ESTIMATION OF CARBON FOOTPRINT: A CASE STUDY FOR MIDDLE EAST TECHNICAL UNIVERSITY

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ABSTRACT

ESTIMATION OF CARBON FOOTPRINT:
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As the amount of the greenhouse gas emission increases, its effect on climate change becomes accordingly important. This fact is proved by the measurements conducted by NASA in terms of mole fraction of CO_2. After 1950's due to rapid rise in industrial activity of post-industrial revolution period, CO_2 amount in the air increased constantly. Atmospheric concentration of CO_2 increases at an accelerating rate (APPENDIX – A). In year 2014, the CO_2 emission value had reached 398.78 ppm. This increase led the investigators to estimate the carbon footprint of daily activities as well as industrial activities. There are many initiatives dealing with the estimation of the carbon footprint due to its critical role in the sustainability which is a way of finding optimal solution for living by considering all economic, social, and environmental aspects of life. Measurement and analysis of carbon footprint is not a new topic however, the methodology and systematic approach is necessary within today's context.

The aim of this thesis is to estimate total carbon footprint of the Middle East Technical University Campus Area in Ankara, consisting of man-made university facilities together with artificial forest and a natural lake. Several carbon emitting activities such as transportation, use of electricity, use of natural gas, food consumption are investigated using 14 years data (2000-2014). METU Forest treated as sink of carbon dioxide and 57.415,72 tons of CO_2 is absorbed until 2007. Although, in the beginning of the thesis, Lake Eymir also assumed as a sink, the research showed that, it is not.

It is seen that the major carbon dioxide emission source in 14 years shifts from natural gas consumption to transportation related activities. Investigations show that the main reason is the energy savings activities in the heating system. In 2014, carbon dioxide emission shares of electricity consumption, transportation related activities, natural gas consumption for heating, and nutritional needs are 40%, 31%, 25% and 4% respectively.

In year 2014, 1815,96 kg CO_2 / capita and 91,67 kg CO_2 / m^2 is calculated at METU Campus in Ankara as the result of deterministic approach. In order to account for the uncertainty in some of the variables the Monte Carlo Simulation was performed. Results show that with 10% probability 50.142.789,54 kg CO_2, 50% probability 53.718.530,31 kg CO_2 is emitted to the atmosphere in year 2014. Most likely with 90% probability the total CO_2 56.036.497,75 kg of CO_2 is emitted to the atmosphere by METU Campus Ankara Facility.

Keywords: Carbon footprint, Campus sustainability, CO_2 emissions, Middle East Technical University Ankara Campus

ÖZ

KARBON AYAK İZİ KESTİRİMİ:
ORTA DOĞU TEKNİK ÜNİVERSİTESİ İÇİN BİR ÇALIŞMA

Turanlı, Ayşe Merve
Yüksek Lisans, Petrol ve Doğal Gaz Mühendisliği
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Sera gazı emisyon miktarları arttıkça iklim değişikliğindeki etkisi daha belirgin hale gelmeye başlamıştır. Bu durum NASA tarafından yapılan mol oranı cinsinden CO_2 ölçümleriyle kanıtlanmıştır. 1950 senesinden sonra sanayi devrimiyle birlikte havadaki CO_2 miktarı sürekli artış göstermiştir. Atmosferdeki CO_2 miktarı yıllar içerisinde ivmeli bir artış göstermiştir (APPENDIX – A). 2014 senesi itibari ile CO_2 emisyon miktarı 398.78 ppm seviyesine yükselmiştir. Bu durum araştırmacıları hem gündelik faaliyetlerin hem de sanayi faaliyetlerinin karbon ayakizini tahminleme çalışmalarına yöneltmiştir. Karbon emisyon miktarının ölçülmesi ile ilgili bir çok girişim bulunmaktadır. Bunun başlıca sebebi; karbon ayakizi ölçümünün aynı zamanda ekonomik, sosyal ve çevresel boyutları göz önünde bulundurarak optimal bir yaşam tarzı bulma yolu olarak değerlendirilebilecek olan sürdürülebilirlik içinde önemli bir parametre olmasıdır.

Bu tezin amacı, Orta Doğu Teknik Üniversitesi için toplam karbon ayakizini hesaplamaktır. Ulaşım, elektrik kullanımı, doğal gaz kullanımı, yemek tüketimi gibi karbon salan faaliyetler 2000-2014 seneleri arasında incelenmiştir. Ormanlık alanlar CO_2 dengeleyici faaliyetler olarak değerlendirilmiştir ve 2007 senesine kadar 57.415,72 ton CO_2 emilmiştir. Tezin başlangıcında, Eymir Gölü CO_2 dengeleyici faaliyetler arasında

değerlendirilmiş ancak araştırmalar gölün CO_2 dengeleyici faaliyetler arasında yer almadığını göstermiştir.

Temel karbon dioksit emisyon kaynağının 14 sene içerisinde doğal gaz tüketiminden ulaşım aktivitelerine kaydığı gözlemlenmiştir. Araştırmalar bunun ana sebebinin ısıtma sistemindeki enerji tasarrufu çalışmaları olduğunu göstermiştir. 2014 senesi için elektrik tüketimi, ulaşım, doğal gaz tüketimi ve beslenme ile alakalı tüketimlerin karbon dioksit emisyonuna katkısı sırasıyla; %40, %31, %25 ve %4'dür

2014 senesi Ankara ODTÜ Kampüsünde, seçilen emisyon kaynakları kullanılarak kişi başı 1815,96 kg CO_2 ve metrekareye 91,67 kg CO_2 düştüğü hesaplanmıştır. Bazı verilerdeki belirsizliklerin etkisini görmek üzere Monte Carlo Simulasyonu uygulanmıştır. Sonuçlara göre 2014 senesi için %10 olasılıkla 50.142.789,54 kg CO_2, %50 olasılıkla 53.718.530,31 kg CO_2 emisyonu atmosfere salınmıştır. En iyi ihtimalle %90 olasılıkla ODTÜ Ankara Kampusünden salınan emisyon miktarı toplam 56.036.497,75 kg'dir.

Anahtar Kelimeler: Karbon ayak izi, Kampüs sürdürülebilirliği, CO_2 emisyonu, Orta Doğu Teknik Üniversitesi Ankara Kampüsü.

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To My Beloved Angels

"There is a life in you, search that life,

Search the secret jewel in the mountain of your body,

Hey you, the passing away friend, look for with all your strength,

Whatever you are looking for, look in yourself not around."

Mevlana

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LEGENDS

APPA	: Association of Physical Plant Administrators
CDD	: Cooling Degree Days
CEF	: Carbon Emission Factor
CFC	: Chlorofluorocarbons
CO_2	: Carbon Dioxide
EIO	: Economic Input Output
EPA	: US Environmental Protection Agency
HDD	: Heating Degree Days
IPCC	: Intergovernmental Panel on Climate Change
IR	: Infrared
LCA	: Life Cycle Assessment
UNFCCC	: United Nations Framework Convention on Climate Change
VMT	: Vehicle Miles Traveled
WWF	: World Wide Fund

CHAPTER 1

INTRODUCTION

Human activities vastly affect the natural balance of the earth. The magnitude of this effect can be described by a term called "climate change". The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer." It refers to any change in climate over time caused by natural variability or human activity (IPCC Guidelines for National Greenhouse Gas Inventories, 2006). On the other hand, United Nations Framework Convention on Climate Change (UNFCCC) refers climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (United Nations, 1992). Both of two definitions are consistent about the direct or indirect effects of the anthropological activities.

The climate change and its impacts on earth became more apparent after 1950's due to the rapid rise in industrial activities. Most climate scientists are agreed on the key parameter of climate change is the increasing amount of greenhouse gas concentration in the air. Solomon et al claimed that even if carbon dioxide emission is stopped now, the effects on climate could be reversed in 1000 years' time (Solomon et al, 2009). Another group of scientists defended that a cause-effect chain is triggered by the changes in green house emission amounts ended up with economic damage (Shine K et al, 2005). According to NASA statistics, "the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels for many years and concentration of carbon dioxide has increased from 315.71 ppm in 1956 to 398.78 ppm in 2014. Ocean acidification is caused by the absorption of 30% of the emitted anthropogenic carbon dioxide in the oceans“(NASA Earth Science Communication Team, 2015). All those evidences have proved that the human factor is one of the major factors in rapid rise of greenhouse gas emissions. Additionally, as the greenhouse gas emission amounts continue to rise, the climate change would cause a change in whole climate system. Limiting or at least being aware of the current condition of greenhouse gases become significant as the consequences become dramatically apparent.

Carbon can be found stored as carbon dioxide in the atmosphere (2%), as biomass in land plants and soils (5%), as fossil fuels in a variety of geologic reservoirs (8%) and as a collection of ions in the ocean (85%) (McKinley G., 2009). The major greenhouse gas emitted by the human activities is the carbon dioxide by 54.7% followed by methane with 30%, other gases with 9.8%, nitrous oxide with 4.9%, and fluorinated gases with 0.6% (IPCC Working Group II, 2007).

As stated in IPCC 4th Assessment Report, “increase in CO_2 concentrations can be explained by direct and indirect activities of humankind such as fossil fuel utilization for transportation, heating and cooling, manufacturing and other industrial activities. Other significant human activities can be observed in land management such as deforestation and crop planting.” Carbon dioxide emissions from human activities are considered the single largest anthropogenic factor contributing to climate change (IPCC Working Group II, 2007).

The first step of improvement is to measure the current condition. Carbon dioxide emission which is the most abundant greenhouse gas can be estimated by using the carbon dioxide footprint concept.

The complexity of the calculation of the carbon footprint makes many researchers to deal with estimation of carbon footprint. Organizational activities such as; transportation, electricity consumption, food consumption, manufacturing, paper utilization, cleaning chemicals emit CO_2 gases (Wiedmann T., and Minx J., 2008). Selection of activities and emission factors are significant decisions for carbon accounting due to its complexity.

This thesis will answer what is the estimated amount of carbon footprint in Middle East Technical University (METU) and points the significance of key parameters for carbon footprint.

CHAPTER 2

LITERATURE

In order to understand the carbon footprint, the basics of carbon emissions, calculation methodology, and similar studies should be known. In this respect, this chapter reviews the meaning of carbon footprint, calculation methodologies of carbon dioxide emissions due to transportation, heating, electricity, and food consumption. Moreover, calculation methodology for offsets such as; forests and lake are reviewed.

2.1. Carbon Footprint

Necessity and importance of carbon footprint calculation can be clarified by understanding what is the climate change and its relationship with greenhouse gas emissions especially the most common one; carbon dioxide. According to US Environmental Protection Agency, EPA, *climate change* refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. As stated in Intergovernmental Panel on Climate Change: "the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time". A different perspective, World Bank, defines climate change as" a fundamental threat to development and the fight against poverty." The World Bank Group is concerned that without bold action now, the warming planet threatens to put prosperity out of reach of millions and roll back decades of development. Although the perspective of the two definitions are different, the main subject on which has agreed is the climate change can and should be avoided due to its catastrophic results.

Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and sub-surface ocean temperatures to rise. Temperatures are in fact rising (US Department of State, 2002). The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability."

Infrared active gases, principally water vapor, carbon dioxide, and ozone naturally present in the Earth's atmosphere, absorb thermal IR radiation emitted by the Earth's surface and atmosphere. The atmosphere is warmed by this mechanism. In turn, it emits IR radiation with a significant portion of this energy acting to warm the surface and the lower atmosphere. As a consequence the average surface air temperature of the Earth is about 30°C higher than it would be without atmospheric absorption and re-radiation of IR energy (Ladley T. et al., 1999).

National Aeronautics and Space Administration (NASA) assumes carbon dioxide amount as the key indicator for climate change. Carbon dioxide is an important heat-trapping greenhouse gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions (NASA Earth Science Communication Team, 2015). Even CH_4 and chlorofluorocarbons (CFCs) have a significant importance; their concentration is significantly less than CO_2.

However an opposing view is proposed, it states; "Climate scientists are obsessed with carbon dioxide. The newly released Fifth Assessment Report of the IPCC claims that "radiative forcing" from human-emitted CO_2 is the leading driver of climate change. Carbon dioxide is blamed for everything from causing more droughts, floods, and hurricanes, to endangering polar bears and acidifying the oceans. But Earth's climate is dominated by water, not carbon dioxide"(Goreham S., 2013).

The answer of “what is the carbon footprint exactly?” can be clarified by understanding the footprint concept. According to some perspective, carbon footprint is related to the ecological footprint concept.

Ecological footprint is a resource and emission accounting tool designed to track human demand on the biosphere’s regenerative capacity (Wackernagel M. et al., 1999; Wackernagel M. et al., 2002). According to World Wide Fund (WWF); ecological footprint is the impact of human activities measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated. More simply, it is the amount of the environment necessary to produce the goods and services necessary to support a particular lifestyle. The ecological footprint and bio-capacity are resource flow measures. However, rather than being expressed in tons per year, each flow is expressed in units of area, annually necessary to provide the respective resource flow (Galli A. et al., 2012).

On the other hand; carbon footprint measures the total amount of greenhouse gas emissions that are directly or indirectly caused by an activity or accumulated over the life stages of a product (Wiedmann T. et al., 2006). Despite its name, carbon footprint is not expressed in terms of area. The total amount of greenhouse gases is simply measured in mass units and no conversion to an area unit takes place. Any conversion into a land area would have to be based on a variety of assumptions that would increase the uncertainties and errors associated with a particular carbon footprint estimate (Galli A. et a.l, 2012).

Another definition for carbon footprint is; "A measure of the total amount of carbon dioxide and methane emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest calculated as carbon dioxide equivalent using the relevant 100-year global warming potential" (Wright L. et al., 2011).

For this thesis; carbon footprint is the amount of carbon dioxide emitted to the atmosphere by the anthropogenic activities on METU Campus as electricity, natural gas, food, and transportation minus the sink; forests.

2.2. Carbon Footprint Calculation Methods

Greenhouse gas calculation generally depends on several standards and the guidelines generated by the NGO's or governments such as; Greenhouse Gas Protocol for accounting and reporting, IPCC 2006 Methodologies, ISO Standards, IEA and etc. Selection of the methodology depends on the scope and purpose of the study.

IPCC uses a country based methodology for estimating inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases. Each country have reduction target and report greenhouse gas inventory annually at national level. This methodology has three levels of detail from Tier 1 to Tier 3. The first one, Tier 1, is the basic applicable methodology. IPCC Guidelines for National Greenhouse Gas Inventories provide equations and default parameter values for calculation of carbon footprint. These values are generalized values. In Tier 2, all the parameters used in the calculation are specific to country or the region. The parameters are appropriate to conditions of the country. Tier 3 which is the most detailed one, called as full carbon accounting with high resolution data. All these approaches do not follow a life cycle approach, which is explained below.

Another method is the Life Cycle Assessment Method. This method's utilization at carbon footprint quantification is described by ISO standards 14040 and 14044 (2006) for product or service level, or in ISO standard 14064-1 (2006) for an organization or company level.

Life cycle assessment steps are (Figure 1);

- Definition of the goal and scope of the study,
- Inventory analysis,
- Life cycle impact assessment (LCIA),
- Interpretation

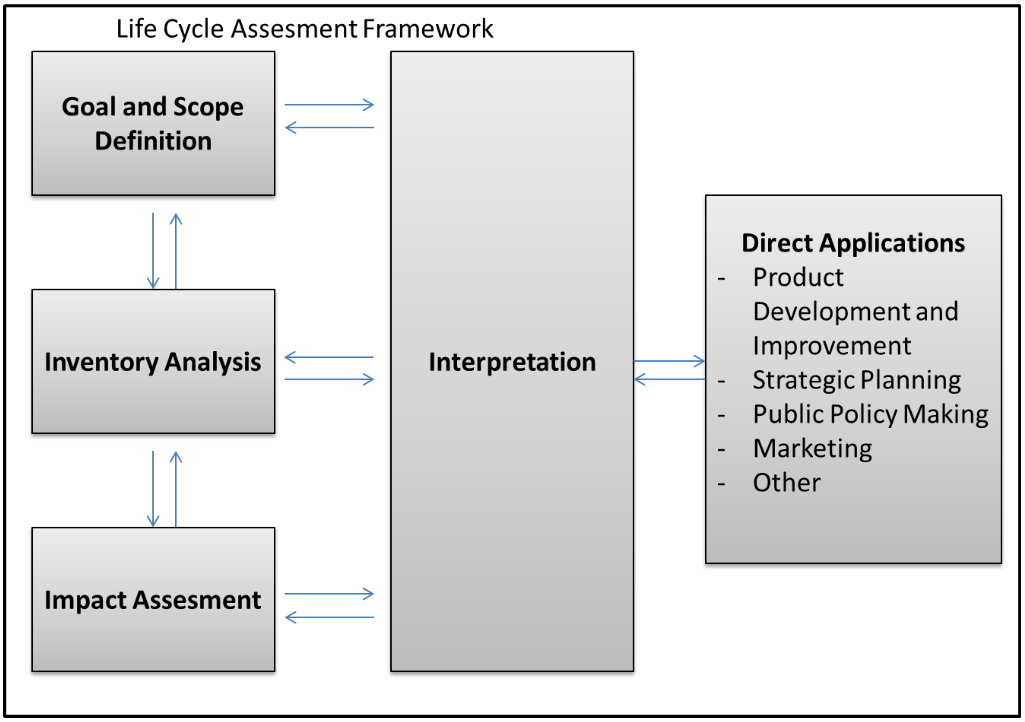

Figure 1 Life Cycle Assessment Framework (ISO Standards 14000 and 14044)

There are two commonly used methodologies for carbon footprint calculation;

1. *Process Analysis Method* aims to identify all the environmental impacts of individual products for a life span. As this method is a bottom-up approach system boundary determination is a critical issue. They suffer from a system boundary problem - only on-site, most first-order, and some second-order impacts are considered (Lenzen M., 2001). This method can be useful in macro or meso levels of calculation.
2. *Environmental Input-Output (EIO) Analysis* provides an alternative top-down approach to carbon foot printing (Wiedmann T. et al., 2006). Economic system acts as a system boundary in such analysis. This analysis works well in micro system levels.

In the light of the literature review, in this thesis the IPCC Tier-1 methodology is utilized.

2.3. Energy Sources

According to IPCC measurements and analysis; the major sector in greenhouse gas emission inventories is the energy sector with approximately 90% share at CO_2 emissions in developed countries. This percentage indicates the importance of energy related CO_2 emissions.

IPCC listed emission source activities as;

- Exploration, exploitation of primary energy sources,
- Conversion of primary energy sources,
- Transmission and distribution of fuels,
- Use of fuels in stationary and mobile applications.

Energy related CO_2 emissions could be understood well by analyzing the World's energy statistics and the shares of the fuel types. Figure 2 shows fuel shares of total primary energy supply.

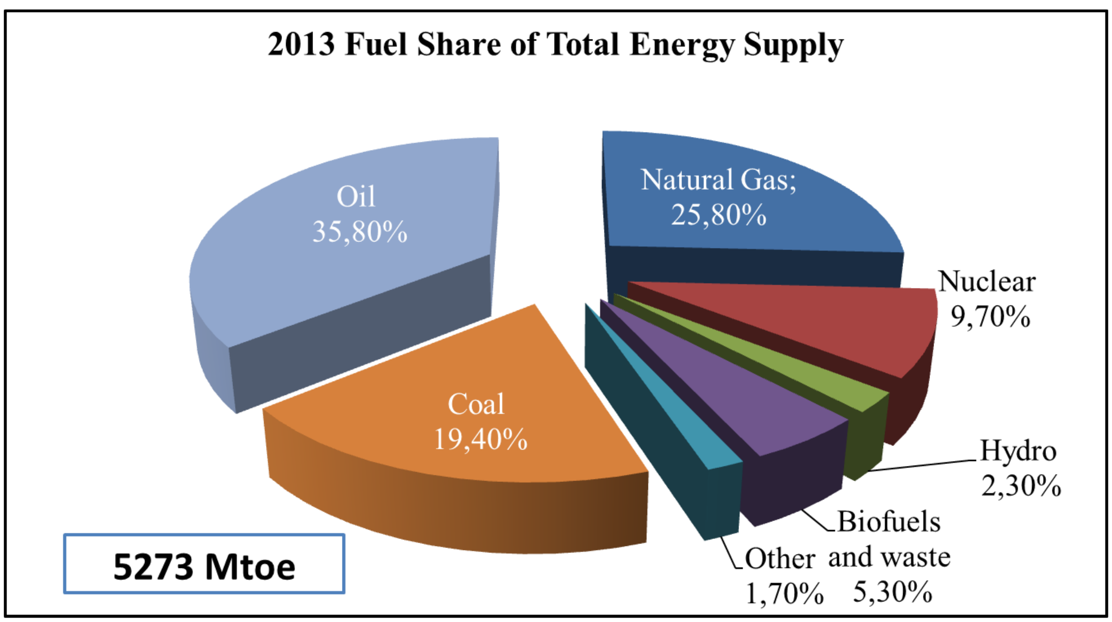

Figure 2 Global Fuel Shares of Total Primary Energy Supply (IEA, 2014)

This distribution is not so different in Turkey; higher portion of the pie chart is shared by hydrocarbon sources (Figure 3).

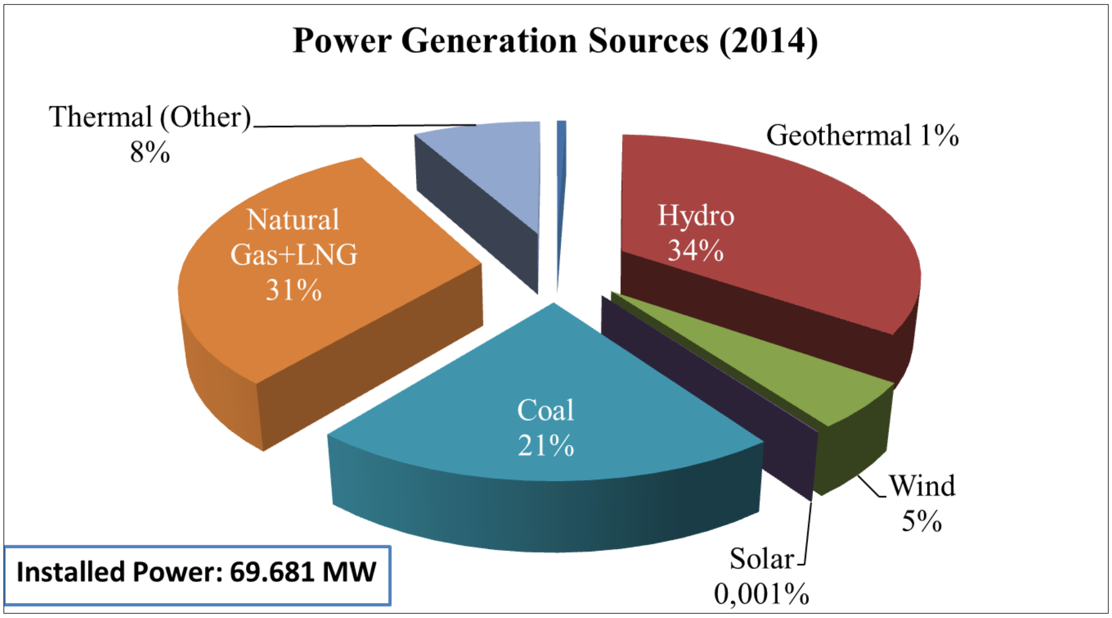

Figure 3 Power Generation Sources for Turkey (TEIAS, 2015)

In this chapter, primary energy source natural gas and secondary energy source electricity are reviewed. For natural gas related calculations, IPCC Guidelines for National Greenhouse Gas Inventories are taken as reference.

Electricity related emissions directly related with the source of production. Thus, country-specific values are necessary at calculations. In this respect, 2012 TUIK National Greenhouse Gas Inventory Report is referenced for electricity calculations. Reported statistics are country specific values such as; population, GDP, electricity consumption, energy production, and CO_2 emissions and CO_2 emission factors.

2.3.1. Primary Energy Sources

2.3.1.1. Natural Gas

Natural gas is formed primarily of methane, it can also include ethane, propane, butane and pentane (Naturalgas.org ,2013). Natural gas is another important energy source and also can be classified as the cleanest fossil fuel when compared with other fossil fuels. However, it is still a source of CO_2 during heat and electricity production. This fact is quantified in the Figure 4.

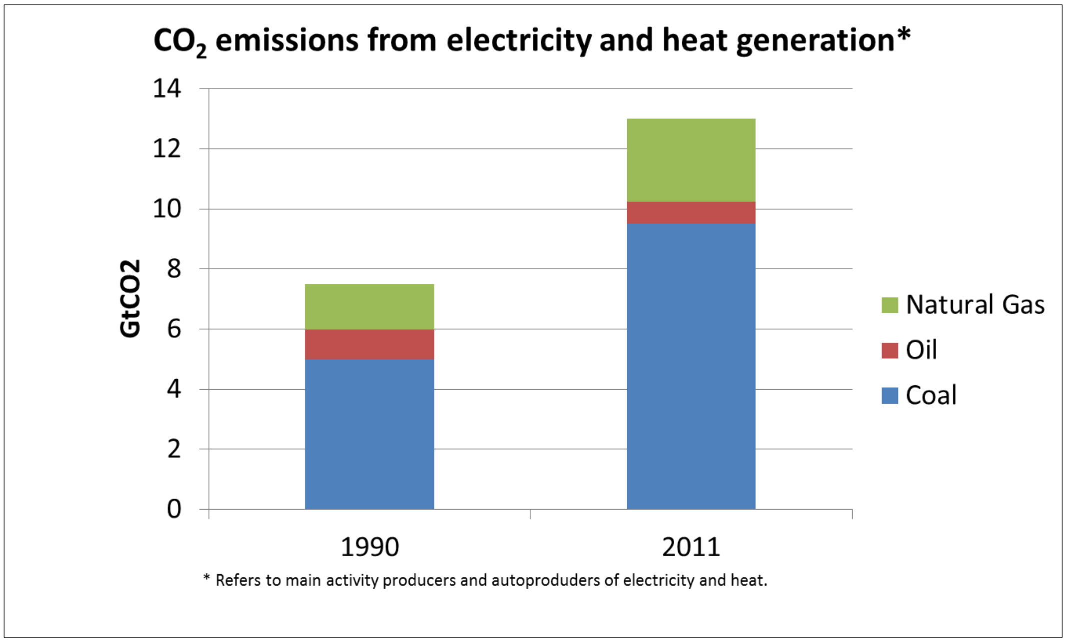

Figure 4 CO_2 emissions from electricity and heat generation (IEA Statistics, 2013)

CO_2 emissions from electricity and heat almost doubled between 1990 and 2011, driven by the large increase of generation from coal (IEA Statistics, 2013).

2.3.2. Secondary Energy Sources

2.3.2.1. Electricity Production

Electricity is the form of energy which is utilized to power machines and electrical devices which are the basic essentials of modern life. According to IEA 2014, Turkey emits 4.04t CO_2 emissions per capita and consumes 2760 kWh electricity per capita. As the economic developments increased, the demand of electricity has been also increased. This demand leads people to find new and more sustainable resources for electricity production hence electricity produced by various sources. These sources can be; fossil fuels such as; coal, natural gas or renewables such as solar, wind, geothermal or other sources such as hydropower and nuclear. Each of those sources produces CO_2 emission during the production of electricity in different amounts.

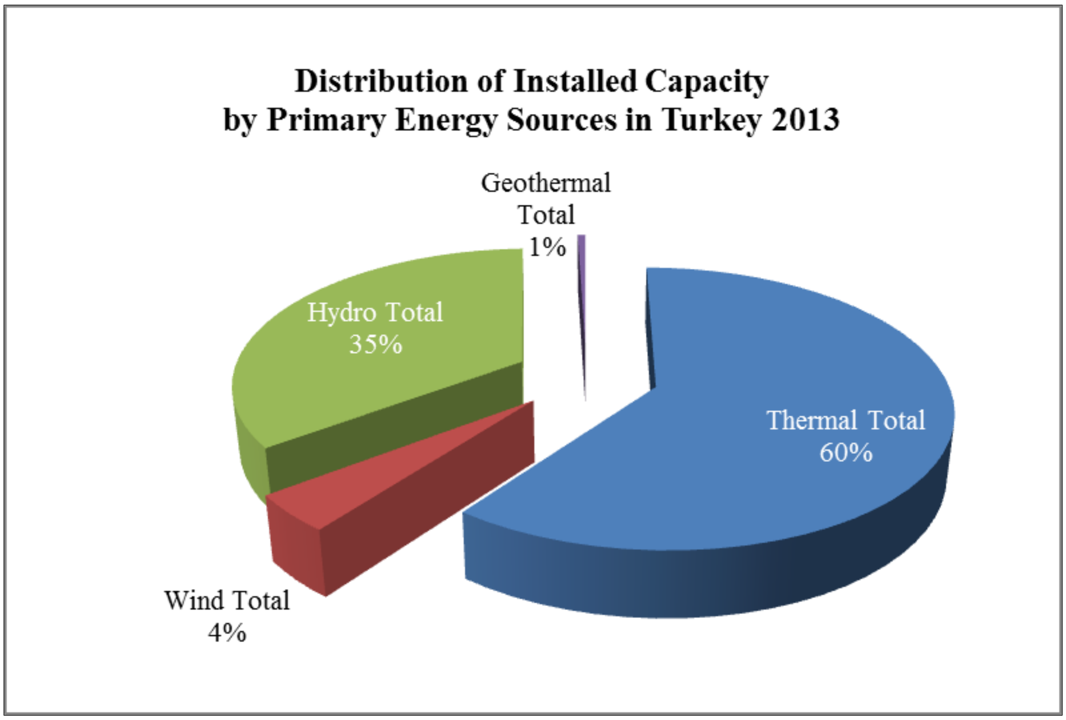

Figure 5 Distribution of sources of electricity (TEIAS, 2013)

Calculation methods for estimation of CO_2 emissions can be differing related to available data and the extent of the study.

One way is to use National Inventory Report reported by TUIK .The National Inventory Report, 2012 contains national greenhouse gas emission estimates for the period 1990-2012. Inventory prepared by a joint work of GHG emission inventory working group including TUIK and Ministry of Energy. The emissions from electricity generation were calculated on the basis of all power plants fuel consumption by the Ministry of Energy.

The other method is designed for grid systems. As the sources of electricity production changes, the emission of each source is different. In this method, the share of each type of fuel and related emission factors became important. Multiplication of the percentage of each source by default emission factor results with a weighted average result.

Turkey has an interconnected electricity distribution system which means the produced electricity can be transferred to another location in case of need. This proves that a shared CO_2 emission factor is needed for calculations.

For power plants the following calculation steps are followed. Fuel consumption determination is the first step of the calculation. The equation can be seen below:

$$FC = FA \times LCV \qquad (1)$$

where;

FC = Fuel consumption (TJ/year)

FA = Fuel amount (kg/year or m^3/year)

LCV = Lower calorific value (kcal/ kg or kJ/m^3)

If fuel amount is not available, dividing the electricity production to average thermodynamic efficiency will give FC:

$$FC = EP \times \eta^{(-1)} \qquad (2)$$

where;

EP = Electricity production (MWh / year)

η = Average thermodynamic efficiency (%)

Carbon dioxide emission is;

$$E = FC \times EF \qquad (3)$$

where;

E = CO_2 emission (kg/year)

EF = CO_2 emission factor (kg CO_2/TJ)

2.4. Transportation

In carbon footprint calculation of a specific area, one of the main criteria is the amount of CO_2 emitted to the atmosphere due to mobility needs of the people. An important factor which causes increments in greenhouse gas due to transportation is the people's demand of to being more mobile. As the fuel technology improves, even the fuel consumption of the unit vehicle is decreasing significantly; the rise in population and improvements in the economy directly cause an increase in the total number of the vehicles (cars, trucks etc.) in the world (IPCC Working Group III, 2007). This rise in the number of the vehicles directly causes an increase in the greenhouse gas emissions. Another factor is globalization which makes people more aware of everything not only in their country borders but also in the other countries. The desire about travelling is growing thus causes an increase in the transportation amounts by means of water, air, and rail. Not only the passenger transportation but also freight transportation increases due to economic developments (WBCSD, 2004).

According to IPCC 4th Assessment Report; 13% share of global greenhouse gas emission is due to transportation. Road, rail, air, and marine transportation constitute primarily sources of transportation related greenhouse gas emissions. Almost all (95%) of the world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel. At OECD Statistics; 61.562,84 thousands tones of CO_2 equivalent, are produced in Turkey by the transportation sector in 2012 while the total CO_2 equivalent value is 439.873,73 thousands tones. These values show that for Turkey transportation share of CO_2 emissions is 13,99% in year 2012.

Greenhouse gas protocol published a guide for calculating CO_2 emissions for mobile sources in 2005 (GHG Protocol, 2005). In line with this guide, "Corporate transportation emissions can take the form of either direct or indirect emissions. Direct emissions refer to only those emissions that are associated with owned or controlled sources, such as company owned vehicle fleets and corporate aircraft. Indirect emissions refer to all other company related emissions, including employee commuting, short-term vehicle rentals, and upstream/downstream transportation emissions, such as those associated with material inputs or consumer use”. In the present work, only direct emissions are considered in the estimation of the carbon footprint caused by transportation.

2.5. Food Production

Food is material consisting essentially of protein, carbohydrate, and fat used in the body of an organism to sustain growth, repair, and vital processes and to furnish energy (Encyclopedia Britannica, online). Another definition for classification of food-chain products is given in the EU foodstuff law (Regulation (EC) No 178/ 2002) which defines foodstuff as any substance or product intended to be, or reasonably expected to ingest by humans. In the respect of this definition two major sources of food supply can be listed as animals and plants. Some foods are obtained directly from plants; but even animals that are used as food supply are feeding with plants (Encyclopedia Britannica, online). In carbon footprint calculation of food sources both plants and animals shall be considered as CO_2 emission sources. Moreover, all of the processes regarding to supply chain of the food should be considered in calculation of carbon footprint of food.

There are many discussions about relationship between dietary choices and the carbon footprint (Carlsson K., 1998; Carlsson K. et al., 2003; Friedl B., 2007; Nef R., 2009). Shifting from an animal-based diet to a plant-based diet suggested as a solution to reduce the climate impacts of food consumption.

Virtanen et al (2011) developed a tool for monitoring the effect of the developments within the food sector, and analyzed Finnish food chain contribution to carbon footprint.

There are several methodologies for estimating the carbon footprint of the food. At macro level, economic input - output model (Suh S. et al., 2004; Hendrickson C. et al., 2006) and at micro level, process-based Life Cycle Assessment (LCA) models of nutritionally balanced standard lunch plates utilized at estimation process. Process-based LCA is mainly concentrated on scientifically analyzing the actual process.

Economic input-output (EIO) model represents the monetary transactions between industry sectors in mathematical form. EIO models indicate what goods or services (or output of an industry) are consumed by other industries (or used as input).

Two potential problems; difficulty of boundary selection and circularity effects can be eliminated by using a combination of economic input-output and life cycle analysis methods. In this method, the bound is very broad and inclusive. Second, since the self-sector transactions are included circularity effects are included in the analysis (Carnegie Mellon University, 2008).

In environmental perspective; model shows how increased demand for output from one sector influences the output of pollutants to the environment.

Another impact analysis method is the “food-mile” approach (Weber et al, 2008). Weber et al (2008) defines “food-miles” as a measure of how far food travels between its production and the final consumer. At the end of study, the effect of food choices found more significant than buying from local markets, which decrease the food miles. Due to limited data, in the present work process LCA Method is used for calculation and CO_2 emission factors are taken from references for the calculation.

2.6. Carbon Dioxide Emission Sink

2.6.1. Forest

Effect of number of trees in world on CO_2 amount is an interesting issue for many scientists. In 1977 Dyson, tried to find an answer to possibility of reversing the rise of CO_2 within few years by shutdown of industrial activities. Alternatives for reversing this rise are discussed in Dyson’s paper. The first alternative is to plant fast-growing trees on a massive scale on marginal land; the other is to grow and harvest swamp-plants and convert them into humus or peat. Both alternatives try to create a carbon bank in the form of trees or peat and unfortunately it is not possible to reverse this rise in the short term (Dyson F.J.,1977).

After, analyzing the effect of number of trees to CO_2 emission amount, the scientists direct their research to concept forest degradation. Deforestation and forest degradation are different terms. Deforestation; human induced conversion of forest to non-forest land uses, is typically associated with large immediate reductions in forest carbon stock, through land clearing. Forest degradation; reduction in forest biomass through non-sustainable harvest or land use practices , can also result in substantial reductions of forest carbon stocks from selective logging, fire and other anthropogenic disturbances, and fuel wood collection (Asner et al., 2005).

The Intergovernmental Panel on Climate Change estimated in 2007 that about 17 percent of greenhouse gas (GHG) emissions, the largest of which is carbon, are from changes in land use, primarily deforestation (IPCC Working Group III, 2007).

IPCC Third Assessment Report concluded that the forest sector has a biophysical mitigation potential of 5.380 $MtCO_2$/year on average up until 2050.

Even it is easier to protect forest or planting tree, measuring the offset of forest is not an easy task. There are several proposed methods; Biome (a large naturally occurring community of flora and fauna occupying a major habitat, e.g. forest or tundra) averages, inventory method, optical remote sensors, very high-resolution airborne optical remote sensors, radar remote sensors and laser remote sensors for estimating the carbon offset.

Steps of "Forest Inventory Method" are listed;

For carbon coniferous tree and broad-leaved tree:

1. *Determine the total(green) weight of the tree*

W = Above-ground weight of the tree in pounds

D = Diameter of the trunk in inches (1 inch=2.54 cm)

H = Height of the tree in feet

For trees with D < 11inch (27.94 cm):

$$W = 0.25D^2H \text{ (pounds)} \qquad (4)$$

For trees with D ≥ 11inch (27.94 cm):

$$W = 0.15D^2H \text{ (pounds)} \qquad (5)$$

2. *Determine the dry weight of the tree*

This is based on an extension publication from the University of Nebraska. This publication has a table with average weights for one cord of wood for different temperate tree species. Taking all species in the table into account, the average tree is 72,5% dry matter and 27,5% moisture. Therefore, to determine the dry weight of the tree, multiply the weight of the tree by 72,5%.

3. *Determine the weight of carbon in the tree*

The average carbon content is generally 50% of the tree's total volume. Therefore, to determine the weight of carbon in the tree, multiply the dry weight of the tree by 50%.

4. *Determine the weight of carbon dioxide sequestered in the tree*

CO_2 is composed of one molecule of carbon and 2 molecules of oxygen. The atomic weight of Carbon is 12,00. The atomic weight of Oxygen is 15,99. The atomic weight of CO_2 is C+2*O=43,99. The ratio of CO_2 to C is 43,99/12,00=3,67. Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3,67.

5. *Determine the weight of carbon dioxide sequestered in the tree per year*

Divide the weight of carbon dioxide sequestered in the tree by the age of the tree. Leoni, Fonseca, and Schöngart (2011) point out the relationship between tree volume (including tree diameter and height) and tree ages in a quantitative approach.

2.6.2. Lakes

Lakes play an important role in carbon cycle, in carbon cycle 3 phases of C; gaseous, dissolved and solid; interact with water. Biotic and abiotic process is occurring in the both presence and absence of the oxygen. Lake chemistry is very different from ocean chemistry.

To assess C processing in lakes, the following mass balance equation was applied:

$$POC_{in} + DOC_{in} + DIC_{in} + DOC_{gw} + DIC_{gw} + TOC_{dep} =$$

$$POC_{out} + DOC_{out} + DIC_{out} + OCs + CO_2flux + \Delta TC_{st}$$

Where TOC is total organic carbon, OC is organic carbon, the subscripted “in” signifies the inflow from the catchment, “gw” is input from groundwater, “dep” is atmospheric wet deposition, “out” is outflow from the lake, “s” is permanent burial in sediment, CO_2 flux is the CO_2 flux between water and atmosphere (positive flux denotes net gas flux from the lake to the atmosphere), and ΔTC_{st} is the change in the pool of C in the lake over each sampling time period (2 weeks to 1 month). POC_{in} and POC_{out} were calculated as the difference of measured TOC and DOC (dissolved organic carbon) from the input and output streams, respectively (Felipe S. et al, 2013).

2.7. Carbon Footprint Studies in Other Universities

In this part of literature review; the carbon footprint estimation studies in different universities and educational units will be outlined. Association of Physical Plant Administrators (APPA) released a comprehensive guideline for reducing carbon footprint in campus. According to APPA, five critical action steps for reducing carbon footprint can be listed as; forming a stakeholder group, provide and maintain a greenhouse gas emission inventory, develop a strategic climate action plan, search for resource investments and implement a tactical plan. Walter Simpson, campus energy officer and co-author of The Green Campus: Meeting the Challenge of Environmental Sustainability (APPA, 2009) states the importance of active involvement of students, faculty, administrators, and staff at creating a green campus. He also, points the important role of facility managers and their team at greening a campus due to their control over physical plants which are the main items that consumes energy. Many factors affecting the campus environmental footprint are under responsibility of managers. This phrase simply summarizes the importance of stakeholders as a whole.

Macalester College (Minnesota, USA) has a study about the transportation related effective carbon emissions and suggests some strategies for reducing total amount of carbon footprint. Macalester University has emitted 2.993 metric tons effective CO_2 due to directly financed air travel in year 2007-2008, represents 15% of overall emissions. According to study; “Relatively little is known about the potential for telecommunication technology to reduce institutional carbon footprints. While digital communication may seem to have the potential to limit trip demand and reduce Macalester’s institutional carbon footprint, closer analysis may reveal the opposite (Cullenward L. et al, 2009). One notable study argues that the substitution of communication for transportation is a widely-held transportation myth (Black W.R., 2001).

Mount Union College has published a sustainability plan to meet the growing concern for sustainability on campus. College has reported the emissions metric tons of CO_2 equivalents for the Fall-Year 2007- 2008. Total estimated value is 15.011 metric tons of CO_2 equivalents. 7,1 metric tons of CO_2 equivalents per full-time enrollment and 14,0 metric tons of CO_2 equivalents per 1000 square feet is estimated in the plan. The estimation is based on the Scope 1 and Scope 2. This means the estimations include the campus owned and purchase related emission sources. Furthermore, campus compared these values with mean for 115 similar four-year residential institutions. The values in terms of metric tons of CO_2 equivalent per full-time enrollment and per 1000 square feet are 7,0 and 11,5 respectively (Mount Union College, 2010).

Colby College (Maine, USA) Climate Action Plan is another practice related to carbon footprint estimation in campus region. This plan states that; "A primary goal of a liberal college education is to develop broadly enlightened individuals prepared to become leaders and innovators who will create solutions to problems and make decisions that will make the world a better place in the future." Young individuals' responsibility for finding solutions for the carbon emission problem is emphasized. University's gross greenhouse gas emissions were 19,170 metric tons equivalent CO_2 in 2009. The interesting part of this work is; emissions peaked around 28,000 metric tons equivalent CO_2 in the early 2000s and in 2003, University began purchasing electricity from 100 percent renewable sources and reducing emissions from electricity purchases to zero (Colby College, 2010).

Colgate University (New York, USA) is another university that has an inventory for carbon emissions. This work is based on Campus Carbon Calculator. There are several universities that used Clean Air-Cool Planet (CA-CP) which is an action-oriented advocacy group that seeks to reduce the threat of global warming. CA-CP tried to produce a standardized greenhouse gas calculator. This non-profit organization Clean Air Cool Planet transferred the carbon footprint calculator to University of New Hampshire. University's gross emissions per full time student were 6.81 metric tons of CO_2 equivalent and 8.14 metric tons of CO_2 equivalent per 1000 square feet. Highest sources of emissions were found to be air travel at 44% of total emissions, fuel oil at 20%, electricity at 9% and faculty and staff commuting at 9% (Colgate University, 2010).

CHAPTER 3

STATEMENT OF PROBLEM

The primary objective of this thesis is to estimate the total carbon footprint of the Middle East Technical University. Concurrently available transportation, electricity consumption, natural gas consumption and food consumption data are selected as key sources of carbon footprint, the METU forest and the Lake Eymir are referred as the key offsets. As the data is limited, regression models are constructed to estimate past and future values.

The main objective of this thesis is to create awareness about carbon footprint due to daily human activities and indirectly about the climate change. Consequences of the human activities to climate can be clarified by quantifying the most abundant greenhouse gas; carbon dioxide emissions. Quantified impact of the daily activities of humankind to atmosphere can be seen directly after this work.

As the main objective is to estimate the carbon footprint, the following steps are followed. The first step is to review the literature for similar studies in foreign universities and in Middle East Technical University. After literature review, key process areas for CO_2 emissions and sink are selected. The scope of the thesis determined according to key process areas and available data. Subsequently, all available data is collected from offices. A significantly important step is the estimating the carbon emission factor for each specific field. All available data and formulations are transferred to Microsoft EXCEL and a user friendly interface is constructed to estimate the total carbon footprint for Middle

East Technical University for 14 years period of time. At the end of the work, the key source with highest CO_2 emission value is determined.

At the end of the study; total carbon footprint of a reputable Turkish Governmental University will be estimated by considering the major parameters and the main reason of the carbon footprint will be detected. Also carbon footprint per person according to years, shares of each emission source will be estimated.

CHAPTER 4

CARBON DIOXIDE EMISSION FACTORS

4.1. Definition of Carbon Dioxide Emission Factors

In the calculation steps of carbon footprint, emission factors share the most critical role for assessing the CO_2 emissions. Emission factor is basically a coefficient that quantifies the emissions or removal of CO_2 per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions (IPCC, 2006).

According to IPCC 2006, choice of the method in calculation of CO_2 emission will affect selection of carbon emission factor. Tier 1 approach uses a default emission factor at calculation, in which several factors do not depend on location of the activity. Tier 2 approach requires a country specific emission factor for the source category and fuel for each greenhouse gas. These emission factors are specific to a country due to differences in fuel type, combustion technology, operating conditions, control technology, quality of maintenance, and age of the equipment used to burn the fuel. As the emission factor is specific to country, the variability is less and more accurate carbon dioxide emission amounts is obtained. Moreover, the uncertainty in calculation is decreased. The last and a more detailed approach Tier 3 calculates emission factor, which includes technology as a variable. Technology refers to combustion process, fuel property or other factors that might influence the calculation results.

Tier 1 and 2 approaches only consider the source of the emission and fuel mix as variable however; Tier 3 addition to source of emission and the used fuel mix, includes the combustion technology in to estimations.

In this thesis, Tier 1 Approach is used due to limitations in the availability of carbon emission factors.

4.2. Calculation of Carbon Dioxide Emission Factors

Carbon dioxide emissions occur by the combustion of fossil fuel and it can be calculated as carbon (CO_2-C) by multiplying the amount of fossil fuel burned by its carbon content and the fraction of the fuel that is oxidized during combustion (Gregg M. and Rotty R., 1984).

<u>Complete combustion of hydrocarbons:</u>

$$\boldsymbol{C_xH_y + \left(x + \frac{1}{4}y\right) O_2 \Leftrightarrow xCO_2 + \frac{y}{2}\, H_2O + \Delta H_r} \qquad (6)$$

where; ΔH_r is the calorific value or the heat released during the reaction.

Carbon content is a parameter, which varies depending on type of fuel. The ratio of carbon content to calorific value is less variable and called as carbon emission factor.

Calorific value of fuel, which is the quantity of heat produced by its combustion, depends on whether the H_2O formed in the liquid or gas phase.

There are two types of calorific value depending on this property:

- **Gross Calorific Value** (Higher Calorific Value or Higher Heating Value) - the water of combustion is entirely condensed and that the heat contained in the water vapor is recovered.
- **Net Calorific Value** (Lower Calorific Value or Lower Heating Value) - the product of combustion contains the water vapor and that the heat in the water vapor is not recovered.

Depending on the hydrogen and the moisture content of the fuel, the gap between net caloric value and gross calorific value can increase.

Mass of carbon in fuel ratio to energy contained in that fuel is reported. This value is multiplied by (44/12) to calculate the CO_2 emission of the fuel. Different fuel types can be compared according to CO_2 emission amounts (Hiete M.et al, 2001).

This thesis focuses on emission factors of fossil fuels used for transportation, electricity production, heating and food production. Also emission factors used for calculation of forest and lake offsets are main concern of the present work.

4.3. Carbon Dioxide Emission Factors (CEF)

In this section, CEFs of natural gas for electricity production and heating purposes, CEFs of gasoline and diesel for transportation and CEFs for food production is compared with references and emission factors are selected for calculation of the total carbon dioxide emission.

a- Transportation:

Crude oil is the unrefined liquid petroleum. All crude oil have carbon content between 83 and 87 wt. % (Speight, 1990). Refined oil is the crude oil, which is subjected to several chemical processes for the removal of some chemical materials such as sulfur, nitrogen, oxygen, and water. These materials are removed due to harmful effects of chemicals to engines or other machineries (BP, website).

Many institutions and countries tried to calculate country specific CEFs of each fuel type. After reviewing the literature Table 1 is obtained for the crude oil and refined oil.

Table 1 Carbon Emission Factor for Crude Oil and Refined Oil (kg CO_2/GJ)

Reference	Crude Oil	Gasoline	Kerosene/ Jet Fuel	Distillate Fuel Oil	Residual Fuel Oil	Diesel	LPG
IPCC 2006[1]	73.3	69.25	71.45	74.01	77.30	74. 1	63.1
US EIA[2]			70.72			74.01	
Greenhouse Gas Emissions and Sinks: 1990 – 2005[2]							57.9
EPA 2009		87.8	97.5		112.7	102.1	56.8

[1]NCV based emission factor, [2] EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007.

As the fuel characteristics are so variable country to country, another CEF calculation approach is to use for generalized calculations. In this approach, vehicle type and fuel consumption amount per km are main factors of emission factors. At the calculation step of carbon dioxide emission amount of private transportation at METU Campus a similar approach is used.

Table 2 summarizes carbon emission factor calculated per vehicle type for US:

Table 2 Vehicle Emission Factors (US EPA 2001)

Vehicle Characteristics		CO_2/km traveled
Vehicle Type	**Liters/100km**	**gram CO_2 / km**
New small gasoline/electric hybrid	4.2	100.1
Small gasoline auto, highway	7.3	175.1
Small gasoline auto, city	9.0	215.5
Medium gasoline auto, highway	7.8	186.8
Medium gasoline auto, city	10.7	254.7
Large gasoline automobile, highway	9.4	224.1
Large gasoline automobile, city	13.1	311.3
Medium Station wagon, highway	8.7	207.5
Medium Station wagon, city	11.8	280.1
Mini Van, highway	9.8	233.5
Mini Van, city	13.1	311.3
Large Van, highway	13.1	311.3
Large Van, city	16.8	400.2
Mid-size, Pick-up Trucks, highway	10.7	254.7
Pick-up Trucks, city	13.8	329.6
Large Pick-up Trucks, highway	13.1	311.3
Large Pick-up Trucks, city	15.7	373.5

Table 2 Continued

Vehicle Characteristics		CO_2/km traveled
Vehicle Type	**Liters/100km**	**gram CO_2 / km**
LPG automobile	11.2	266
Diesel automobile	9.8	233
Gasoline light truck	16.8	400
Gasoline heavy truck	39.2	924
Diesel light truck	15.7	374
Diesel heavy truck	33.6	870
Light motorcycle	3.9	93
Diesel bus	35.1	1034.61

Furthermore, a similar approach is vehicle-mile approach. U.S. Government is defined vehicle miles of travel or vehicle miles traveled as a measurement of miles traveled by vehicles in a specified region for a specified time period (U.S. Department of Transportation, website). Vehicle miles traveled was divided by average gas mileage to determine gallons of gasoline consumed per vehicle per year and emission factor are listed per vehicle type for other GHG's also:

Table 3 Emission Factors by Vehicle Type (Inventory of U.S Greenhouse Gas Emissions and Sinks: 1990 - 2012)

Vehicle Type	CO_2 Factor (kg / unit)	CH_4 Factor (g / unit)	N_2O Factor (g / unit)	Units
Medium and Heavy duty Truck	1.456	0.018	0.011	vehicle-mile
Passenger Car A	0.368	0.018	0.013	vehicle-mile
Light duty Truck B	0.501	0.024	0.019	vehicle-mile
Medium and Heavy duty Truck	0.296	0.0036	0.0022	ton-mile
Rail	0.026	0.0020	0.0007	ton-mile
Waterborne Craft	0.042	0.0004	0.0027	ton-mile
Aircraft	1.301	0.0000	0.0400	ton-mile

b- Electricity Production

i. Coal

The emission factor for CO_2 describes the emissions of CO_2 per unit of energy in coal. According to formation conditions of coal in other words geological conditions, coal can be classified as lignite, subbituminous coal, bituminous coal, or anthracite. It is necessary to determine CEF of coal according to type of coal. Works related to Turkey specific CEFs per coal types are still in progress, thus the global CEF values are used.

World is depended on coal energy with 40% for electricity needs. It is the fastest growing thus the fastest consumed source of energy for 21st century (IEA, 2013).

Table 4 Carbon Dioxide Emission Factor for Coal (kg CO_2 / GJ)

Reference	Bituminous coal	Sub-bituminous coal	Wood, wood waste	Lignite
IPCC, 1996[1]	94.53	94.53 kg CO_2 / GJ		
US EIA			100.44 kgCO_2/ GJ	
EPA 2014 revision	100.28	103.48	98.96	
EPA Base Case 2000	100.10	102,75		231.55

[1] Net Calorific Value based emission factor

The emission factors for other fuel types; fuel oil and natural gas are given in former and latter sections respectively.

c- Heating:

i. Natural Gas

Natural gas is also a main player in energy supply. The CEF values are checked for natural gas from different sources. Although, the composition of natural gas is not so variable, different references are compared (Table 5).

Table 5 Carbon Dioxide Emission Factor of Natural Gas

Reference	Natural gas	Liquefied Natural Gas
IPCC, 1996, Volume 2, Section 1	56.06 kg CO_2 / GJ [1]	
The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Argonne National Laboratory [2]		4.46 kg CO_2/gal
Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005[3]	0.054 kg CO_2/scf	
EPA Winter 1998 Base Case	117 lbs/mmBtu	

[1]Net Calorific Value based emission factor [2]Transportation Technology R&D Center, available online at: http://www.transportation.anl.gov/software/greet/. [3]EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007

CHAPTER 5

STUDY AREA

One of the best practice areas of sustainability are educational institutions. Measurement of carbon footprint is the one of the critical step of assessment of sustainability. Middle East Technical University, one of the best reputable universities in the world, has the opportunity and responsibility to be the pioneer in this area for creating awareness about the current situation of carbon footprint by using appropriate methodologies.

The study area is Middle East Technical University campus which is located in central Anatolia region of Turkey with 39.8914° N, 32.7847° E coordinates. The location map can be seen in Figure 6. The campus includes Lake Eymir and a techno polis area where small and middle enterprises dedicated on research and development are present. Middle East Technical University is one of the largest campuses in the Ankara with approximately 4500 hectares land with the forest area of 3043 hectares, including the Lake Eymir. This area has been forested entirely through the efforts of the University employees and students since early 1960's. Total population of the campus is 26.500 in 2013-2014 academic years. In the calculations, academic personnel, administrative personnel, and students are included. Population of METU techno polis and the METU residents does not counted in the calculations.

Figure 6 Location Map of METU (Google Earth)

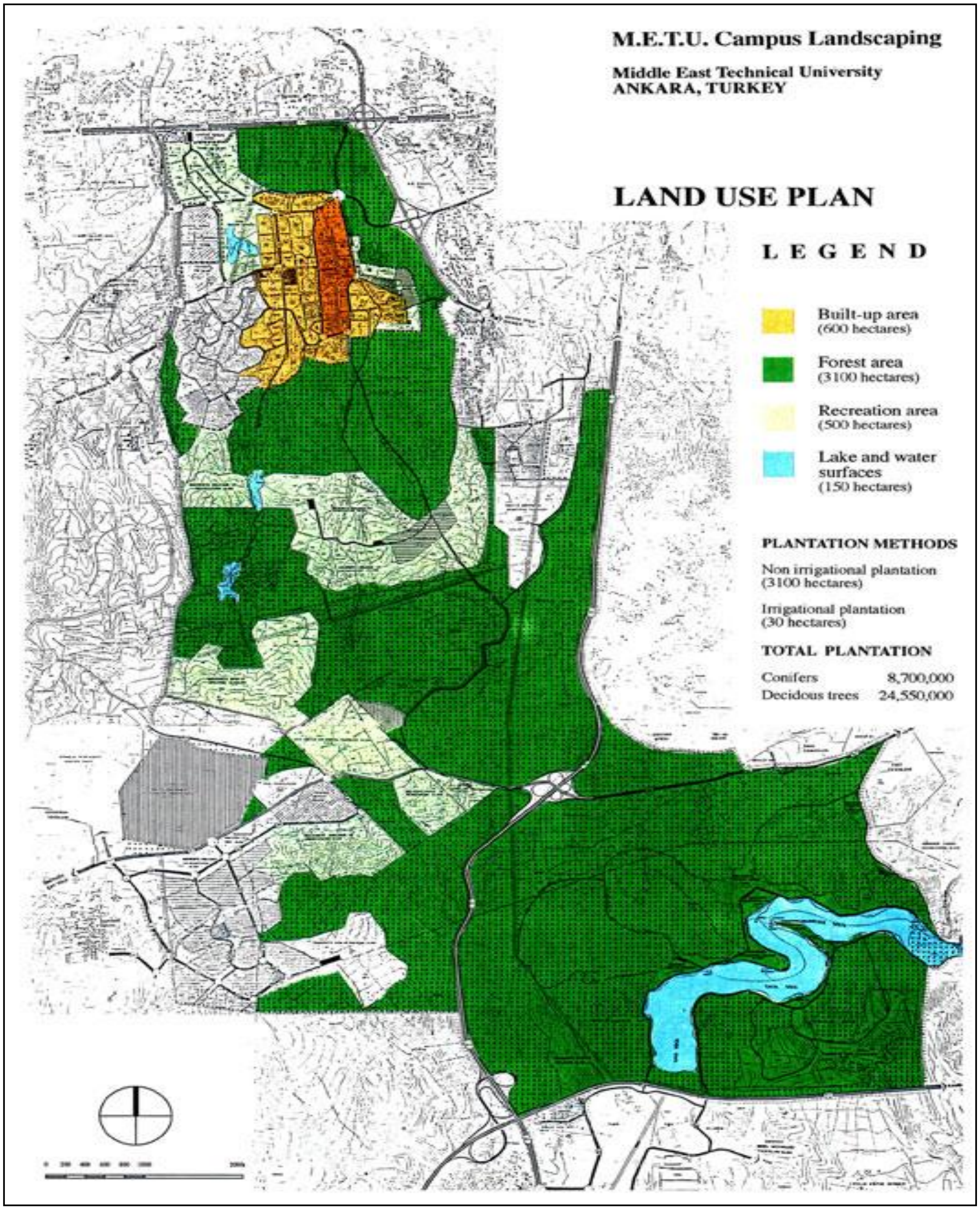

Figure 7 Study Area

Study area will be analyzed according to main contributors to CO_2 emissions;

- Transportation,
- Food Consumption,
- Electricity Usage,
- Heating (Natural Gas) Demand,
- Offsets
    - Forests
    - Lake Eymir

5.1. Earlier Studies Performed in the Study Area

In this section, the studies conducted in Middle East Technical University is presented according to field of study.

The first field is the sustainable transportation in the campus area. In this master thesis Altıntaşı (2013) aimed to assess different scenarios for sustainable transportation at METU. Objective is to suggest a more sustainable transportation system with reduced carbon emissions.

There are two studies related an alternative transportation mode monorail at METU Campus. These initiatives are also indirectly related with sustainable transportation systems which aim to reduce carbon emissions by promoting mass transportation. Comparison of car vs. mass transport carbon footprint measurements is discussed in former sections.

The second field of study is electricity and heating. Throughout in the Özgirgin's thesis (2004), eight different natural gas fired cogeneration power plant designs are developed regarding different gas turbine and steam turbine configurations, for METU Campus. The third field of study is about the Lake Eymir. There are important studies about the hydrological and hydro chemical properties of the lake (Elahdab 2006). Also, Kalvenas (2014) estimated the carbon dioxide flux of the Lake Eymir and Lake Mogan.

The last field is the forestation. There is an extensive study about the tree wealth of the METU Campus. In 2007, METU campus is analyzed in term of number of the trees and the future potential and guide for future works (ODTÜ Amenejman Planı, 2007).

CHAPTER 6

METHODOLOGY OF ESTIMATION CO_2 EMISSIONS FOR METU

In this thesis, 2006 IPCC Guidelines for National Greenhouse Gas Inventories and TUIK National Greenhouse Gas Inventory Report 1990-2012 references are used for calculating the emission factors. As explained in the previous section Tier 1 is selected as the scope of the thesis. The choice of tier is done according to generalized decision tree from IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2007).

There are several requirements, assumptions, and constraints for application process.

The major data are:

- A data related to amount of fuel consumed
- A default emission factor

The main equation is:

$$Emissions_{GHG,\,fuel} = Fuel\ Consumption_{fuel} / Calorific\ Value * Emission\ Factor_{GHG,\,fuel} \tag{7}$$

Where;

$Emissions_{GHG,\,fuel}$ = Emissions of a given GHG by type of fuel (kg GHG)

$Fuel\ Consumption_{fuel}$ = Amount of fuel combusted (kg)

$Calorific\ Value_{fuel}$ = Calorific value of a fuel is a measure of its value for heating purposes (TJ)

Emission Factor GHG, fuel = Default emission factor of a given GHG by type of fuel (kg gas/TJ).

For CO_2, it includes the carbon oxidation factor which is an indication of efficiency of combustion, assumed to be 1 for this study.

Total emission can be calculated by adding all emissions from different fuels:

$$Emission_{GHG} = \Sigma\, Emissions_{GHG,\, fuel} \qquad (8)$$

According to the table found in APPENDIX – B the selected values are summarized in Table 6

Table 6 Emission Factors for Fuel Types Used for METU Study

Fuel	Emission Factor (kg CO_2/ TJ on Net Calorific Basis)
Motor Gasoline	69.300
Diesel Oil	74.100
Natural Gas	56.100

6.1. Calculation Procedure

The first step of the calculation is the collection of necessary data from university's related offices. Those are; Office of Transportation, Office of Central Heating & Water Support, Office of Electrical Works, Office of Forestation & Landscape Planning. Then as a second step, an emission factor for each category was selected.

After necessary unit conversions are applied, multiply consumption data with the relevant emission factor to find total carbon dioxide emission amount of the METU Campus. After calculating the whole data, by using Minitab draw time series graph. Analysis is made to show relationships between time and variables and relationships with each other. Regression models are used to estimate missing data. Goodness of fit (R^2) value is a value to indicate the difference between modeled and actual data. In the thesis, 60% and upper R^2 values are accepted as the model explains the trend sufficiently.

All CO_2 emissions are calculated and the shares of each emission source are analyzed. Furthermore, research is conducted for CO_2 sink and the current situation is presented.

CHAPTER 7

METU STATUS ANALYSIS

As stated in Chapter 6, several key areas for carbon dioxide emissions are selected to analyze the carbon dioxide emission inventory of university and data is collected from the related offices. Scope of calculations is determined by data availability. As there is a limitation in data, regression models are generated and estimated data is reported. Analysis is conducted for the time interval 2000-2014.

7.1. Consumption of Electricity

All electricity demand of METU Campus is provided from the data of electricity purchased each year. Amounts of purchased electricity are provided by Office of Electrical Works (Table 7).

Table 7 Yearly Electricity Consumptions of METU (Office of Electrical Works)

Years	Electricity Consumption (kWh)
2001	19.389.000
2002	12.290.340
2003	12.512.115
2004	17.343.760
2005	25.803.930
2006	21.211.290
2007	19.087.372
2008	26.415.270
2009	28.739.466
2010	32.312.921
2011	32.220.847
2012	34.042.392
2013	32.489.022
2014	33.452.152

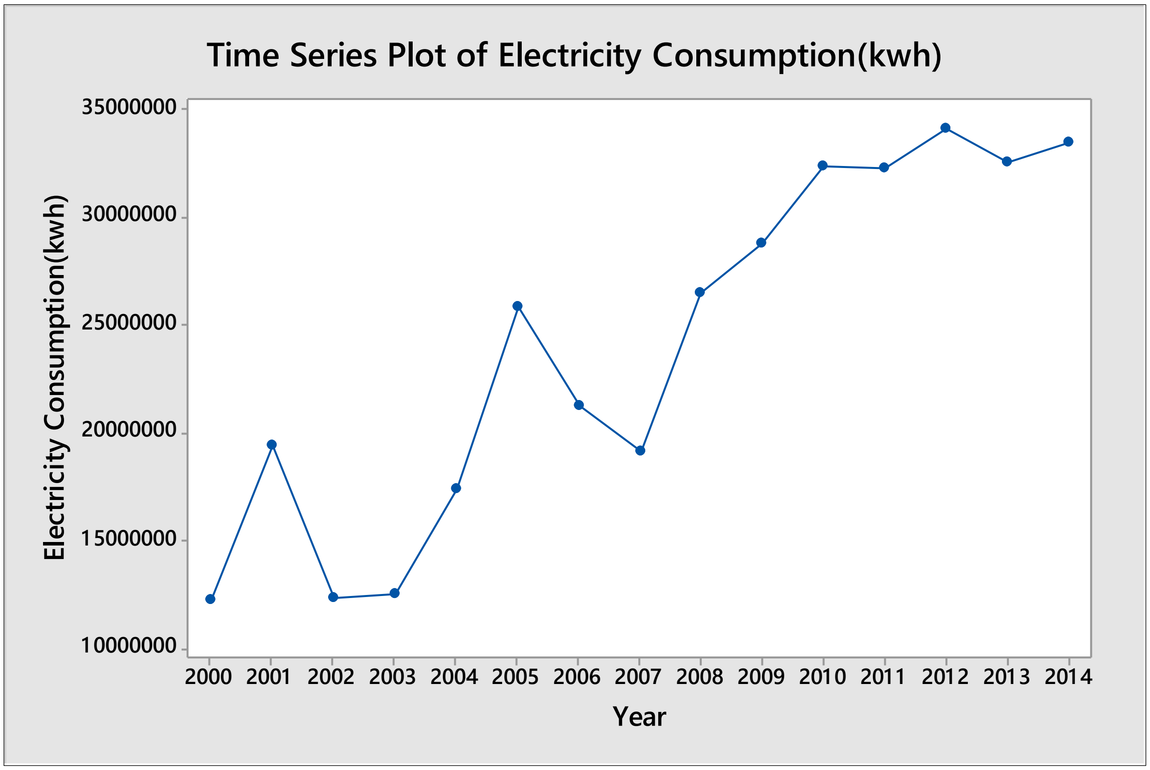

Figure 8 Time Series Plot of Electricity Consumption

In the time series shown in Figure 8, it can be seen 2001 and 2005 are outliers. After private communication with Office of Electrical Works, responsible person stated that the data points at 2001 and 2005 are not expected results thus it can be an error in data recording. However, the relationship between purchased electricity and other factors such as total area and weather conditions are analyzed.

As electricity data of the year 2000 was missing, an estimated value is calculated by using linear regression model. Relationship between electricity consumption and years is analyzed. As the value of goodness of fit (R^2) increases, the difference between actual and estimated values decreases. Goodness of fit test results of regression models; cubic, quadratic, and linear are compared and cubic model is selected as the best fit regression model. Model explains 86,7% of the relationship.

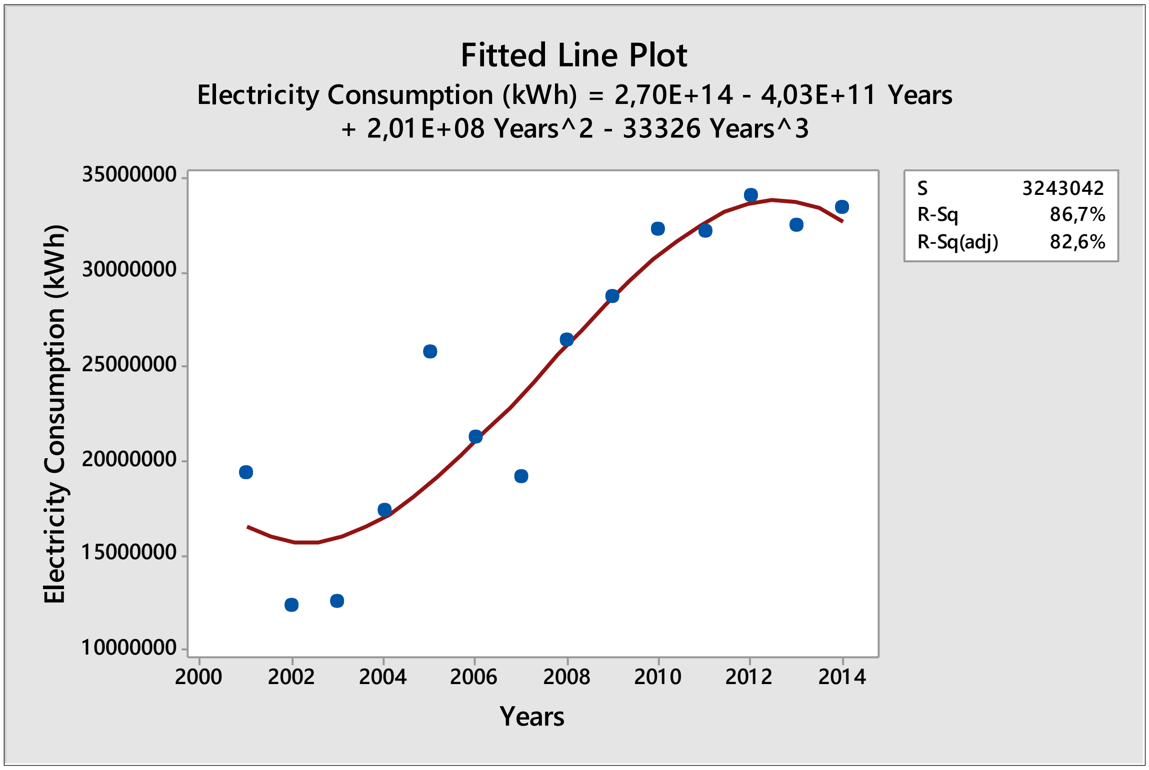

Figure 9 Cubic Regression Model

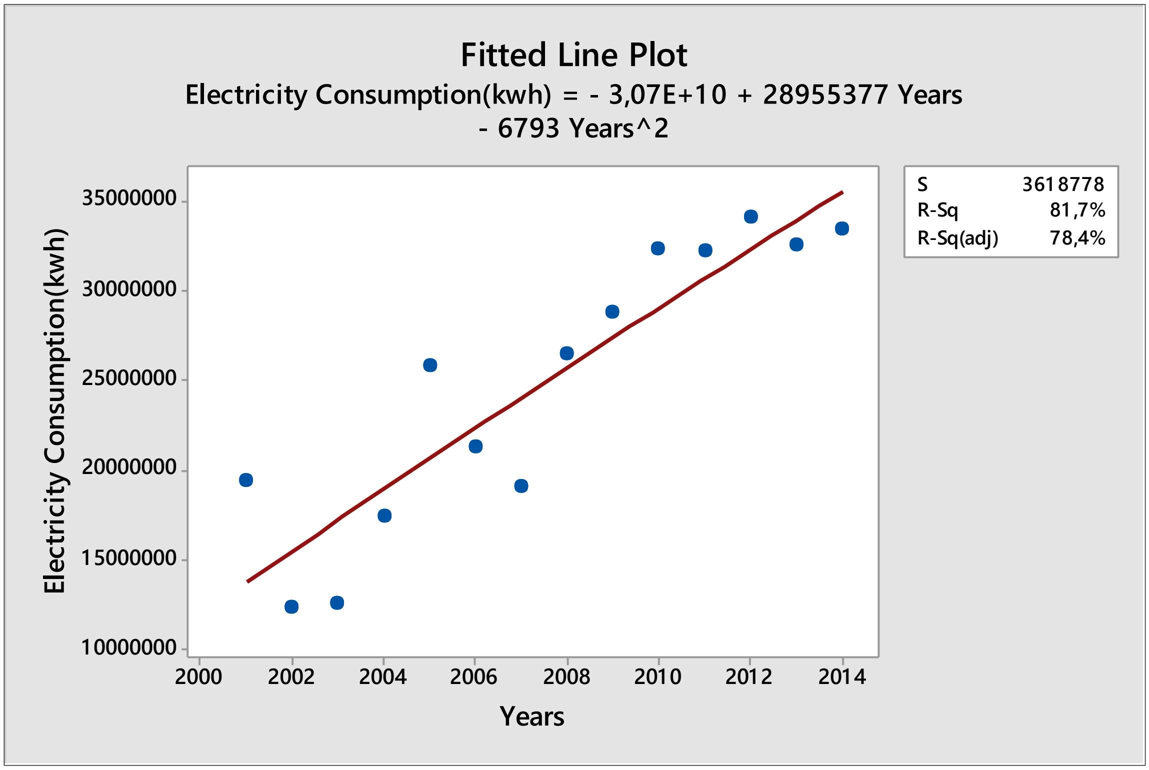

Figure 10 Quadratic Regression Model

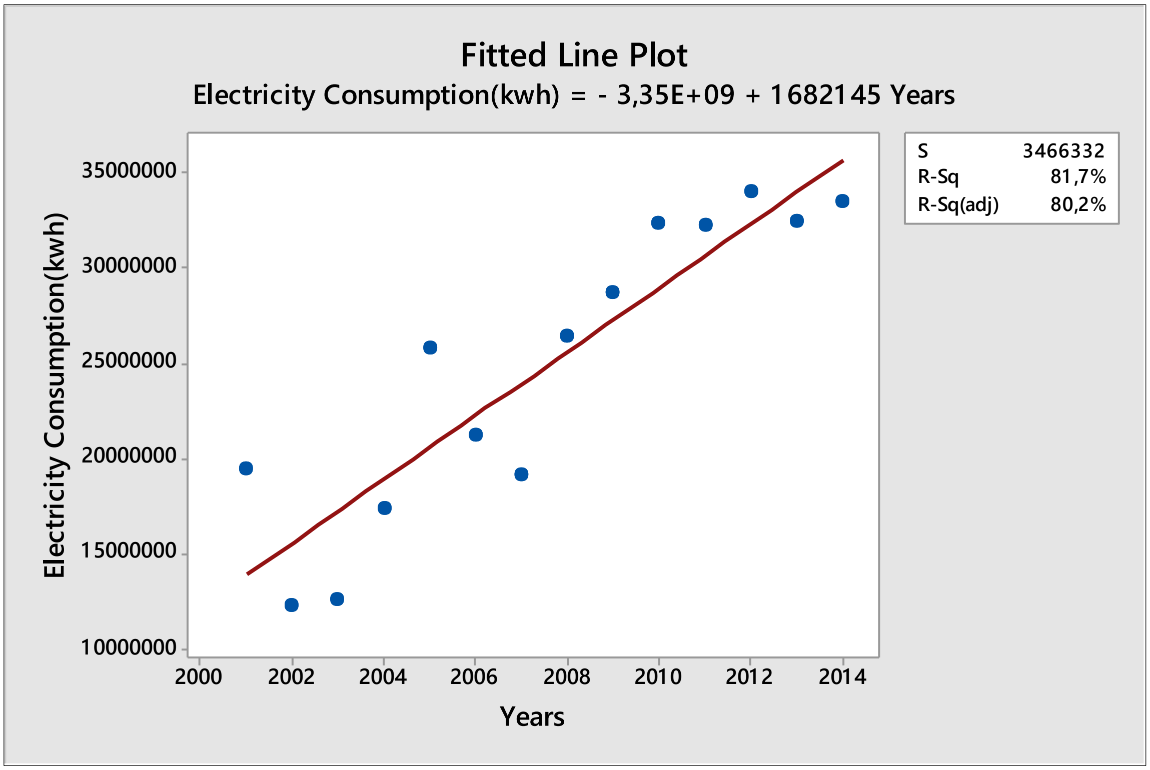

Figure 11 Linear Regression Model

In Figure 11, the relationship between the consumption of electricity and years can be seen in results of Minitab.

F-test is conducted to test the significance of the linear regression. As the values are lower than 0,05, it can be said that the relationship is significant.

Even the R^2 value for cubic regression model is high, linear regression model is selected as the real life model due to known fact that as the capacity of university increases; the electricity consumption will also increase. The below equation is used for the estimation of the consumed electricity in year 2000.

$$\textit{Electricity Consumption (kWh)} = -3{,}35\ E{+}09 + 1682145 * \textit{Years} \quad (9)$$

Electricity Consumption $_{2000}$= 12.191.761,01 kWh

Closed area of the campus can be a factor that triggers the electricity consumption. As the m^2 of closed area increased, electricity demand will also increase. METU's total physical closed area is taken from Operation Reports of METU (Directorate of Strategy Development (2008-2014)). Closed area calculation includes; METU Campus except METU techno polis and METU residents.

The available m^2 of the closed area in METU is listed in Table 8

Table 8 Closed Area of METU (METU Operation Reports, 2008-2014)

Years	Total Closed Area (m^2)
2008	420.474
2009	420.474
2010	421.428
2011	421.428
2012	421.428
2013	423.933

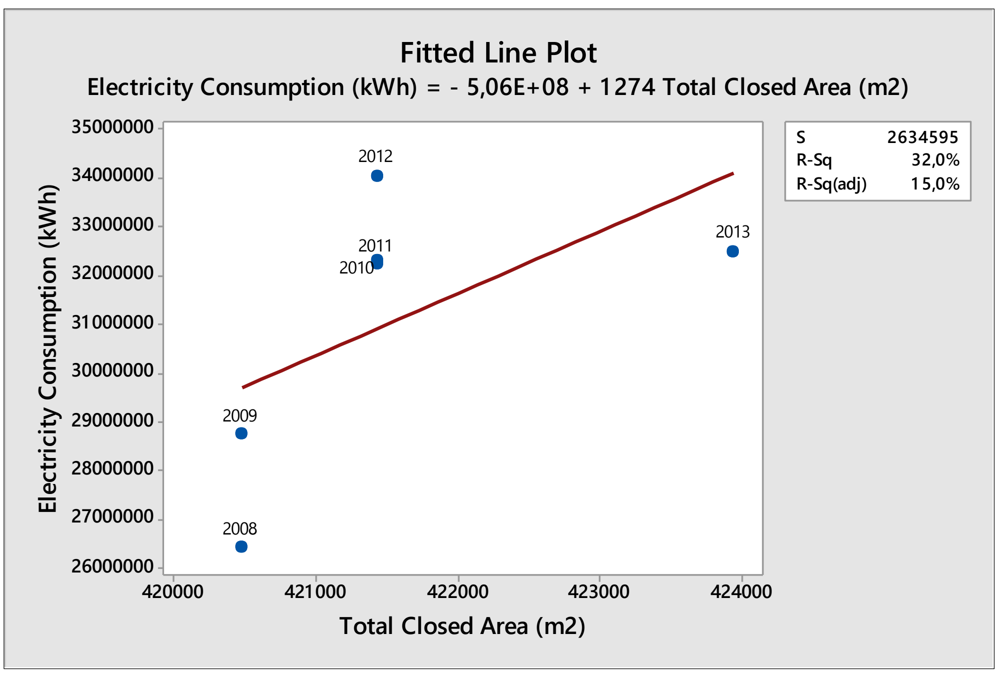

Figure 12 Electricity Consumption vs Building Area

A regression analysis is conducted for electricity consumption and closed area. Regression model fits 32% of the real values. Number of data is insufficient to estimate and explain carbon dioxide emissions due to electricity consumption

The equation below is obtained:

Electricity Consumption (kWh) = - 5,06E+08 + 1274 Total Closed Area (m^2) *(10)*

Another factor which produces a change in the electricity consumption is the weather conditions of the Ankara. As the heating or cooling facilities are insufficient, additional heating/cooling equipment would be used. Relationship between average temperatures of Ankara affects the total electricity consumption at METU Campus.

General Directorate of Meteorology has provided heating degree days (HDD) and cooling degree days (CDD) values. Heating degree day is a term used to reflect necessary energy demand to heat a building. It is the difference between average optimum temperature of the building and the outside temperature. In the calculations optimum temperature has taken as 18˚ C.

HDD = (18 – Tm) x day if Tm ≤ 15 °C

HDD = 0 if Tm > 15 °C

Tm = Mean Temperature

Cooling Degree Days is a term used to reflect necessary energy demand to cool the building. It is calculated as:

CDD = (Tm - 22) x day if Tm > 22 °C

CDD = 0 if Tm < 22 °C

Terms are directly related to consumption of energy for heating and cooling. As the temperature is below 15 °C or above 22 °C, the consumed electricity may be increase due to usage of heating/cooling equipment. The relationship between Degree Days values and natural gas consumption is also analyzed.

Table 9 Heating Degree Days and Cooling Degree Days (General Directorate of Meteorology, 2014)

Year	HDD	T ≤15 °C	CDD	T >22 °C
2007	2517	0	380	0
2008	2528	0	312	0
2009	2267	0	141	0
2010	2028	0	366	0
2011	2709	223	152	57
2012	2421	181	308	93
2013	2327	204	165	68
2014	2150	214	264	74

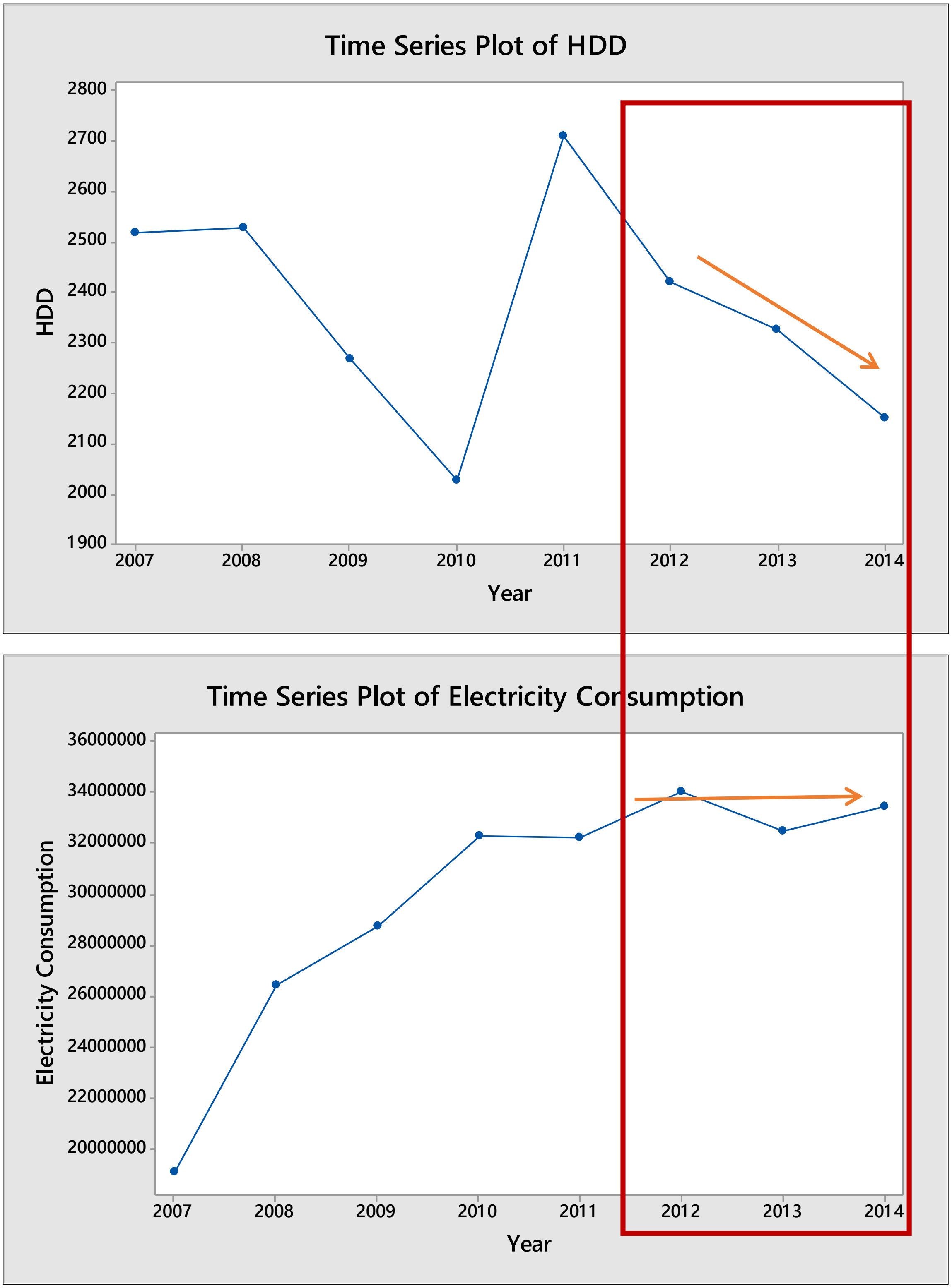

Figure 13 Time Series Plot of HDD

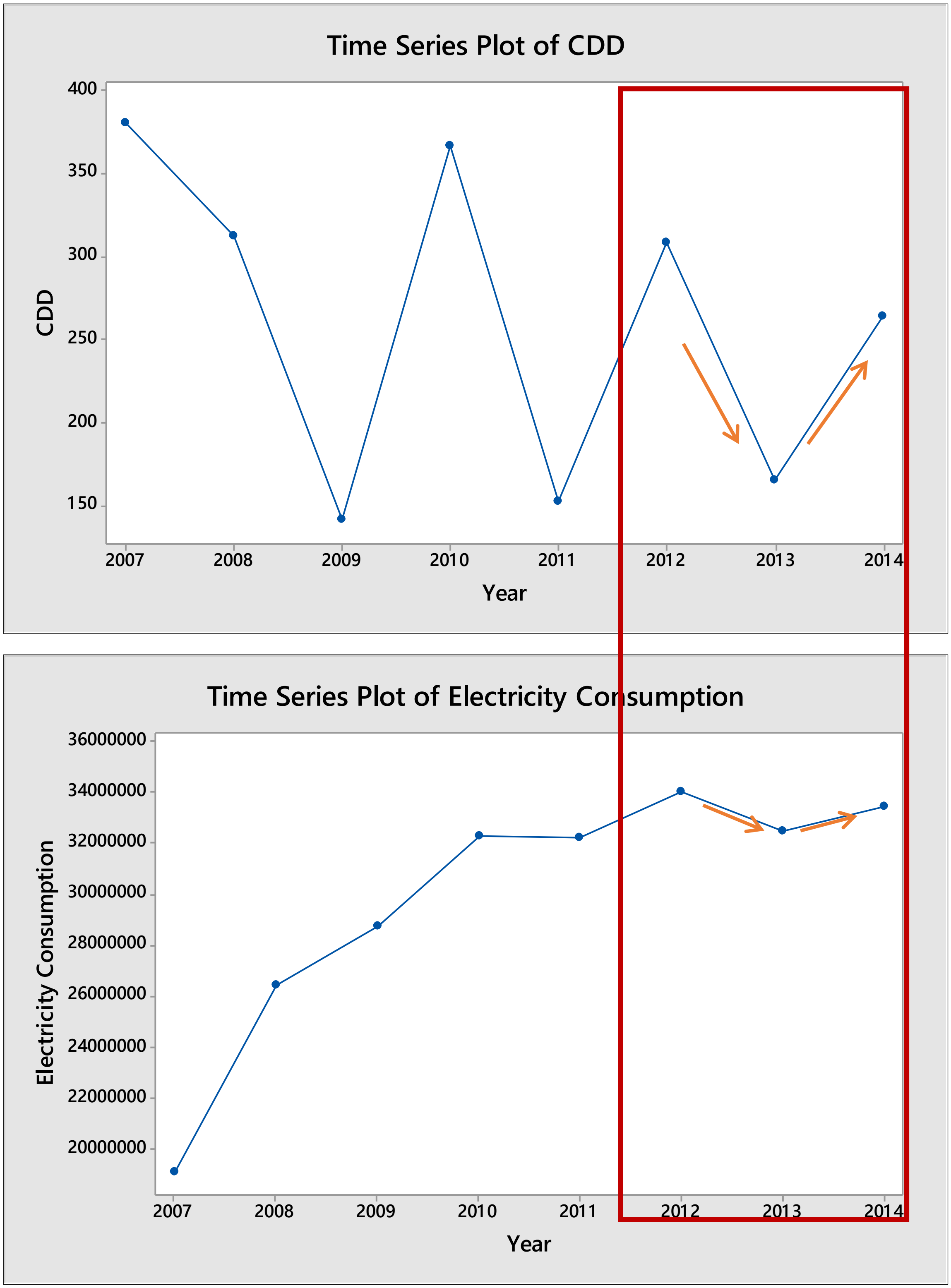

Figure 14 Time Series Plot for CDD

There is no significant relationship between HDD / CDD and electricity consumption as expected as can be seen in Figure 13 and Figure 14. As the HDD decreases, amount of electricity consumed nearly stays constant. However, CDD's behavior nearly same with the purchased electricity data for last three years. This relationship can be an evidence for usage of air conditions and space heaters in personal offices and laboratories, as the cooling needs increased (Figure 14).

Carbon dioxide emission factor selection of electricity depends on several factors:

- The energy mixture of the country
- Technology of the energy plants (efficiency)

As explained in the Part Electricity Production, to calculate total CO_2 emissions specific emission factors are necessary. Two calculation methods are used. First method's reference is the TUIK 2012 National GHG Inventory Report. The available data are the total CO_2 emissions (ton) due to electricity production and the total electricity produced (GWh) from 1990 to 2012 (APPENDIX – C). Plant-specific net calorific values were used to calculate heat values that led to emissions and carbon contents and oxidation ratios are taken from IPCC guidelines in the report.

Carbon dioxide emission is calculated as;

$$E = \text{Consumed Electricity (kWh)} \times EF \qquad (11)$$

where;

E = CO_2 emission (kg/year)

EF = CO_2 emission factor (kg CO_2/kWh)

In Table 10, emission factors are listed. There is a decreasing trend in the values because percent share of natural gas as source of electricity production increases and emits less CO_2 (APPENDIX – B).

Table 10 Emission Factors (TUIK, 2012)

Years	Emission Factor (kg CO_2/kWh)
2000	0,77
2001	0,76
2002	0,72
2003	0,66
2004	0,68
2005	0,68
2006	0,65
2007	0,65
2008	0,62
2009	0,61
2010	0,69
2011	0,68
2012	0,67
2013	0,68
2014	0,68

Calculation results are given in the Table 11.

Table 11 Total CO_2 Emissions Due to Electricity Consumption (TUIK Method)

Years	Total CO_2 Emissions (kg)
2000	9.360.206,48
2001	14.663.925,43
2002	8.853.015,89
2003	8.214.908,33
2004	11.709.352,47
2005	17.671.515,21
2006	13.733.249,83
2007	12.384.954,82
2008	16.336.890,35
2009	17.641.586,23
2010	22.159.648,78
2011	21.835.302,28
2012	22.729.900,87
2013	22.044.224,35
2014	22.697.720,35

Another approach is to obtain data from Ministry of Energy and Natural Resources and TUIK databases. The necessary data are;

- Electricity production per fuel type
- CO_2 emission amounts per fuel type

Assumptions are made for the calculation. First one is the only three types of sources for electricity production is used; coal, fuel oil and natural gas. It is assumed that renewable sources do not emit CO_2. Coal emission factor is the average value of import coal and lignite (Ministry of Energy and Natural Resources, 2014).

Table 12 CEF for Coals (Ministry of Energy and Natural Resources, 2014)

Fuel Type	CEF (Tons CO_2/MWh)
Import Coal	1,092
Lignite	1,653

By utilizing available data emitted CO_2 amount per 1 MWh electricity production values are calculated in Table 13.

Table 13 Emission Factors for Sources of Electricity

(Ministry of Energy and Natural Resources, 2014

Fuel Type	Ton CO_2/ MWh
Coal	1,373
Fuel Oil	1,269
Natural Gas	0,479

As METU does not produce electricity, Turkey's general share of fuel for electricity production is taken as reference for calculations. From the TUIK webpage, the shares are listed as;

Table 14 Shares of Fuel Types for Producing Electricity (TUIK, 2014)

Years	Coal	Liquid fuels	Natural Gas
2000	0,31	0,07	0,37
2001	0,31	0,08	0,40
2002	0,25	0,08	0,41
2003	0,23	0,07	0,45
2004	0,23	0,05	0,41
2005	0,27	0,03	0,45
2006	0,26	0,02	0,46
2007	0,28	0,03	0,50
2008	0,29	0,04	0,50
2009	0,29	0,02	0,49
2010	0,26	0,01	0,46
2011	0,29	0,00	0,45
2012	0,28	0,01	0,44
2013	0,27	0,01	0,44
2014	0,29	0,01	0,48

$$E = \Sigma \text{ (Consumed Electricity) x (\% of fuel source) x (} CO_2 \text{ Emission Factor)} \qquad (12)$$

Total electricity consumption data is multiplied with the percentages and total emission amount is calculated.

Table 15 Total CO_2 Emissions Due to Electricity Consumption (Percentage Method)

Years	CO_2 Emitted (kg)
2000	8.430.213,86
2001	14.160.718,84
2002	7.875.349,10
2003	7.688.412,53
2004	9.994.505,67
2005	16.161.984,49
2006	13.018.929,40
2007	12.670.421,56
2008	18.112.634,24
2009	18.968.570,94
2010	19.178.474,37
2011	19.931.863,36
2012	20.686.325,16
2013	18.970.590,96
2014	21.435.604,04

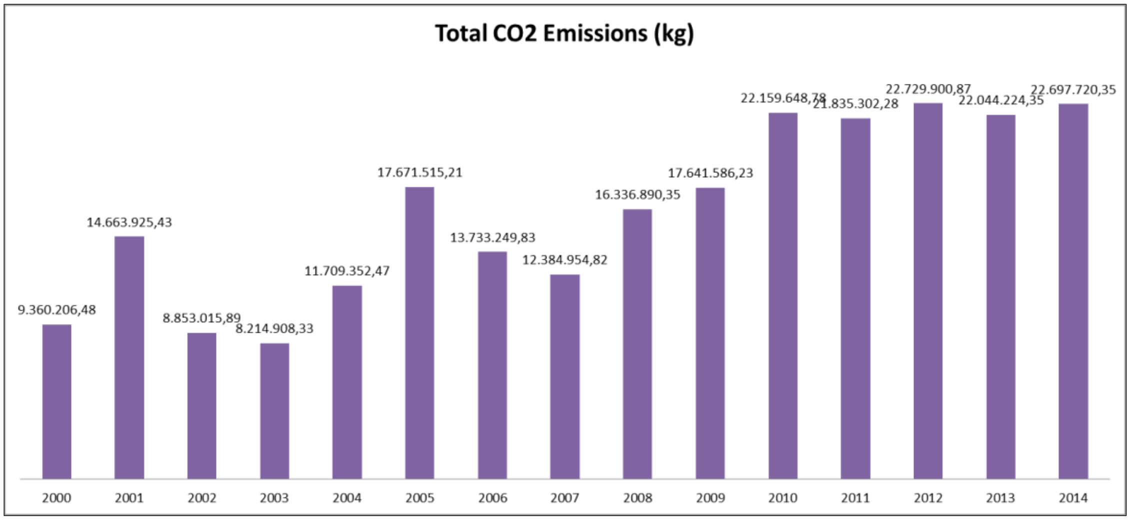

Figure 15 CO_2 emitted due to Electricity Consumption for METU

Regression equation for the relationship between CO_2 emitted and years is:

$$\textit{Total } CO_2 \textit{ Emissions (kg)} = -2{,}10E{+}09 + 1055018 \textit{ Years} \tag{13}$$

As the share of natural gas source (which have lower CO_2 emission factor) has increased, amount of CO_2 emissions have decreased. This is a good evidence of the importance of the fuel type at production for the CO_2 emission amounts.

As the results of the methods are compared there is not a significant difference (Table 11 and Table 15). In first method, TUIK uses the plant specific data obtained by questionnaires. However, in the percentage method only share of the each fuel type is considered. As TUIK has more reliable and accurate data, this method is used for the calculation of the overall CO_2 emissions.

7.2. Natural Gas Used for Heating

University has one heating center and three active heat boilers. Heat boilers can produce 65 ton/h steam, and their burning natural gas capacity is 5000 m^3/h. Both natural gas and #4 fuel oil can be utilized as fuel. However, fuel oil is used if natural gas supply is not available or restricted and also in the calculation period, all heating requirements have supplied by the natural gas.

Heating System Related CO_2 Emissions:

Office of Central Heating & Water Support provided consumed natural gas values for last 14 years in terms of m^3. In the table, data of the year 2014 includes only 10 months data. November and December months' data does not available.

The data can be seen in Table 16.

Table 16 Yearly Natural Gas Consumption of METU

(Office of Central Heating & Water Support, 2014)

Years	Natural Gas Consumption (m^3)
2000	12. 589.000
2001	10.357.000
2002	11.708.000
2003	11.827.000
2004	11.706.402
2005	10.483.418
2006	10.360.352
2007	9.513.889
2008	9.142.000
2009	8.626.694
2010	8.189.981
2011	9.352.596
2012	8.684.347
2013	9.048.314
2014	6.750.996

The time series graph (Figure 16) of the data is drawn and the general trend is illustrated (Figure 17).

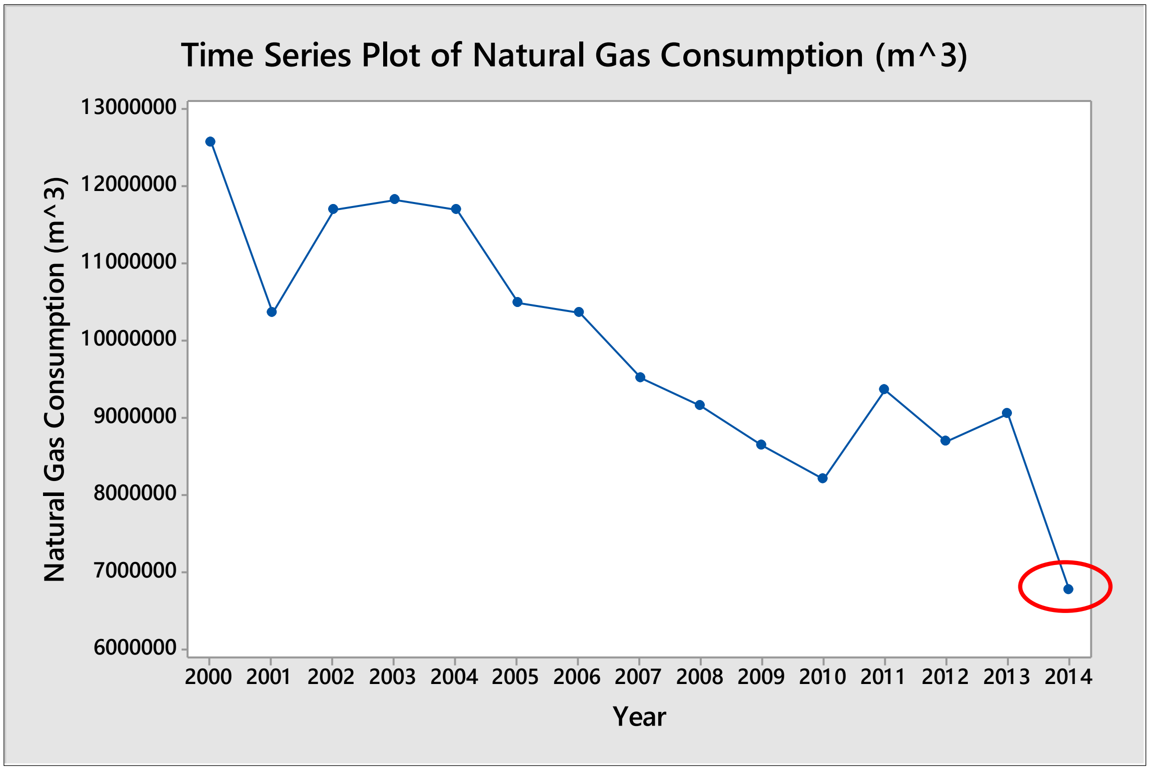

Figure 16 Time Series Plot of Natural Gas for METU

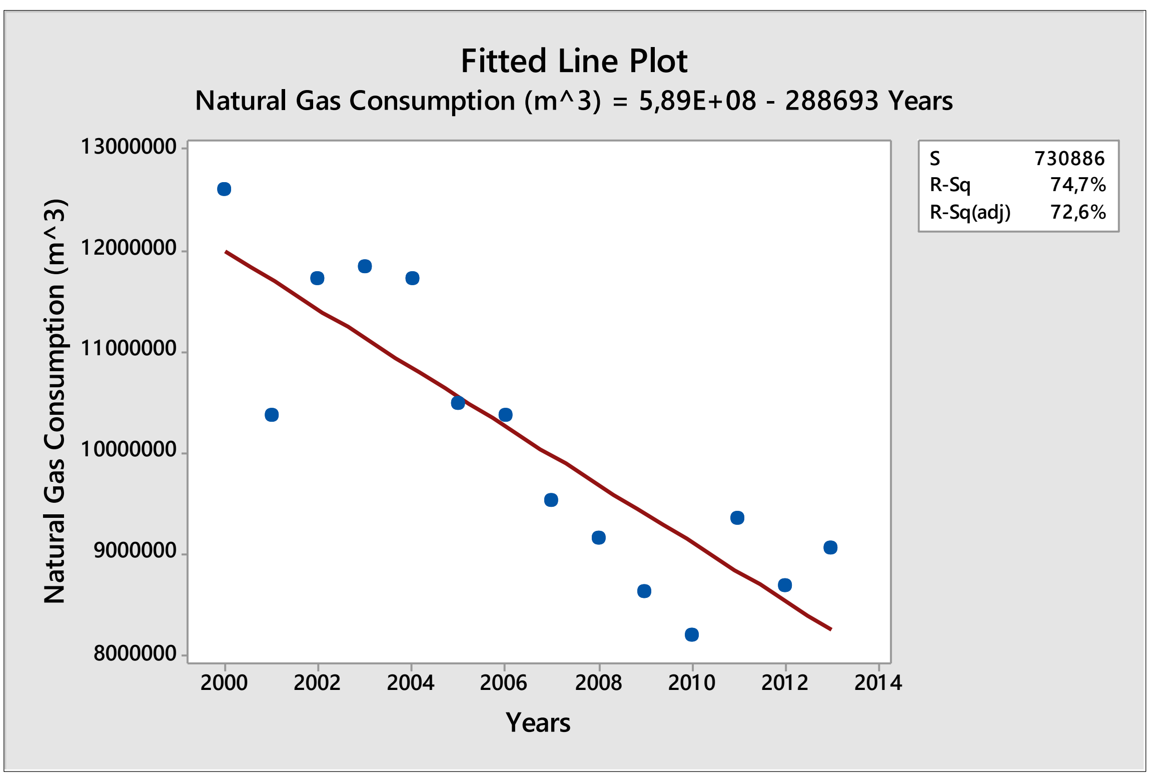

Figure 17 Fitted Line Plot of Natural Gas Consumption for METU

The red circle data is the 2014’s data and does not include the last 2 months data. Thus, in the regression analysis the year 2014 is excluded. As it can be seen in the graphs, decreasing trend is observed. To understand this decreasing trend, increases in the university’s closed area are controlled. Even the closed area of university has increased this alone cannot be explain the increase in the natural gas consumption (Figure 16).

This decreasing trend at natural gas consumption led us to investigate system improvements or energy saving policies. After private communication with Manager of Central Heating & Water Support Office, the following improvements are listed. Major precautions have taken to prevent heat leakages after 2007. Water treatment system is renewed, quality of water in the system is increased, and boilers life span is also increased. Amount of waste water vapor is automated by constructing a new system. Heat exchangers are changed by a new type and this minimizes energy loss. The automatic heat control system increased the efficiency of the heating. This system provides heating at specific times at specific temperatures. System provides necessary heat at working hours. Another energy saving step is to renew windows with double-glazing (METU Heating System and Actions for Energy Saving, 2007). These practices provide a major amount of energy saving thus CO_2 emissions due to natural gas consumption decreases.

Another important factor is the weather conditions of the Ankara. As the heating degree days increase, heating requirements increase thus the demand of natural gas also increase. The relationship between cold days and the natural gas consumption is analyzed.

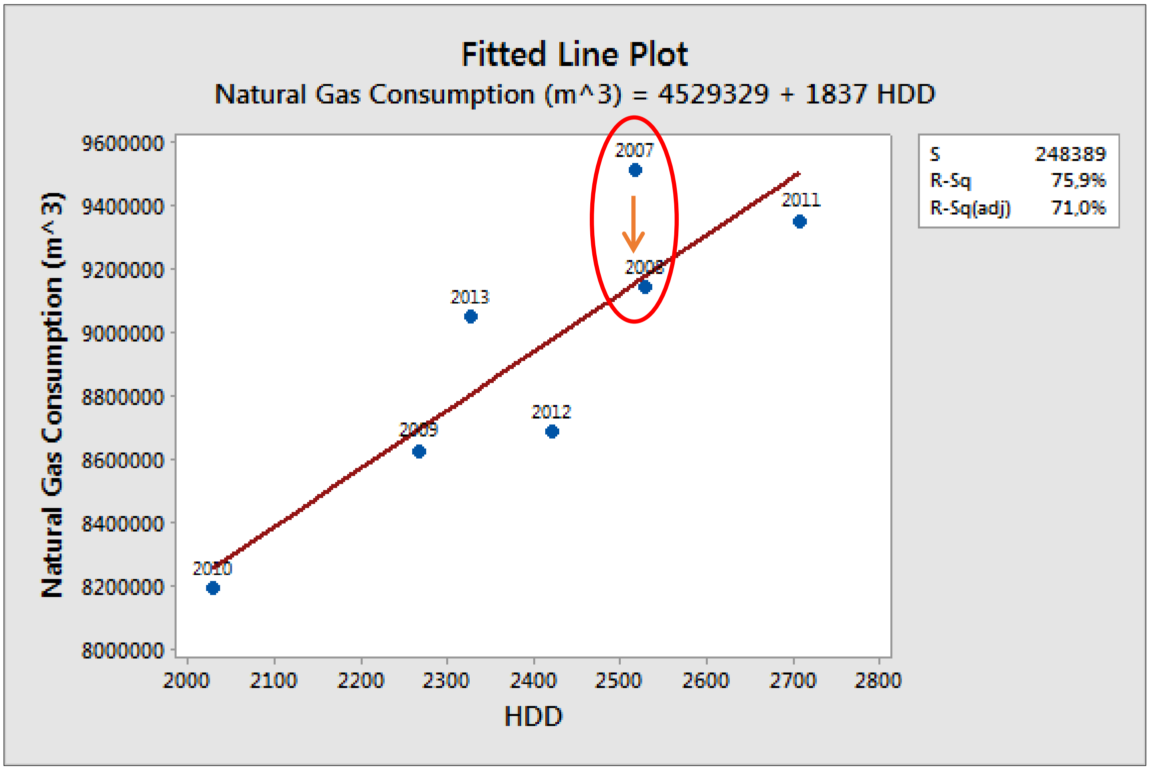

Figure 18 Regression Model for Natural Gas Consumption vs HDD

It is expected to see a linear relationship between natural gas consumption and HDD. The linear regression model explains the relationship between natural gas consumption and HDD, and R^2 value is 75,9%. However, two specific years 2007 and 2008 are important in the analysis. Even though, HDD values are nearly the same, the natural gas consumption is decreasing from 2007 to 2008. This is another evidence for energy saving activities.

As the closed area and weather conditions are considered, there should be improvements in the heating system. Because, as the closed area and HDD value increase it is expected to have a better goodness of fit value, a direct relationship between cold days and heating need thus natural gas consumption.

The carbon dioxide emission factor is selected as; 56,10 kg CO_2 / GJ (IPCC, 2006). The natural gas consumption data, provided by Office of Central Heating & Water Support, is in terms of m^3. For calculation, a unit conversion is necessary. Convert unit of natural gas from billion m^3 to GJ by multiplying with 37.681.200 GJ/billion m^3 to calculate overall emission amount.

The total emission amounts are given in Table 17.

Table 17 Total Emission amount of METU due to Natural Gas Consumption

Year	Natural Gas Consumptions (m^3)	Natural Gas Amount (GJ)	Emission Amount (kg)
2000	12.589.000,00	474.368,60	26.612.079,96
2001	10.357.000,00	390.264,20	21.893.820,97
2002	11.708.000,00	441.171,50	24.749.720,57
2003	11.827.000,00	445.655,60	25.001.276,49
2004	11.706.402,00	441.111,30	24.746.342,53
2005	10.483.418,00	395.027,80	22.161.057,92
2006	10.360.352,00	390.390,50	21.900.906,81
2007	9.513.889,00	358.494,80	20.111.555,71
2008	9.142.000,00	344.481,50	19.325.413,86
2009	8.626.694,00	325.064,20	18.236.100,61
2010	8.189.981,00	308.608,30	17.312.926,31
2011	9.352.596,00	352.417,00	19.770.595,97
2012	8.684.347,00	327.236,60	18.357.974,17
2013	9.048.314,00	340.951,30	19.127.369,58
2014	6.750.996,00	254.385,60	14.271.033,87

The decreasing trend in the consumption directly affects the emission amount released to the atmosphere. This shows all of the improvements in heating system such as insulation and automation of the system directly decreases CO_2 emissions.

7.3. Transportation System

University has several policies related to the regulation of traffic on the campus. The first practice is the sticker system given to each car or public transportation vehicle regularly enters the campus. This practice is a preventive action to lessen the number of vehicles in the campus site. As the numbers of the cars are determined by the university, CO_2 emissions due to vehicles with stickers are considered in Tier-1. The other practice is to have ring service in the campus. Transport system can be analyzed in two main headings:

- Private Cars and Public Transport
- Bus Fleet of METU

The data used in this study are provided by METU Management of Transportation.

Private Cars and Public Transport:

Office of Domestic Services has provided the total number of cars with sticker. There are 11 types of stickers depending on the entrance location. University has 4 entrance locations: A1, A4, A7, and A8 gates. However, it is assumed that each car enters and exits from gate A1 for calculation purposes. The total numbers of private cars increased by time due to increase in total population on campus.

Table 18 Yearly Number of Cars with stickers in METU (Management of Transportation)

Years	Number of cars (with sticker)
2000	8.766
2001	8.792
2002	8.047
2003	7.857
2004	9.124
2005	9.248
2006	9.742
2007	9.740
2008	9.533
2009	9.649
2010	10.435
2011	10.740
2012	12.080
2013	12.311
2014	12.538

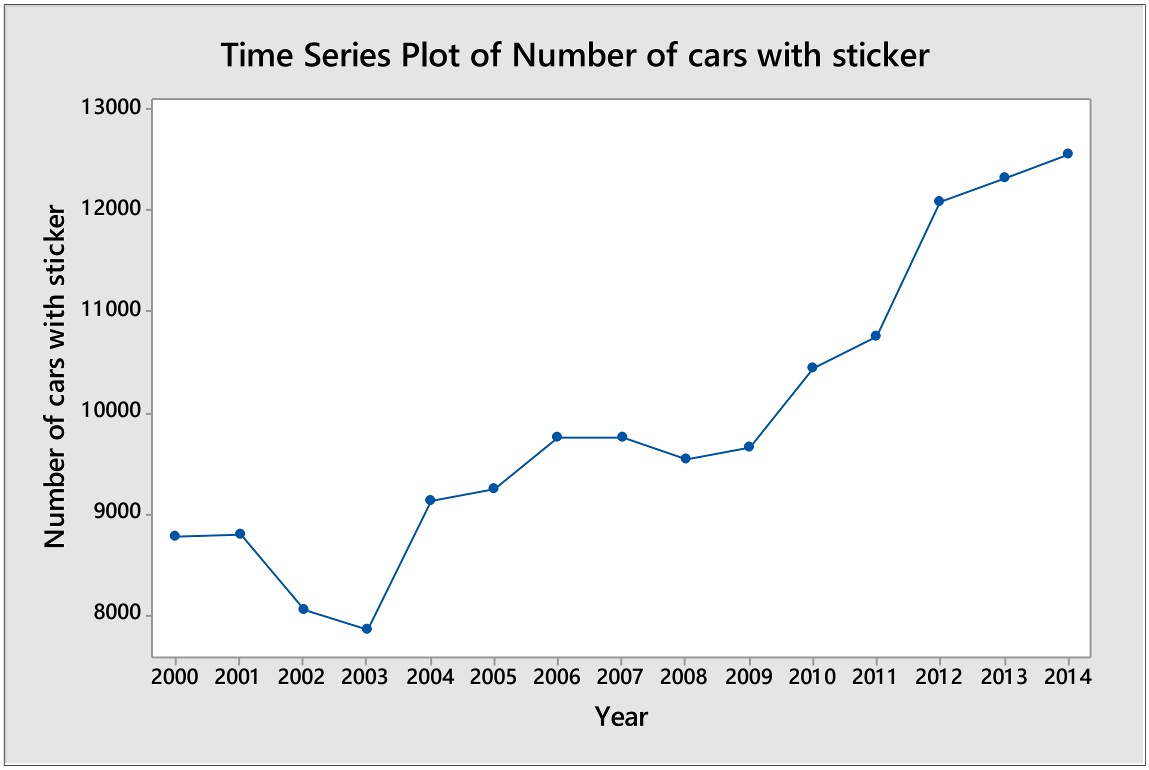

Figure 19 Time Series of Number of Cars in Campus

After 2009, as the number of private cars increased in the Ankara, also people who wanted to drive to school with their private cars also increased. Although, there are some regulations related to limiting the number of cars in the campus it was not possible to control the increase in the private cars.

Several assumptions were made for the calculation of number of cars thus their CO_2 emissions. According to experience of the Management of Transportation, number of cars without stickers is nearly 20% of cars with sticker. By using Google Earth, distance between A1 gate to faculties is measured and 12 km is taken as an average distance for a car to reach the destination. This number was multiplied by 2 for a round trip evaluation. The duration of car travel is calculated by using the assumptions listed. The traffic at METU is depended on academic calendar. An academic year is 9 months and 20 working days a month, which gives 180 days for a year.

The shares of cars per fuel type have taken from General Directorate of Public Security from 2004 to 2014. For the years 2000-2003, it is assumed that the share is same with the year 2004.

Table 19 Share of the cars per fuel types (General Directorate of Public Security, 2012)

Year	Total	Gasoline	(%)	Diesel	(%)	LPG	(%)
2004	5 400 440	4 062 486	75,2	252 629	4,7	793 081	14,7
2005	5 772 745	3 883 101	67,3	394 617	6,8	1 259 327	21,8
2006	6 140 992	3 838 598	62,5	583 794	9,5	1 522 790	24,8
2007	6 472 156	3 714 973	57,4	763 946	11,8	1 826 126	28,2
2008	6 796 629	3 531 763	52,0	947 727	13,9	2 214 661	32,6
2009	7 093 964	3 373 875	47,6	1 111 822	15,7	2 525 449	35,6
2010	7 544 871	3 191 964	42,3	1 381 631	18,3	2 900 034	38,4
2011	8 113 111	3 036 129	37,4	1 756 034	21,6	3 259 288	40,2
2012	8 648 875	2 929 216	33,9	2 101 206	24,3	3 569 143	41,3
2013	9 283 923	2 888 610	31,1	2 497 209	26,9	3 852 336	41,5
2014	9 857 915	2 855 078	29,0	2 882 885	29,2	4 076 730	41,4

Another assumption is related with how much fuel is necessary for an average car. A medium gas auto, in city consumes 10,70 liters / 100 km and 254,7 gram CO_2 / km, LPG auto consumes 11,2 liters / 100 km and 266 gram CO_2 /km and diesel auto consumes 9,8 liters / 100 km and 233 gram CO_2 / km (Table 2) (EPA,2001).

Calculation steps are:

- Total Numbers of Car = (Cars with stickers) + (Cars with stickers)*0,2
- Total Number of Car for each fuel type
- Total Distance per Car = Σ Numbers of Car each fuel type * 24 (km)
- Total CO_2 Emission = Σ Total Distance (km) * Emission Factor (g CO_2/km)

After applying all assumptions the calculation results are given in Table 20.

Table 20 Emission Calculation of METU from transportation of private cars

Years	Number of cars (with card)	With no cards (Assumption 20%)	Total cars	Total distance	Total Emission (gCO_2)	Total Emission ($kgCO_2$)
2000	8.766,00	1.753,20	10.519,20	45.442.944,00	10.977.256.462,09	10.977.256,46
2001	8.792,00	1.758,40	10.550,40	45.577.728,00	11.009.815.059,86	11.009.815,06
2002	8.047,00	1.609,40	9.656,40	41.715.648,00	10.076.886.008,49	10.076.886,01
2003	7.857,00	1.571,40	9.428,40	40.730.688,00	9.838.957.794,05	9.838.957,79
2004	9.124,00	1.824,80	10.948,80	47.298.816,00	11.425.563.308,25	11.425.563,31
2005	9.248,00	1.849,60	11.097,60	47.941.632,00	11.759.237.057,96	11.759.237,06
2006	9.742,00	1.948,40	11.690,40	50.502.528,00	12.490.177.584,45	12.490.177,58
2007	9.740,00	1.948,00	11.688,00	50.492.160,00	12.559.954.071,80	12.559.954,07
2008	9.533,00	1.906,60	11.439,60	49.419.072,00	12.429.682.321,79	12.429.682,32
2009	9.649,00	1.929,80	11.578,80	50.020.416,00	12.622.568.119,29	12.622.568,12
2010	10.435,00	2.087,00	12.522,00	54.095.040,00	13.667.905.117,58	13.667.905,12
2011	10.740,00	2.148,00	12.888,00	55.676.160,00	14.064.187.446,64	14.064.187,45
2012	12.080,00	2.416,00	14.496,00	62.622.720,00	15.820.950.192,11	15.820.950,19
2013	12.311,00	2.462,20	14.773,20	63.820.224,00	16.099.435.379,55	16.099.435,38
2014	12.538,00	2.507,60	15.045,60	64.996.992,00	16.373.414.566,39	16.373.414,57

It is seen that, in turkey there is a shift from gasoline to LPG and diesel. This shift lessens the total CO_2 emitted to the atmosphere in years. If all cars use gasoline as fuel, more CO_2 would be emitted.

METU Bus Fleet:

University has its own fleet for transportation inside the campus. Total fuel consumption of this fleet is given according to types of fuels in Table 21.

Table 21 Yearly fuel consumption of Bus Fleet of METU

Years	Euro diesel / Diesel (l)	Gasoline(l)
2010	454.120	47.122
2011	505.204	41.221
2012	532.603	33.486
2013	343.373	23.117

Fuel emission factors are taken from IPCC GHG Emission Guideline as default values. The emission factor for gasoline is 69,25 kg CO_2 / GJ and for diesel 74,1 kg CO_2 / GJ. A conversion is necessary for amount of diesel and gasoline. 1 m^3 of diesel is 38,6 GJ (Calorific Value 45,5 MJ/kg) and 1 m^3 of gasoline is 34,2 GJ according to Berkeley's webpage (Berkeley.com, 2015).

Table 22 Yearly CO_2 Emissions of METU Fleet

Year	Euro diesel (l)	Emission due to Diesel (kg CO_2)	Gasoline (l)	Emission due to Gasoline (kg CO_2)
2010	454.120,00	1.295.872,74	47.122,00	1.421.538,52
2011	505.204,00	1.441.645,59	41.221,00	1.551.574,47
2012	532.603,00	1.519.831,13	33.486,00	1.609.132,18
2013	343.373,00	979.846,10	23.117,00	1.041.494,92

The reason of the decrease in the purchased amount of euro diesel and gasoline is the shift from university fleet to outsourced fleet. Thus in the thesis, the data estimated before 2010 assumed be same as 2010 data and 2014 data assumed to be equal with 2013. It is a fact that the consumed amount of fuels on the campus does not change. University outsourced the bus service thus did not purchase the fuel.

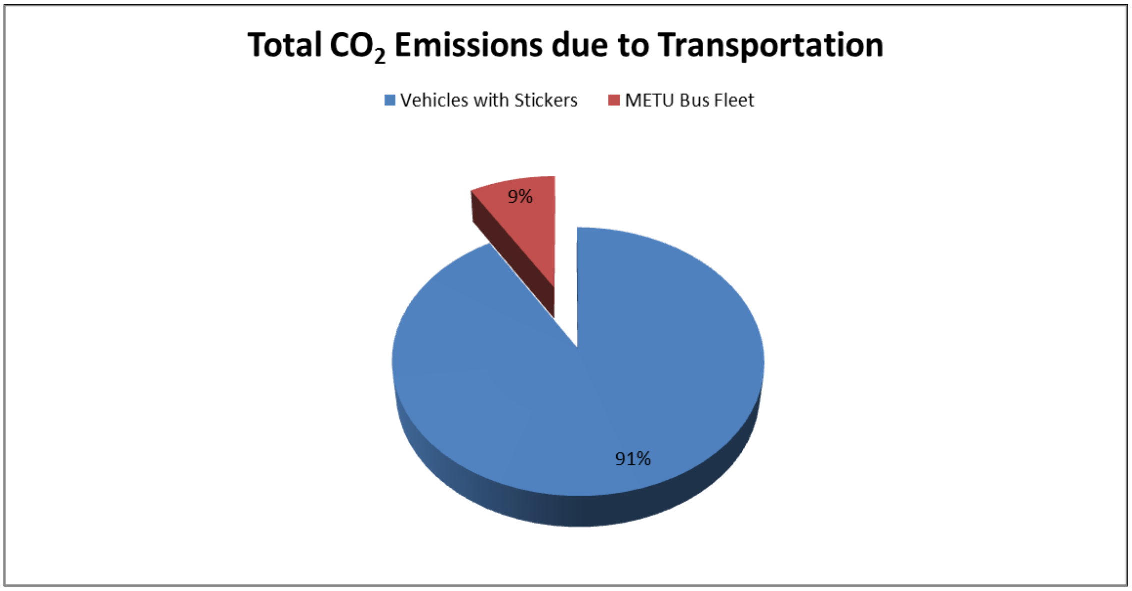

Figure 20 Shares of METU Bus Fleet and Vehicles with Stickers

Figure 20 show that the public transport shares a small portion of the CO_2 emissions due to transportation. Public transport should be promoted and the share of the vehicles with stickers should be decreased.

7.4. Consumption of Food

The last key source for CO_2 emissions is food consumption. Calculation of emissions due to food is a complicated task due to its different production steps. In this study, the contribution of only 5 main type of food is analyzed to narrow down the scope. Consumed number of bread, amount of vegetables, fish, red meat, and white meat are the available data for the calculation. Data was provided by Office of Cafeterias (Table 23).

Table 23 Yearly food consumption of METU (Office of Cafeterias)

Years	Bread (kg)	Vegetables (kg)	Fish (kg)	Red Meat (kg)	Chicken (kg)
2004	52000000	277000	38500	53000	94000
2005	48000000	307000	22000	65000	82000
2006	52000000	297000	22500	65000	82000
2007	62000000	285000	15500	71000	69000
2008	64000000	293000	15500	58000	74000
2009	58000000	285000	15000	60000	70000
2010	46000000	237000	14000	52000	57000
2011	44000000	240000	13500	52000	70000
2012	46000000	238000	13600	52000	90000
2013	64120000	260000	14500	70000	116000
2014	76000000	277000	12500	66500	94500

Several references are used to find emission factor of each type of food. The emission factors and references are listed (Table 24)

Table 24 Food Emission Factor References

Type of Food	Emission Factor (kg CO_2/kg Type of Food)	Reference
Red Meat	23,97	Williams et al., (2008)
Fish	3,30	Nielsen et al., (2003)
Vegetables	0,25	Romero-Gámez et al., (2011)
Bread	0,84	Nielsen et al., (2003)

Total amount of CO_2 Emissions calculated are given in Table 25.

Table 25 Yearly CO_2 Emission of METU from Food Consumption

Years	CO_2 emissions due to Bread consumption (kg)	CO_2 emissions due to Vegetable consumption (kg)	CO_2 emissions due to Fish consumption (kg)	CO_2 emissions due to Meat consumption (kg)	CO_2 emissions due to Chicken consumption (kg)	Total CO_2 Emission (kg)	Extend to total population Total CO_2 Emission (kg)
2000*	-	-	-	-	-	1.775.470,00	11.061.888,29
2001*	-	-	-	-	-	1.775.470,00	11.061.888,29
2002*	-	-	-	-	-	1.775.470,00	11.061.888,29
2003*	-	-	-	-	-	1.775.470,00	11.061.888,29
2004	43.680,00	69.250,00	127.050,00	1.270.410,00	265.080,00	1.775.470,00	11.061.888,29
2005	40.320,00	76.750,00	72.600,00	1.558.050,00	231.240,00	1.978.960,00	12.329.712,38
2006	43.680,00	74.250,00	74.250,00	1.558.050,00	231.240,00	1.981.470,00	12.345.350,69
2007	52.080,00	71.250,00	51.150,00	1.701.870,00	194.580,00	2.070.930,00	12.902.722,27
2008	53.760,00	73.250,00	51.150,00	1.390.260,00	208.680,00	1.777.100,00	11.072.043,84
2009	48.720,00	71.250,00	49.500,00	1.438.200,00	197.400,00	1.805.070,00	11.246.308,13
2010	38.640,00	59.250,00	46.200,00	1.246.440,00	160.740,00	1.551.270,00	9.665.032,61
2011	36.960,00	60.000,00	44.550,00	1.246.440,00	197.400,00	1.585.350,00	9.877.364,64
2012	38.640,00	59.500,00	44.880,00	1.246.440,00	253.800,00	1.643.260,00	10.238.167,10
2013	53.860,80	65.000,00	47.850,00	1.677.900,00	327.120,00	2.171.730,80	13.530.751,58
2014	63.840,00	69.250,00	41.250,00	1.594.005,00	266.490,00	2.034.835,00	12.677.835,98

* Estimated

Due to missing data for the years 2000-2003, a linear regression model is used and the equation below is obtained:

$$\textit{Total emissions due to food consumption (kg)} = -3{,}11E{+}08 + 155351\ \textit{Year} \qquad (14)$$

As the regression model's goodness of fit value is not enough to forecast the last year's data thus the value for 2000, 2001, 2002, and 2003 was taken as a constant 1.775.470 kg CO_2 per year.

On average 5000 person uses the cafeteria in year 2014, however the total population is different. To understand the overall CO_2 due to food consumption, it is assumed that 16% of the total population eat from the cafeteria and this value extended to total population by multiplying total CO_2 emitted with 1 / (0,16) at Table 25.

CHAPTER 8

MONTE CARLO SIMULATION

As our equation for estimating the CO_2 emissions at university consists of many sub categories that incudes uncertainties, need for a probability simulation has arisen. Monte Carlo simulation is used to forecast total CO_2 emissions in the years 2013 and 2014 by using the @RISK which is an add-in software program to Microsoft EXCEL. Monte Carlo uses random numbers with respect to distribution of the uncertain parameters.

The first step of the method is to construct the quantitative model. The model can be seen in the equation (15).

$$CO_2\ Emissions_{\ Total} = \Sigma\,(CO_2\ Emissions_{\ Electricity} + CO_2\ Emissions_{\ Natural\ Gas} + CO_2\ Emissions_{\ Transportation} + CO_2\ Emissions_{\ Food}) \qquad (16)$$

where;

- CO_2 Emissions $_{\text{Electricity}}$ = Consumed Electricity (kWh) * CEF
- CO_2 Emissions $_{\text{Natural Gas}}$= Consumed Natural Gas (m^3) * CEF
- CO_2 Emissions $_{\text{Transportation}}$= CO_2 Emissions $_{\text{Vehicles with stickers}}$ + CO_2 Emissions $_{\text{METU Bus Fleet}}$
    - ✓ CO_2 Emissions $_{\text{Vehicles with stickers}}$ = Total number of cars with sticker * tri(CEF) * tri(Distance)*180 (days)
    - ✓ CO_2 Emissions $_{\text{METU Bus Fleet}}$ = Fuel Consumed (lt) * CEF

- CO_2 Emissions $_{Food}$ =Red Meat (kg)* CEF + White Meat(kg) * CEF+ Fish(kg) * CEF + Bread (kg) * CEF + Vegetables (kg) * CEF

The changing input parameters are distance and CEF for transportation. Triangular distribution is used for the parameters. For transportation, the distance was an uncertain parameter. The listed values are selected for the calculation:

- ✓ *Min distance from A1 to Target Department:* 12 km (round trip)
- ✓ *Average distance from A1 to target destination:* 24 km (round trip)
- ✓ *Max distance from A1 to target destination:* 27 km (round trip)

Other uncertain parameter was the fuel types used by the cars. The followings are used in the model:

- ✓ *CEF Optimistic (All cars use gasoline)* = $CEF_{Gasoline}$ = 254,7 g CO_2/km
- ✓ *CEF Pesimistic (The share of the LPG and diesel is increased to 50% LPG and 50% Diesel)* = CEF_{LPG} * 0,5 + CEF_{Diesel} * 0,5 = 249,5 g CO_2/km
- ✓ *CEF Most Likely (Share is the same with the Turkey)* = CEF_{LPG} * Share of LPG + CEF_{Diesel} * Share of Diesel + $CEF_{Gasoline}$ * Share of Gasoline = 251,91 g CO_2/km

Due to uncertainties in the model, stochastic approach is used. Number of iteration is selected as 100.000 and simulation model run for one time.

It can be said, with 10% probability 50.142.789,54 kg CO_2, 90% probability 56.036.497,75 kg CO_2 is emitted to the atmosphere in year 2014. Most likely with 50% the total CO_2 53.718.530,31 kg of CO_2 is emitted to the atmosphere (Figure 21).

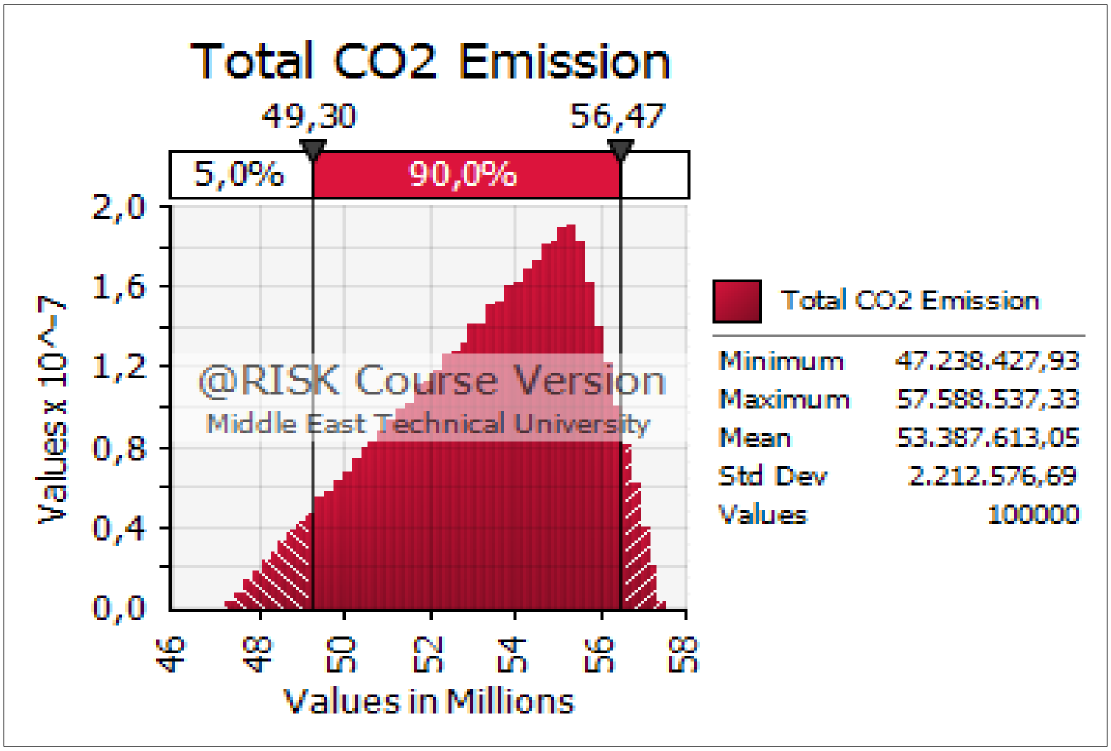

Figure 21 Results of Monte Carlo Simulation (2014)

The same simulation is constructed for 2013, the results for the 90%, 50% and 10% probabilities are following; 60.019.568,88, 57.742.369 and 54.228.681,8 kg CO_2 emission. The statistics related year 2013 is in the Figure 22.

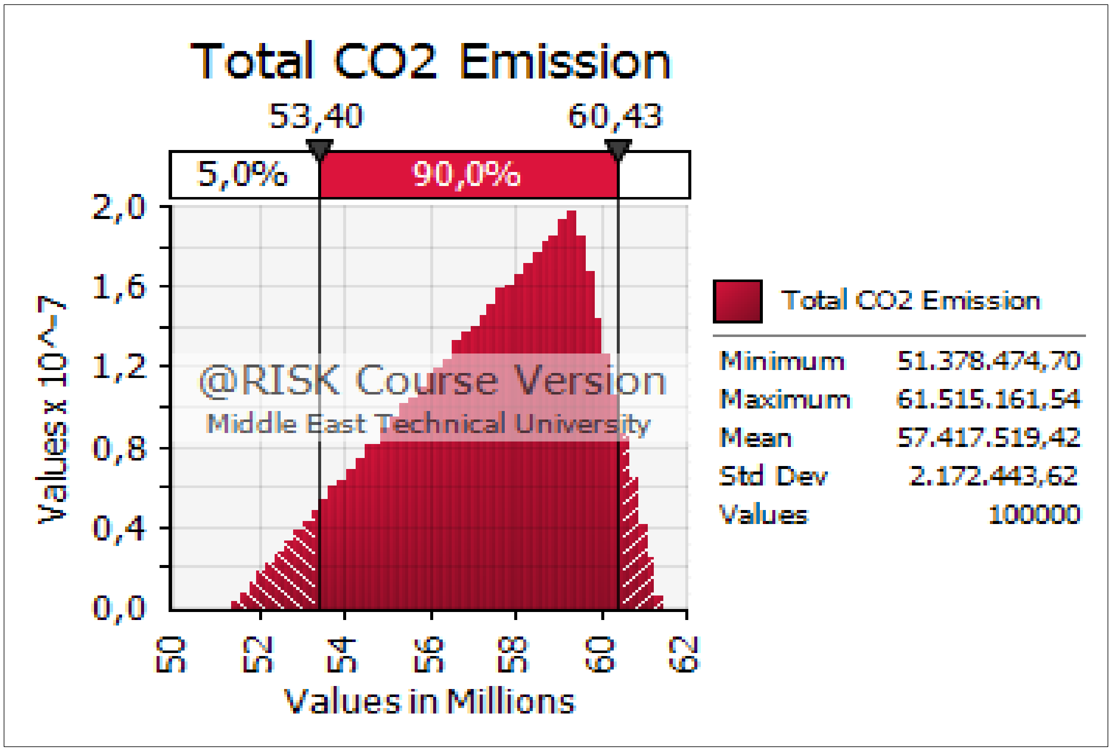

Figure 22 Results of Monte Carlo Simulation (2013)

As the results of the Monte Carlo Simulation are compared with the deterministic method, the total CO2 emissions calculated with deterministic approach in both 2013 and 2014 are in the 90% confidence interval. Monte Carlo Simulation explains the behavior of the uncertain parameters with probabilities.

CHAPTER 9

OFFSETS

9.1. Forest

Study Area is located on 39° 48’ 40’’ – 39° 54’ 35’’ north latitudes and 32° 45’ 42’’ – 32° 50’ 59’’ east longitudes. Middle East Technical University published a detailed forest management plan in 2007 (METU Forest Management Plan, 2007). Depending on this data, there are four different types of stance that is reported in the cadastral map. Table 26 shows the types and the properties of the each stance.

Table 26 Area coverage of different type of stance in METU

Type of stance	Area (Hectare)
Çkbc3	0,6
ÇkSBma	2,4
Çkb2	0,9
Total	**3,9**

Çkbc3: Totally dense black pine area consisting of young and stake pole stage trees

Çkb2: Medium Density black pine area consisting stake pole stage trees

ÇkSBma: Dense mixture of black pine, cedar and almond area consisting young stage trees

Each stand is coded accordingly:

1- *Types of Tree:*

Çk: Black Pine, Çs: Scotch pine, S: Cedar, Dş: Ash tree, Bm: Almond, Ah: Wild pear, Dy: Others

2- *Developmental Period of the stance:*

The classification is based on diameter of the trees:

(a) 0 - 7.9 cm: Young Stage

(b) 8 - 19.9 cm: Stake Pole Stage

(c) 20 - 35.9 cm: Slim Tree

(d) 36 - 51.9 cm: Medium Tree

(e) Above 52 cm: Thick

3- *Density of the stance*

0- Density Below 10% - Dense

1- Density between 11-40% - Low Density

2- Density 41-70% - Medium Density

3- Density 71-100% - Totally Dense

4- Density above 100% - Tangled

For example, Çkbc3 represents a totally dense, pole stage and slim black pines area.

9.1.1. Calculation Methodology of Carbon Dioxide Absorption in METU Campus by trees

Several constants will be assumed in the calculation of carbon sequestration by trees. The constants can be seen below. Carbon coniferous trees are black pine, scotch pine and cedar. Broad leaved trees are ash tree, almond and wild pear trees.

1. *Determine the dry weight of the tree:*

Multiply the volume of the tree with constants below;

- For carbon coniferous tree – 0,473
- For broad leaved tree – 0,640

2. *Determine the total biomass of the tree above the ground:*

Multiply the dry weight of the tree with constants below;

- For carbon coniferous tree – 1,2
- For broad leaved tree – 1,25

3. *Determine the carbon content of the tree above the ground:*

By assuming 45% of the tree is composed of carbon multiply both carbon coniferous tree and broad leaved tree by 0,45 value.

4. *Determine the carbon content of the tree below the ground:*

Multiply the carbon amount of the tree above ground with constants below;

- For carbon coniferous tree – 0,2
- For broad-leaved tree – 0,15

5. *Determine Dead and Live Vegetation:*

Multiply both carbon above tree and carbon below tree with the constants below;

- For carbon coniferous tree and broad leaved tree - 0,4

6. *Determine total biomass:*

Add up dead vegetation, live vegetation, and carbon of the tree below the ground.

7. *Determine the carbon content amount at the ground:*

The carbon content of tree (stem, branches and roots is approximately 58% of their biomass. Multiply total biomass with 0,58 for 2 types of trees.

8. *Determine the weight of carbon dioxide sequestered in the tree*

Multiply the weight of carbon in the tree by 3,67 where 43.99/12.00 is the ratio of CO_2 atomic weight over that of oxygen.

9.1.2. Results of Carbon Dioxide Absorption in METU Campus by trees

In this thesis, as the increments per area classification is available; CO_2 sink is calculated per area.

There are 3 classes of area:

- Class A - Archeological Protected Area
- Class B - Natural Protected Area
- Class C - Esthetic View

Estimation of total forest volume for each class in year 2007 is given in Table 27.

Table 27 Total forest volume per class

Class	Total Forest Volume (m^3)	Increment of volume per year (m^3)
A	1.886	125
B	51.919	3741
C	8.892	603

Total volume: 62.659 m^3

The ratio of the carbon coniferous tree to total trees is 99%.

This table is constructed by adding increment of each type for each year:

Table 28 Total Forest Volume (m^3)

	Total Forest Volume (m^3)							
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
A Class	1886	2011	2136	2261	2386	2511	2636	2761
B Class	51919	55660	59401	63142	66883	70624	74365	78106
C Class	8892	9495	10098	10701	11304	11907	12510	13113
Total	62697	67166	71635	76104	80573	85042	89511	93980

Determination of the dry weight of trees:

Table 29 Total dry weight of trees (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	29.359,12	31.451,82	33.544,52	35.637,22	37.729,92	39.822,62	41.915,32	44.008,01
Broad leaved tree	401,26	429,86	458,46	487,07	515,67	544,27	572,87	601,47

Total biomass above ground:

Table 30 Total biomass above ground (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	35.230,95	37.742,19	40.253,43	42.764,66	45.275,90	47.787,14	50.298,38	52.809,62
Broad leaved tree	501,58	537,33	573,08	608,83	644,58	680,34	716,09	751,84

Determination of the carbon content of the tree above the ground:

Table 31 Total Carbon of the trees above ground (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	15.853,93	16.983,98	18.114,04	19.244,10	20.374,16	21.504,21	22.634,27	23.764,33
Broad leaved tree	225,71	241,80	257,89	273,97	290,06	306,15	322,24	338,33

Determination of the carbon content of the tree below the ground:

Table 32 Total Carbon of the trees below ground (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	3.170,79	3.396,80	3.622,81	3.848,82	4.074,83	4.300,84	4.526,85	4.752,87
Broad leaved tree	33,86	36,27	38,68	41,10	43,51	45,92	48,34	50,75

Determination of Dead and Live Vegetation:

Table 33 Dead and Live Vegetation (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	7.609,88	8.152,31	8.694,74	9.237,17	9.779,59	10.322,02	10.864,45	11.406,88
Broad leaved tree	103,83	111,23	118,63	126,03	133,43	140,83	148,23	155,63

Determination of Total Biomass:

Table 34 Total Biomass (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	26.634,60	28.533,09	30.431,59	32.330,09	34.228,58	36.127,08	38.025,57	39.924,07
Broad leaved tree	363,39	389,29	415,20	441,10	467,00	492,90	518,81	544,71

Carbon Content at the Ground:

Table 35 Carbon Content At the Ground (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	15.448,07	16.549,19	17.650,32	18.751,45	19.852,58	20.953,71	22.054,83	23.155,96
Broad leaved tree	210,77	225,79	240,81	255,84	270,86	285,88	300,91	315,93

Multiply Total Biomass with 3.67 to find total CO_2 amount:

Table 36 Total CO_2 Sink (Tons)

	2007	2008	2009	2010	2011	2012	2013	2014
Carbon coniferous tree	56.642,91	60.680,38	64.717,85	68.755,32	72.792,78	76.830,25	80.867,72	84.905,19
Broad leaved tree	772,81	827,90	882,98	938,07	993,16	1.048,24	1.103,33	1.158,41
Total	57.415,72	61.508,28	65.600,83	69.693,39	73.785,94	77.878,49	81.971,05	86.063,60

In 2007, total CO_2 sink is calculated as 57.415,72 tons; this value is the total CO_2 amount which is absorbed by the trees in the METU campus until 2007. As the volumes and types of trees are missing for yearly basis, in the evaluation it can be said a greater amounts of CO_2 sink have occurred after 2007.

In the Forestry Management Report (2007), the increments per diameter interval for each class of area are given. For each diameter interval, there is a specific value for increment in terms of m^3/year. It is assumed that for 14 years, all tree's diameters stayed in the same diameter interval, thus have the same increment ratio for 14 years. The difference between the current year and the previous one is the carbon dioxide absorption in year current year. This just gives an idea of how much carbon dioxide can be absorb by the METU forest. It is found as 4.092,55 tons CO_2 / year for each year. The real value is much higher than this value due to diameter interval change and the trees with higher diameters could absorb more carbon dioxide.

In addition to that tree inventory, METU also initiates independent arbor days to increase number of trees in the METU Campus. Total trees planted in those events are listed as:

Table 37 Total Planted Trees

Years	Total Planted Trees
2008	21.000
2009	14.000
2010	20.000
2011	28.000
2012	32.000
2013	48.000
2014	103.000

In evaluation of the trees contribution to CO_2 sink, both the increments in the volume and the additional planted trees should be considered.

9.2. Lake Eymir

Many factors affect the role of lakes in the global carbon cycle such as: hydrology (timing and flux of water transporting DOC); water residence time; vegetation; atmospheric deposition to terrestrial system; seasonality of lake condition; autochthonous production due to littoral vegetation, phytoplankton or benthic algal mats; microbial dissolved organic matter degradation, and photo decay caused by change in irradiance water quality (pH, iron, and NO^{-3}) and stratification; sedimentation caused by change in salinity and pH (Tranvik et al., 2009).

Lakes contribute in two ways to carbon cycle. There is a carbon loss by mineralization and sedimentation and also a carbon dioxide escape. It is important to investigate if a lake behaves as sink or source for CO_2 emissions (Algesten G. et al., 2003).

In this thesis, Lake Eymir, which is located at 39° 57'/N, 32° 53'/E, is analyzed. The drainage area of the lake is 971 km^2; surface area is 1,20-1,25 km^2, and mean depth is 3.1 m (Levi E. et al., 2013). The range for CO_2 Flux from Lake Eymir is -106 to 1757 mg C/m^2d in years 2007 -2010 in dry periods and 17-1757 mg C/m^2d in wet period 2009-2010. These data show that it cannot be said for every season, Lake Eymir functions as a sink source (Kalvenes J., 2014).

CHAPTER 10

RESULTS AND DISCUSSION

In this study, four main sources of carbon dioxide emissions and two main sources of carbon dioxide sink were selected and analyzed for the time interval 2000-2014. While calculating the emissions caused by heating, transportation, and nutritional needs, the default IPCC emission factors are used as described in Chapter 4. For emission caused by electricity needs, TUIK reference is used in the calculations.

In the beginning of the study, although Lake Eymir was selected as a sink for carbon dioxide emissions, it is revealed that Lake Eymir does not act as a sink for every season thus in the calculations Lake Eymir was not evaluated. The other carbon dioxide offset was trees in the study area. In 2007, an extensive work was conducted by Regional Directorate of Forestry to calculate the types and volumes of the trees in the METU Campus including all the forest area owned by the METU Management. By utilizing the data published, at the end of the work total amount of carbon dioxide absorbed by the trees is calculated until 2007 and it is found as 57.415,72 tons of CO_2. To evaluate contribution of each year, an assumption is made. All trees stay in the same diameter interval for next year and sink estimated as 4.092,55 tons CO_2 / year. Absorption amount of carbon dioxide is directly related with diameter interval. As the tree grows, it absorbs more carbon dioxide. It can be said that; this assumption underestimates the total carbon dioxide absorb for each year because in real conditions, trees may grow enough to change their diameter interval in time which changes the total CO_2 absorbed by trees.

From year 2000 to 2014, CO_2 emissions are calculated and the following results are obtained for METU Campus (Table 38).

Table 38 Overall CO_2 Emissions for the time interval 2000 - 2014

Years	Electricity [CO_2 Emitted (kg)]	Natural Gas [CO_2 Emitted (kg)]	Transportation [CO_2 Emitted (kg)]	Food [CO_2 Emitted (kg)]	Total [CO_2 Emitted (kg)]
2000	9.387.655,98	26.612.079,96	12.121.160,49	1.775.470,00	49.896.366,43
2001	14.735.640,00	21.893.820,97	12.153.719,09	1.775.470,00	50.558.650,06
2002	8.849.044,80	24.749.720,57	11.220.790,04	1.775.470,00	46.595.025,41
2003	8.257.995,90	25.001.276,49	10.982.861,82	1.775.470,00	46.017.604,21
2004	11.793.756,80	24.746.342,53	12.569.467,34	1.775.470,00	50.885.036,67
2005	17.546.672,40	22.161.057,92	12.903.141,09	1.978.960,00	54.589.831,41
2006	13.787.338,50	21.900.906,81	13.634.081,61	1.981.470,00	51.303.796,92
2007	12.406.791,80	20.111.555,71	13.703.858,10	2.070.930,00	48.293.135,61
2008	16.377.467,40	19.325.413,86	13.573.586,35	1.777.100,00	51.053.567,61
2009	17.531.074,26	18.236.100,61	13.766.472,15	1.805.070,00	51.338.717,02
2010	22.295.915,49	17.312.926,31	15.089.443,64	1.551.270,00	56.249.555,44
2011	21.910.175,96	19.770.595,97	15.615.761,92	1.585.350,00	58.881.883,85
2012	22.808.402,64	18.357.974,17	17.430.082,37	1.643.260,00	60.239.719,18
2013	22.092.534,96	19.127.369,58	17.140.930,30	2.171.730,80	60.532.565,64
2014	22.747.463,36	14.271.033,87	17.517.318,60	2.034.835,00	56.570.650,83

When the total emission in 2007 is compared with the total absorbed CO_2; it is seen that all the emission is compensated with the CO_2 absorbed by the trees and negative CO_2 emission is observed. In addition, total CO_2 emissions due to selected key sources are 57.570,65 tons and total CO_2 absorbed by the trees are 86.063,6 tons in 2014. This indicates that with the selected key sources of CO_2 emissions, METU does not act as CO_2 emitting organization moreover, it act as a sink source for Ankara in 2014.

The maximum increase in the CO_2 emissions is realized in the years between 2009- 2010. In that interval 4.910 tons CO_2 emitted and approximately 4.092,55 tons are absorbed. More trees should be planted to compensate the total CO_2 emissions due to anthropologic activities.

Monte Carlo Simulation is used for evaluate the uncertainties by 100.000 times simulations and the result shows that with 90% percentile the total CO_2 emission is 56.036,5 tons .

The share of CO_2 emission amounts in terms of natural gas, electricity, transportation, and food is analyzed for 14 years and shares of cumulative emission amounts can be seen (Figure 23).

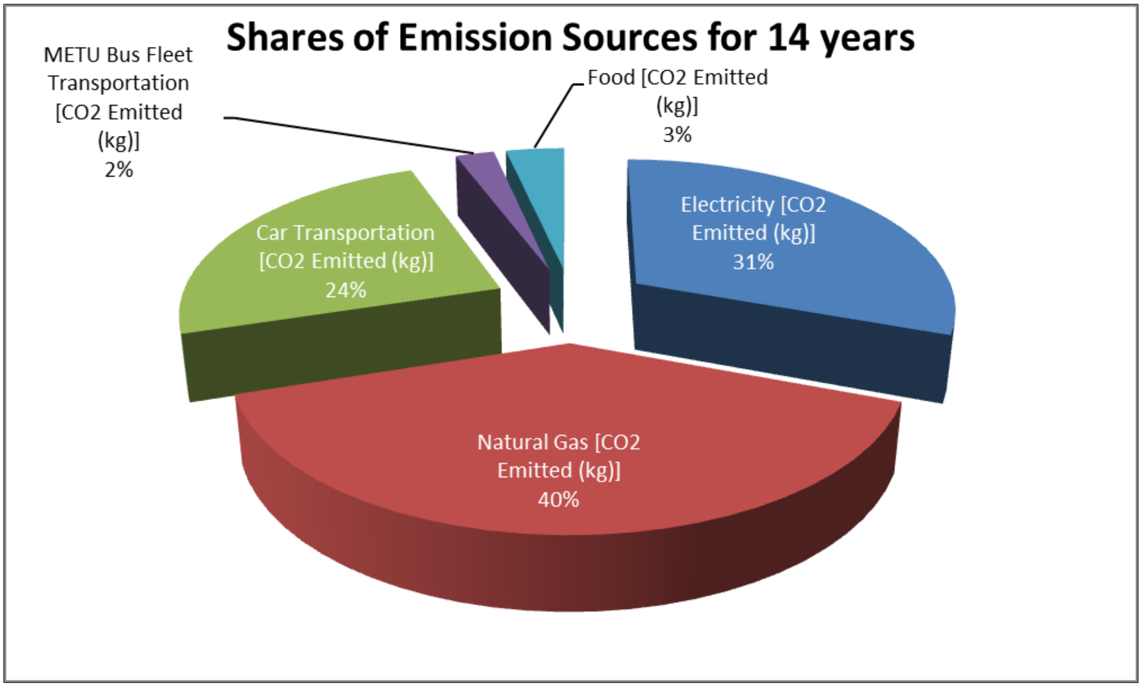

Figure 23 Shares of Cumulative CO_2 Emission in 14 years

Natural gas for heating purposes has the biggest share in terms of carbon dioxide emissions. It is followed by electricity, transportation, and food consumption.

When 2014 shares are analyzed, a different situation is observed (Figure 24). Carbon dioxide emission due to transportation has the highest value and this value is followed by emissions due electricity consumption. This is an evidence for the energy savings thus decrease in the consumed natural gas.

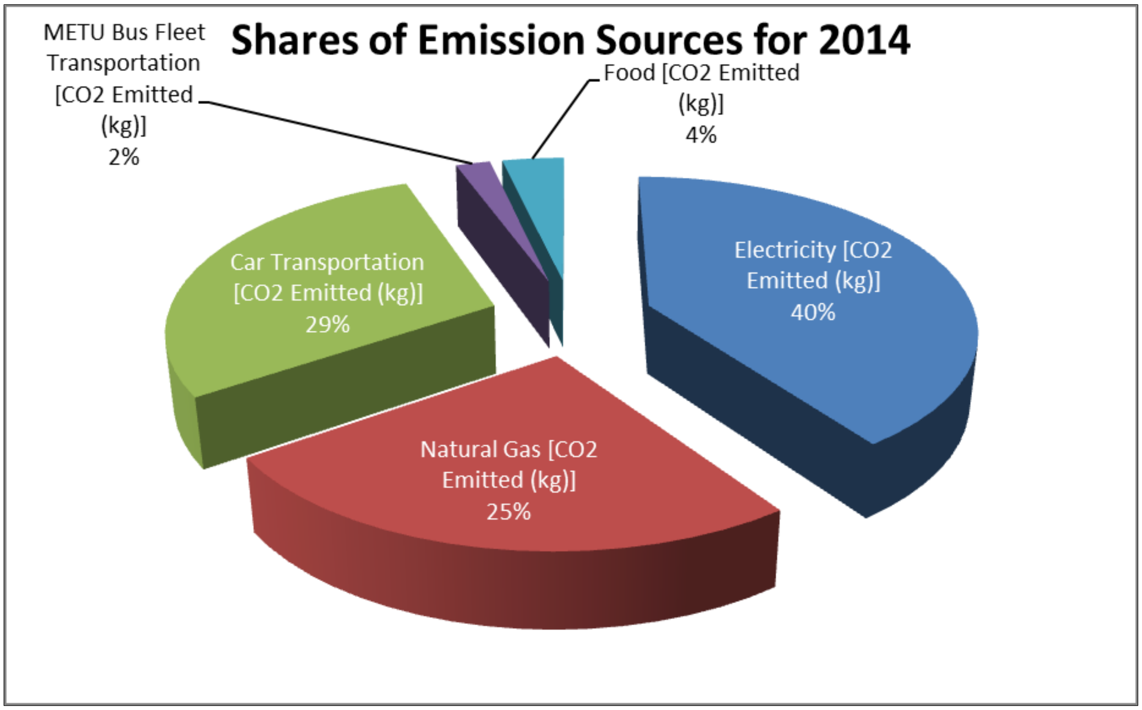

Figure 24 Shares of Emission Sources in 2014

For the evaluation of 14 years, the distribution is given (Figure 25). Even emission amounts related with natural gas consumption is the highest value, it has a decreasing trend. Emissions related to electricity consumption and private car transportation have an increasing trend. Electricity is one of major carbon emission source. Electricity is purchased and the amounts of emissions are directly related with the fuel type of electricity produced nationwide. This means even the university decreases the electricity demand it is alone not sufficient to decrease the emissions. Governments have a big role in decreasing the carbon dioxide emissions by changing the fuel types for producing electricity. As the population increase in the campus, electricity demand also increases. Although alone not enough but nevertheless the need of a detailed analysis is a must to reduce carbon dioxide emissions due to electricity.

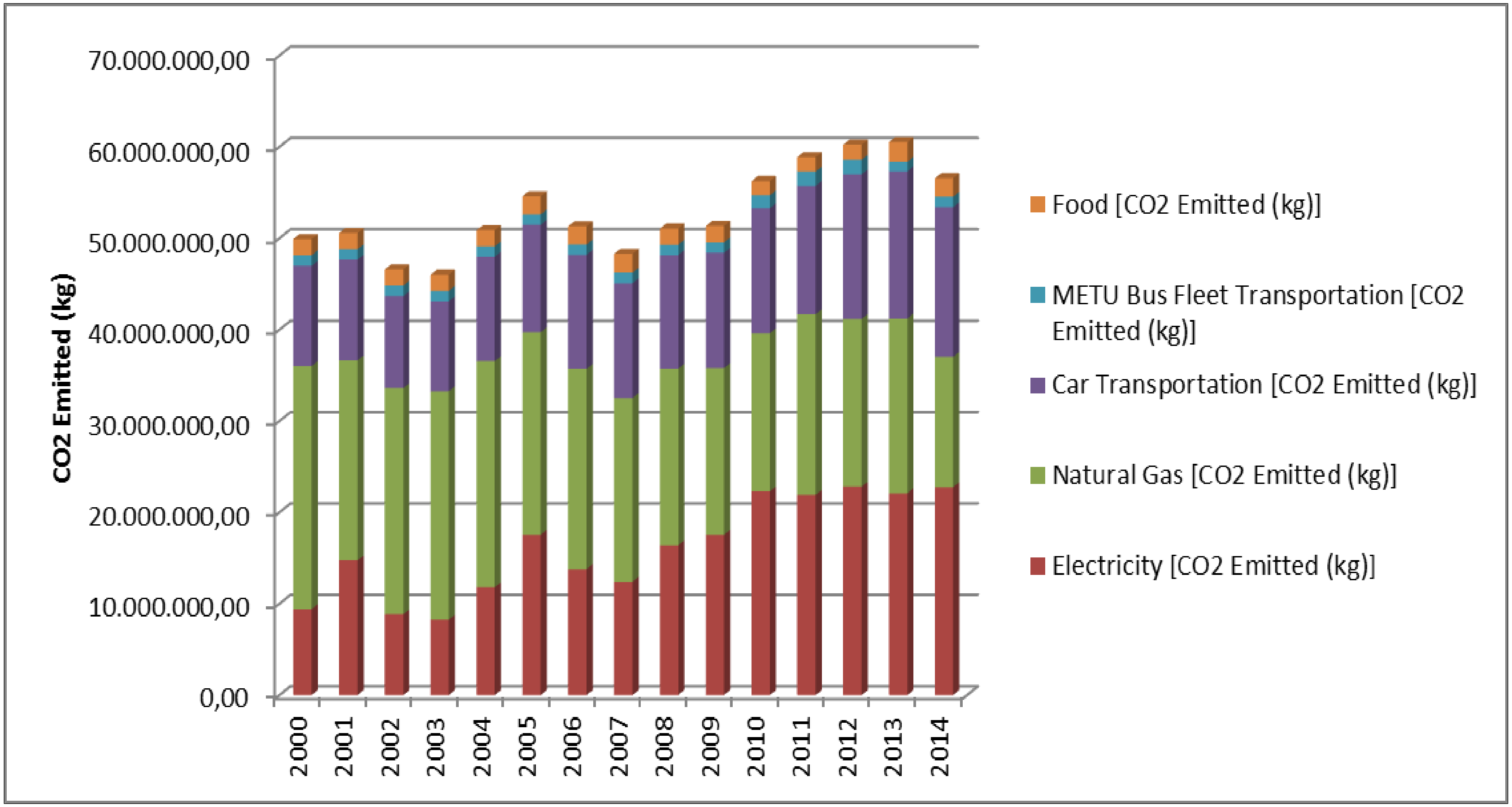

Figure 25 Total CO_2 amount for categories in 14 years

Relationship between total CO_2 emitted versus years is modelled and the linear regression model is obtained with a R^2 value of 63,8%:

$$Total\ [CO_2\ Emitted\ (kg)] = -\ 1{,}64E{+}09 + 841376\ Years \qquad (17)$$

From 2004 to 2014, CO_2 emitted per capita is calculated (Table 39).

Table 39 Total CO_2 Emitted per Capita (2004-2014)

Year	Total / Per Capita [CO_2 Emitted (kg)]
2004	2.031,58
2005	2.123,79
2006	1.972,62
2007	1.842,69
2008	1.985,90
2009	1.863,07
2010	2.032,65
2011	2.067,99
2012	2.048,62
2013	2.016,14
2014	1.815,96

The per capita values only cover 4 main sources of emission; natural gas consumption for heating, electricity consumption, transportation needs and food consumption (only basic items). It is important to remember, there are other emission sources such as waste, chemicals used at cleaning, paper usage and etc. The carbon footprint of the university is expected to be higher than the values given.

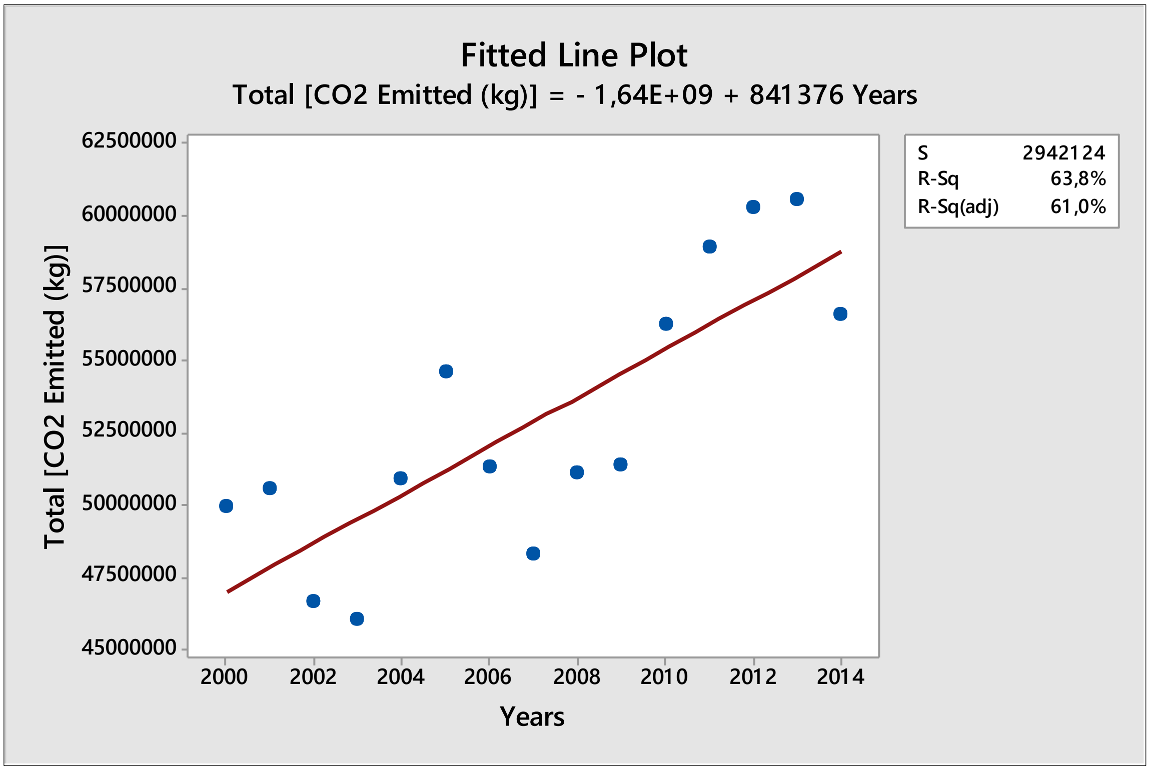

Figure 26 Linear Regression Model of Total CO_2 Emissions vs Years

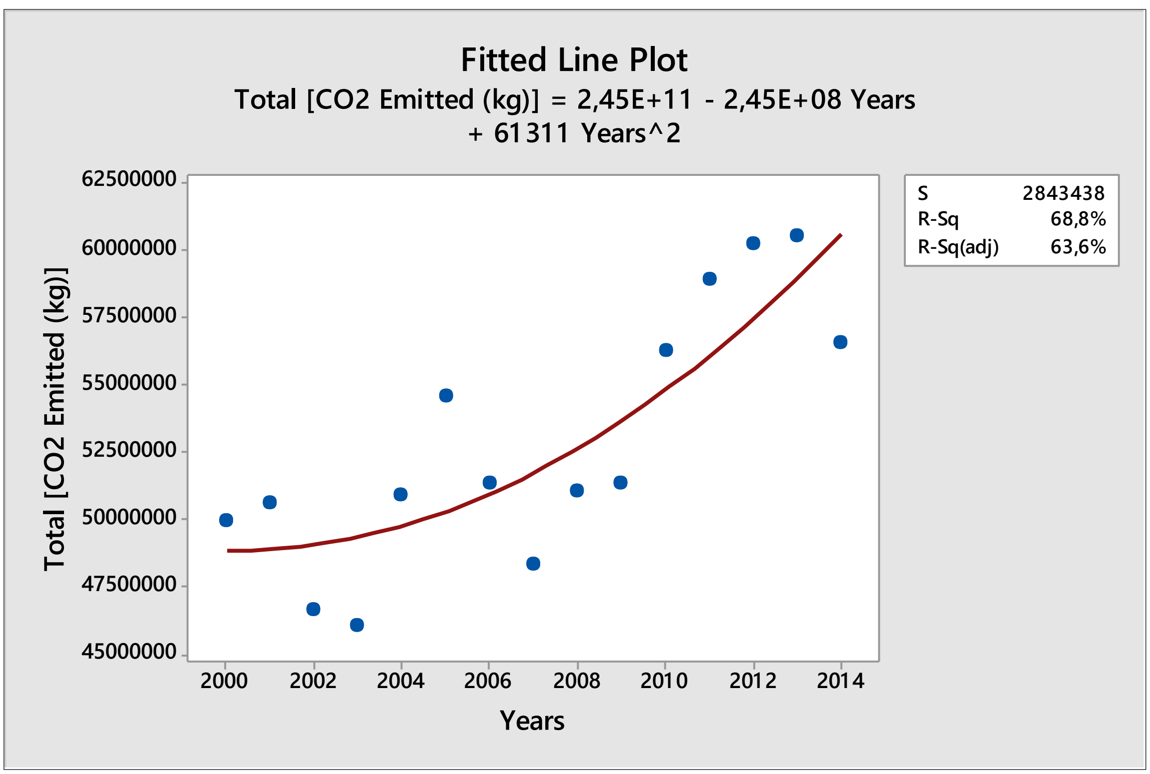

Figure 27 Quadratic Regression Model of Total CO_2 Emissions vs Years

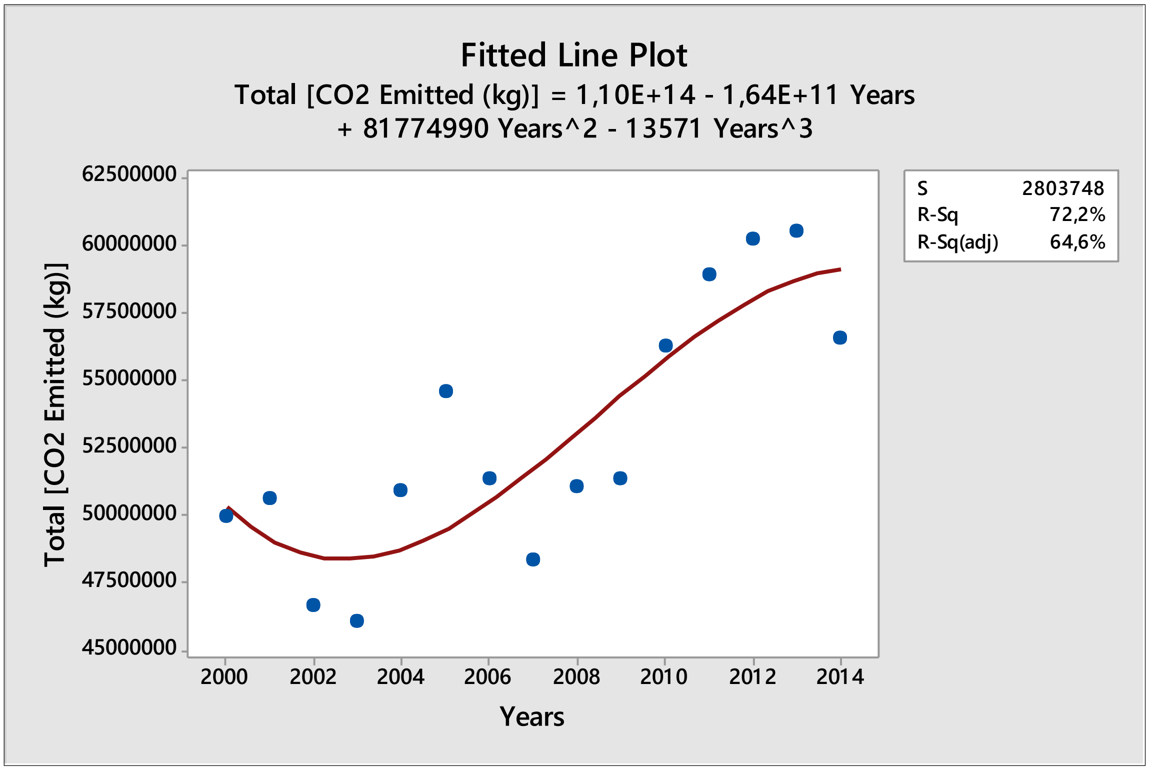

Figure 28 Cubic Regression Model of Total CO_2 Emissions vs Years

These equations can be used to predict carbon dioxide emission (kg) for a value of year, or find the settings (condition of sources of emissions) for year that corresponds to a desired value or range of values for carbon dioxide emission (kg).

After that analysis, the relationship between population and carbon dioxide emission amount is quantified.

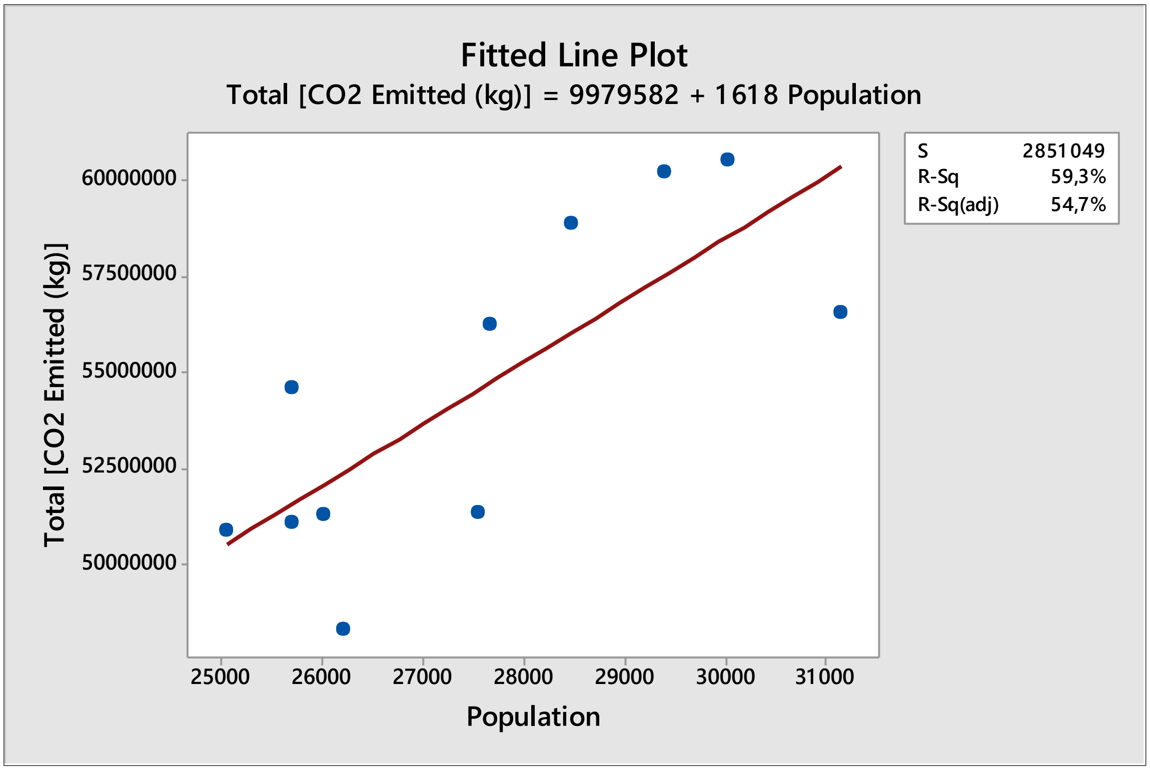

Figure 29 Regression for Carbon dioxide Emission vs Total Population

The fitted equation for the linear model that describes the relationship between Y and X is:

$$\textit{Total } [CO_2 \textit{ Emitted (kg)}] = 9979582 + 1618 \textit{ Population} \qquad (18)$$

Only population data could not explain the increase in CO_2 emissions.

Forest is a major carbon dioxide off set item. Middle East Technical University is so advantageous in terms of off sets. Every year, an adequate amount of trees are planted and added to forest inventory.

CHAPTER 11

CONCLUSION

In this study, four main sources of carbon dioxide emission; electricity, natural gas, transportation, and food consumption and two sources of carbon dioxide sink; METU Forest and Lake Eymir were analyzed to investigate their contributions to Middle East Technical University's carbon footprint.

Lake Eymir was not evaluated due to its current position in the carbon cycle. It does not act as carbon sink every season according the work of Kalvenas (2014), thus the presence of lake does not affect the results of this work.

The conclusions obtained from this study can be summarized as follows:

It is assumed that natural gas, electricity, transportation, and food constitute the total carbon dioxide emissions and for comparison percentages are calculated. Natural gas consumption plays a major role in the carbon dioxide footprint calculations with 40% share in total carbon dioxide emissions for 14 years (2000-2014) however; the share of natural gas consumption in total carbon dioxide emissions for 2014 is 25%. In calculation, the global carbon dioxide emission factor from IPCC (2007) is used which does not change for years. This decrease is directly related with the consumption of natural gas. In analysis, it is seen that the energy saving activities have a significant effect on carbon footprint. Those activities directly decrease the carbon dioxide emission amounts. The difference between 2000 and 2014 in carbon dioxide emission amounts due to natural gas consumption is 12.341.046,09 kg CO_2. At a minimum this much carbon dioxide emission was prevented with the precautions taken for energy saving.

The electricity consumption analysis revealed that, the 19% share of electricity related carbon dioxide emissions to total carbon dioxide emissions in 2000 increased to 40% share in 2014. As the capacity of the METU increases, the demand for the electricity increases. This thesis shows that even the consumption data is significant for calculations another important factor is the share of the fuel type in electricity production. Natural gas has lower carbon dioxide emission factors compared to coal and fuel oil. As the share of production of electricity by using natural gas increased, the emission amounts are decreased. For years 2010-2011, even the consumption of electricity decreased the share of the electricity production by using natural gas shifts to coal and the carbon dioxide emission was increased.

This thesis shows that contribution of the transportation requirement to carbon dioxide emissions is 26% share for time interval 2000-2014. This topic has analyzed in two parts. The first part includes the vehicles which are not owned by university but number of vehicles could be controlled and in the second part the university bus fleet related consumptions are calculated. Bus fleet's contribution to total carbon footprint is lower than the private or public transportation vehicles' contribution. Between 2000 – 2014, 209.422.674,91 kg CO_2 is emitted in to the atmosphere due to transportation needs of people. As the number of students, staff and academicians with cars increases, the carbon dioxide emitted to atmosphere also increases. Moreover, fuel type and kilometers travelled plays an important role in carbon dioxide emissions.

In the evaluation of the carbon dioxide emissions due to nutritional needs only main foods; bread, red meat, chicken, and fish are considered. It is expected to have higher values as the other foods are also evaluated. Red meat has the largest share of the emissions in food category by 78% in 2014. Red meat is followed by chicken, vegetable, bread and fish as compared in terms of the carbon dioxide emitted to the atmosphere. Purchased amounts also compared and it is seen that even the red meat has the highest carbon footprint; it is in the third place in terms of amount of purchased (kg's). This research showed that even the purchased amount of red meat is low, it emits more carbon dioxide.

Forests are the main carbon dioxide sink for the Middle East Technical University. Trees are grouped as carbon coniferous and broad leaved trees and 99% of the trees are carbon coniferous (ODTÜ Amenajman Planı, 2007). Calculation of the emission requires a detailed work beforehand. The diameters of each tree is significant in the both volume and increment calculation. The forest management report is used to calculate carbon dioxide emissions until 2007. The total value is found as 57.415,72 tons of CO_2. In year 2014, total emissions including the factors electricity, natural gas, transportation and food consumption is 56.570.650,83 kg CO_2. The CO_2 emissions per year are calculated as 2 tons CO_2 on average. On average, minimum 4.092,55 tons CO_2 / year is absorbed by the trees. Each year the increment could be differ so more trees should be planted for neutralizing the CO_2 emissions caused by human activities.

All in all, this research shows that in 2014 Middle East Technical University emitted 1815,96 kg CO_2 / capita and 91,67 kg CO_2 / m^2 in deterministic approach and with 90% probability the total CO_2 emitted to the atmosphere is 1800 kg CO_2 / capita. As discussed earlier, other schools which have published their carbon footprint, have higher value for carbon dioxide emission due to their scope. Other schools also included the emissions related with agriculture, solid wastes, and commuters. Even the comparison of the total carbon dioxide emission amounts is not possible, heating fuels, electricity consumption, and transportation related carbon dioxide emissions have the largest share in the other school examples like in Middle East Technical University.

CHAPTER 12

RECOMMENDATIONS

During this research there were some limitations. For Middle East Technical University case, emission factors were significant for the results. Presently country specific emission factors are not made public so the calculations are made using Tier 1 of IPCC calculation methodology. It is expected that if country specific emission factors are used the numbers may change.

Another factor is data in university. As there were not such carbon dioxide emission calculation practices in university, administrative units also have some difficulties in providing data. At the beginning of this thesis, the aim was to handle and analyze data from 1990 to present however in all offices there were missing data. Construction of an integrated information system is recommended for the university. An integrated system will be useful, in this way all offices (Central Heating & Water Support, Electrical Works, and Cafeterias etc.) can contribute.

It is recommended that at least 10 years of reliable data is necessary and must be collected for future research.

As the main focus is educational institutions there are constraints depending on the main goal is to educate people. For example, the utilization of electricity is depended on the classes' time schedule. Also, classes needed to be heated during active educational semesters.

University purchases the produced electricity and natural gas from system. For electricity, if it is feasibly possible, university can produce its own electricity by utilizing solar panels, windmills or other renewable sources of energy. About natural gas, the importance of heat insulation of buildings and automation is proved to be important in calculations. Even when the population and the heated building numbers have increased; the total consumed natural gas has decreased.

The usage of electricity can be reduced by some efficiency activities. METU Management should promote energy saving activities. Especially, rising public awareness can be first step of an overall approach for consuming electricity more efficient.

Trees play most important role in reduction of carbon dioxide emissions. The number of trees to be planted per year should be increased to neutralize the CO_2 emissions due to daily activities at METU Campus.

REFERENCES

Algesten G., Sobek S., Bergstrom A., Agren A., Tranvik L., and Jansson M. (2003), Role of Lakes for Organic Carbon Cycling in the Boreal Zone, Global Change Biology, (10), 141–147.

Altıntaşı O. (2013), Assessment of Scenarios for Sustainable Transportation at METU. MSc Thesis, Ankara: METU.

Association of Physical Plant Administrators APPA (2009), Practical Guide to Reducing the Campus Carbon Footprint. Guideline, APPA.

Asner G.P., Knapp D.E., Broadbent E.N., Oliveira P.J.C., Keller M., and Silva J.N., (2005), Selective Logging In the Brazilian Amazon, Science, 310(5747), pp. 480-482.

Berkeley.com (2015), Engineering Conversion Factors. Available online: http://astro.berkeley.edu/~wright/fuel_energy.html (Accessed 13 February, 2014).

Black W.R. (2001), A Reflection on Green Campuses, The Green Campus, Page 8, An Unpopular Essay on Transportation. Journal of Transport Geography. (9) 1-111

BP (2014). How Refining Works, www.bp.com/en/global/corporate/about-bp/what-we-do/making-fuels-and-products/how-refining-works.html (Accessed 16 February, 2014).

Carlsson Kanyama (1998), Climate Change and Dietary Choices; How Can Emissions of Greenhouse Gases from Food Consumption Be Reduced, Food Policy, 277-293.

Carlsson Kanyama, A., Pipping Ekström M., and Shanahan, H. (2003), Food and Life Cycle Energy Inputs: Consequences of Diet and Ways to Increase Efficiency, Ecological Economics, 44, 293-307.

Carnegie Mellon University Green Design Institute (2008), Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model, Available online: http://www.eiolca.net/Method/LCAapproaches.html (Accessed 1 January, 2013).

Colby College (2010), Colby College Climate Action Plan.

Cullenward L., DeLanghe K., Stonehill M. (2009), An Institutional Carbon Footprint: The Assessment of Transportation Related eCO2 Emissions and Applied Study of Mitigation Policies for Macalester College. MSc Thesis.

General Directorate of Public Security (2012), Distribution of Cars Registered to the Traffic by Fuel Type, Web Page.

Dyson F.J. (1977), Can We Control Carbon Dioxide in the Atmosphere, Energy, 2: 287–291.

Earth Science Communications Team at NASA Jet Propulsion Laboratory (2015), Global Climate Change; Vital Signs of the Planet, http://climate.nasa.gov/vital-signs/carbon-dioxide/ (Accessed 02 April 2014).

Elahdab T. (2006), Investigation of algae distribution in Eymir Lake using site measurements and remotely sensed data. MSc Thesis, Ankara: METU.

Felipe S. Pacheco, Fabio Roland, and John A. Downing (2013), Eutrophication reverses whole-lake carbon budgets, Inland Waters 4, pp. 41-48

Friedl B., Hammer M., Jäger J., Lorek S., Omann I., Pack A., (2007), Final Report Year Sustainable Food Consumption: Trends and Opportunities. SERI.

Galli A, Wiedmann T. , Ercin E., Knoblauch D., Ewing B., Giljum S. (2012) , Integrating Ecological, Carbon and Water footprint into a "Footprint Family" of indicators: Definition and role in tracking human pressure on the planet, Ecological Indicators, 2012: 100–112.

General Directorate of Meteorology (2014). HDD and CDD Values, Web page.

GHG Protocol (2005). Calculating CO2 Emissions from Mobile Sources Guideline.

Goreham S. (2013), Climate Change Is Dominated by the Water Cycle, Not Carbon Dioxide. Available online: http://communities.washingtontimes.com/neighborhood/climatism-watching-climate-science/2013/oct/7/climate-change-dominated-water-cycle-not-carbon-di/ (Accessed 01 January, 2014).

Gregg M. and Rotty R. (1984). Carbon Dioxide Emissions from Fossil Fuels: A Procedure for Estimation and Results for 1950–1982, Tellus, 1984: 232–261.

Hendrickson C.T., Lave L.B., Matthews H.S., (2006), Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach, Resources for the Future Press, Washington, D.C.

Hiete M., Ulrich B., and Otto R. (2001), Calculation of Global Carbon Dioxide Emissions: Review of Emission Factors and a New Approach Taking Fuel Quality into Consideration, Global Biogeochemical Cycles, 2001: 169-181.

Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, IGES, Japan.

Intergovernmental Panel on Climate Change Working Group II (2007), Fourth Assessment Report: Climate Change 2007, Cambridge, United Kingdom: Cambridge University Press. Available online: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml (Accessed 19 February, 2014).

Intergovernmental Panel on Climate Change Working Group III (2001), Third Assessment Report. Available online: http://www.ipcc.ch/ipccreports/tar/ (Accessed 19 February, 2014).

Intergovernmental Panel on Climate Change Working Group III (2007), Fourth Assessment Report: Climate Change Mitigation. Available online: https://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch5.html (Accessed 19 February, 2014).

Intergovernmental Panel on Climate Change Working Groups I, II and III (2007), Climate Change 2007: Synthesis Report. IPCC, Geneva, Switzerland. Available online: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm (Accessed 19 February, 2014).

International Energy Agency (2014). Key World Energy Statistics, IEA.

International Energy Agency Statistics (2013). CO_2 Emissions from Fuel Combustion Highlights, IEA.

Kalvenas J. (2014), Estimation of Carbon Dioxide Flux In Shallow Lakes In Turkey, MSc Thesis, Ankara: METU.

Ladley T., Sudquist E., Schwartz S., Hall D., Fellows J.,Killeen T (1999),Climate Change and Greenhouse Gases, Eos, 1999: 453-458.

Lenzen M. (2001). Errors in Conventional and Input-Output-based Life-Cycle Inventories, Journal of Industrial Ecology 4(4): 127-148.

Leoni, J. M., da Fonseca S. F., and Schöngart, J. (2011), Growth and population structure of the tree species Malouetia tamaquarina (Aubl.) (Apocynaceae) in the central Amazonian floodplain forests and their implication for management, Forest Ecology and Management, Vol. 261 Nr. 1, pp. 62–67.

Levi E., Çakıroğlu A.I., Bucak T., Odgaard B. V., Davidson T. A., Jeppesen E., and Beklioğlu M. (2013). Similarity between contemporary vegetation and plant remains in the surface sediment in Mediterranean lakes, Freshwater Biology Vol. 59, Issue 4 pp.724–736,.

McKinley G. (2009), Carbon and Climate; Basic Information on the Major Components of the Global Carbon Cycle, http://carboncycle.aos.wisc.edu/ (Accessed 01 January 2014).

METU Directorate of Strategy Development (2008-2014). Operation Reports of METU. Available online: http://sgdb.metu.edu.tr/faaliyet-raporu (Accessed 1 February, 2015).

METU Office of Cafeterias (November 2014 and March 2015), Private Communication.

METU Office of Electrical Works (September 2014 and March 2015), Private Communication.

METU Office of Central Heating & Water Support (2007). METU Heating System and Actions for Energy Saving Presentation.

METU Office of Central Heating & Water Support (September 2014 and January 2015), Private Communication.

METU Management of Transportation.(May 2014 and April 2015) , Private Communication.

Mount Union College (2010), Sustainability Plan Incorporating a Climate Action Plan.

Naturalgas.org (2013), Overview of Natural Gas, http://naturalgas.org/overview/background/ (Accessed 25 February, 2014).

Neff R. (2009), Measurement and Communication of Greenhouse Gas Emissions from U.S. Food Consumption via Carbon Calculators, Ecological Economics, 186-196.

ODTÜ Amenajman Planı (2007)

Özgirgin E. (2004), Utilization of Natural Gas, Optimization of Cogeneration / Combined Cycle Applications in Campus Environment. MSc Thesis, Ankara: METU.

Shine, K., Fuglestvedt J., Hailemariam K., Stuber N. (2005), Alternatives to the Global Warming Potential For Comparing Climate Impacts of Emissions of Greenhouse Gases, Climate Change, 68(3), 281–302, Available online at: 10.1007/s10584-005-1146-9.

Simpson W. A Reflection on Green Campuses. In The Green Campus, 8.

Solomon, S., Platter G.K., Knutti R., and Friedlingstein P. (2009), Irreversible Climate Change Due to Carbon Dioxide Emissions, Proc. Nat. Acad. Sci., 106, 1704-1709, Available online :http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2632717/. (Accessed 12 January, 2014).

Speight J.G. (1990), Petroleum Composition and Properties, Fuel Science and Technology Handbook, p. 71-121, Marcel Dekker, New York.

Suh S., Lenzen M., Treloar G., Hondo H., Horvath A., Huppes G., Jolliet O., Klann U., Krewitt W., Moriguchi Y., Munksgaard J., Norris G., (2004). System boundary selection in life-cycle inventories using hybrid approaches. Environment Science Technology 38 (3), 657-664.

Taylor B. (2010), Colgate University's 2008-09 Comprehensive Carbon Inventory.

The Editors of Encyclopedia Britannica (2005). Food, Encyclopedia Britannica. http://global.britannica.com/EBchecked/topic/212568/food (Accessed July, 2014).

Tranvik L. J., Downing J. A., Cotner J. B., Loiselle S. A., Striegl R. G., Ballatore T. J., Weyhenmeyer G. A. (2009). Lakes and Reservoirs As Regulators Of Carbon Cycling And Climate. Limnology and Oceanography, 54(6), 2298–2314.

Turkish Statistical Institute TUIK (2014), Turkey in Statistics 2013.

United Nations (1992), United Nations Framework Convention on Climate Change Convention.

US Department of State (2002), US Climate Action Report 2002, Washington DC.

US Department of Transportation (2014), Planning Glossary, http://www.fhwa.dot.gov/Planning/glossary/glossary_listing.cfm?sort=definition&TitleStart=V (Accessed 20 March, 2014).

US Environmental Protection Agency (EPA) (2014). Climate Change: Basic Information, http://www.epa.gov/climatechange/basics/ (Accessed 01 January, 2014).

Virtanen Y., Kurppa S., Saarinen M., Katajajuuri J., Usva K., Mäenpää I., and Nissinen A. (2011). Carbon Footprint of Food Approaches from National Input - Output Statistics and LCA of a Food Portion. Journal of Cleaner Production, 19, 1849-1856.

Wackernagel M., Onisto L., Bello P., Linares Al. C., Falfán I. S. L., García J. M., Guerrero A. I. S., Guerrero Ma. G.S. (1999), National Natural Capital Accounting with the Ecological Footprint Concept, Ecological Economics. 29, 375-390.

Wackernagel, M., B. Schulz, D. Deumling, A. Callejas Linares, M. Jenkins, V. Kapos, C. Monfreda, J. Loh, N. Myers, R. Norgaard and J. Randers (2002), Tracking the Ecological Overshoot of the Human Economy, Proc. Natl. Acad. Sci. 99(14), 9266-9271.

Weber C., Matthews H. (2008), Food-Miles and the Relative Climate Impacts of Food Choices in the United States. Environment Science Technology, 42, 3508–3513.

Wiedmann T., Minx J. (2008), A Definition of Carbon Footprint. Ecological Economics Research Trends, Nova Science Publishers, 1-11. Available online: https://www.novapublishers.com/catalog/product_info.php?products_id=5999.

Wiedmann T., Minx J., Barrett J. and Wackernagel M. (2006), Allocating Ecological Footprints to Final Consumption Categories with Input-Output Analysis, Ecological Economics 56(1): 28-48.

World Bank Group (2015), Climate Change, http://www.worldbank.org/en/topic/climatechange (Accessed 01 May, 2014).

World Business Council for Sustainable Development (2004), Mobility 2030: Meeting the Challenges to Sustainability. Available online: http://www.wbcsd.ch/ (Accessed 01 May, 2014)

Wright L., Kemp S., Williams I. (2011), Carbon Foot printing: Towards a Universally Accepted Definition, Carbon Management 2 (1): 61–72.

APPENDIX – A

ATMOSPHERIC CO_2

Table 40 Atmospheric CO_2 expressed as a mole fraction in dry air, micromol/mol, abbreviated as ppm (November 21, 2010 | Nature Geoscience - GlobalCarbonProject.org)

Date	Decimal	Average	Interpolated	Trend	#days
1958	1.958.208	315.71	315.71	314.62	NA
1959	1.959.042	315.62	315.62	315.70	NA
1960	1.960.042	316.43	316.43	316.51	NA
1961	1.961.042	316.93	316.93	317.03	NA
1962	1.962.042	317.94	317.94	318.06	NA
1963	1.963.042	318.74	318.74	318.91	NA
1964	1.964.042	319.57	319.57	319.67	NA
1965	1.965.042	319.44	319.44	319.48	NA
1966	1.966.042	320.62	320.62	320.63	NA
1967	1.967.042	322.07	322.07	322.07	NA
1968	1.968.042	322.57	322.57	322.55	NA
1969	1.969.042	324.00	324.00	323.98	NA
1970	1.970.042	325.03	325.03	325.04	NA
1971	1.971.042	326.17	326.17	326.26	NA
1972	1.972.042	326.77	326.77	326.86	NA
1973	1.973.042	328.54	328.54	328.58	NA
1974	1.974.042	329.35	329.35	329.44	NA
1975	1.975.042	330.68	330.68	330.81	31
1976	1.976.042	331.66	331.66	331.82	25
1977	1.977.042	332.69	332.69	332.75	29

Table 40 Continued

Date	Decimal	Average	Interpolated	Trend	#days
1978	1.978.042	335.10	335.10	335.11	26
1979	1.979.042	336.21	336.21	336.23	31
1980	1.980.042	337.80	337.80	337.95	30
1981	1.981.042	339.36	339.36	339.41	31
1982	1.982.042	340.92	340.92	341.03	30
1983	1.983.042	341.64	341.64	341.79	31
1984	1.984.042	344.05	344.05	344.15	31
1985	1.985.042	345.25	345.25	345.35	29
1986	1.986.042	346.54	346.54	346.56	26
1987	1.987.042	348.38	348.38	348.31	30
1988	1.988.042	350.38	350.38	350.36	29
1989	1.989.042	352.89	352.89	352.83	31
1990	1.990.042	353.79	353.79	353.74	30
1991	1.991.042	354.87	354.87	354.85	29
1992	1.992.042	356.17	356.17	356.12	30
1993	1.993.042	356.86	356.86	356.84	28
1994	1.994.042	358.22	358.22	358.13	27
1995	1.995.042	359.87	359.87	359.76	31
1996	1.996.042	362.04	362.04	361.84	31
1997	1.997.042	363.04	363.04	362.85	31
1998	1.998.042	365.18	365.18	365.01	30
1999	1.999.042	368.12	368.12	367.92	27
2000	2.000.042	369.25	369.25	369.06	27
2001	2.001.042	370.52	370.52	370.36	29
2002	2.002.042	372.45	372.45	372.23	29
2003	2.003.042	374.87	374.87	374.63	31
2004	2.004.042	377.00	377.00	376.79	31
2005	2.005.042	378.47	378.47	378.21	31
2006	2.006.042	381.35	381.35	381.11	26
2007	2.007.042	382.93	382.93	382.74	23
2008	2.008.042	385.44	385.44	385.26	31
2009	2.009.042	386.94	386.94	386.66	31
2010	2.010.042	388.50	388.50	388.23	28
2011	2.011.042	391.25	391.25	390.97	29

Table 40 Continued

Date	Decimal	Average	Interpolated	Trend	#days
2012	2.012.042	393.12	393.12	392.88	30
2013	2.013.042	395.54	395.54	395.30	31
2014	2.014.042	397.80	397.80	397.56	31
2015	2.015.042	399.96	399.96	399.72	30

APPENDIX – B

IPCC DEFAULT EMISSION FACTORS

Table 41 Default Emission Factors for Stationary Combustion in the Energy Industries (IPCC, 2006)

TABLE 2.2
DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN THE ENERGY INDUSTRIES
(kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel		CO_2			CH_4			N_2O		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Crude Oil		73 300	71 100	75 500	r 3	1	10	0.6	0.2	2
Orimulsion		r 77 000	69 300	85 400	r 3	1	10	0.6	0.2	2
Natural Gas Liquids		r 64 200	58 300	70 400	r 3	1	10	0.6	0.2	2
Gasoline	Motor Gasoline	r 69 300	67 500	73 000	r 3	1	10	0.6	0.2	2
Gasoline	Aviation Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
Gasoline	Jet Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
Jet Kerosene		r 71 500	69 700	74 400	r 3	1	10	0.6	0.2	2
Other Kerosene		71 900	70 800	73 700	r 3	1	10	0.6	0.2	2
Shale Oil		73 300	67 800	79 200	r 3	1	10	0.6	0.2	2
Gas/Diesel Oil		74 100	72 600	74 800	r 3	1	10	0.6	0.2	2
Residual Fuel Oil		77 400	75 500	78 800	r 3	1	10	0.6	0.2	2
Liquefied Petroleum Gases		63 100	61 600	65 600	r 1	0.3	3	0.1	0.03	0.3
Ethane		61 600	56 500	68 600	r 1	0.3	3	0.1	0.03	0.3
Naphtha		73 300	69 300	76 300	r 3	1	10	0.6	0.2	2
Bitumen		80 700	73 000	89 900	r 3	1	10	0.6	0.2	2
Lubricants		73 300	71 900	75 200	r 3	1	10	0.6	0.2	2
Petroleum Coke		r 97 500	82 900	115 000	r 3	1	10	0.6	0.2	2
Refinery Feedstocks		73 300	68 900	76 600	r 3	1	10	0.6	0.2	2
Other Oil	Refinery Gas	n 57 600	48 200	69 000	r 1	0.3	3	0.1	0.03	0.3
Other Oil	Paraffin Waxes	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
Other Oil	White Spirit and SBP	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
Other Oil	Other Petroleum Products	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
Anthracite		98 300	94 600	101 000	1	0.3	3	r 1.5	0.5	5
Coking Coal		94 600	87 300	101 000	1	0.3	3	r 1.5	0.5	5
Other Bituminous Coal		94 600	89 500	99 700	1	0.3	3	r 1.5	0.5	5
Sub-Bituminous Coal		96 100	92 800	100 000	1	0.3	3	r 1.5	0.5	5
Lignite		101 000	90 900	115 000	1	0.3	3	r 1.5	0.5	5
Oil Shale and Tar Sands		107 000	90 200	125 000	1	0.3	3	r 1.5	0.5	5
Brown Coal Briquettes		97 500	87 300	109 000	n 1	0.3	3	r 1.5	0.5	5
Patent Fuel		97 500	87 300	109 000	1	0.3	3	n 1.5	0.5	5
Coke	Coke Oven Coke and Lignite Coke	r 107 000	95 700	119 000	1	0.3	3	r 1.5	0.5	5
Coke	Gas Coke	r 107 000	95 700	119 000	r 1	0.3	3	0.1	0.03	0.3
Coal Tar		n 80 700	68 200	95 300	n 1	0.3	3	r 1.5	0.5	5
Derived Gases	Gas Works Gas	n 44 400	37 300	54 100	n 1	0.3	3	0.1	0.03	0.3
Derived Gases	Coke Oven Gas	n 44 400	37 300	54 100	r 1	0.3	3	0.1	0.03	0.3
Derived Gases	Blast Furnace Gas	n 260 000	219 000	308 000	r 1	0.3	3	0.1	0.03	0.3
Derived Gases	Oxygen Steel Furnace Gas	n 182 000	145 000	202 000	r 1	0.3	3	0.1	0.03	0.3
Natural Gas		56 100	54 300	58 300	1	0.3	3	0.1	0.03	0.3

Table 41 Continued

TABLE 2.2
DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN THE ENERGY INDUSTRIES
(kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel		CO_2			CH_4			N_2O		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Crude Oil		73 300	71 100	75 500	r 3	1	10	0.6	0.2	2
Orimulsion		r 77 000	69 300	85 400	r 3	1	10	0.6	0.2	2
Natural Gas Liquids		r 64 200	58 300	70 400	r 3	1	10	0.6	0.2	2
Gasoline	Motor Gasoline	r 69 300	67 500	73 000	r 3	1	10	0.6	0.2	2
	Aviation Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
	Jet Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
Jet Kerosene		r 71 500	69 700	74 400	r 3	1	10	0.6	0.2	2
Other Kerosene		71 900	70 800	73 700	r 3	1	10	0.6	0.2	2
Shale Oil		73 300	67 800	79 200	r 3	1	10	0.6	0.2	2
Gas/Diesel Oil		74 100	72 600	74 800	r 3	1	10	0.6	0.2	2
Residual Fuel Oil		77 400	75 500	78 800	r 3	1	10	0.6	0.2	2
Liquefied Petroleum Gases		63 100	61 600	65 600	r 1	0.3	3	0.1	0.03	0.3
Ethane		61 600	56 500	68 600	r 1	0.3	3	0.1	0.03	0.3
Naphtha		73 300	69 300	76 300	r 3	1	10	0.6	0.2	2
Bitumen		80 700	73 000	89 900	r 3	1	10	0.6	0.2	2
Lubricants		73 300	71 900	75 200	r 3	1	10	0.6	0.2	2
Petroleum Coke		r 97 500	82 900	115 000	r 3	1	10	0.6	0.2	2
Refinery Feedstocks		73 300	68 900	76 600	r 3	1	10	0.6	0.2	2
Other Oil	Refinery Gas	n 57 600	48 200	69 000	r 1	0.3	3	0.1	0.03	0.3
	Paraffin Waxes	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
	White Spirit and SBP	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
	Other Petroleum Products	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
Anthracite		98 300	94 600	101 000	1	0.3	3	r 1.5	0.5	5
Coking Coal		94 600	87 300	101 000	1	0.3	3	r 1.5	0.5	5
Other Bituminous Coal		94 600	89 500	99 700	1	0.3	3	r 1.5	0.5	5
Sub-Bituminous Coal		96 100	92 800	100 000	1	0.3	3	r 1.5	0.5	5
Lignite		101 000	90 900	115 000	1	0.3	3	r 1.5	0.5	5
Oil Shale and Tar Sands		107 000	90 200	125 000	1	0.3	3	r 1.5	0.5	5
Brown Coal Briquettes		97 500	87 300	109 000	n 1	0.3	3	r 1.5	0.5	5
Patent Fuel		97 500	87 300	109 000	1	0.3	3	n 1.5	0.5	5
Coke	Coke Oven Coke and Lignite Coke	r 107 000	95 700	119 000	1	0.3	3	r 1.5	0.5	5
	Gas Coke	r 107 000	95 700	119 000	r 1	0.3	3	0.1	0.03	0.3
Coal Tar		n 80 700	68 200	95 300	n 1	0.3	3	r 1.5	0.5	5
Derived Gases	Gas Works Gas	n 44 400	37 300	54 100	n 1	0.3	3	0.1	0.03	0.3
	Coke Oven Gas	n 44 400	37 300	54 100	r 1	0.3	3	0.1	0.03	0.3
	Blast Furnace Gas	n 260 000	219 000	308 000	r 1	0.3	3	0.1	0.03	0.3
	Oxygen Steel Furnace Gas	n 182 000	145 000	202 000	r 1	0.3	3	0.1	0.03	0.3
Natural Gas		56 100	54 300	58 300	1	0.3	3	0.1	0.03	0.3

APPENDIX – C

TURKEY EMISSION DATA

Table 42 Emissions Due to Electric Energy Production (TUIK 2012 National GHG Inventory Report)

Years	CO2 Emisssions (1000 tons)	CH4 Emisssions (1000 tons)	N2O Emisssions (1000 tons)	CO2 Eq. Emisssions (1000 tons)
1990	30.325,45	0,45	0,34	30.441,07
1991	33.036,20	0,45	0,38	33.163,33
1992	37.958,32	0,57	0,44	38.107,78
1993	36.117,85	0,56	0,42	36.259,01
1994	42.458,31	0,64	0,50	42.625,30
1995	43.750,40	0,68	0,49	43.917,51
1996	47.291,81	0,74	0,54	47.473,84
1997	53.233,32	0,84	0,60	53.436,49
1998	58.898,69	0,94	0,65	59.120,23
1999	64.553,77	1,05	0,68	64.785,18
2000	72.117,84	1,36	0,71	72.367,25
2001	74.543,17	1,38	0,72	74.795,29
2002	68.836,31	1,31	0,63	69.057,70
2003	69.004,73	1,34	0,61	69.220,60
2004	70.526,94	1,31	0,62	70.747,25
2005	83.716,19	1,47	0,75	83.980,28
2006	85.356,64	1,49	0,77	85.627,65
2007	100.699,98	1,72	0,90	101.016,45
2008	101.514,16	1,70	0,93	101.838,14
2009	96.326,71	1,56	0,83	96.618,14
2010	106.863,90	4,31	1,32	107.362,96
2011	116.315,18	1,84	1,06	116.682,11
2012	116.760,78	1,96	1,05	117.127,30

Table 43 Turkey's Electric Energy Production (TUIK 2012 National GHG Inventory Report)

Years	Electricity Production (GWh) Termic	Emission Factor (kg CO2 eq. / kWh)	Emission Factor (kg CO2/kWh)
1990	34.315,30	0,89	0,88
1991	37.481,70	0,88	0,88
1992	40.704,60	0,94	0,93
1993	39.779,00	0,91	0,91
1994	47.656,70	0,89	0,89
1995	50.620,50	0,87	0,86
1996	54.302,80	0,87	0,87
1997	63.396,90	0,84	0,84
1998	68.702,90	0,86	0,86
1999	81.661,00	0,79	0,79
2000	93.934,20	0,77	0,77
2001	98.562,80	0,76	0,76
2002	95.563,10	0,72	0,72
2003	105.101,00	0,66	0,66
2004	104.463,70	0,68	0,68
2005	122.242,30	0,69	0,68
2006	131.835,10	0,65	0,65
2007	155.196,20	0,65	0,65
2008	164.139,19	0,62	0,62
2009	156.923,43	0,62	0,61
2010	155.827,59	0,69	0,69
2011	171.638,27	0,68	0,68
2012	174.871,69	0,67	0,67

APPENDIX – D

MONTE CARLO SIMULATION DETAILED RESULTS

Table 44 Monte Carlo Simulation Results for 2014

Summary Statistics for Total CO2 Emission			
Statistics		**Percentile**	
Minimum	47238427,93	**5%**	49295948
Maximum	57588537,33	**10%**	50142790
Mean	53387613,05	**15%**	50791051
Std Dev	2212576,688	**20%**	51337643
Variance	4,8955E+12	**25%**	51819618
Skewness	-0,47475580	**30%**	52261193
Kurtosis	2,400308485	**35%**	52659994
Median	53718530,31	**40%**	53032910
Mode	55408859,23	**45%**	53388218
Left X	49295947,51	**50%**	53718530
Left P	5%	**55%**	54036360
Right X	56465604,68	**60%**	54337413
Right P	95%	**65%**	54628612
Diff X	7169657,169	**70%**	54901767
Diff P	90%	**75%**	55174910
#Errors	0	**80%**	55434267
Filter Min	Off	**85%**	55710673
Filter Max	Off	**90%**	56036498
#Filtered	0	**95%**	56465605

Table 45 Monte Carlo Simulation Results for 2013

Summary Statistics for Total CO2 Emission			
Statistics		**Percentile**	
Minimum	51378474,7	**5%**	53395331
Maximum	61515161,54	**10%**	54228682
Mean	57417519,42	**15%**	54869755
Std Dev	2172443,622	**20%**	55403334
Variance	4,71951E+12	**25%**	55879384
Skewness	-0,47463626	**30%**	56311220
Kurtosis	2,400617518	**35%**	56704093
Median	57742369	**40%**	57070243
Mode	59249069,09	**45%**	57417268
Left X	53395330,73	**50%**	57742369
Left P	5%	**55%**	58053798
Right X	60434661,08	**60%**	58349911
Right P	95%	**65%**	58633987
Diff X	7039330,353	**70%**	58907512
Diff P	90%	**75%**	59171997
#Errors	0	**80%**	59427496
Filter Min	Off	**85%**	59698925
Filter Max	Off	**90%**	60019569
Filtered	0	**95%**	60434661