents are listed in *Table 5.23*.

Table 5.23 Current direct greenhouse gas emissions in CO_2 eq., 2017

Greenhouse Gas	CO_2 Equivalent in Tg
CO_2	0.133392315
CH_4	0.103647276
N_2O	0.01311847
Total	**0.250158061**

Total emission in CO_2 equivalents for the year 2017 is 0.25016 Tg CO_2. CO_2 equivalents of the direct greenhouse gas emissions for Projection-I for the next ten years is presented in *Table 5.24*.

Table 5.24 Projection-I direct greenhouse gas emissions in CO_2 eq., 2018-2027

Year	CO_2	CH_4	N_2O	Total (CO_2 eq.)
2018	0.137403742	0.106630876	0.013498526	**0.257533144**
2019	0.141516131	0.109691302	0.013888335	**0.265095768**
2020	0.145791415	0.112806507	0.014286384	**0.272884306**
2021	0.15015721	0.116002611	0.014694479	**0.2808543**
2022	0.15466144	0.119337105	0.01511953	**0.289118075**
2023	0.159320887	0.122660226	0.015545543	**0.297526656**
2024	0.164097607	0.126228671	0.0159998	**0.306326078**
2025	0.16902466	0.129898468	0.016467166	**0.315390294**
2026	0.174107415	0.133541246	0.016933806	**0.324582466**
2027	0.179323728	0.137321106	0.01741719	**0.334062024**

Emissions in CO_2 equivalents for Projection-II covering 2018 through 2027 is displayed in *Table 5.25*.

Table 5.25 Projection-II direct greenhouse gas emissions in CO_2 eq., 2018-2027

Year	CO_2	CH_4	N_2O	Total (CO_2 eq.)
2018	0.133145459	0.103422517	0.013090622	**0.249658599**
2019	0.132804565	0.102989699	0.013038897	**0.248833161**
2020	0.132349124	0.102436947	0.012972556	**0.247758627**
2021	0.131356948	0.101330685	0.01283864	**0.245526273**
2022	0.12993733	0.099790796	0.012651689	**0.242379815**
2023	0.127782074	0.097473086	0.012370043	**0.237625202**
2024	0.125386292	0.094827084	0.012049418	**0.232262794**
2025	0.12162184	0.090752455	0.01155462	**0.223928915**
2026	0.1192555	0.087677093	0.011187883	**0.218120476**
2027	0.112574262	0.080357339	0.010300166	**0.203231767**

5.4 Evaluation of the Results

5.4.0 Accomplished Work

The thesis investigated the reductions in direct greenhouse gas emissions originated from EGO public transport buses over a period of ten years by means of fleet planning and altering the fuel use patterns. To do so, direct greenhouse gas inventory of 2017 is prepared utilizing the highest tier approaches while revealing the big difference with the fuel sold method adopted by Turkish Statistical Institute which is the responsible institution for the greenhouse gas inventory preparation.

To this respect, through plotting a route, the thesis makes a significant contribution to the obligations that the Ankara Municipality must fulfil within the scope of the National Climate Change Action Plan.

5.4.1 Direct Greenhouse Gas Inventory of 2017

Currently, greenhouse gas inventories are prepared using fuel sold method instead of the VKT method. The difference in values of direct greenhouse gas emissions calculated in Chapter 5 adopting both methods exposes the significant difference between the methods which contradicts the IPCC's fundamental principles of inventory preparation. *Figure 5.4* displays the CO_2 emissions of 2017 from EGO public transport buses calculated using both Tier 1 and Tier 2 approaches.

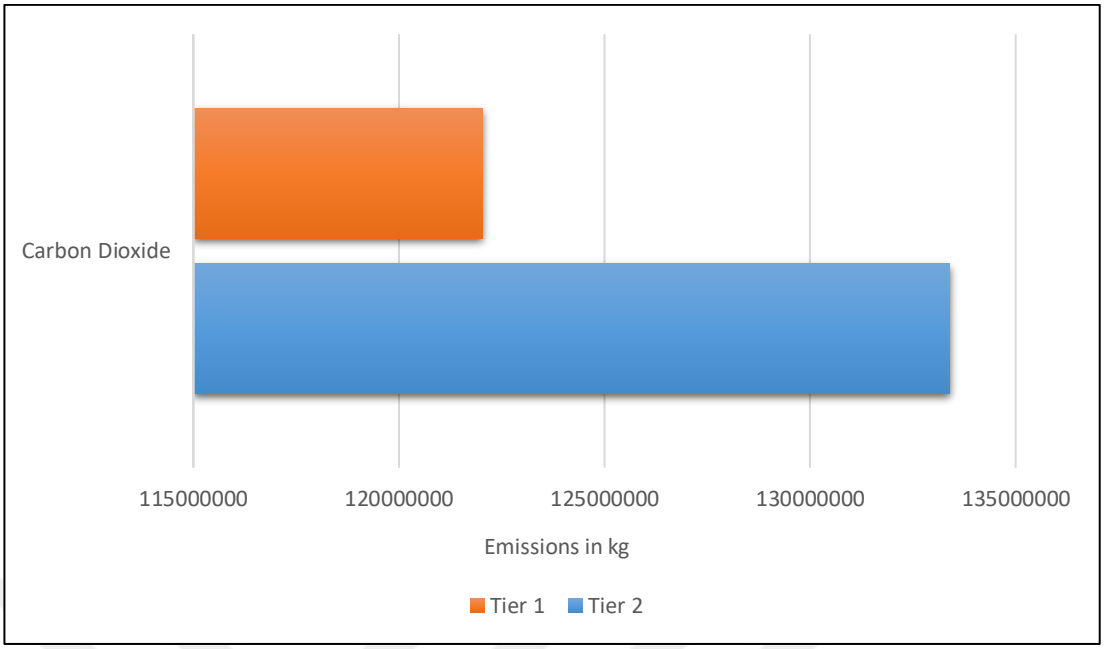

Figure 5.4 CO_2 emissions calculated with both the lowest and the highest tiers

Tier 1 and Tier 2 approaches are appropriate for CO_2 emission calculations due to the fact that CO_2 emission factors depend on the carbon content of the combusted fuel. Both approaches are fuel based; however, in Tier 2 approach country-specific emission factors are used differently from default emission factors of Tier 1 approach. As the figure above indicates, Tier 1 approach estimated CO_2 emission 9% less than Tier 2 approach due to the uncertainties in emission factors of Tier 1 approach. Hence, Tier 2 is the most accurate approach for CO_2 emission calculations. Arguably, the difference in CO_2 emission values is not significant compared to the difference in calculated CH_4 and N_2O emission values with Tier 1 and Tier 3 approaches. *Figure 5.5* and *Figure 5.6* display the differences in CH_4 and N_2O emissions of 2017 from EGO public transport buses utilizing both fuel sold and VKT methods, that is, Tier 1 and Tier 3 approaches.

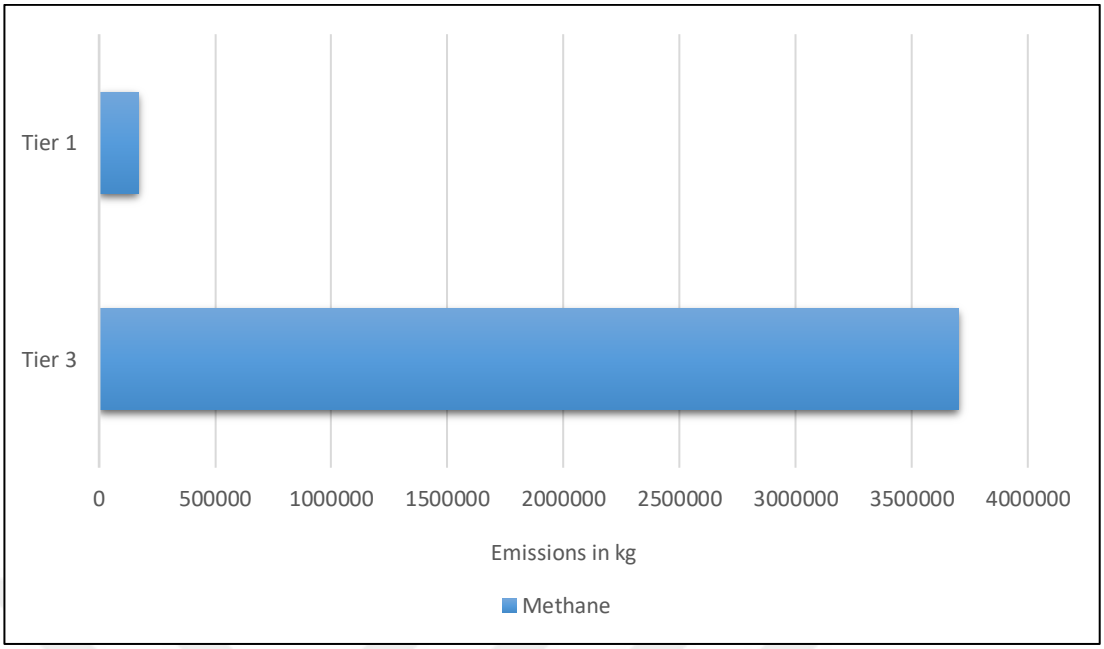

Figure 5.5 CH_4 emissions calculated with both the lowest and the highest tiers

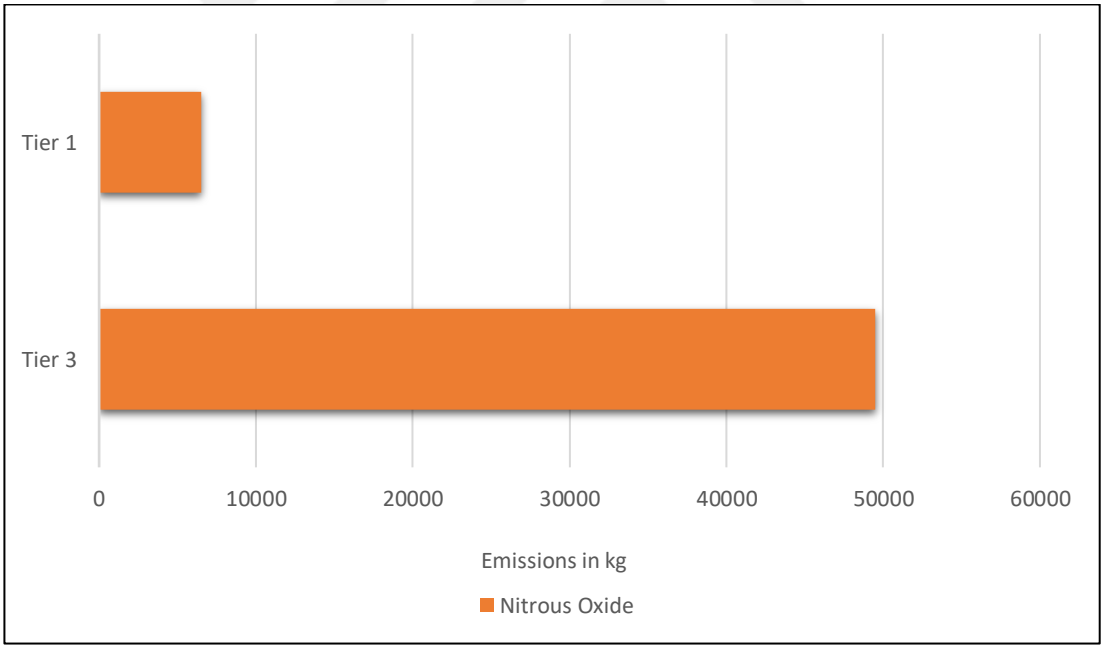

Figure 5.6 N_2O emissions calculated with both the lowest and the highest tiers

Using Tier 1 approach increases the uncertainties and reduces the accuracy in CH_4 and N_2O emission calculations perceptibly. This is due to the fact that Tier 1 approach is fuel based and use default emission factors paying no regard to combustion conditions

and vehicle technology whereas Tier 3 approach uses kilometers travelled data and accounts for vehicle type and technology through the use of country-specific emission factors.

Figure 5.5 exhibits that Tier 1 approach estimated CH_4 emissions 2092% less than Tier 3 approach because of the uncertainties in emission factors and using fuel statistics instead of kilometers travelled data. Due to the same reason, Tier 1 approach estimated N_2O emissions 661% less than Tier 3 approach.

Figure 5.4 to *Figure 5.6* shine light on the essentialness of using the appropriate tier approaches and country-specific emission factors in emission calculations. Therefore, an adequate inventory must be prepared using the highest tier approaches. Direct greenhouse gas emissions originated from EGO public transport buses in 2017 utilizing the highest tiers are expressed in *Table 5.26*.

Table 5.26 Direct greenhouse gas emission inventory of EGO in kilotons, 2017

CO_2 (kt)	CH_4 (kt)	N_2O (kt)
133.39	3.70	0.050
Total in CO_2 eq. (kt)	**250.2**	

In 2017, EGO public transport buses have contributed 250 kilotons of CO_2 eq.. Dividing the amount of emissions in CO_2 eq. by the population, CO_2 emission per capita, also called carbon footprint, is found (for population see *Table 5.11)*. Carbon footprint is total emissions released to the environment in CO_2 eq. as a result of an individual's activity.

$$CO_2\ eq.per\ capita = 250.2 \div 5{,}445{,}026 = 4.5950 \times 10^{-5}\ kt\ CO_2\ eq. \qquad (5.18)$$

For public transportation, carbon footprint of an individual living in Ankara is 45.950 kg in 2017. With the increase in population, emissions from public transport buses will increase as well. The thesis made two projections to predict the direct greenhouse gas emissions of the next ten years. Projection-I estimated emissions based on the fuel use and vehicle fleet expansion pattern of EGO from 2008 to 2017. Projection-II investigated the reductions in emissions introducing electric buses to the fleet and altering fuel use and expansion patterns. Both projections are made to account for the

annual 2% increase in passenger capacity. Total kilometers driven is assumed to increase by 3% every year.

5.4.2 Projection-I

From 2018 to 2027, estimated direct greenhouse gas emissions of Projection-I are displayed in *Figure 5.7*.

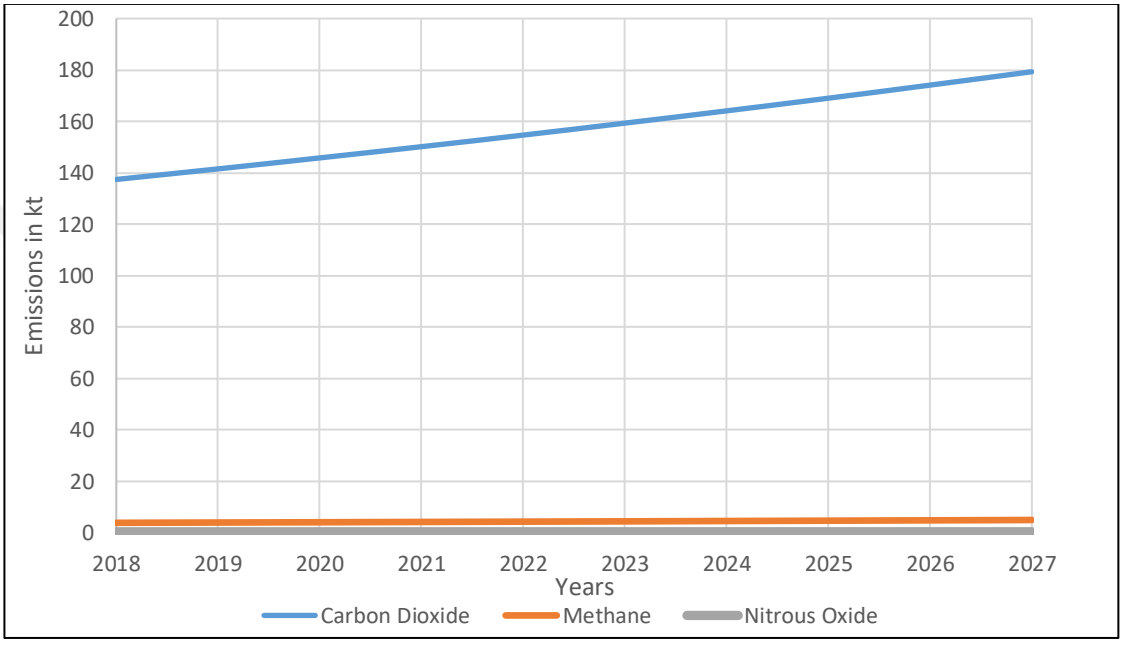

Figure 5.7 Estimated CO_2, CH_4 and N_2O emissions of Projection-I, 2018-2027

Projection-I predicted annual average 3% increase in CO_2, 2.9% increase in both CH_4 and N_2O emissions. With Prediction-I, from 2018 to 2027, CO_2 emissions increase 31%, CH_4 and N_2O emissions increase 29%. The increase in emissions in CO_2 eq. versus the increase in the number of buses is exhibited in *Figure 5.8*.

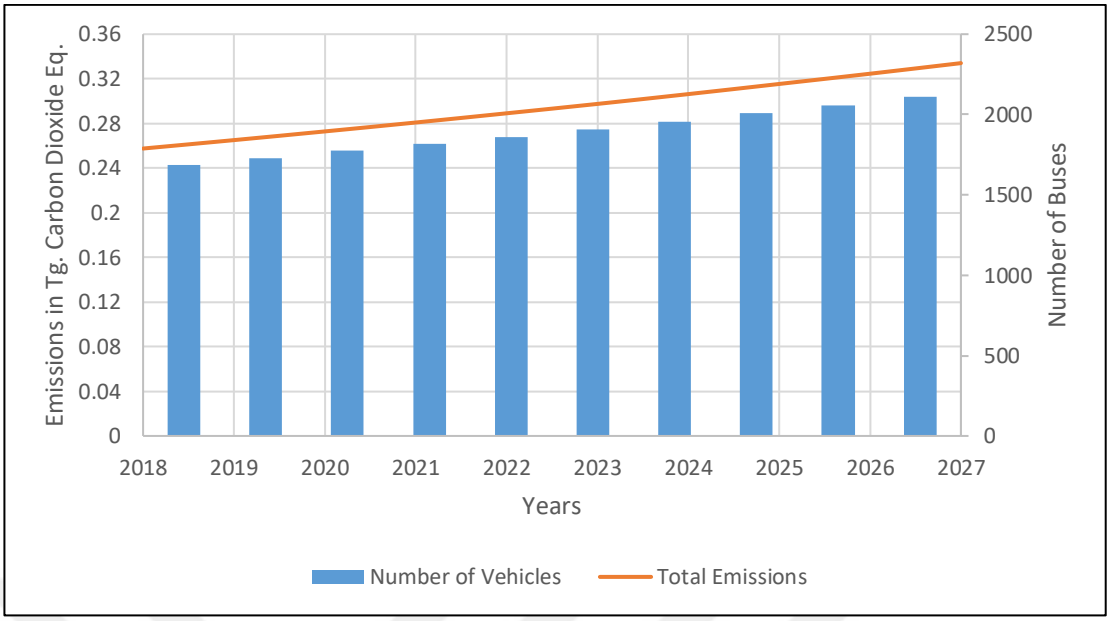

Figure 5.8 Estimated emissions of Projection-I in CO_2 eq. vs. the number of buses, 2018-2027

With a 25% increase in the number of buses, total emissions in CO_2 eq. are estimated to increase 30% in 2027 compared to 2018. The increase in emissions is due to the increase in the amount of fuel combusted. The amount of fuel consumed along with their respective costs between 2017 and 2027 are indicated in *Table 5.27*.

Table 5.27 Projection-I fuel consumed and total cost per year, 2017-2027

Year	Diesel Oil Consumed (L)	CNG consumed (m^3)	Total Cost (TL)
2017	7,531,477.55	53,216,654.17	**187,754,036.2**
2018	7,814,364.134	54,747,721.14	**193,533,820.7**
2019	8,103,637.751	56,318,223.26	**199,457,338.8**
2020	8,432,477.98	57,916,402.46	**205,682,064**
2021	8,761,956.845	59,556,184.55	**212,023,595.5**
2022	9,086,212.344	61,267,214.58	**218,529,096.1**
2023	9,475,060.91	62,971,580.24	**225,385,296**
2024	9,805,301.118	64,802,868.41	**232,252,071.4**
2025	10,150,568.02	66,686,098.57	**239,345,931.5**
2026	10,567,232.65	68,554,531.36	**246,807,223.7**
2027	10,977,349.4	70,493,555.76	**254,423,136.7**

Notes:

***** Diesel oil price = 5.71 TL/L (last updated: 25.06.2018) [41]

* CNG price = 2.72 TL/m^3 (last updated: 15.05.2018) [42]

Projection-I estimated an average of 3% increase in fuel cost per year. Today's fuel cost of 187,754,036 TL will increase by 36% climbing up to 254,423,137 TL in 2027.

5.4.3 Projection-II

Both Projection-I and Projection-II attain the same result which is expanding the fleet over the years to account for the increase in population and total kilometers driven. The distinctive feature of Projection-II which separates it from Projection-I is that Projection-II aims to increase the passenger capacity and total kilometers driven while reducing direct greenhouse gas emissions.

As it is made clear in previous chapters that fossil fuel combustion is the cause of greenhouse gas emissions. To accommodate for the increasing demand for transportation, instead of commissioning more vehicles that combust fossil fuel, alternative solutions that pay regard to environment must be sought.

In the activity reports of EGO, equipping the vehicle fleet with CNG, hybrid and electric buses is featured as one of the strategic objectives. The number of CNG buses is shown as the performance indicator [40, 43, 44].

Making Projection-II, first direct greenhouse gases emitted when the fleet is only composed of CNG buses versus when it's only composed of diesel buses are investigated. In theory, CO_2 emission factors for CNG buses are much lower compared to diesel buses, therefore CO_2 emissions should be lower under the same conditions; however, Projection-II revealed the total opposite. In *Figure 5.9* and *Figure 5.10*, both cases are compared.

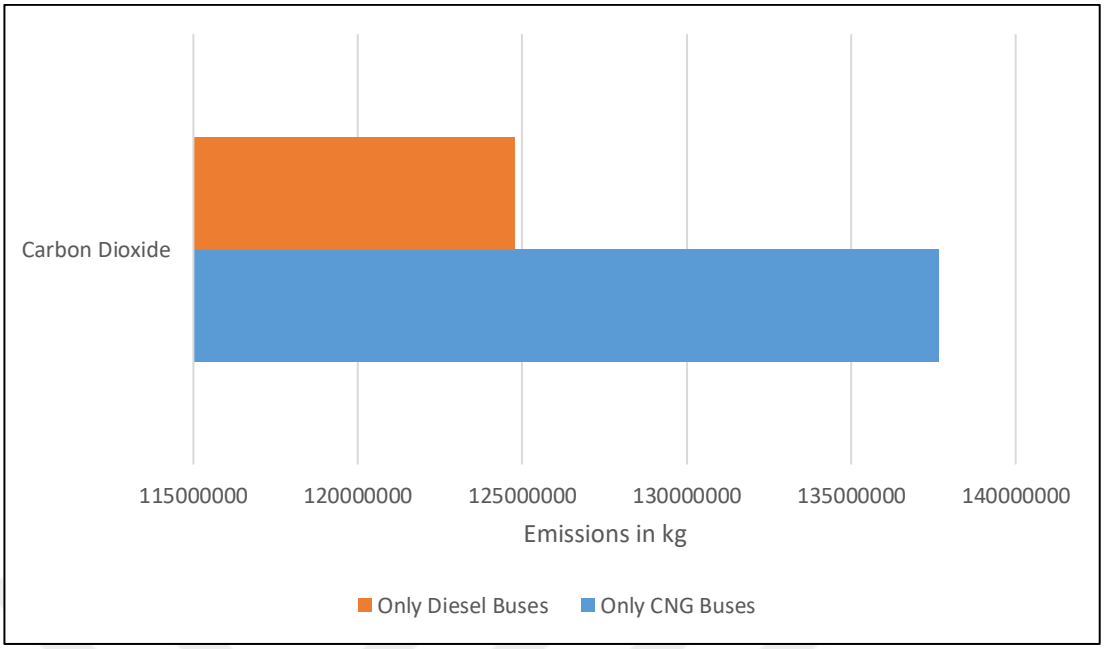

Figure 5.9 CO_2 emissions from the fleet composed of only diesel buses vs. only CNG buses, 2017

Figure 5.9 displays that if EGO vehicle fleet of 2017 composed of only CNG buses, more CO_2 emissions would be emitted contrary to what is expected. This is because of the significant difference in fuel economy values between CNG and diesel buses. Diesel buses travel the same distance as CNG buses combusting less fuel; therefore revealing the significance of the factor of fuel economy. In brief, CNG fuel emits less amount of CO_2 emission when combusted compared to diesel oil. However, travelling the same distance, a CNG vehicle will emit more CO_2 emission than a diesel vehicle if its fuel economy value is significantly more than the diesel vehicle, which is the case for EGO.

CO_2 has the largest radiative forcing, hence it is regarded as the most important factor in climate change. However, CH_4 and N_2O have the second and third largest radiative forcing after CO_2 (see Chapter 2). Hence, they are also of significance.

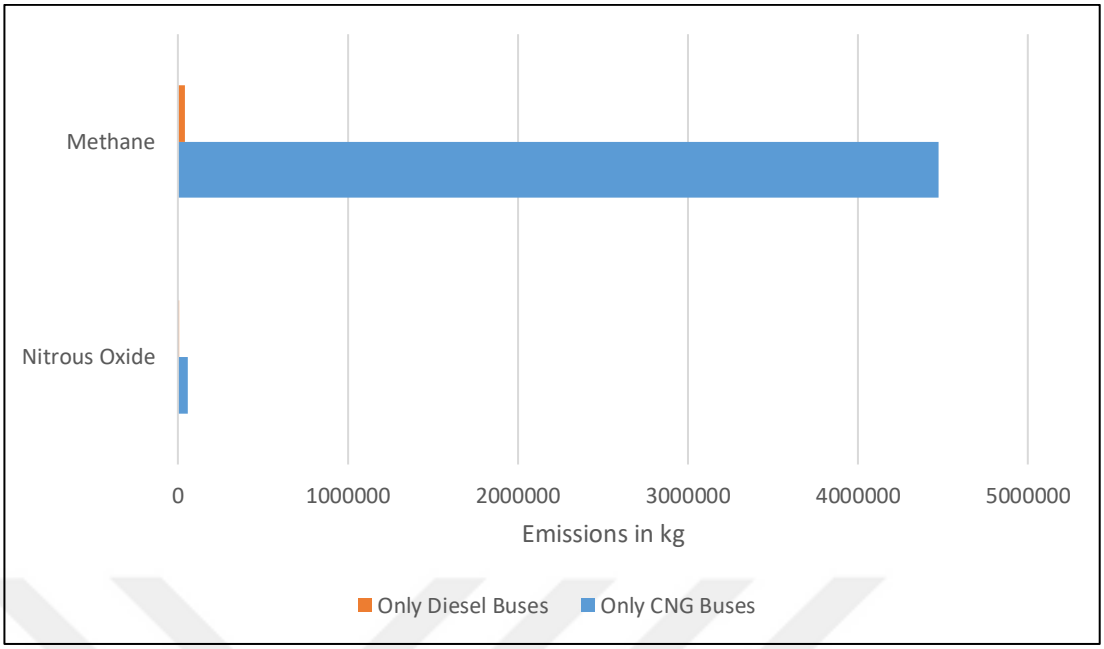

Figure 5.10 CH_4 and N2O emissions from the fleet composed of only diesel buses vs. only CNG buses, 2017

CH_4 and N_2O emission factors are higher for CNG buses than diesel buses which explains the emissions in *Figure 5.10*. Similarly, fuel economy factor has an influence on the difference in CH_4 and N_2O emissions between the fleet of only diesel and only CNG buses.

To reduce greenhouse gas emissions, Projection-II suggested the addition of electric buses to the fleet which emit no emissions at all. Examining *Figure 5.9* and *Figure 5.10*, to account for the increase in passenger capacity, it was concluded that fleet expansion must be made with diesel buses of lowest fuel consumption.

For calculation purposes, SILEO S-12 electric bus is chosen as a reference. The influential features in this choice were that S-12 buses offer 400 km range with a single charge and are domestically produced [45].

Relatively small cities like Elazig and Eskisehir with populations of 583,671 and 860,620 respectively have equipped their fleet with electric buses already [46]. Eskisehir have purchased 4 electric buses and Elazig have purchased 15 articulated electric buses [47].

Even these comparingly small cities (which are not the only two examples) have taken a step against climate change. Uniquely, EGO is the first organization to completely stop the use of gasoline and start the use of CNG in public transport buses. However, the capital couldn't maintain its leadership on equipping its vehicle fleet with electric buses and must take an urgent step towards environmental protection. In Projection-II, 50 electric buses are chosen as the starting point which correspond to 3% of the current fleet and 30 more added each year but the capital must once again set an example to the other cities by composing its fleet entirely of electric buses.

From 2018 to 2027, estimated direct greenhouse gas emissions of Projection-II are displayed in *Figure 5.11*.

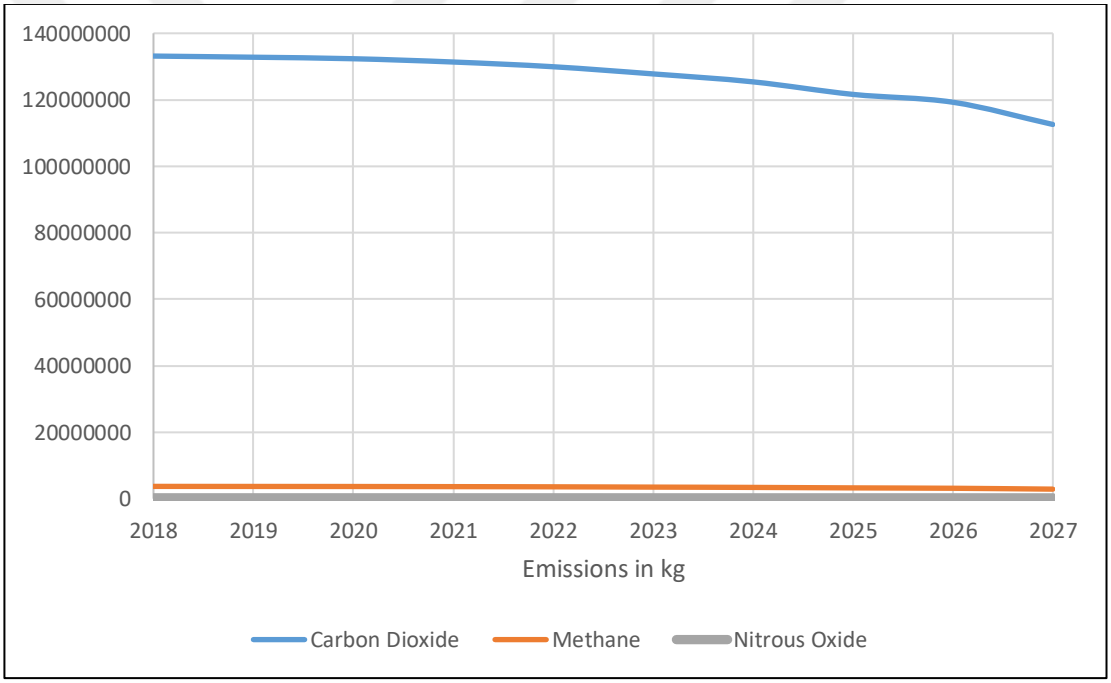

Figure 5.11 Estimated CO_2, CH_4 and N_2O emissions of Projection-II, 2018-2027

Projection-II predicted annual average 1.8% decrease in CO_2, 2.7% decrease in CH_4 and 2.6% decrease in N_2O emissions. With Projection-II, from 2018 to 2027, CO_2 emissions decrease 15%, CH_4 emissions decrease 22% and N_2O emissions decrease 21%. The decrease in emissions in CO_2 eq. versus the increase in the number of buses is expressed in *Figure 5.12*.

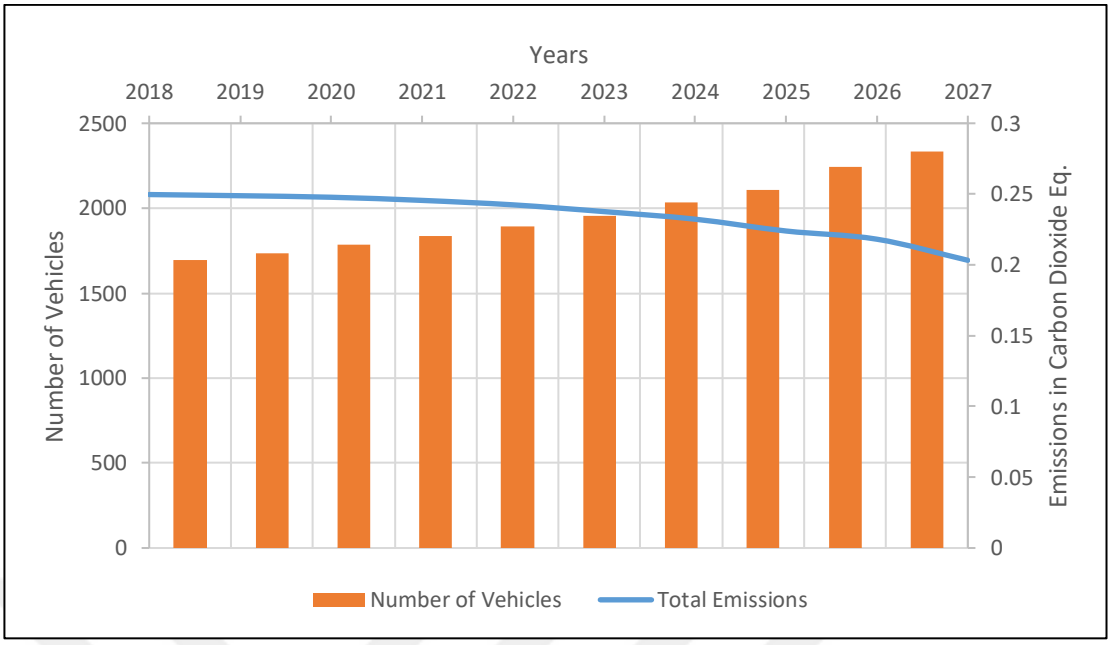

Figure 5.12 Estimated emissions of Projection-II in CO_2 eq. vs. the number of buses, 2018-2027

With a 38% increase in the number of buses, total emissions in CO_2 eq. are estimated to decrease 19% in 2027 compared to 2018. With the addition of electric buses, the amount of fuel combusted decreased, therefore total amount of emissions decreased. The amount of fuel consumed along with their respective costs between 2017 and 2027 are illustrated in *Table 5.28*.

Table 5.28 Projection-II fuel consumed and total cost per year, 2017-2027

Year	Diesel Oil Consumed (L)	CNG Consumed (m^3)	Total Cost (TL)
2017	7,531,477.55	53,216,654.2	**187,754,036.2**
2018	7,531,477.55	53,101,048.4	**187,439,588.4**
2019	7,583,271.62	52,877,772.9	**187,128,023.1**
2020	7,641,681.297	52,592,726	**186,686,215**
2021	7,727,511.363	52,022,632.4	**185,625,649.9**
2022	7,832,143.877	51,229,263.2	**184,065,137.3**
2023	7,982,477.04	50,035,241.1	**181,675,799.6**
2024	8,179,043.57	48,671,778.2	**179,089,575.5**
2025	8,452,800.44	46,572,519.5	**174,942,743.5**
2026	8,842,332.29	44,985,781.1	**172,851,042**
2027	9,365,429.507	41,214,232.4	**165,579,314.7**

Notes:

***** Diesel oil price = 5.71 TL/L (last updated: 25.06.2018) [41]
* CNG price = 2.72 TL/m^3 (last updated: 15.05.2018) [42]

Projection-II estimated an average of 1% decrease in fuel cost per year. The cost of 187,754,036 TL in 2017 will decrease 12% receding to 165,579,315 TL. Within ten years, 22,174,722 TL will be saved.

5.4.4 Comparison of Projection-I and Projection-II

Estimated CO_2 emissions of Projection-I and Projection-II are compared in *Figure 5.13*.

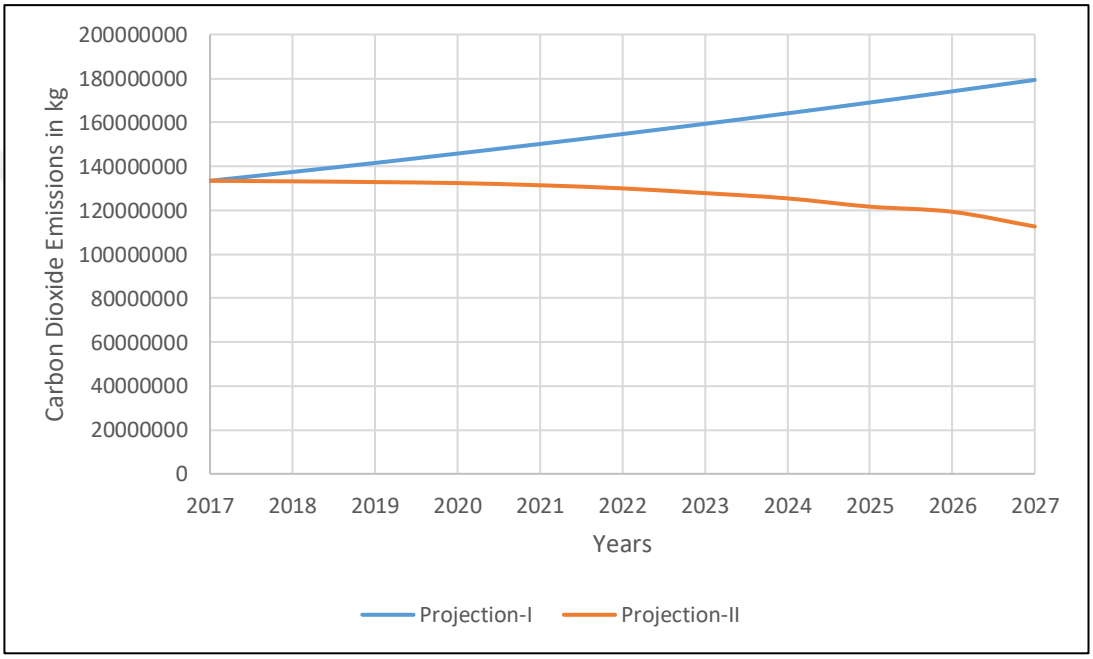

Figure 5.13 Estimated CO_2 emissions of Projection-I compared to Projection-II, 2017-2027

CO_2 emissions of Projection-I increase rapidly over the period of ten years. On the contrary, CO_2 emissions of Projection-II show a substantial decrease. In 2027, Projection-II will produce 37% less CO_2 emission than Projection-I. That is, if Projection-II is utilized for fleet expansion instead of the current trend, 67 kilotons of CO_2 emission will have been avoided in 2027. The percentage of emission that can be avoided increases even more in the case of CH_4 and N_2O emissions. Estimated CH_4 emissions of Projection-I and Projection-II are compared in *Figure 5.14*.

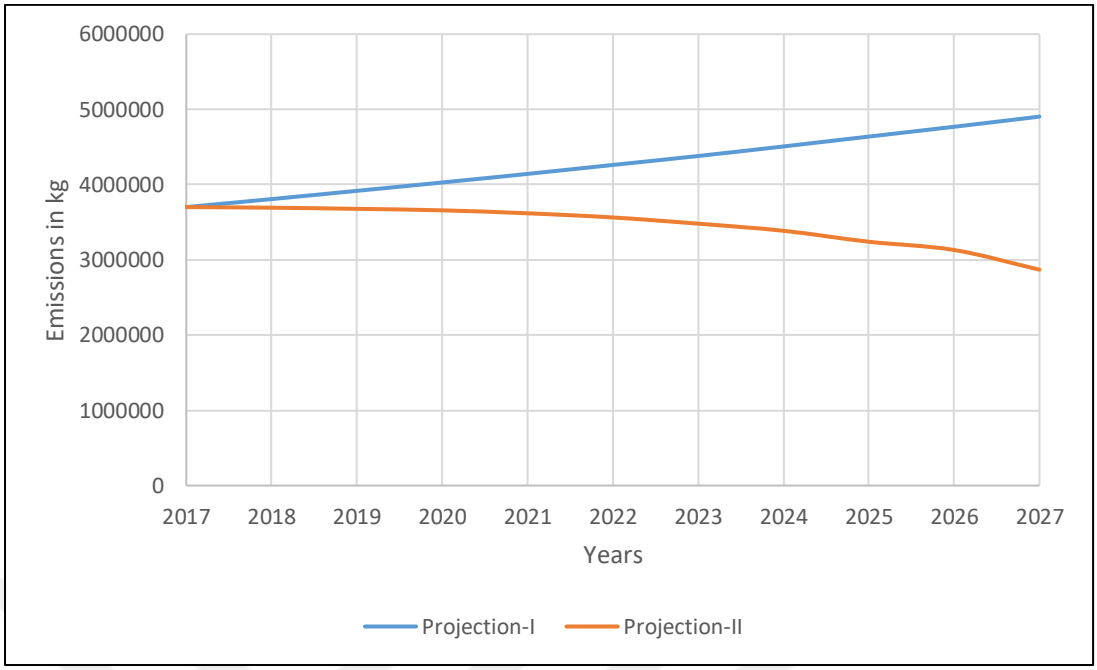

Figure 5.14 Estimated CH_4 emissions of Projection-I compared to Projection-II, 2017-2027

As with CO_2 emissions, CH_4 emissions of Projection-II show a significant decrease in amount over the period of ten years. Projection-II estimated CH_4 emissions to be produced 41% less than that of Projection-I in 2027 from public transport buses. Meaning, 2 kilotons of CH_4 emissions will have been avoided in 2027. A similar situation exists in estimated N_2O emissions of Projection-II. Estimated N_2O emissions of Projection-I and Projection-II are compared in *Figure 5.15*.

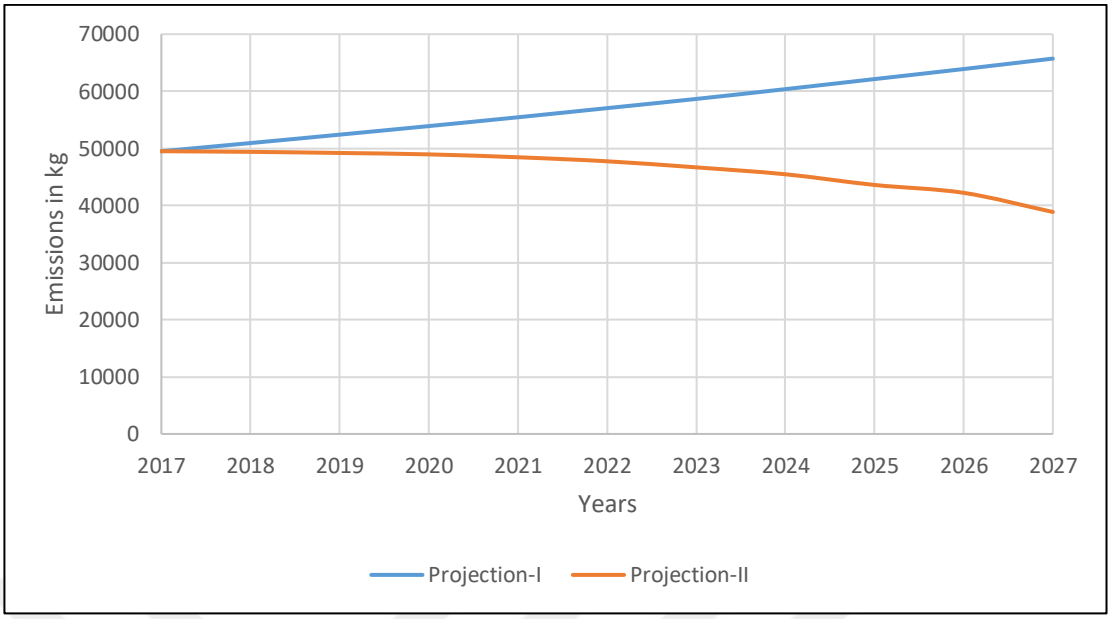

Figure 5.15 Estimated N_2O emissions of Projection-I compared to Projection-II, 2017-2027

In 2027, Projection-II estimated to produce 41% less N_2O emission compared to Projection-I. This percentage corresponds to 27 tons of N_2O emissions which will have been avoided in 2027. The decrease in emissions is due to the reduction in fuel combusted. Apart from environmental benefits, reducing the amount of fuel consumed will present economic benefits as well. The fuel cost of Projection-I is compared to that of Projection-II in *Figure 5.16*.

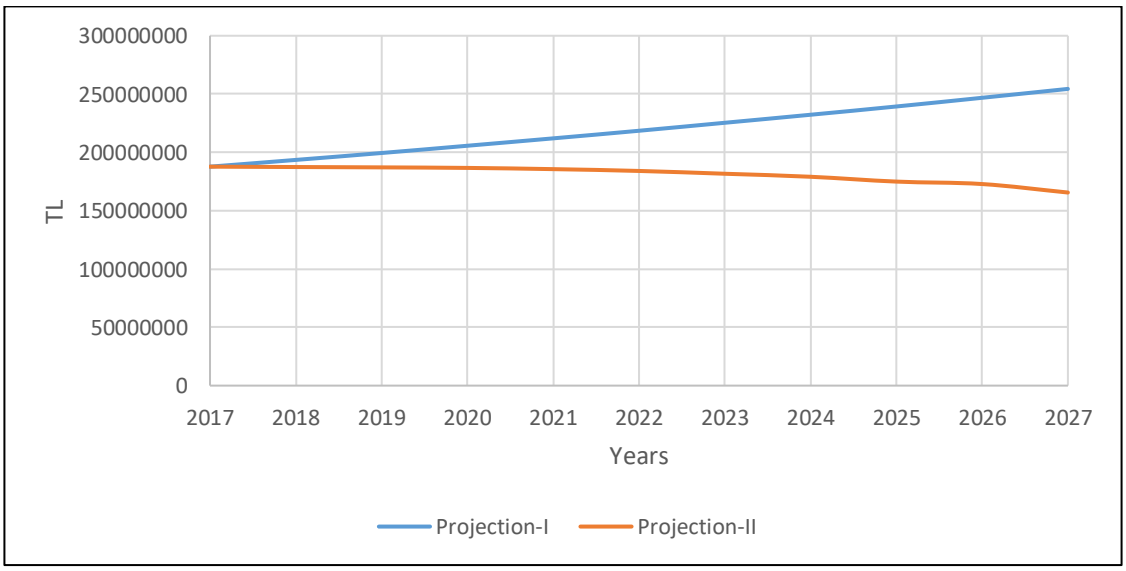

Figure 5.16 Estimated fuel cost of Projection-I compared to Projection-II, 2017-2027

Projection-II estimated a significant amount of decrease in the cost of fuel. In 2027, the fuel consumed will cost 35% less with Projection-II compared to Projection-I. Meaning, 88,843,822 TL will have been saved in 2027.

5.5 Fulfillment of the Aim and Objectives of the Thesis

The aim of this thesis was to investigate the reductions of direct greenhouse gas emissions originated from EGO public transport buses. In order to achieve this aim, the thesis focused on four key objectives.

The first step in investigating the reductions in direct greenhouse gas emissions was to prepare an adequate direct greenhouse gas inventory of 2017. Current inventories use fuel sold method instead of VKT method which brings uncertainties to emission calculations.

By force of the Paris Agreement, Turkey declared its target to reduce the amount of greenhouse gases. In order to set a target to reduce emissions, an inventory of quality reflecting accurate values of emissions without under or over estimating must be prepared, otherwise the authenticity of this target cannot be mentioned.

The thesis showed that the current way of calculating emissions underestimate anthropogenic emissions and prepared an accurate inventory, calculating the direct greenhouse gas emissions of 2017 using highest tiers and appropriate methods.

It is concluded in the thesis that emission factors influence emission calculations dearly. Calculating country-specific emission factors instead of using default emission factors decrease the uncertainties in emission calculations to a great extent. The thesis calculated emission factors for public transport buses using diesel oil and CNG.

The aim of the thesis is fulfilled by achieving a continuous reduction in direct greenhouse gases through fleet planning and altering the fuel use. Also, a projection was made estimating the direct greenhouse gas emissions of the next ten years. The thesis compared these two showing that a great amount of greenhouse gas emissions can be avoided.

5.6 Conclusion

In this chapter, country-specific emission factors for diesel oil and CNG are calculated. Resulting direct greenhouse gas emissions from 2017 are calculated using both lowest and highest tiers. Direct greenhouse gas emissions from both projections for the next ten years are estimated utilizing the highest tiers.

The chapter revealed the gap in values of direct greenhouse gas emissions between lowest and highest tier approaches. Compared to Tier 1 approach, CO_2 emissions are 9.3% more when calculated with Tier 2 approach, CH_4 emissions are 2091.7% more and N_2O emissions are 660.5% more when calculated with Tier 3 approach. Although the gap between CO_2 emissions is relatively small compared to CH_4 and N_2O emissions, the difference in the amount of emissions between tiers contradicts with the principles specified by the IPCC Guidelines. An adequate inventory must be accurate; reported greenhouse gas emissions cannot be underestimated.

This chapter displayed that in Projection-I, CO_2 emissions increase by an average of 3%, CH_4 and N_2O emissions increase by an average of 2.9% every year. In 2027, projected emissions will climb to 0.33406 Tg CO_2 eq.

In Projection-II however, CO_2 emissions decrease by an average of 1.7%, CH_4 and N_2O emissions decrease by 2.5% and 2.4% respectively, every year. Projected emissions in 2027 will recede to 0.20323 Tg CO_2 eq.

Compared to Projection-I, with Projection-II 37% less CO_2 and 41% less CH_4 and N_2O emissions will be emitted in 2027. Meaning, 67 tons of CO_2, 2 kilotons of CH_4 and 27 tons of N_2O emissions will be avoided, while saving 88,843,822 TL by means of reducing the amount of fuel combusted.

CHAPTER 6

DISCUSSION AND CONCLUSION

It is evident that the driving force of the climate change is the constant increase in the atmospheric burden of the greenhouse gases due to anthropogenic activities which disrupt the natural course of the Earth by means of enhancing their heat- trapping abilities. Each greenhouse gas contributes to climate change to a different extent. CO_2, CH_4 and N_2O are the direct greenhouse gases and their abundance in the atmosphere influences the climate for a very long period of time due to their lifespans of decades to centuries. The atmospheric abundances of greenhouse gases have been increasing at an alarming level since pre-industrial times, increasing the global average temperature 0.85°C. The adverse effects of global warming is agreed to be unstoppable if it is to reach 2°C.

Transportation sector is the second largest contributor of the total greenhouse gas emissions with 23%. Dominant source of transportation sector emissions is road transportation with 91.44%. It is known that the automobile dependency has a significant influence in road transportation emissions. Although road transportation is one of the biggest contributors of greenhouse gas emissions, it is also the most eligible sub-sector to reduce them. Greater use of public transportation will serve a relatively effortless method of reducing road transportation emissions without enforcing new government regulations, through reducing the amount of fuel consumed by means of cutting the number of automobiles on the road. Public transportation can reduce greenhouse gas emissions even further if the fuel use habits are altered. In this thesis, the reductions of greenhouse gas emissions from EGO public transport buses by altering the fuel use patterns and fleet planning are investigated. CO_2, CH_4, and N_2O emissions, which are the largest contributors to the climate change, are calculated adopting IPCC methodologies. In calculations, for CO_2 Tier 2 approach, for CH_4, and N_2O Tier 3 approach is employed, tier approaches being the highest for each category.

By force of the UNFCCC, party countries are required to submit national greenhouse gas inventories to UNFCCC Secretariat. These inventories must be equipped with the

principles of transparency, completeness, consistency, comparability and accuracy which are set out by the IPCC Guidelines. By means of utilizing fuel sold method that lack calculated country-specific emission factor in CH_4 and N_2O emissions, Turkish national greenhouse gas inventories lack accuracy. Current national inventories also follow IPCC methodology and calculate CO_2 emissions from transportation sector utilizing Tier 2 approach with calculated country-specific emission factors. However, in the latest Turkish national greenhouse gas inventory (2015), it is stated that carbon content of natural gas is calculated dividing total carbon mass (kg Carbon) by average net calorific value (Gj/kg) of the fuel. Making a unit analysis in this relation reveals the unit of carbon content to be kg^2/GJ and not kg/GJ as indicated in the Annex 3. Therefore country-specific emission factor for natural gas in the national inventory should be re-investigated.

In this thesis, CO_2 emissions were observed to have the largest share in total direct greenhouse gases of 2017. CO_2 emissions were followed by CH_4 and N_2O emissions, respectively. These emissions were calculated with both current tier approaches used in the national inventory and the highest tier approaches to show the large gap between the approaches.

In direct greenhouse inventory calculations of 2017, Tier 1 approach estimated CO_2 emissions 9% less than Tier 2 approach. Both approaches are fuel based and depend on the carbon content. Emission factors and NCVs are the distinctive features that separate the two approaches. NCVs both play role in the calculation of CO_2 emission factor and fuel sold values. Compared to Tier 1 approach, Tier 2 approach calculated CO_2 emission factor, NCV and fuel sold values for CNG vehicles were 1.5% less, 2.3% more and 12.7% more, respectively. Those of diesel vehicles were 0.4% less, 0.4% less and 0.8% more respectively than calculated values of Tier 1 approach.

Having the second and third largest radiative forcing respectively makes CH_4 and N_2O emissions important constituents of climate change. Tier 1 approach estimated CH_4 and N_2O emissions 2092% and 661% less respectively compared to Tier 3 approach. The large gap exposed that fuel sold method is not reflective of the actual values of CH_4 and N_2O emissions. Fuel sold method and default emission factors should be used if kilometers travelled data and emission factors can absolutely not be derived.

The indicated differences between the currently used tier approach and the highest tier approaches signify the importance of calculating country-specific emission factors and utilizing the highest tier approaches. If fuel statistics are unknown, then CO_2 emissions can be calculated using Tier 1 approach because arguably, the difference in CO_2 emissions is not significant compared to the difference in CH_4 and N_2O emissions.

The thesis estimated the direct greenhouse gas emissions of the next ten years observing the trend between 2008 and 2017 in fuel use and fleet expansion in Projection-I. The thesis also illustrated a significant amount of decrease in direct greenhouse gas emissions through altering the fuel use patterns and fleet planning along with the addition of electric buses. Both projections took accounts of annual 2% increase in the passenger capacity and 3% increase in the total kilometers driven.

Projection-I predicted annual 3% increase in CO_2 emissions, 2.9% increase in both CH_4 and N_2O emissions. With projection-I, current emissions of 250.2 kilotons of CO_2 eq. is observed to escalate to 334.1 kilotons of CO_2 eq. in 2027, showing an increase of 34%. From 2017 to 2027, the amount of diesel oil combusted increased 46%, the amount of CNG combusted increased 32.5% and corresponding cost of fuel increased 36% reaching up to 254,423,137 TL.

EGO's strategic objective on the environmental protection is to compose its vehicle fleet with CNG buses and cease the use of diesel oil. CO_2-wise, it is theoretically accurate because the carbon cost of CNG is less compared to that of diesel oil. To construct Projection-II, cases where the vehicle fleet of 2017 was composed of only CNG buses and only diesel buses were examined. It is observed that the fleet of only CNG buses emitted 10% more CO_2 emissions than the fleet of only diesel buses and 3% more than the current fleet. The reason behind this is identified as the factor of fuel economy. CNG buses consume more fuel covering the same amount of distance than diesel buses of same conditions. Apart from CO_2, fleet of only diesel buses emit 98% less CH_4 emissions and 85% less N_2O emissions compared to the current fleet of 2017. Hence, it was decided to decommission the CNG buses of high fuel combustion rates and expand the fleet with diesel vehicles having low fuel combustion rates in Projection-II.

Projection-II predicted annual 1.8% decrease in CO_2 emissions, 2.7% decrease in CH_4 emissions and 2.6% decrease in N_2O emissions. Total emissions of 250.2 kilotons of CO2 eq. in 2017 is observed to decrease to 203.2 kilotons of CO_2 eq., exhibiting a decrease of 19% in 2027. From 2017 to 2027, the amount of consumed diesel oil increased 24%, the amount of CNG consumed decreased 23%. The cost of fuel decreased 12%, receding to 165,579,315 TL.

Examining both predictions, it is deduced that if the current trend in fuel use and fleet expansion maintains its course, in 2027 the amounts of CO_2, CH_4 and N_2O emissions will extend all the way to 179.3 kilotons, 4.9 kilotons and 0.07 kilotons, respectively. With the addition of 50 electric buses corresponding to 3% of the current fleet and adding 30 more each year which is only 1.8% of the current fleet along with altering fuel use patterns, in a period of ten years, 67 kilotons of CO_2, 2 kilotons of CH_4 and 0.027 kilotons of N_2O emissions will be avoided respectively. By means of combusting less amount of fuel, 88,843,822 TL will be saved in 2027.

Direct greenhouse gas emissions will continue to increase if current trend continues. Ankara needs urgent measures to prevent this increase. Emissions must be reduced through adding electric buses to the fleet, having the aim of equipping the fleet with only electric buses. The capital must set an example both domestically and internationally by equipping its entire vehicle fleet of electric buses. As Projection-II concludes, even only 3% addition with only 1.8% annual increase of electric buses, public transportation will not only benefit the environment by reducing emissions, it will also benefit the community having economic and social benefits through reducing fuel dependency, air pollution and health issues.

The interest in public transportation is not yet at a level that constitutes an alternative to automobiles. The number of individually-owned automobiles has been growing significantly over the years. Ankara takes the first place in having the most automobiles per capita with as much as 252 automobiles per thousand people. In order to decrease automobile dependency, actions towards encouraging public transportation must be taken by the government with the cooperation of local governments, non-governmental organizations and citizens.

Development Plans and NCCAP set out policies and objectives that target emission reduction and encouragement of public transportation; however, the effective implementation of these policies and objectives hasn't been actualized. The lack of facilitated coordination, effective division of responsibilities and data collection among institutions responsible with environmental management are observed to be the underlining causes that preclude the actualization of the policies and objectives. The lack of accuracy in national greenhouse gas inventories ensues from the same reason.

The first step in environmental management must be the clear division of work between institutions; ambiguities in responsibilities must be avoided. The infrastructure that allows the data collection jointly among the institutions must be established. To allow for the use of higher tiers in inventory preparation for road transportation sub-sector emissions, following data must be gathered;

1. **The amount of fuel consumed data by each sector and sub-sector listed in the IPCC Guidelines.** Note that fuel consumed data must be intrinsic to each of these sectors and sub-sectors. For instance, natural gas consumption data for road transportation sub-sector must be the amount of natural gas combusted in road vehicles only; must be distinguished from the amount used in houses or industries.

2. **The amount of fuel consumed data by vehicle type, technology and age.** Vehicles must initially be split into types such as; passenger cars, heavy duty trucks and buses etc. , then each type must be further split into fuel types, age and emission control technologies (euro standards, uncontrolled, catalytic converter, etc.).

3. **Carbon content, NCV, sulfur content, oxidation factor data**. Carbon contents, NCVs, oxidation factors and sulfur contents of ach type of fuel consumed must be determined. Especially carbon content and NCV are used in emission factor calculations; therefore, determination of these data are of significant importance.

4. **Kilometers travelled data.** Kilometer travelled by each fuel and vehicle type, age, emission control technology, operation conditions (e.g. climate) and road type (urban, rural, highway) must be recorded.

5. **Emission factor data.** Emission factors must be determined for each fuel type, vehicle type, age, emission control technology, operating conditions and road type.

6. **Cold start emissions.** The number of starts information must be known for each fuel type, vehicle type, age, emission control technology, operating conditions and road type.

These data must be gathered and reported by the responsible institutions annually. An accessible data-base must be built. Some data such as number of starts and kilometers travelled by passenger cars are harder to reach. An electronic equipment placed inside the vehicles could be designed to record these data and the use of it must be encouraged by legal regulations. In the next five years data collection must be complete and the first proper inventory must be published in 2024, since time is of the essence.

By force of the Paris Agreement, Turkey announced to reduce greenhouse emissions from its 21% rise at the time by 2030. However, the continuous investment on fossil fuel plants is in opposition to actualize the declared target. Greenhouse gas emissions will remain an issue unless prioritization of fossil fuels in the country policies is changed. Also, the emission reduction objectives of NCAAP is observed to be in contrast with the seriousness of the problem that is climate change. NCAAP must be updated to impose restrictions and embody numerical reduction targets for each sector.

Investigating successfully implemented policies of developing and developed countries, following suggestions are made to reduce greenhouse gas emissions due to the excessive dependency on automobiles and to encourage greater use of public transportation;

1. Investments on integrated and sustainable public transportation systems that are people-oriented, safe, comfortable, less time consuming and in coordination with each other should be made.

2. Every establishment, institution, organization, company, university etc. should be legally required to calculate and report its emissions.

3. Emission limit should be imposed on establishments, institutions, organizations, companies, universities etc. Those who exceed the limit should be subjected to deterrent penalties, while those who stay below the limit should be rewarded with a tax reduction.

4. Road transportation must be balanced with other public transportation systems such as subways as well as walking and cycling.

5. Investments on bicycle lanes and pedestrian ways should be made.

6. Parking areas should be reduced and parking fees should be increased.

7. The number of automobiles owned by a household should be controlled. Households owning more than one car should be subjected to high taxes.

8. High taxes should be levied on vehicles of certain ages and using high emission fuels. Taxes for electric vehicles and vehicles using clean fuel should be considerably less.

9. The use of high emission fuels such as gasoline and diesel oil should be restricted.

10. To ease traffic congestion, investment on new roads should not be made since it will only serve as a short term solution. New roads will only result in more automobiles.

11. Car-free urban attraction centers should be established that only enable walking and cycling.

12. Investments on park-and-ride facilities should be made. The vehicle fleet of these facilities should only be composed of electric vehicles.

13. One day of the year should be celebrated as a car-free day and only the use of public transportation should be allowed on this day.

Investments made on people-oriented, reliable public transportation systems that are coordinated with each other, emphasize pedestrian access and safety and promote cycling and walking will not only reduce greenhouse gas emissions but also will make

significant economic and social contributions by means of increasing air quality, easing traffic congestion, improving public health, providing budget balance and time efficiency.

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APPENDICES

Appendix A: Tier 1 CO_2 Emissions Calculation in Detail.

Appendix B: Tier 2 CO_2 Emission Calculation in Detail.

Appendix C: Tier 1 CH4 and N2O Emissions Calculation in Detail.

Appendix D: Tier 3 CH4 and N2O Emissions Calculation in Detail.

Appendix E: Validity of the Emission Factors.

Appendix A -Tier 1 CO_2 Emissions Calculation in Detail

In order to convert fuel sold data to energy units, default NCV and Avogadro's Law is utilized. Avogadro's Law states that the volume of any gas at standard temperature and pressure (STP) is 22.4 L/mol [48]. For fuel sold data, default NCVs and default emission factors, see *Figure 5.1*, *Table 5.1* and *Table 5.2*.

Step by step calculation of Tier 1 CO_2 emission from EGO buses using CNG is as follows:

$$Fuel\ sold = 53{,}216{,}654.17\ m^3 \cdot \left(\frac{1000L}{m^3}\right) \cdot \left(\frac{1\ mol\ NG}{22.4\ L}\right) \cdot \left(\frac{16\ g}{1\ mol\ NG}\right) \cdot \left(\frac{1\ Gg}{10^9\ g}\right)$$

$$= 38.011896\ Gg\ Natural\ gas \quad \text{(A.1)}$$

$$Fuel\ sold = 38.011896\ Gg\ NG \cdot \left(48.0\ \frac{TJ}{Gg}\right) = 1824.57101\ TJ\ Natural\ gas \quad \text{(A.2)}$$

$$Emission = 1824.57101\ \ TJ\ NG \cdot \left(56{,}100\ \frac{kg}{TJ}\right) = 102{,}358{,}433.7\ kg\ CO_2 \quad \text{(A.3)}$$

Step by step calculation of Tier 1 CO_2 emission from EGO buses using diesel oil is as follows:

$$m = \rho \times v \quad \text{(A.4)}$$

Where,

m = Mass in kg

ρ = Density in kg/L ($\rho_{\text{diesel oil}}$ = 0.820 kg/L)

v = Volume in L

$$m = \left(0.820\ \frac{kg}{L}\right) \cdot (7{,}531{,}477.55\ L) = 6{,}175{,}811.591\ kg\ diesel\ oil \quad \text{(A.5)}$$

$$Fuel\ sold = 6{,}175{,}811.591\ kg\ diesel\ oil \cdot \left(\frac{Gg}{10^6 kg}\right)$$

$$= 6.17581\ Gg\ diesel\ oil \quad \text{(A.6)}$$

$$Fuel\ sold = 6.17581\ Gg\ diesel\ oil \cdot \left(43.0\,\frac{TJ}{Gg}\right) = 265.55983\ TJ\ diesel\ oil \quad \text{(A.7)}$$

$$Emission = 265.55983\ TJ\ diesel\ oil \cdot \left(74{,}100\,\frac{kg}{TJ}\right)$$

$$= 19{,}677{,}983.4\ kg\ CO_2 \quad \text{(A.8)}$$

Appendix B –Tier 2 CO_2 Emissions Calculations in Detail

Tier 2 approach requires fuel statistics. For buses using CNG, the chemical composition data guaranteed by Petroleum Pipeline Corporation (BOTAS) are given in *Table B.1*.

Table B.1 Chemical composition of natural gas by molecular percentage [49]

Constituent	Formula	Molecular Percentage
Methane	CH_4	Min. 82%
Ethane	C_2H_6	Max. 12%
Propane	C_3H_8	Max. 4%
Butane	C_4H_{10}	Max. 2.5%
Pentane and other heavy carbons	C_5H_{12}	Max. 1%
Carbon dioxide	CO_2	Max. 3%
Oxygen	O_2	Max. 0.5%
Nitrogen	N_2	Max. 5.5%

Specifications of natural gas used in EGO buses are displayed in Table B.2.

Table B.2 Fuel specifications of natural gas used in EGO buses [49]

Fuel Specifications	
Density (at STP,293 K, 100 kPa)	0.71 kg/m^3
Net Calorific Value	49.085 MJ/kg
Carbon Content	73.98%

The exact composition of the natural gas used in EGO buses is not available. Chemical composition of natural gas is arranged based on data guaranteed by BOTAS and carbon content of the fuel shown in *Table B.3*.

Table B.3 Arranged chemical composition of natural gas based on carbon content.

Constituent	Mol Percentage A	Density (kg/m^3) B	Mass (kg) C=A x B	Carbon Ratio D	Mass of Carbon (kg) E=C x D
Methane	91.50%	0.714	0.65331	12/(12+4)=0.75	0.4899825
Ethane	4.80%	1.339	0.064272	0.8	0.0514176
Propane	1.80%	1.963	0.035334	0.8181818	0.028909636
Butane	0.30%	2.588	0.007764	0.8275862	0.006425379
Pentane	0.09%	2.626	0.0023634	0.833333	0.0019695
CO_2	0.69%	1.963	0.0135447	0.272727	0.003694009
O_2	0.20%	1.428	0.008856	-	-
N_2	0.62%	1.249	0.0077438	-	-
Total	**100%**		**0.7871879**		**0.582398625**

Table B.3 shows that the mass of 1 m^3 of natural gas is 0.7872 kg. The mass of carbon in 1 m^3 of natural gas is 0.5824 kg. The carbon content of natural gas used in EGO buses is therefore:

$$Carbon\ content = (0.5824/0.7872) \times 100 = 73.98\% \quad \text{(B.1)}$$

Country-specific CO_2 emission factor for CNG is then calculated converting to the energy units using NCV (see Table B.2) as follows:

$$Emission\ factor, co_{2_{CNG}} = \left(\frac{44}{12}\right) \cdot \left(\frac{0.7398}{49.085\,\frac{MJ}{kg}}\right) \cdot \left(\frac{10^6\ MJ}{TJ}\right)$$

$$= 55263.31873\,\frac{kg}{TJ} \quad \text{(B.2)}$$

$$Fuel\ sold = 53{,}216{,}654.17\ m^3 \cdot \left(\frac{0.7872\ kg}{1\ m^3 NG}\right)$$

$$= 41{,}892{,}150.16\ kg\ NG \quad \text{(B.3)}$$

$$Fuel\ sold = 41{,}892{,}150.16\ \ kg\ NG \cdot \left(49.085\,\frac{MJ}{kg}\right) \cdot \left(\frac{10^{-6} TJ}{MJ}\right)$$

$$= 2056.27619\ TJ\ Natural\ Gas \quad \text{(B.4)}$$

$$Emission = 2056.27619\ \ TJ\ NG \cdot \left(55263.31873\,\frac{kg}{TJ}\right)$$

$$= 113{,}636{,}646.5\ kg\ CO_2 \quad \text{(B.5)}$$

For buses using diesel oil, fuel statistics are exhibited in Table B.4.

Table B.4 Fuel specifications of diesel oil used in EGO buses [4, 49]

Fuel Specifications	
Density (at STP,293 K, 100 kPa)	829.4 kg/m^3
Net Calorific Value	0.0428435 GJ/kg
Carbon Content	86.261%

Country-specific CO_2 emission factor for diesel oil is calculated converting to the energy units using NCV as follows:

$$Emission\ factor, co_{2_{diesel\ oil}} = \left(\frac{44}{12}\right) \cdot \left(\frac{0.86261}{0.0428435\,\frac{GJ}{kg}}\right) \cdot \left(\frac{GJ}{10^{-3}\ TJ}\right)$$

$$= 73824.5786\,\frac{kg}{TJ} \quad \text{(B.6)}$$

Tier 2 CO_2 emission from EGO buses using diesel oil is then calculated as follows:

$$Fuel\ sold = \left(0.8294\,\frac{kg}{L}\right) \cdot (7{,}531{,}477.55\ L) \cdot \left(0.0428435\ \frac{GJ}{Kg}\right) \cdot \left(\frac{10^{-3}\ TJ}{GJ}\right)$$

$$= \ 267.62653\ TJ\ diesel\ oil \quad \text{(B.7)}$$

$$Emission = 267.62653\ TJ \cdot \left(73824.5786\,\frac{kg}{TJ}\right) = 19{,}757{,}415.8\ kg\ CO_2 \quad \text{(B.8)}$$

Appendix C- Tier 1 CH4 and N2O Emissions Calculation in Detail.

Tier 1 approach uses default values of NCV and emission factor. For default NCVs and default emission factors see *Table 5.1* and *Table 5.2*. Step by step calculation of Tier 1 CH_4 and N_2O emissions from EGO buses using CNG is as follows:

$$Fuel\ sold = 53{,}216{,}654.17 m^3 \cdot \left(\frac{1000\ L}{m^3}\right) \cdot \left(\frac{1\ mol\ NG}{22.4\ L}\right) \cdot \left(\frac{16\ g}{1\ mol\ NG}\right) \cdot \left(\frac{Gg}{10^9\ g}\right)$$

$$= 38.011896\ Gg\ Natural\ gas \quad \text{(C.1)}$$

$$Fuel\ sold = 38.011896\ Gg\ NG \cdot \left(48.0 \frac{TJ}{Gg}\right)$$

$$= 1824.57101\ TJ\ Natural\ Gas \quad \text{(C.2)}$$

$$Emission = 1824.57101\ TJ \cdot \left(92 \frac{kg}{TJ}\right) = 167{,}860.5329\ kg\ CH_4 \quad \text{(C.3)}$$

$$Emission = 1824.57101\ \ TJ \cdot \left(3 \frac{kg}{TJ}\right) = 5473.71303\ kg\ N_2O \quad \text{(C.4)}$$

Step by step calculation of Tier 1 CH_4 and N_2O emissions from EGO buses using diesel oil is as follows:

$$m_{diesel} = \left(0.820\ \frac{kg}{L}\right) \cdot (7{,}531{,}477.55\ L)$$

$$= 6{,}175{,}811.591\ kg\ diesel\ oil \quad \text{(C.5)}$$

$$Fuel\ sold = 6{,}175{,}811.591\ \ kg\ diesel\ oil \cdot \left(\frac{Gg}{10^6 kg}\right) \cdot \left(43.0 \frac{TJ}{Gg}\right)$$

$$= 265.5599\ TJ\ diesel\ oil \quad \text{(C.6)}$$

$$Emission = 265.5599\ \ TJ\ diesel\ oil \cdot \left(3.9 \frac{kg}{TJ}\right) = 1035.68361\ kg\ CH_4 \quad \text{(C.7)}$$

$$Emission = 265.5599\ \ TJ\ diesel\ oil \cdot \left(3.9 \frac{kg}{TJ}\right) = 1035.68361\ \ kg\ N_2O \quad \text{(C.8)}$$

Appendix D- Tier 3 CH4 and N2O emissions Calculation in Detail.

To the author's knowledge, there's not yet a method of calculating CH_4 and N_2O emission factors. Meaning, CH_4 and N_2O emission factors are not calculated but measured.

In order to make more accurate calculations, default CH_4 and N_2O emission factors provided by 2006 IPCC Guidelines are rearranged based on fuel economy values of the buses with different models and years. Default CH_4 and N_2O emission factors are exhibited in *Table D.1*.

Table D.1 Default CH_4 and N_2O emission factors (mg/km) [32]

Vehicle Type	N2O Emission Factor	CH4 Emission Factor
Light Duty Vehicles		
Methanol	39	9
CNG	27-70	215-725
LPG	5	24
Ethanol	12-47	27-45
Heavy Duty Vehicles		
Methanol	135	401
CNG	185	5983
LNG	274	4261
LPG	93	67
Ethanol	191	1227
Buses		
Methanol	135	401
CNG	101	7715
Ethanol	226	1292

In 2006 IPCC Guidelines, it is stated that emission factors are derived using fuel density and fuel economy values [32]. To elaborate further, emission factors in g/kg are multiplied by the density of the fuel in kg/L, then divided by the fuel economy in km/L to obtain emission factors in mg/km [50].

For buses using CNG:

The assumed fuel consumption value listed in the 2006 IPCC Guidelines for vehicles using natural gas as fuel is 9 km/L [32]. Hence, default emission factors in *Table D.1* are multiplied by the assumed fuel consumption value of 9 km/L, then divided by the

actual fuel consumption values of EGO buses. The adjusted emission factors are introduced in *Table D.2*, for fuel consumption values of EGO buses see *Table 5.5*.

Table D.2 CH4 and N2O emission factors for CNG buses distributed by model and year

Year	Model	Fuel Economy (km/L)	Emission Factor (mg/km)	
			N_2O	CH_4
2007	MAN Solo	1.38889	654.47948	49993.16001
2008	MAN Solo	1.38889	654.47948	49993.16001
2009	MAN Solo	1.38889	654.47948	49993.16001
2010	MAN Solo	1.38889	654.47948	49993.16001
2011	MAN Solo	1.38889	654.47948	49993.16001
2012	MAN Articulated	1.05263	863.5513	65963.34895
2013	MAN Articulated	1.05263	863.5513	65963.34895

Tier 3 CH_4 and N_2O emissions are calculated multiplying total distance travelled in a year by the vehicle with the appropriate emission factor. For distance travelled data, see *Table 5.4*.

CH_4 and N_2O emissions from MAN Solo 2007 buses using CNG are calculated as follows:

$$Emission_{CH_4} = 13{,}805{,}972\ km \cdot \left(49993.16001 \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 690{,}204.1673\ kg\ CH_4 \quad \text{(D.1)}$$

N_2O emission is calculated repeating the same steps as CH_4 emission calculation using the N_2O emission factor instead of CH_4 emission factor.

$$Emission_{N_2O} = 13{,}805{,}972\ km \cdot \left(654.47948 \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 9035.72538\ kg\ N_2O \quad \text{(D.2)}$$

CH_4 and N_2O emissions for all models and years can be calculated repeating the same calculations plugging in the respective values.

For buses using diesel oil:

Guidelines list default fuel economy for diesel oil as 5 km/ L. Default emission factors in the Guidelines are adjusted to reflect more accurate values in the same manner with the buses using CNG. Default and adjusted CH_4 and N_2O emission factors for buses using diesel oil are exhibited in *Table D.3* and *Table D.4*, respectively.

Table D.3 Default CH4 and N2O emission factors for diesel urban buses [32]

Vehicle Type	Vehicle Technology	Fuel	Emission Factor (mg/km)	
			N_2O	CH_4
Heavy Duty Truck & Bus	GVW<16t*	Diesel Oil	30	85
	GVW>16t	Diesel Oil	30	175
	Urban Buses	Diesel Oil	30	175
Notes: *GVW: Gross Vehicle Weight				

Table D.4 Adjusted CH4 and N2O emission factors for diesel buses distributed by model and year

Year	Model	Fuel Economy (km/L)	Emission Factor (mg/km)	
			N_2O	CH_4
1999	Mercedes Solo	2.04082	73.49987	428.74923
1999	Mercedes Articulated	1.25	120	700
2006	MAN Solo	2.04082	73.49987	428.74923
2012	Mercedes Articulated	1.63934	91.50024	533.75139
2013	Mercedes Articulated	1.63934	91.50024	533.75139

Tier 3 CH_4 and N_2O emissions from diesel buses are calculated repeating the same steps as CNG buses; by multiplying total distance travelled in a year by the vehicle with the appropriate emission factor. For distance travelled data, see *Table 5.4*.

CH_4 and N_2O emissions from Mercedes Articulated 2012 buses using diesel oil are calculated as follows:

$$Emission_{CH_4} = 7{,}102{,}982\ km \cdot \left(533.75139 \frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 3{,}791.2265\ kg\ CH_4 \qquad \text{(D.3)}$$

$$Emission_{N_2O} = 7{,}102{,}982\ km \cdot \left(91.50024\,\frac{mg}{km}\right) \cdot \left(\frac{kg}{10^6\ mg}\right)$$

$$= 649.9246\ kg\ N_2O \tag{D.4}$$

CH_4 and N_2O emissions for all models and years can be calculated repeating the same steps plugging in the respective values.

Appendix E- Validity of Emission Factors.

Emission factors have a significant role in emission calculations. CO_2 emission factors are influenced by the carbon content of the fuel and not the combustion process itself. Tier 1 approach takes account of pre-determined averaged carbon content of the fuels. Tier 2 approach is similar with Tier 1 approach. Distinctively, Tier 2 CO_2 emission factors accounts for the carbon content of the fuel consumed in a specific country, which is Turkey in this case. The comparison of Tier 1 and Tier 2 CO_2 emission factors is exhibited in *Table E.1*.

Table E.1 Default CO_2 emission factors vs. country-specific CO_2 emission factors

Fuel Type	Default CO_2 EF(kg/TJ)			Country-specific EF(kg/TJ)
	Default	Lower	Upper	
Gas/ Diesel Oil	74,100	72,600	74,800	73824.5786
CNG	56,100	54,300	58,300	55263.31873

Table E.1 indicates the lower and upper limits of default CO_2 emission factors. It is seen that calculated country-specific emission factors for both diesel oil and CNG lie between the intervals given in *Table E.1*. Hence if fuel statistics are unavailable, default CO_2 emission factors can be used in CO_2 emission calculations; however, instead of using the default, emission factors should be selected between the intervals in line with the domestic fuel quality.

Dissimilar to CO_2 emission factor, CH_4 and N_2O emission factors primarily depend on vehicle and combustion technology. Tier 1 CH_4 and N_2O emission factors are fuel based averaged default emission factors whereas calculated Tier 3 CH_4 and N_2O emission factors account for vehicle and combustion technology. Hence, fuel based Tier 1 emission factors should not be used in emission calculations. IPCC Guidelines also offer default CH_4 and N_2O emission factors for emissions calculated using VKT method. *Table E.2* and *Table E.3* display the comparison of VKT based default CH_4 and N_2O emission factors and Tier 3 CH_4 and N_2O emission factors.

Table E.2 Default CH_4 and N_2O emission factors [32]

Buses	N2O Emission Factor	CH4 Emission Factor
CNG	101	7715
Diesel Oil	30	175

Table E.3 Tier 3 CH_4 and N_2O emission factors

Year	Model	Emission Factor (mg/km)	
		N_2O	CH_4
2007	MAN Solo	654.47948	49993.16001
2008	MAN Solo	654.47948	49993.16001
2009	MAN Solo	654.47948	49993.16001
2010	MAN Solo	654.47948	49993.16001
2011	MAN Solo	654.47948	49993.16001
2012	MAN Articulated	863.5513	65963.34895
2013	MAN Articulated	863.5513	65963.34895
1999	Mercedes Solo	73.49987	428.74923
1999	Mercedes Articulated	120	700
2006	MAN Solo	73.49987	428.74923
2012	Mercedes Articulated	91.50024	533.75139
2013	Mercedes Articulated	91.50024	533.75139

From *Table E.2* and *Table E.3*, it is seen that there is a large gap in values of default and calculated CH_4 and N_2O emission factors. This is due to the fact that default emission factors are averaged for certain vehicle technologies and emission control technology, vehicle technology and operating conditions significantly affect CH_4 and N_2O emission factors. Emission factors vary as the technologies applied vary.

IPCC states in 2006 Guidelines that default emission factors are calculated with assumed fuel consumption values of 9 km/L for natural gas vehicles and 5 km/L for diesel vehicles. However, the fuel consumption value of CNG EGO buses range from 1.05 km/L to 1.39 km/L, while for diesel buses, it ranges from 1.25 km/L to 2.04 km/L. EGO buses consume much more fuel than the assumed fuel consumption in the Guidelines.

It is highly encouraged by the IPCC Guidelines to use higher tiered emission factors in emission calculations and tables included in this section exhibit a clear example.

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