DEVELOPMENT OF GREENHOUSE GASES (GHG) REDUCTION SCENARIOS WITH WELL TO WHEEL CONCEPT FOR PASSENGER CARS

by

AYŞEGÜL SERAP MÖNÜR

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APPROVED BY:

Assoc. Prof. Dr. Nilgün Cılız (Thesis Supervisor)	. . . .
Assoc. Prof. Dr. Burcu Onat (Thesis Co-advisor)	. . . .
Prof. Dr. Nadim Copty	. . . .
Assoc. Prof. Dr. Burak Demirel	. . . .
Assoc. Prof. Dr. Ülkü Alver Şahin	. . . .

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ABSTRACT

DEVELOPMENT OF GREENHOUSE GASES (GHG) REDUCTION SCENARIOS WITH WELL TO WHEEL CONCEPT FOR PASSENGER CARS

Road transportation is substantially contributing to climate change. Considering greenhouse gas (GHG) emission, which directly affect climate change, is largely driven by passenger car operations in road transportation and passenger cars constitute more than 50% of registered vehicles in Turkey, Turkey should focus to reduce GHG emission from passenger car operations. In this context, the proposed thesis covers the impacts of exchanging new vehicle technologies and introducing alternative fuel/energy types, through implementing different End of Life Vehicles (ELVs) regulations, on decreasing GHG emissions for passenger cars. Four scenarios are determined based on potential ELVs regulations.

Scenario A is created according to not implementing any ELVs regulation. Scenario B is selected based on implementing Turkey's 2003 ELVs regulation again for two years. In scenario C, the ELVs regulation is broadened to be perpetual. Finally, scenario D is designed to have more electrical car contribution till the end of 2023, as planned in EU. A Well-to-Wheel (WTW) analysis, the common Life Cycle Assessment (LCA) methodology for transportation, is adapted in this study to evaluate the full life cycle of fuel/energy consumed in each scenario. The life cycle inventory part of LCA is conducted by a statistical model which forecasts the fuel/energy consumption till the end of 2023 based on last five year averages and increasing trends. GaBi 6.0 software program is used as the LCA tool for Life cycle impact assessment and CML 2001 is used as LCA methodology. GHG emissions change is assessed according to global warming potential as the impact category indicator.

The results of WTW analysis reveal that 1.0% reduction in global warming potential will be achieved by applying a ELVs regulation for a limited time period in Turkey. The reduction will be 2.8% if the regulation is perpetual. Furthermore, the global warming potential can be decreased by 3.4% if the electrical car contribution will be increased to 4.2% by the end of 2023 in Turkey, as oppose to be 0.8%, if no action is taken.

ÖZET

BİNEK ARAÇLAR İÇİN KUYUDAN TEKERLEĞE KONSEPTİ İLE SERA GAZI DÜŞÜŞ SENARYOLARININ GELİŞTİRİLMESİ

Karayolu taşımacılığı iklim değişikliğine büyük ölçüde katkıda bulunmaktadır. İklim değişikliğini direkt etkileyen sera gazı emisyonunun büyük ölçüde karayolu taşımacılığındaki binek araç kullanımından kaynaklandığı ve Türkiye'deki kayıtlı araçların %50'sini binek araçların teşkil ettiği göz önüne alındığında, Türkiye binek araçlardan kaynaklanan sera gazı emisyonunun azaltılmasına odaklanmalıdır. Bu bağlamda, önerilen tez, binek araçlar için, farklı ömrünü tamamlamış araçlar (ÖTA) yönetmeliklerinin uygulanması yoluyla değişen yeni araç teknolojilerinin ve alternatif yakıt tipi sunumunun sera gazı emisyonu azalımına etkilerini kapsamaktadır. Potensiyel ÖTA yönetmeliklerini baz alan dört senaryo tanımlanmıştır.

Senaryo A, hiçbir ÖTA yönetmeliği uygulanmamasına göre oluşturulmuştur. Senaryo B, Türkiye'nin 2003 ÖTA yönetmeliğinin tekrar iki yıl uygulanması baz alınarak seçilmiştir. Senaryo C'de, ÖTA yönetmeliği sürekli olacak şekilde genişletilmiştir. Son olarak, senaryo D, 2023 sonuna kadar, Avrupa Birliği'nde de planlanan, daha fazla elektrikli araç katkısı için dizayn edildi. Taşımacılık için en yaygın Yaşam Döngüsü Değerlendimesi (YDD) metodu olan Kuyudan Tekerleğe (KT) analiz, her senaryo için tüketilen yakıt/enerjinin beşikten mezara yaşam döngüsünü değerlendirmek için uyarlanmıştır. YDD'nin Yaşam döngüsü envanteri aşaması için, son beş yılın averajlarını ve artış eğilimlerini baz alarak, 2023 sonuna kadar yakıt/enerji tüketimini tahmin eden istatistiksel bir model oluşturulmuştur. YDD aracı olarak GaBi 6.0 ve YDD yöntembilimi olarak da CML 2001 kullanılmıştır. Sera gazı emisyon değişimi, etki kategori göstergesi olan küresel ısınma potansiyeline göre değerlendirilmiştir.

KT analiz sonuçlarına göre, Türkiye'de ömrünü tamamlamış araçlar yönetmeliğinin belli bir dönemde uygulanması, küresel ısınma potansiyelinde %1.0'lik; uygulamanın surekli olması ise %2.8'lik düşüş sağlayacaktır. Ayrıca, hiçbir teşvik olmaması durumunda 2023 sonunda, %0.8 olacak elektrikli araç katkısı %4.2'ye çıkarılırsa, küresel ısınma potansiyelinde %3.4'lük düşüş sağlanabilecektir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**	**Units used**
CH_4	Methane	(g/km)
CO_2	Carbon dioxide	(g/km)
ELVs	End of Life Vehicles	
EU	European Union	
kg CO_2^- $_{eq}$.	kg CO_2 Carbon dioxide equivalents	
	Unit for potential contribution to global warming	
LCA	Life Cycle Assessment	
LCI	Life Cycle Inventory	
LCIA	Life Cycle Impact Assessment	
LPG	Liquified Petroleum Gas	
ISO	International Organisation for Standardisation	
GHG	Greenhouse gas	
GWP	Global Warming Potential	(kg CO_2^- eq.)
NO_x	Nitrogen oxides	(g/km)
N_2O	Nitrous oxide	(g/km)
PM	Particulate Matter	($\mu g/m^3$)
SETAC	Society of Environmental Toxicology and Chemistry	
UN	United Nations	
UNEP	United Nations Environment Programme	
WTW	Well-to-Wheel Analysis	
WTT	Well-to-Tank Analysis	
TTW	Tank-to-Wheel Analysis	

1. INTRODUCTION

Air pollution is one of the most important environmental problems in developing countries. The World Health Organization states that 2.4 million people die every year from causes directly attributable to air pollution, and 1.5 million of these deaths attributable to indoor air pollution (OECD, 2008). In Europe, transportation has the largest share of total greenhouse gas (GHG) emission after the energy sector, and road transport alone contributes about 18% of European Union (EU) total carbon dioxide emission (EU Transport GHG: Routes to 2050 II project, 2012).

The essential effect of air pollution is greenhouse gas effect because of the fact that it directly causes climate change. The atmosphere, environment and human health are affected from GHG emissions and climate change (Uherek et al., 2010). The United Nations Framework Convention on Climate Change formally identifies six gases as GHG and also only CO_2, CH_4 and N_2O are of particular concern to the transportation sector.

Turkey ratified the Kyoto protocol on 26 February 2009 and the United Nations Framework Convention on Climate Change in May 2004. While Turkey does not have any responsibility for reducing GHG emissions according to the Kyoto protocol, Turkey committed to apply requirements of developing and implementing policies to prevent climate change and taking necessary measures to increase energy efficiency and energy saving (Altay et al., 2010). According to these agreements and decisions, related regulations will be applied for adapting these decisions to decrease GHG emissions in Turkey. The Ministry of Energy and Natural Resources has produced a number of modeling studies estimating the total greenhouse gas emissions in Turkey by 2020, if action is not taken. They calculated that greenhouse gas emission will climb to 687 million tonnes in 2020 (Turkes, 2013; Ulueren, 2012). According to National GHG Inventory, fuel combustion emission contributed 75.3% of the total emission in 2009. Transportation constituted 17% of the fuel combustion and road transportation is accountable for 85% of transportation based CO_2 emission. The number of passenger cars in traffic was 1.7 million in 1990 and it increased to 7.5 million in 2009 (Turkey Climate Change, 5th Declaration, 2013).

Turkey applied a regulation of banning vehicles, which were produced before 1985, having older engine technology from traffic and managed decreasing high CO_2 emissions from these vehicles. This regulation was an End of Life Vehicles (ELVs) Regulation (7/8/2003 and regulation no: 25192). As a result of this ELVs regulation, total 145.000 vehicles were banned from traffic in 2003 and 2004 (Sahin et al., 2011).

The aim of this study is to assess different ELVs regulation scenarios in terms of GHG emissions reduction in Turkey from passenger cars operations. The GHG emissions calculations for all scenarios are based on EU emission factors

Four scenarios are determined based on similar ELVs regulations and future projections. The first scenario of the study is selected as benchmark scenario to measure the other three scenarios impact against. The benchmark scenario, scenario A, is created according to not implementing any ELVs regulation. Scenario B is selected based on implementing the 2003 ELVs regulation again for two years. In the scenario C, the ELVs regulation is broadened to be perpetual rather than limiting the implementation period. According to Turkey's National Climate Change Action Plan, it is aimed to increase energy efficiency of the transportation sector, introduce regulations for increasing alternative energy usage and increase interest in electrical vehicles until 2023 (NCCAP, 2011). With regard to incentivizing electrical vehicles, scenario D is assumed to have higher contribution of electrical passenger cars in traffic by the end of 2023 in Turkey. The number of electrical passenger cars in traffic is estimated considering expectation in various European countries.

Life Cycle Assessment (LCA) provides "cradle to grave" assessment opportunity for products or "well to wheel" assessment opportunity for transportation fuels and vehicles. LCA is used to evaluate the environmental impacts of a product or an activity by identifying and quantifying energy and materials used and wastes and emissions released to the environment throughout the entire life cycle of the product or activity, including extracting and processing of raw materials, manufacturing, transportation, use, re-use, recycling, and final disposal. The outcome of the LCA is universal metric of CO_2 equivalent GHG emissions per unit fuel used (Lattanzio, 2013). The common LCA methodology for transportation is Well-to-Wheel (WTW). A WTW assessment includes two main phases; "Well to Tank" (WTT) and "Tank to Wheel" (TTW). The production of fuel and transport to station for consumer use are the WTT phase and TTW covers the vehicle operation cycle.

In this study, WTW analysis is used to evaluate the life cycle of fuel/energy production and consumption due to passenger cars operations. A statistical model is built for Life cycle inventory (LCI) part of LCA and GaBi 6.0 software program is used as the LCA tool for Life cycle impact assessment (LCIA).

In the LCI part of the study, Turkey's next decade passenger car need and corresponding fuel consumption according to different fuel and emission technology types are forecasted based on the previous five years averages and trends. The previous years' data is obtained from Turkish Statistical Institute and Automotive Distributors Corporation.

In the LCIA part of the study, while different potential environmental impact categories, such as acidification, eutrophication, human health and climate change are important for full evaluation of fuel/energy production and consumption, a special emphasis is placed on climate change category, because GHG emissions associated with consumption of fuels/energy are the major contributors to global warming. CML 2001 – Nov. 2010, Global Warming Potential impact assessment method is selected to analyze the GHG emissions for all scenarios.

A sensitivity analysis is also conducted at the end of the study to investigate the robustness of the forecasting model. Sensitivity analysis is a useful statistical technique to assess the impact of variability of the inputs used in models (Fasso, 2006).

2. REVIEW OF LITERATURE

2.1. General Overview of Climate Change and Global Warming Effects

The 20th century has been a scene for the progression of technology and industrialization. These developments come along with certain requirements. Urbanization can be defined as the most important one of these requirements. These developments and urbanization, however, are progressively causing more waste production, toxic substances usage, natural resources depletion, and as a result, global warming, climate change, pollution, ozone layer depletion, acidification, eutrophication, deforestation and countless other environmental impacts have been observed (Bereketli et al., 2013). Urbanization is the most important key factor for future economic development planning, natural resources allocation and environmental management. Urban communities directly affect global climate change (Fusilli et al., 2014). The effects of urbanization and climate change are dangerous and seriously threaten the world's sustainable development (Global report on Human Settlements, 2011). According to the US National Oceanic and Atmospheric Administration (NOAA), warm temperature trends, sea surface temperatures and oceanic heat content will continue to rise, which support the conclusions of the Intergovernmental Panel on Climate Change (IPPC).

Accessibility is a key element of urbanization and well-being for societies after industrialization. With the growth of economic and social networks over 20th century, transportation has become a crucial factor in economic growth and social interaction in developing countries (Gorham, 2002; Maclean et al., 2003; Yagcitekin et al., 2014). However, the energy sources used for common transportation have a huge negative impact on the environment and human health. The fossil fuel combustion associated with transportation results in emissions of pollutants that are now recognized as being responsible for damaging human health, natural environmental sources, and it contributes to global climate change and consequently global warming (Maclean et al., 2003; Ahman, 2001; Silva et al., 2006). Air emissions from transportation can be also associated with GHG. The concentration of these gases in the stratosphere causes global warming and climatologists' studies show that global climate change will be associated with a lot of environmental impacts (Lattanzio, 2013). So, we can say that global warming issue is at an alarming level worldwide nowadays (Lee et al., 2013).

Combustion of fossil fuel such as coal, oil and gas provides over three-quarters of the world's energy requirements. The GHG are produced during combustion of fossil fuels in vehicles. Transportation includes the combustion of fossil fuels to produce energy translated in to motion (Gorham, 2002; Hekkert et al., 2005). The primary GHG emitted through fuel combustion is CO_2 (Bilgen et al., 2008). Generally, N_2O and CH_4 emissions have a relatively small proportion of overall transportation related GHG emissions (approximately 2%). However, for gasoline fueled highway vehicles N_2O and CH_4 could have more significant proportion of total GHG emissions (approximately 5%) (U.S. EPA, 2007a; TGGPI, 2008).

According to The International Energy Agency (IEA) forecasts, carbon dioxide emissions from transportation will increase by 92% between 1990 and 2020. Introducing new vehicle technologies and alternative fuels are the key factors for reducing the impact of GHG emissions related to transportation (Lattanzio, 2013; Hekkert et al., 2005; Kohler et al., 2013; Duke et al., 2009). New technologies for vehicles and traffic management will be the most important way to lower emissions from transportation sector (Van der Zwaan et al., 2013).

Globally, the largest single source of GHG emissions is power (25 percent), followed by industries (19 percent), transportation (13 percent), buildings (9 percent), land-use change and forestry (17 percent), agriculture (14 percent), and waste & wastewater activities (3 percent). In addition, emissions from the global power sector have grown dramatically in recent decades (Madrigal et al., 2010).

Additionally, Figure 2.1 shows the distribution of greenhouse gases emissions in Europe for all sectors. Figure 2.2 illustrates the distribution of greenhouse gases emissions based on transportation sector types in Europe (EU Transport GHG: Routes to 2050 II project, 2012).

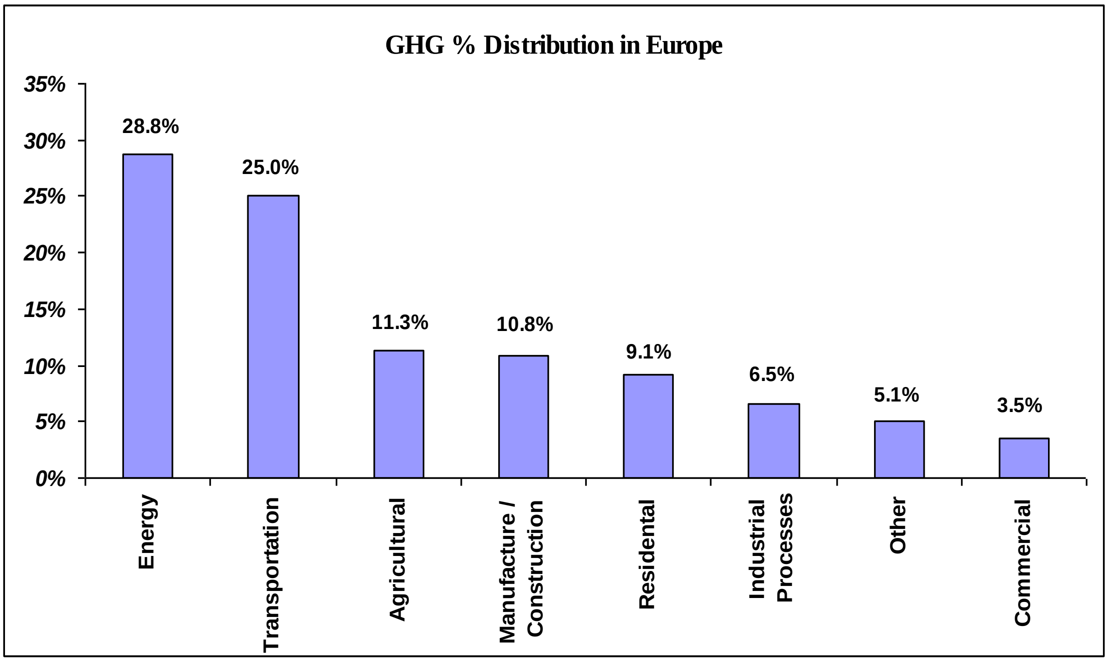


Figure 2.1. Greenhouse Gas Emissions Distribution by Sectors in EU (EU Transport GHG: Routes to 2050 II project, 2012).

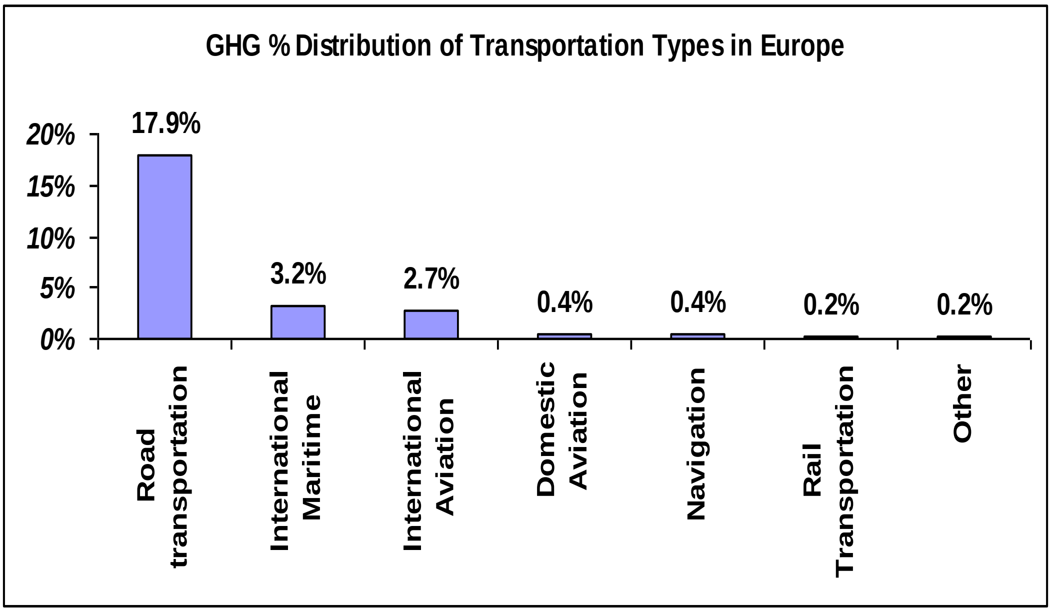


Figure 2.2. Greenhouse Gas Emissions Distribution of Transportation in EU (EU Transport GHG: Routes to 2050 II project, 2012).

The second biggest greenhouse gases emitting sector in EU is transportation after energy. In Europe many of EU15 countries are facing overshoot of their Kyoto commitments and road transport sector is identified as one of the main sources of rising CO_2 (Fontaras et al., 2010). Road transport emits about one-fifth of overall CO_2 emissions in EU (EU Transport GHG: Routes to 2050 II project, 2012).

According to IPPC Fourth Assessment Report, climate change has negative effects on the earth, especially on the Mediterranean Basin. Turkey, which is located in this region, is in the high risk group. The total GHG emissions of Turkey increased significantly in the period 1990 to 2007 because of the steady population growth and intensive industrialization. More than 90% of passengers and goods are transported by road in Turkey. In 2011, nearly 2.7 million m^3 of gasoline, 11.5 million m^3 of diesel and 5.2 million m^3 of liquefied petroleum gas (LPG) were consumed for transportation in Turkey (Melikoglu, 2014). In 2007, the main GHG emission is defined as CO_2 and GHG emissions are calculated based on following distribution: 81.7% CO_2, 14.6% CH_4 and 2.6% N_2O (EEA, Climate Change Mitigation-Turkey, 2010).

Table 2.1 illustrates total GHG emissions in Turkey from 1990 to 2007. Turkey’s total CO_2 emission is calculated as 304.47 million tons (Mt) in 2007. Researches show that emissions grew by 36% compared to 2000 levels and by 118% compared to 1990 levels (Erdogdu, 2010).

Table 2.1. Total GHG emissions in Turkey (in million tons of CO_2-Equiv.) (Erdogdu, 2010).

	1990	1995	2000	2005	2007
CO_2	139.56	171.85	223.81	256.43	304.47
CH_4	29.21	42.54	49.27	49.32	54.38
N_2O	1.26	6.33	5.74	3.43	9.65
F Gases	0	0	1.14	3.24	4.13
Total	170.06	220.72	279.96	312.42	372.64

2.2. Well-to-Wheel Analysis

Life Cycle Assessment (LCA) is the most effective method for assessing environmental impact, defining problems and suggesting improvement strategies of products or applications (Bereketli et al., 2013). LCA makes it possible to choose the best process or service considering environmental and human health impacts (U.S. EPA, 2006b).

Life cycle assessment is a “cradle-to-grave” approach. “Cradle-to-grave” begins with the raw materials acquisition to create the product and final disposal at the point when all materials are returned to the earth (U.S. EPA, 2006a). In this way, to find out the environmental consequences of a product through all of its life activities can be possible with LCA (Contadini et al., 2002; Rabitzer et al., 2004).

2.2.1. Phases of LCA

ISO 14040 and ISO 14044 describe the required and recommended elements of LCAs (UNEP/SETAC, 2009). ISO 14040 describes the framework of LCA analysis as the goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and life cycle interpretation phases. These phases are indicated in Figure 2.3.

2.2.1.1. Goal and Scope Definition

Goal and scope definition is the key step of LCA. It includes the determination of study purpose and process applications (ISO 14040). The system boundaries of the study and functional unit are described in this stage. The functional unit is a quantitative measure for the product/service (Finnveden et al., 2009; Finnveden et al., 2005; Rabitzer et al., 2004).

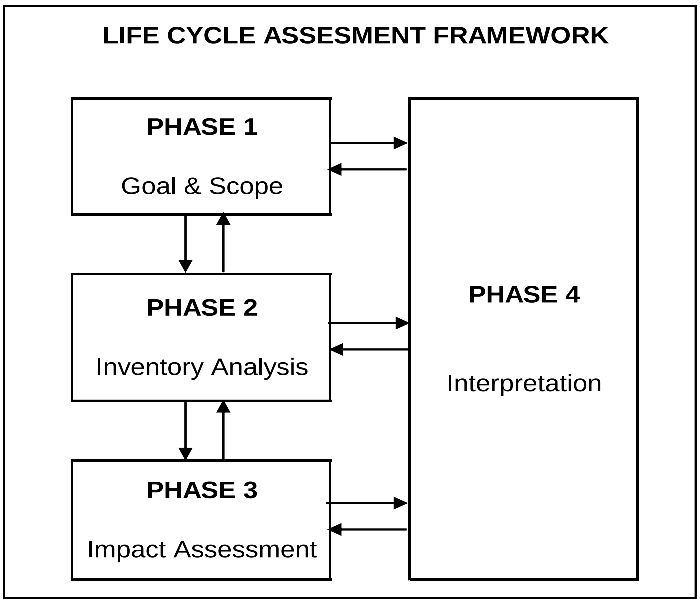


Figure 2.3. LCA Framework (ISO 14040).

2.2.1.2. Life Cycle Inventory (LCI)

The inventory analysis is a methodology for estimating resource requirements and waste flows released at the product's life cycle. The Inventory analysis stage involves the collection of data about the quantities of pollutants released to environment and the amount of energy and raw materials requirements (U.S. EPA, 2006c; Hauschild, 2005).

LCI analysis aims to create inventory flows and outline for a product system. Inventory flows include inputs of energy and raw materials and outputs to environment. All of the data must be related to the functional unit.

2.2.1.3. Life Cycle Impact Assessment

The purpose of life cycle impact assessment (LCIA) is described as understanding and evaluating the potential human health and environmental impacts of the environmental resources (ISO 14040; U.S. EPA, 2006d; Hauschild, 2005). LCIA has the following key steps:

1. Selection and Definition of Impact Categories
2. Classification
3. Characterization
4. Normalization
5. Grouping
6. Weighting

According to ISO 14042, the first three steps are mandatory while the other steps are optional depending on the goal and scope definition of the study (ISO 14042, U.S. EPA, 2006d).

Impact categories determination is the first step of LCIA and it should include potential human health and environmental impacts of the LCI (U.S. EPA, 2006d). Table 2.2 shows commonly used impact categories.

The aim of the classification step is to organize and combine the LCI results into impact categories. In this step, input and output parameters of the inventory are assigned to the impact categories.

Last mandatory step, which is characterization, makes it possible to compare different LCI results within each impact category. Science based conversion factors are used for the impact characterization and they are named as characterization factors (U.S. EPA, 2006d).

Normalization, Grouping and Weighting steps are optional steps for LCIA. Normalization calculates the magnitude of the category indicator results through comparing across impact categories. Normalized data can only be compared within an impact category. Grouping step involves sorting or ranking indicators. LCIA data can be grouped by characteristics such as emissions or location, and by a ranking system such as high, low or medium priority (U.S. EPA, 2006d; Hauschild, 2005). Weighting step can be described as the conversion of indicator results of impact categories by using numerical factors (U.S. EPA, 2006b). Generally, weighting includes identifying the underlying values of stakeholders, determining weights to place on impacts and applying weights to impact indicators.

Table 2.2. Commonly used impact categories (U.S. EPA, 2006d).

Impact Category	**Emissions**
Global Warming	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydro Choloroflurocarbons (HCFCs) Methly Bromide (CH_3Br)
Acidification	Sulphur Oxide (SO_x) Nitrogen Oxides (NO_x) Hydrochloric Acid (HCL) Hydrofluoric Acid (HF) Ammonia (NH_4)
Eutrophication	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates and Ammonia (NH_4)
Ozone Depletion	Chlorofluorocarbons (CFCs) Hydro Chlorofluorocarbons (HCFCs) Halons Methly Bromide (CH_3Br)
Photochemical Smog	Non-methane Hydrocarbon (NMHC)
Terrestrial Toxicity	Toxic chemicals with a reported lethal concentration to rodents
Aquatic Toxicity	Toxic chemicals with a reported lethal concentration to fish
Human Health	Total releases to air, water, and soil
Resource Depletion	Quantity of minerals used, Quantity of fossil fuels used
Land Use	Quantity disposed of in a landfill or other land modifications
Water Use	Water used or consumed

2.2.1.4. Life Cycle Interpretation

Life Cycle Interpretation is the last phase of LCA process. Interpretation phase can be defined as a systematic technique to identify, quantify, check and evaluate information from the results of the LCI and the LCIA, and also communicate them effectively. According to ISO 14043, the following steps are identified to apply life cycle interpretation for the LCI and the LCIA results:

- Identification of the significant issues based on the LCI and LCIA
- Evaluation which considers Completeness, Sensitivity, and Consistency Checks
- Conclusion, Recommendations and Reporting (ISO 14043, 2000)

Life cycle interpretation also provides a readily understandable, complete and consistent presentation of the results of an LCA study, in accordance with the goal and scope definition of the study (ISO 14043, 2000).

2.2.2. Life Cycle Assessment for Different Purposes

According to ISO 14040 and ISO 14044, a LCA can be performed with various approaches according to study purpose or subject. For example, LCA provides “cradle to grave” assessment opportunity for products or “well to wheel” assessment opportunity for transportation sector. LCAs for general purposes are briefly mentioned in next pages.

2.2.2.1. Cradle to Grave Analysis

Cradle to Grave Analysis can be described as a technique to define the potential environmental impacts throughout all life stages of product from raw material acquisition, production, distribution, usage and disposal phases (EEA, 1997).

2.2.2.2. Cradle to Gate Analysis

Cradle to Gate Analysis is a partial product's life cycle from raw material extraction to factory gate (Lovins, 2008). It includes information for materials through production of semi-manufactured product to final product (EEA, 1997).

2.2.2.3. Cradle to Cradle Analysis

Cradle to Cradle Analysis is a specific kind of cradle to grave assessment which is used to minimize the environmental impact of products and resource requirements by employing sustainable production, operational and disposal practices. Companies increase resource productivity by implementing sustainable production strategy as cradle to cradle assessment (Lovins, 2008).

2.2.2.4. Gate to Gate Analysis

Gate to Gate Analysis includes only determined inputs and outputs in system boundary stage of the study. Upstream activities (agricultural production, transport or storage) and downstream activities (distribution or use) are not included in gate to gate analysis (Finkbeiner, 2013). The information of each gate to gate analysis can be linked to a full cradle to gate analysis.

2.2.2.5. Well to Wheel Analysis

Well to Wheel Analysis (WTW) can be used for determination of full fuel cycle emissions which includes fuel production & distribution and vehicle operations emissions (Ma et al., 2012; Hekkert et al., 2005; Campanari et al., 2009). One of the most relevant WTW studies has been published by General Motors. Firstly, energy requirements and greenhouse gas emissions were analyzed; and then, the emissions of the other pollutants were also added with updated study (Argonne Report, 2001; Brinkman et al., 2005; Torchio et al., 2010).

WTW includes two main assessment phase; "Well to Tank" (WTT) and "Tank to Wheel" (TTW). Vehicle operations part (TTW) provides the most complete picture of fuel usage impact on GHG emissions, this part can contribute up to 70-80% of WTW emissions (Lattanzio, 2013; Silva et al., 2006). Well to tank analysis includes required energy and released greenhouse gases emissions from raw material extraction, transport, refinery and distribution stages (Greet Model, 2013). Tank to Wheel analysis provides to evaluation the impacts of the energy consumed and GHG emissions released from the vehicles usage (Foley et al., 2011; Pont, 2007). Accordingly, WTW analysis can be determined as the aggregation of the WTT and TTW phases, and accounts for the total primary energy consumed by the vehicle (Foley et al., 2011; Brinkman, 2005; U.S. EPA, 2007b). Figure 2.4 shows that WTT, TTW and also WTW analysis stages (U.S. EPA, 2007b; Foley et al., 2011).

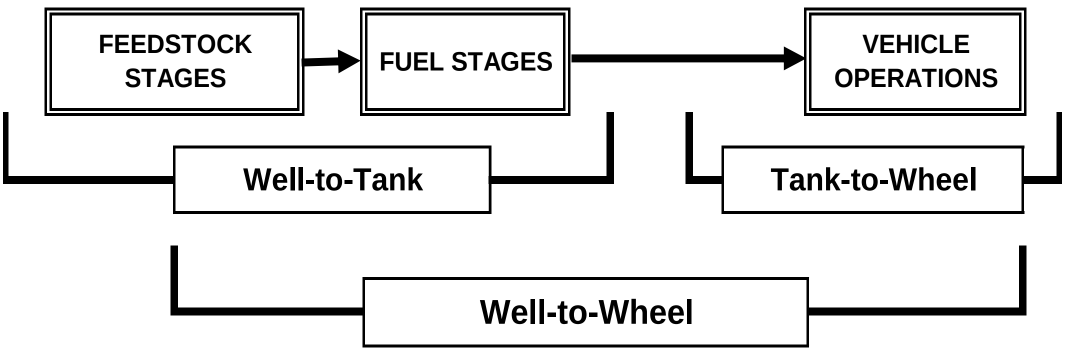


Figure 2.4. Well-to-Wheel Diagram (U.S. EPA, 2007b and Foley et al., 2011).

The WTW analysis is related to specific aspects, such as vehicle size, electricity mix, vehicle speed, etc. Traditionally, the WTW analysis can be applied for energy and GHG emissions, but other pollutants (NO_X, PM and SO_X) can also be added to the WTW analysis in some studies depending on the scope (Torchio et al., 2010).

3. MATERIALS AND METHODS

3.1. Introduction

This study examines different ELVs regulation scenarios in terms of GHG emissions reduction in Turkey, using a well-to-wheel life cycle analysis. In this study, four scenarios are compared; first scenario is based on no regulatory applications and other three scenarios are based on possible ELVs regulation applications.

Inventory analysis part of WTW assessment is conducted by statistical computations. GaBi 6.0 software is used as a WTW analysis tool for life cycle impact assessment. These two parts are followed with a sensitivity analysis at the end of the study. In the statistical part, the amount of GHG emissions and total fuel consumptions are computed. The results of the statistical part are used as inputs for GaBi 6.0 model for assessing each scenario's GHG emissions on a common scale, kg CO_2 equivalent (PE International, 2013).

3.2. Well-to-Wheel Analysis

3.2.1. The Goal and Scope Definition

The aim of this study is to compare the GHG reduction in exhaust emission from transportation in Turkey for 2023, based on possible applications of ELVs regulations scenarios.

The scope of this study contains both fuel/energy production cycle and vehicle usage stages. The scope of the study is summarized in Figure 3.1. The WTT stage is the fuel/energy production cycle and it starts from raw material acquisition to fuel station. The TTW stage refers to the vehicle usage stage in traffic.

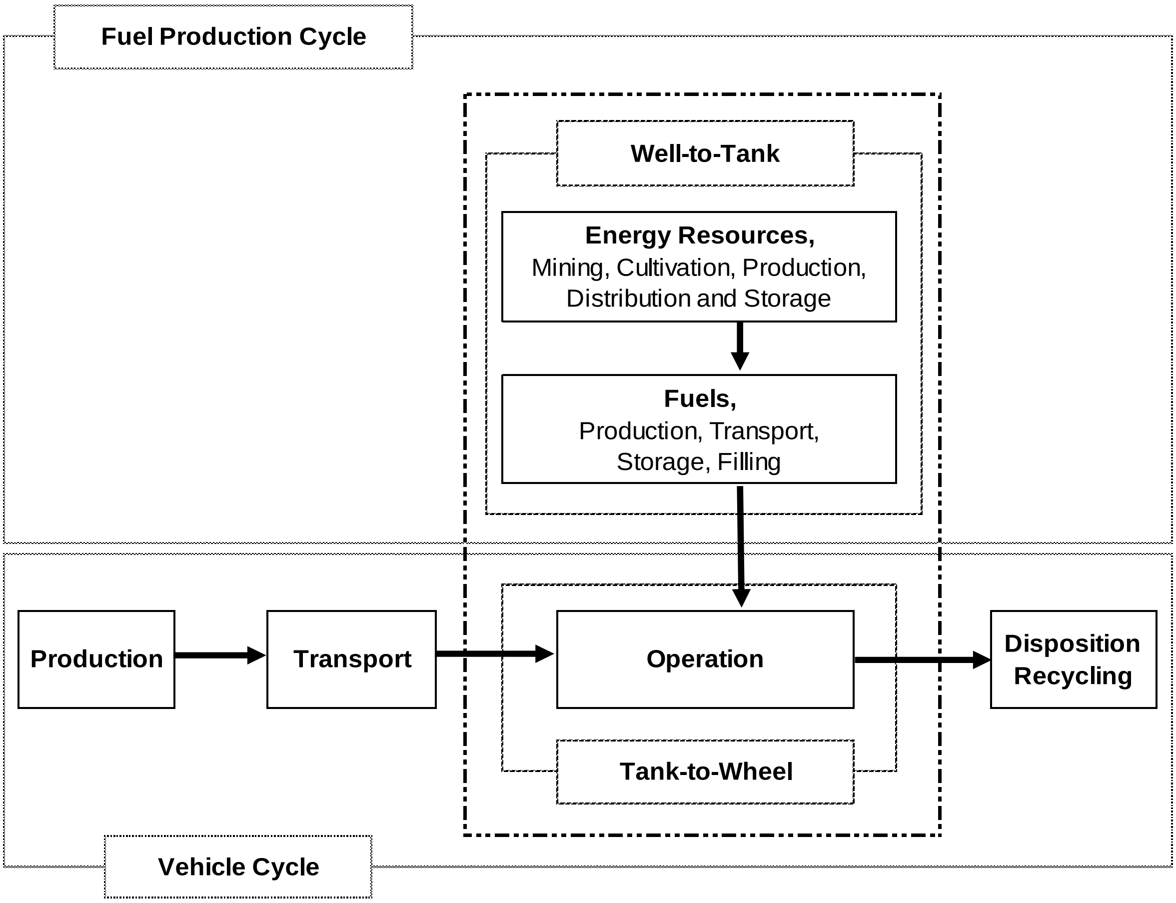


Figure 3.1. The scope of this study (Hoshi and Kaji, 2004).

As per Turkish Statistical Institute's Road Motor Statistics 2013 report, passenger cars constitute 52% of the registered vehicles in Turkey, which makes passenger cars a big contributor of GHG emissions in transportation sector. Also, passenger cars will likely be the fastest growing in emissions (IEA, 2008; Brand et al., 2012). Successful application of ELVs regulations for passenger cars will achieve the major reduction in total GHG emissions from transportation sector. Hence, this study was carried out for passenger cars.

In this study, functional unit of the WTW analysis is determined as the total fuel/energy consumption of passenger cars for one year in Turkey.

Turkey has to implement environmental action plans because of the fact that it is a member of G20 major economies and an associate member of the EU. Also, Turkey signed Kyoto Protocol on 26 February 2009 and the United Nations Framework Convention on Climate Change in May 2004 (Altay et al., 2010; Melikoglu, 2014). Turkey determined national climate change action plans and new regulations in order to reduce GHG emissions (Altay et al., 2010; NCCAP, 2011). According to Turkey's National Climate Change Action Plan, it is aimed to increase number of electrical vehicles in traffic until 2023 (NCCAP, 2011). In addition, ELVs regulations have been applied to ban vehicles having older engine technology from traffic. 145.000 end-of-life vehicles were banned from traffic over two years with latest ELVs regulation, which was effective in 2003 and 2004 (Sahin et al., 2011).

In this frame, this study focuses on the global warming potential of GHG emissions from passenger cars in transportation sector in Turkey until the end of 2023. Four different scenarios are developed for this study and Table 3.1 shows the list of four scenarios. These scenarios are determined based on the last ELVs regulation applications in Turkey and relevant regulatory applications and European emissions standards for passenger cars directives.

Table 3.1. List of Scenarios.

Scenario A	With no ELV regulation application
Scenario B	Applying the same ELVs regulation applied in 2003 (7/8/2003 and regulation no: 25192)
Scenario C	Removing all 30+ years old passenger cars (Pre Euro Technology passenger cars)
Scenario D	Removing all 30+ years old passenger cars (Pre Euro Technology passenger cars) and increasing electrical vehicles in traffic to 4.2% by 2023

The details of each scenario are presented in Table 3.2.

All these scenarios are analyzed to find out each ELVs regulations potential GHG emissions reduction based on WTW Analysis.

Table 3.2. Details of Scenarios.

Scenario A	The base scenario assumes there will be no ELVs regulation application till 2023. In this scenario the regular growth in passenger car sector is maintained and it assumes the fuel type dynamics will follow similar pattern like recent past five years, 2008 to 2012.
Scenario B	The repetition of the ELVs regulation (7/8/2003 and regulation no: 25192) applied in Turkey. The ELVs regulation was applied for passenger cars in 2003 and as a result 30% of the end-of-life vehicles were removed from traffic over two years, 2003-2004. Pre-Euro engine technology is accepted as the oldest engine technology for passenger cars and their emission factors are higher than the other engine technologies according to EURO emission standards. In Scenario B, a reduction of 30% in Pre-Euro passenger cars is aimed to be achieved in 2013 and 2014 in Turkey. The Pre Euro passenger cars will be replaced with Euro 5 technology passenger cars. Because Euro 5 technology has lower emission than pre-Euro technology, the total GHG emissions is expected to be lower in Scenario B.
Scenario C	It is assumed that the passenger cars which are more than 30 years old will be removed from traffic continuously and 80% of these passenger cars will be replaced with new technology passenger cars. All removed passenger cars cannot be replaced with a new one in reality because all consumers won't have required economic conditions for having a new car. 30+ years old passenger cars were produced using older engine technology which emits higher CO_2 than current technology and they are accepted as older technology worldwide. In many European countries, ELVs regulations are applied to 20+ to 30+ years old vehicles, and generally, vehicles more than 30 years old are not allowed in traffic.
Scenario D	It is a different version of scenario C. Similarly scenario D assumes that all 30+ years old passenger cars will be removed from traffic, however scenario D assumes new registered passenger cars would be more electrical passenger cars. The contribution of electrical passenger cars is assumed to increase year after year. According to Turkey's National Climate Change Action Plan, it's aimed to increase usage of alternative energy technologies in transportation sector; especially various incentives will be introduced for increasing interest in electric vehicles. Global climate change is one of the most important drivers for searching alternatives to petroleum based transport fuels in EU (Moriorty et al., 2013). European countries have important targets to increase alternative fuel/energy consumption for transportation. One of the important examples is Germany. In 2013, only 7,000 of the 43,000,000 passenger cars are electrical in Germany. The count of electric vehicles is aimed to increase to 1,000,000, approximately 2% of total vehicles, in 2020. Another important example can be Irish action plan about electric vehicles in November 2008. The Irish Minister for Transport has determined a target for 10% (230,000 vehicles) of the private car fleet to be powered by electricity by 2020 (Brady et al., 2011). Similar targets for number of alternative fuel technology cars in traffic are set for different European countries. The target for scenario D is determined to achieve 4% of passenger cars to be powered by electricity by 2023 in Turkey.

GaBi 6.0 software is used for the WTW analysis to calculate the global warming potential of four scenarios in this study. The analysis of the WTW results for this study focuses on the GWP impact category and assesses the results of each scenario based on kg CO_2 eq. Gabi 6.0 database for each fuel type is utilized for the WTT stage of the WTW analysis and vehicle operations' GHG emission amounts are calculated based on the statistical model (PE International, 2013).

GHG emissions are calculated based on Euro emission factors for gasoline and diesel and based on Emission Inventory Guidebook for LPG (EMEP/EEA, 2007; EMEP/EEA, 2009; Sahin et al., 2011). Electrical vehicles do not emit GHG at point of use, however the GHG emission impact of electrical vehicles comes from the electricity used to charge the vehicles (Samaras et al., 2008; Hoyer, 2008). The emission factors for each fuel type and technology are presented in Table 3.3.

Table 3.3 The emission factors (g/km) for each fuel type and technology (EMEP/EEA, 2007; EMEP/EEA, 2009; Sahin et al., 2011).

g/km		**Gasoline**					
		CO_2	**CO**	**HC**	**CH_4**	**NO_X**	**N_2O**
PRE EURO	**<1993**	270	46	7	0.131	2.5	0.022
EURO 1	**1993 - 2008**	200	2.4	0.18	0.026	0.41	0.022
EURO 4	**2009 - 2010**	200	0.5	0.1	0.002	0.08	0.002
EURO 5	**>2011**	140	0.25	0.05	0.002	0.04	0.002
		Diesel					
PRE EURO	**<1993**	170	0.4	0.14	0.011	0.57	0.002
EURO 1	**1993 - 2008**	170	0.4	0.14	0.011	0.5	0.002
EURO 4	**2009 - 2010**	160	0.07	0.1	0.002	0.25	0.009
EURO 5	**>2011**	160	0.07	0.05	0.002	0.01	0.009
		LPG					
All		178	7.1	0	0.06	2.16	0

3.2.2. The System Boundaries

One of the key aspects of this study is to forecast the growth in passenger car count and the changes of fuel usage mix of these cars in Turkey in the next decade. The statistic data were obtained from TUIK and examined to understand the trends which impact the count of passenger cars and fuel type distribution in Turkey. The assumptions are taken based on statistical averages and the period for calculating averages are selected as per the past data trends and determined relevantly.

The four scenarios have common and specific assumptions depend on the ELVs regulations expected impacts.

The common assumptions across the scenarios can be listed as follows:

- The number of new passenger cars registration for first year (2013) is taken as 550,000 and the new passenger car registration is assumed to grow 4% every year. According to Turkish Statistical Institute's September 2013 data, Table 3.4 shows the number of new passenger car registration by fuel type from 2007 to 2012. The average new passenger car registration in last 3 years is 551,219 per year and the average in last 5 years is 472,962 per year. Considering the recent years' steady high demands, 550,000 is considered as the appropriate starting point. The yearly growth rate of new passenger car registration varied between -18% to 23% in last 15 years and average growth rate is 4%, after removing the highest outlier.

Table 3.4. Number and distribution (%) of new passenger car registration in Turkey from 2007 to 2012 (Turkish Statistical Institute, September 2013).

Year	Gasoline	Dist. (%)	Diesel	Dist. (%)	LPG	Dist. (%)	Elc.	Dist. (%)	Others	Dist. (%)	Total
2007	172076	48.7	174119	49.3	7300	2%		0.0		0.0	353495
2008	175420	49.7	168320	47.7	9417	3%		0.0	11	0.0	353168
2009	199769	55.8	147030	41.1	11182	3%		0.0	5	0.0	357986
2010	213082	43.9	257720	53.1	14814	3%	2	0.0	1	0.0	485619
2011	222052	36.9	365760	60.7	11559	2%	31	0.0	2846	0.5	602248
2012	211901	37.5	340237	60.1	11987	2%	166	0.0	1500	0.3	565791
Total	**1194300**		**1453186**		**66259**		**199**		**4363**		**2718307**

- The fuel type distribution of new passenger car registration is kept proportionally same between gasoline, diesel and LPG (liquefied petroleum gas) as in 2012 and new electricity passenger cars assumed to be the total of last 2 years electric passenger cars. The 2012 new passenger cars registration contained 37.5% gasoline, 60.1% diesel, 2.1% LPG and 0.03% electric passenger cars. Table 3.5 shows the assumed contribution of each fuel type to new passenger car registration.

Table 3.5. The forecasted distribution of new passenger car registrations by fuel type.

	Distribution (%)			
Year	**Gasoline**	**Diesel**	**LPG**	**Electricity**
2013	37.4	60.6	2.0	0.1
2014	37.3	60.5	2.0	0.1
2015	37.3	60.5	2.0	0.2
2016	37.3	60.5	2.0	0.3
2017	37.2	60.4	2.0	0.4
2018	37.1	60.2	2.0	0.7
2019	37.0	60.0	2.0	1.1
2020	36.7	59.6	2.0	1.7
2021	36.3	58.9	2.0	2.8
2022	35.7	57.9	1.9	4.5
2023	34.7	56.2	1.9	7.2

- The number of passenger cars removed from traffic in Turkey is determined by the last 5 years averages for each model year and each fuel type. An illustration can be as follows:

  For 2013, the removal of 20 years old gasoline passenger cars is calculated as 0.4% of all 20 years old gasoline passenger cars in traffic as the similar passenger cars removal ratios were 0.4% in 2008, 0.4% in 2009, 0.6% in 2010, 0.3% in 2011 and 0.2% in 2012 (average 0.4%).

- Converting gasoline passenger cars to LPG passenger cars is a common practice in Turkey. The model considers similar conversions will take place in future. The number of gasoline passenger cars conversion to LPG passenger cars for each model year is determined by the last 5 years averages. Following illustration may explain the calculation:

  For 2013, it is calculated that 15.9% of 15 years old gasoline passenger cars would be converted to LPG. The conversion ratios of 15 years old gasoline passenger cars were 14.5% in 2008, 14.1% in 2009, 17.6% in 2010, 17.4% in 2011 and 15.7% in 2012 (average 15.9%).

- Each passenger car is assumed to travel 10,000 km per year (Sahin et al., 2011).

- A mid-size passenger car consumption is considered to determine fuel/energy consumption for each fuel type, which are listed as follows in table 3.6.

Table 3.6. Fuel/energy consumption for each fuel type technology.

Gasoline passenger car (Ntziachristos et al., 2014)	8.1 liter/ 100 km
Diesel passenger car (Ntziachristos et al., 2014)	6.1 liter/ 100 km
LPG passenger car (IEA ETSAP, 2010)	5.8 kg / 100 km
Electric passenger car (Howey et al., 2011)	62 MJ / 100 km

- The emission factors are defined based on the engine technology. In this study, the engine technology is determined by the year of manufacturing. The assumptions are as follows:
    - Passenger cars manufactured before 1993 are considered as Pre Euro
    - Passenger cars manufactured between 1993 and 2008 are considered as Euro 1
    - Passenger cars manufactured between 2009 and 2010 are considered as Euro 4
    - Passenger cars manufactured after 2010 are considered as Euro 5
    - It is assumed that there will be no new major technology change till 2023, hence all the new passenger cars in the model are considered as Euro 5
- The fuel/energy processes of Gabi 6.0 database is used for WTT stage of the WTW analysis of all scenarios
- The usage stage (TTW) of the WTW analysis of all scenarios are based on the statistical model outputs

As scenario A is the base scenario, there is no further specific assumption for scenario A.

The specific assumptions for scenario B are follows:

- It is assumed that additional to regular removal, 30% of Pre EURO passenger cars will be removed from traffic in 2 years, 2013 & 2014. The 2003 ELVs regulation yielded 30% extra passenger car removal over 2 years. Similar impact is assumed for scenario B.
- Each passenger car removal is assumed to be replaced with one new passenger car as the proposed regulation incentivizes the owners to change their older engine technology based passenger cars with new one.

The specific assumptions for scenario C are follows:

- It is assumed all 30+ years old passenger cars will be removed from traffic and this will continue perpetually.
- There can be antique passenger cars which will not be removed, however these type of passenger cars are not taken into consideration in this study
- It is assumed that not all passenger cars will be replaced with a new passenger car as this is not voluntary removal and not all owners will afford to buy a new passenger car. It is assumed one out of five owners will not be able buy a new passenger car.

The specific assumptions for scenario D are follows:

- The same 3 specific assumptions for C are applied for scenario D
- Additionally in scenario D, electrical passenger car contribution within new passenger car registration is assumed to be more. In scenario C, it is forecasted that the electrical passenger cars will constitute 1% of the total passenger cars in traffic in 2023. In scenario D, the target for electrical passenger car contribution in traffic in 2013 is set for 4%. To achieve 4% electrical passenger cars existence in traffic, it is assumed that 10%, 20%, 30%, 40% and 50% of the replaced passenger cars will be electrical in 2013, 2014, 2015, 2016 and 2017-2023. The electrical cars contribution within replaced passenger cars increase is assumed to be gradual because there will not be enough production of electric cars immediately in the initial years.

Table 3.7 shows the summary of the assumptions.

Table 3.7. Assumptions summary.

List of assumptions	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario D**
The number of new passenger cars registration for first year (2013)	550,000			
The fuel type distribution of new passenger car registration	Same as 2012 distribution (latest data point)			
The number of passenger cars removed from traffic	Last 5 years average			
Conversion rate from gasoline passenger cars to LPG passenger cars	Last 5 years average			
Each passenger car travel per year	10,000 km			
Fuel/energy consumption for each fuel type technology (per 100 km)	Gasoline: 8.1 liter Diesel: 6.1 liter LPG: 5.8 kg Electric: 62 MJ			
Engine technology according to model year	PRE EURO: <1993 EURO1: 1993-2008 EURO4: 2009-2010 EURO5: >2011			
Additional passenger car removals	-	30% in 2013 30% in 2014	All 30+ years old (except Antique cars)	-
Additional passenger car removals replacement ratio	-	5 to 5	4 to 5	4 to 5
Electricity car target (% of total passenger cars in traffic in 2023)	0.80	0.80	1.10	4.20

3.3. Inventory Analysis – Statistical Part

The number of passenger cars in Turkey has been increasing constantly and is expected to increase in the next decade. The statistical model for the study showed that the number of passenger cars will increase 80% till 2023, from 8.6 million in 2012 to 15.6 million in 2013. Figure 3.2 displays the actual from 2007 to 2012 and forecasted number of passenger cars in Turkey till the end of 2023 (Scenario A). Actual data are obtained from Turkish Statistical Institute.

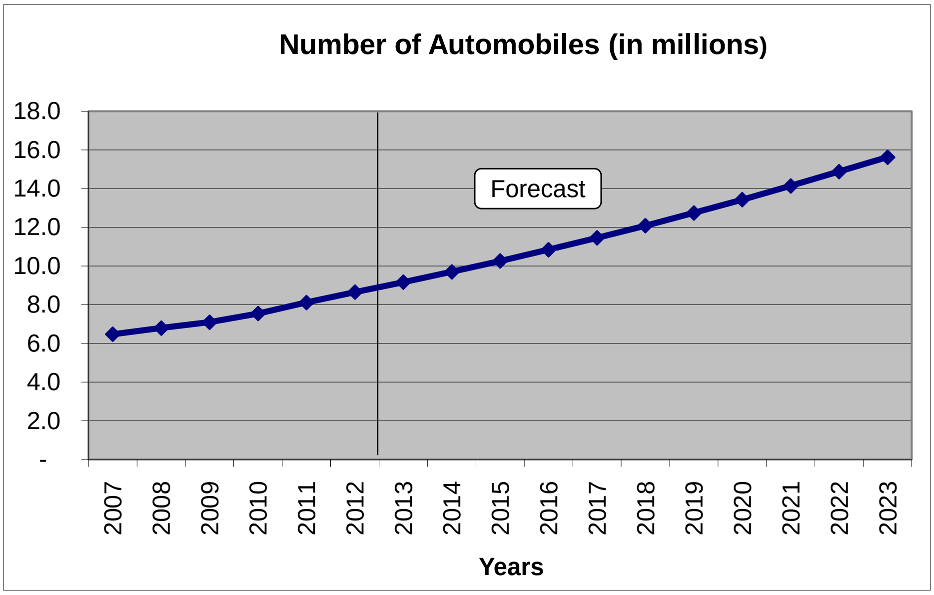


Figure 3.2. Number of passenger cars in Turkey (Turkish Statistical Institute, Sep 2013).

The fuel type and age distribution will also change considering the trends. The average age of passenger cars in Turkey was 10.6 years as of 2007 and increased to 11.6 years in 2012. It is expected to further increase to 13.8 by 2023 as per scenario A. In scenario B,C and D the average age is expected to be lower compared to scenario A as replacement of older engine technology based passenger cars with new passenger cars are proposed. The average age of passenger cars by 2023 is calculated to be 13.1 years for scenario B, 11.0 years for scenario C and D. Scenario C and D have the same age distribution, the difference between scenario C and D is the fuel distribution. Figure 3.3 shows the passenger car distribution in Turkey from 2007 to 2023 (2007 to 2012 are actual and 2013 to 2023 are forecast) by fuel type for each scenario, accordingly.

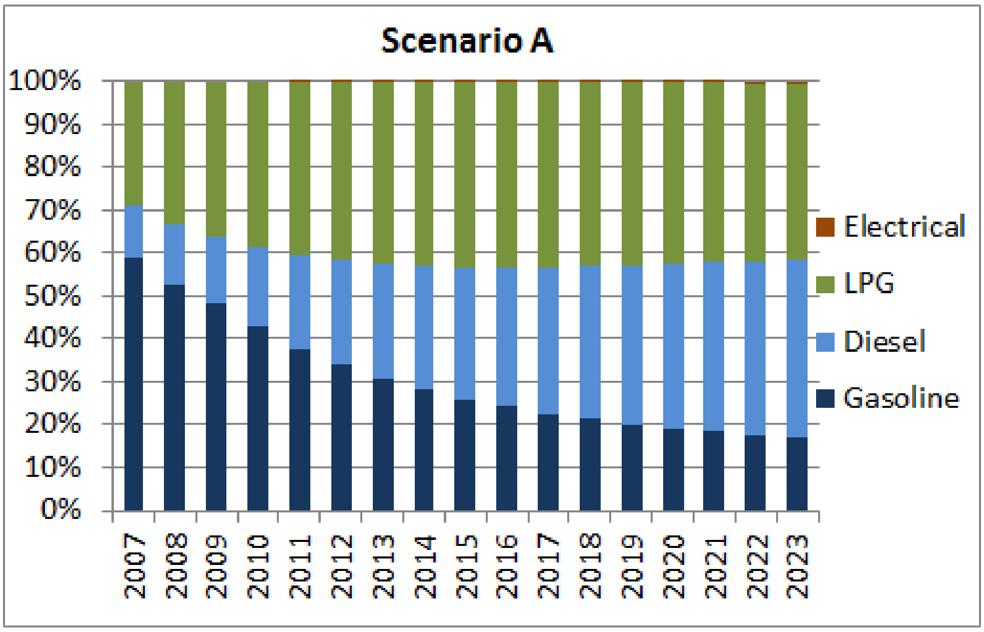


Figure 3.3. Distribution (%) of passenger cars in Turkey for scenario A.

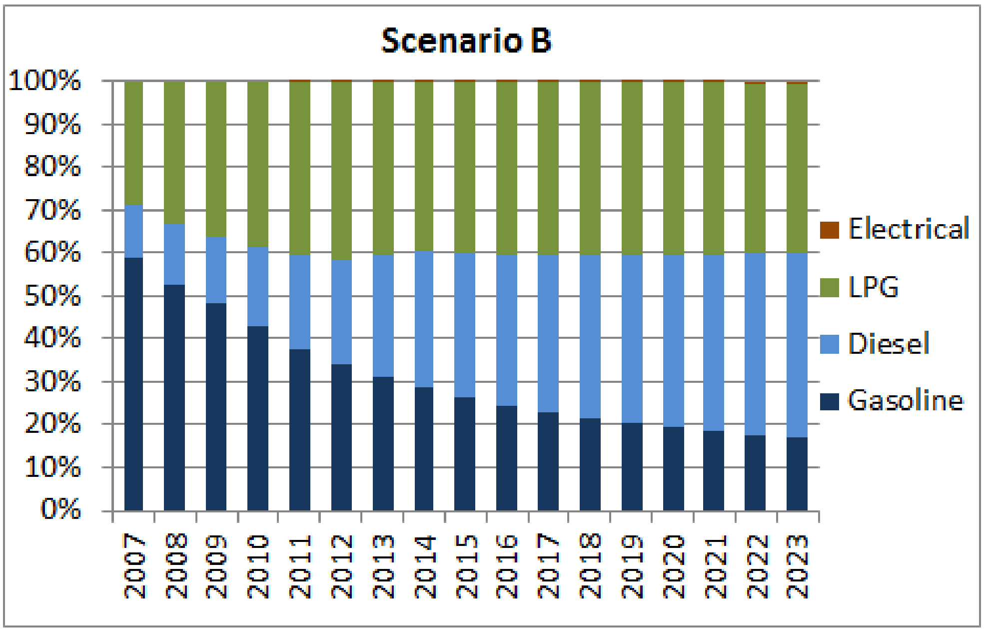


Figure 3.4. Distribution (%) of passenger cars in Turkey for scenario B.

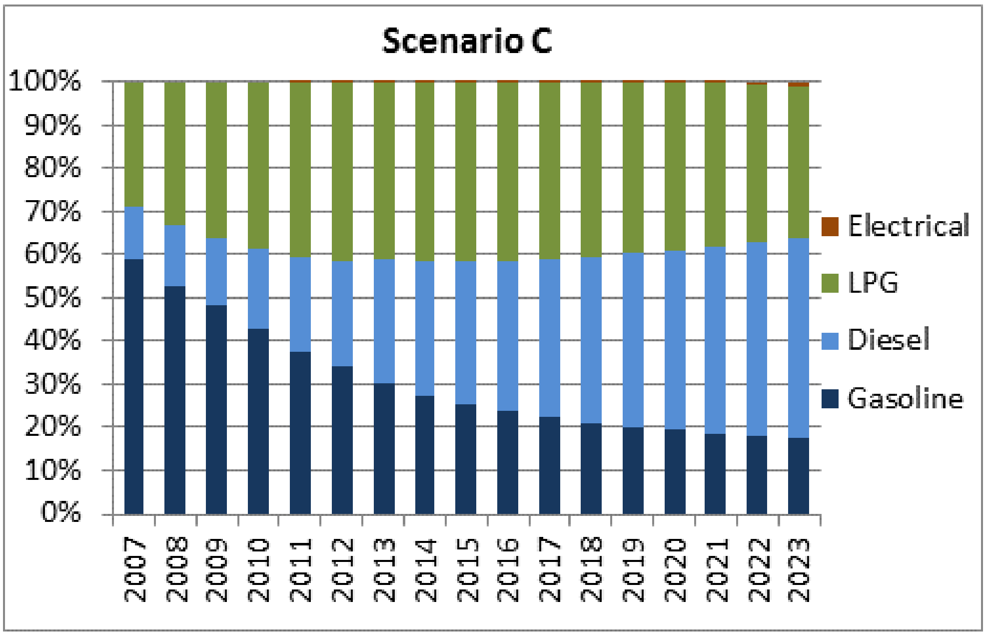


Figure 3.5. Distribution (%) of passenger cars in Turkey for scenario C.

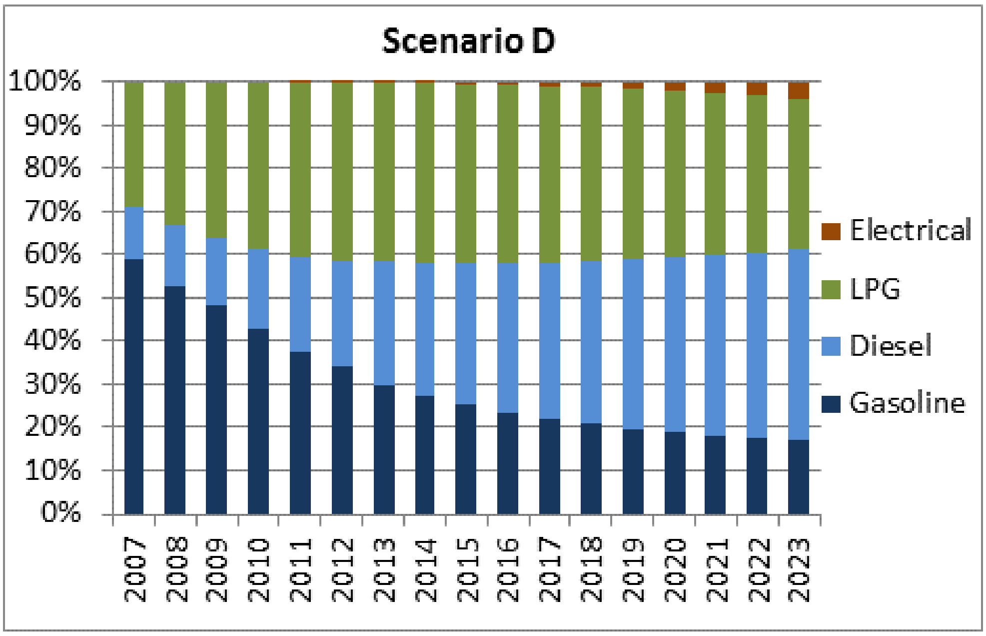


Figure 3.6. Distribution (%) of passenger cars in Turkey for scenario D.

There are two variables which differentiate the GHG emissions in this study. These two variables are fuel type and model year. Fuel type differentiates the GHG as each fuel type emits different amount of GHG and emissions from production of each fuel type is different. Model year determines the technology used in the passenger cars which haves four different variants in Turkey: Pre Euro, Euro 1, Euro 4 and Euro 5.

Once the number of passenger cars in Turkey is calculated according to model year and fuel type for each year till the end of 2023, the mileage for each category is calculated based on 10,000 km per year assumption.

The mileage calculation is a key step of the statistical part, because both GHG emission factors and fuel/energy consumptions are available in terms of 100 km traveled.

At the final step of the statistical model, the total GHG emissions and fuel/energy consumption amounts for each fuel type, model year and year are calculated. The statistical model outputs are used in GaBi 6 as inputs in order to evaluate the global warming potential.

The following tables (Table 3.8- 3.11) show the outputs of statistical model (which are used as inputs for GaBi 6):

Table 3.8. Scenario A – Forecasted amount of GHG emission and fuel/energy consumption in Turkey till the end of 2023.

USE PHASE	**in millions**	**Kg**							**Kg**			**MJ**
		CO_2	**CO**	**HC**	**CH_4**	**NO_X**	**N_2O**		**Gasoline**	**Diesel**	**LPG**	**Elec.**
	2013	16552	554	41	4	109	1		1686	1243	2261	3
	2014	17291	548	38	4	113	1		1632	1418	2424	7
	2015	18081	545	35	4	117	1		1592	1600	2582	12
	2016	18923	543	32	4	121	1		1562	1790	2734	22
	2017	19812	543	30	4	126	1		1543	1986	2881	38
	2018	20749	544	28	4	130	1		1532	2189	3025	65
	2019	21733	547	26	4	134	1		1529	2399	3166	110
	2020	22763	551	24	4	138	1		1534	2616	3306	186
	2021	23832	556	23	4	143	1		1543	2839	3445	315
	2022	24935	562	21	4	147	1		1556	3067	3585	531
	2023	26044	570	20	4	152	1		1567	3294	3725	747

Table 3.9. Scenario B – Forecasted amount of GHG emission and fuel/energy consumption in Turkey till the end of 2023.

	in	Kg							Kg			MJ
	millions	**CO_2**	**CO**	**HC**	**CH_4**	**NO_X**	**N_2O**		**Gasoline**	**Diesel**	**LPG**	**Elec.**
USE PHASE	**2013**	16417	507	36	3	104	1		1694	1316	2170	4
	2014	17048	461	28	3	103	1		1652	1563	2244	9
	2015	17869	464	26	3	107	1		1611	1745	2405	14
	2016	18738	468	24	3	112	1		1582	1934	2561	24
	2017	19654	473	22	4	117	1		1562	2130	2713	40
	2018	20616	480	21	4	121	1		1550	2334	2861	67
	2019	21623	487	20	4	126	1		1545	2544	3008	112
	2020	22674	495	19	4	131	1		1547	2761	3154	189
	2021	23764	504	18	4	136	1		1554	2984	3299	317
	2022	24886	514	17	4	140	1		1564	3212	3444	533
	2023	26013	525	16	4	145	1		1573	3439	3590	749

Table 3.10. Scenario C – Forecasted amount of GHG emission and fuel/energy consumption in Turkey till the end of 2023.

	in	Kg							Kg			MJ
	millions	**CO_2**	**CO**	**HC**	**CH_4**	**NO_X**	**N_2O**		**Gasoline**	**Diesel**	**LPG**	**Elec.**
USE PHASE	**2013**	16145	446	26	3	100	1		1625	1328	2181	4
	2014	16913	443	24	3	105	1		1577	1511	2336	8
	2015	17716	441	21	3	108	1		1545	1704	2477	14
	2016	18563	438	19	3	112	1		1524	1907	2609	24
	2017	19441	435	16	3	115	1		1513	2121	2728	42
	2018	20352	430	14	3	118	1		1512	2348	2832	72
	2019	21301	427	12	4	120	1		1522	2586	2924	124
	2020	22306	428	11	4	123	1		1538	2829	3020	209
	2021	23290	420	9	4	124	1		1567	3098	3071	364
	2022	24316	416	8	4	125	1		1597	3367	3131	620
	2023	25300	408	6	4	125	1		1638	3657	3144	1078

Table 3.11. Scenario D – Forecasted amount of GHG emission and fuel/energy consumption in Turkey till the end of 2023.

	in	Kg							Kg			MJ
	millions	**CO_2**	**CO**	**HC**	**CH_4**	**NO_X**	**N_2O**		**Gasoline**	**Diesel**	**LPG**	**Elec.**
USE PHASE	**2013**	16099	445	26	3	100	1		1618	1318	2180	191
	2014	16857	443	24	3	105	1		1570	1500	2335	233
	2015	17642	440	21	3	108	1		1536	1689	2475	314
	2016	18457	438	19	3	112	1		1511	1886	2606	448
	2017	19285	434	16	3	115	1		1494	2090	2724	669
	2018	20131	430	14	3	117	1		1485	2304	2826	957
	2019	21006	426	12	4	120	1		1487	2527	2915	1303
	2020	21945	426	11	4	122	1		1496	2757	3008	1651
	2021	22811	418	9	4	123	1		1512	3002	3055	2275
	2022	23729	413	8	4	124	1		1531	3251	3109	2962
	2023	24558	404	6	4	124	1		1556	3510	3116	4034

3.4. Modeling Tool – GaBi6

This study evaluates different ELVs regulation scenarios impact on GHG emission from passenger car transportation in Turkey using WTW analysis. For this purpose, GaBi 6.0 software is selected as the LCA tool in this study in order to perform the WTW analysis.

The GaBi is software developed by PE International and the LBP University of Stuttgart and is in compliance with ISO standards. Gabi allows users to analyze different life cycle stages, its activities and environmental flows. It contains databases which are built based on both industry sources and literature.

The most granular plan, which constitutes all required processes, is a one year plan for each scenario. Figure 3.4 shows an example of both WTT and TTW stages for a one year plan. Diesel at station, gasoline at station, LPG at station and electricity grid mix processes contain the fuel/energy production, refinery, transportation of fuel to stations and storage emissions for respective fuel/energy types. The usage phase is single process which contains the GHG emissions resulted from vehicles operations.

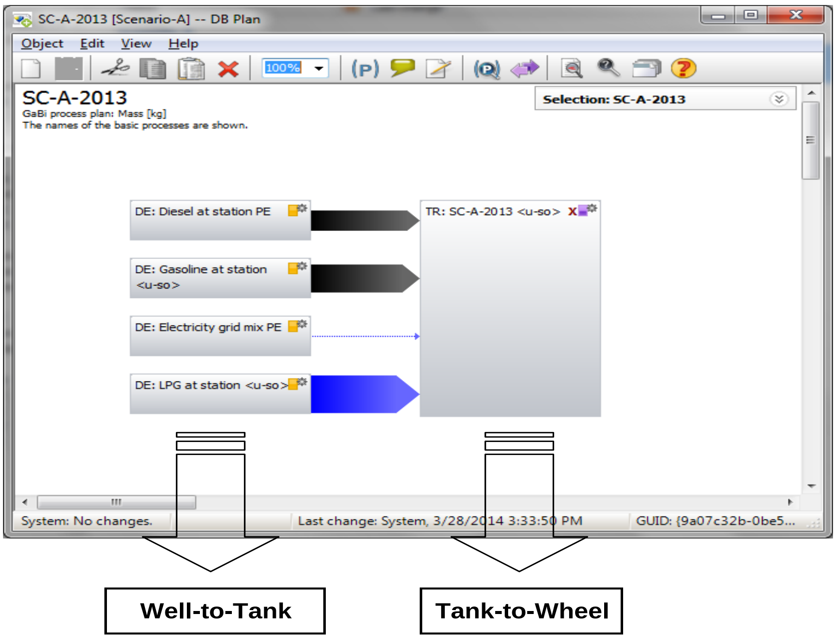


Figure 3.7. Sample granular plan - Scenario A – 2013.

4. RESULTS AND DISCUSSION

The aim of this study is to compare possible ELVs regulation applications impact on GHG reduction in exhaust emission from passenger cars with different fuel types in Turkey from 2013 until 2023. A statistical model is built for Life cycle inventory part of LCA and GaBi 6.0 software program is used as the LCA tool for Life cycle impact assessment. The common LCA methodology for transportation is WTW. A WTW assessment, includes two main phases; “Well to Tank” (WTT) and “Tank to Wheel” (TTW). WTW analysis is used to compare the impacts of each scenario. The results of each scenario are evaluated in impact assessment part of LCA.

4.1. Impact Assessment

The impact assessment phase (LCIA) of a LCA focuses on assessing the potential environmental impacts. LCIA phase has six key steps. The first three steps are mandatory (which are selection & definition of impact category, classification and characterization) and the other steps are optional depending on the goal and scope definition of the study according to ISO 14042 (U.S. EPA, 2006d). The impact assessment starts with selection and definition of impact categories. In accordance with the aim of this study, global warming potential is identified as the impact category.

Classification step is to organize and combine the LCI results into impact categories. Characterization step is the last mandatory step and provides to compare different LCI results within each impact category. In this study, Gabi 6.0 software is used as the LCA tool because it is a widely used LCA tool, both by professionals and researchers. The obtained results from statistical part are interpreted through classification and characterization in the impact assessment phase. The inventory data were classified according to its global warming potential on the environment.

4.1.1. Classification

In the classification step, the impact categories are selected according to CML 2001 methodology.

CML 2001 – Nov. 2010, Global Warming Potential impact assessment method is selected to analyze the GHG emissions for all scenarios. CML 2001 was developed by the Institute of Environmental Sciences, Leiden University, the Netherlands (CML 2001). It considers the following baseline impact categories: abiotic resource depletion; global warming; ozone layer depletion; human toxicity; fresh water, marine aquatic and terrestrial ecotoxicity; photochemical oxidation; acidification; eutrophication and land competition. The general structure and model of the CML 2001 method (baseline impact categories) is presented in Figure 4.1.

CML 2001 is a software tool which performs the technical steps of a LCA and it computes the LCA inventory calculations. By restricting quantitative modeling to early stages in the cause-affect chain, CML 2001 limits uncertainty. It contains the characterization factors for all baseline characterization methods mentioned in LCA (such as GWP 100, POCP etc.). The baseline indicators are category indicators at “mid-point level” (problem oriented approach)” and baseline indicators can be used for simplified studies. The terms mid-point and end-point mean the location of the environmental impact category indicator. The category indicator can be located at any point between the LCI results and the category end-points (where the environmental effect occurs).

The focus in this sturdy is determined as global warming potential because the main environmental issue caused by passenger cars operations is global warming impact. More than 90% of passengers and goods are transported by road in Turkey. Carbon dioxide emissions from road transport grew by 79% compared to 1990 levels in 2007 (National Climate Change Action Plan, 2011-2023). According to Turkish Statistical Institute May 2013 data, passenger cars constitutes 51.2% of total vehicles in Turkey. In 2007, the main GHG emission is defined as CO_2 and GHG emissions are calculated based on following distribution: 81.7% CO_2, 14.6% CH_4 and 2.6% N_2O (EEA, Climate Change Mitigation-Turkey, 2010).

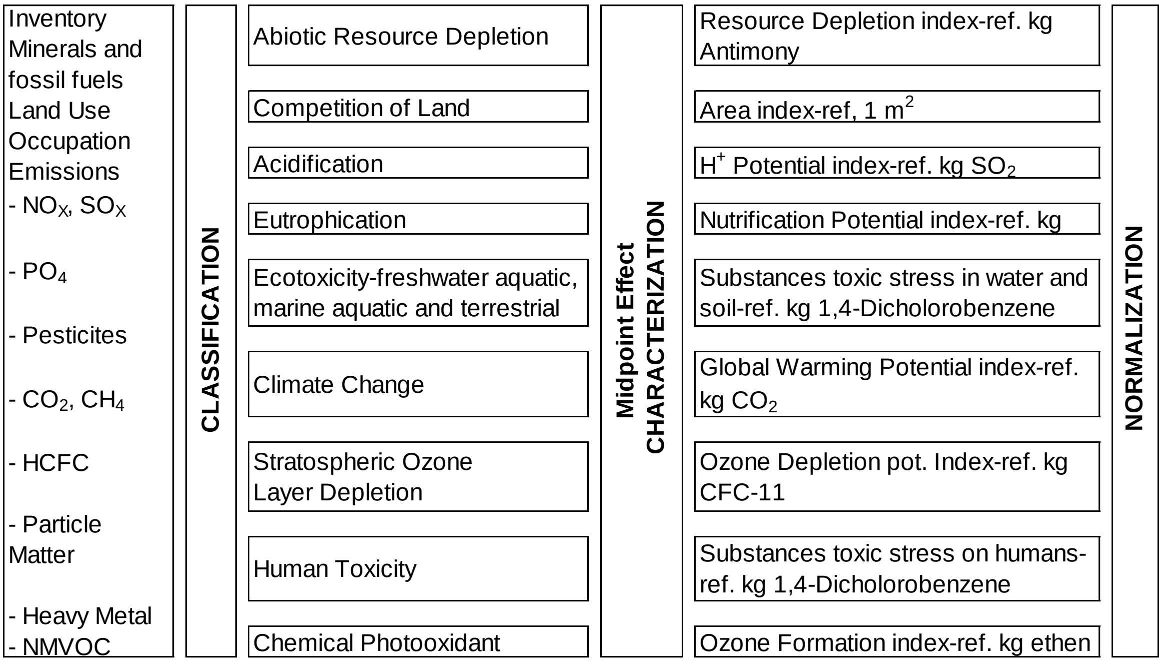


Figure 4.1. General structure and model of the LCIA method - CML 2001 (Reno et al., 2011).

CO_2, CH_4 and N_2O are the major emissions to air for CML 2001 global warming impact category. According to these emissions released to air from life cycle of passenger cars for each scenario, results summarized in Table 4.1 (total emissions amount till the end of 2023 are obtained).

Table 4.1. Major GHG emissions and resource consumption for each scenario.

in million kg	**CO_2**	**CH_4**	**N_2O**	**Resource consumption**
Scenario A	272418	347	10.8	6662562
Scenario B	270592	341	11.0	6996106
Scenario C	266382	335	10.9	7304245
Scenario D	264769	334	10.8	12498296

According to literature, the primary GHG emitted through fossil fuel combustion is CO_2 (Bilgen et al., 2008). Generally, N_2O and CH_4 emissions have a relatively small proportion of overall transportation related GHG emissions (approximately 2%). As results show in this study, the highest emission of GHG is CO_2 for all scenarios.

When air emissions for each scenario are compared, scenario A, in total, has higher GHG emission than the others because no ELVs regulation is applied as per scenario A. Whereas Scenario D has the lowest GHG emissions.

When each major GHG emissions are compared for all scenarios, the results show that scenario D has the lowest emissions for all GHG. CO_2 and CH_4 are highest in scenario A, due to the fact that the number of passenger cars with older engine technology is highest in Scenario A and older engine technology based vehicles contribute considerably to global warming. All other scenarios have lower emissions as ELVs regulations are applied and older technology passenger cars are replaced with newer technology passenger cars. As the percentage of passenger cars with better EURO emission factors increase, GHG emissions become lower. In Scenario D, not only a ELVs regulation is applied to improve emission technology, but also electric passenger car contribution is increased. Electrical passenger cars have the lowest emission factors and this makes scenario D the best in terms of low GHG emissions. However, highest resource consumption is also observed in scenario D because of higher water requirement for electricity production (Jaramillo et al., 2007).

The total and year by year amount of GHG emissions to air and recourse consumption are summarized in Table 4.2 for all scenarios. All scenarios' GaBi charts for GHG emissions to air and resource consumptions are available in APPENDIX A.

4.1.2. Characterization

Characterization is carried out to directly compare the life cycle inventory results within global warming impact category. Figure 4.2 shows the global warming potential equivalency factors used for environmental quantities according to CML 2001 in GaBi 6.0 as an example.

Table 4.2. The total and year by year amount of GHG emissions to air and recourse consumption.

Total GHG emissions (in million kg)	**Total (2013-2023)**	**Year**											
Resources			**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Scenario A	6662562		322612	359887	399869	443421	491500	546066	610217	689254	791991	933285	1074459
ScenarioB	6996106		338463	391722	431732	475327	523404	577939	642039	721010	823664	964866	1105941
ScenarioC	7304245		338830	378127	420891	467885	520620	581890	654905	743467	867762	1035461	1294407
ScenarioD	12498296		416461	471655	545847	644423	781558	950383	1145805	1343889	1663437	2010267	2524571
Emissions toAir			**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Scenario A	2607202		163078	175206	188283	202278	217159	232903	249498	266916	285103	303976	322802
Scenario B	2718585		168339	185770	198897	212958	227859	243598	260169	277547	295682	314500	333266
Scenario C	2741869		166726	179682	193843	209063	225449	243150	262072	281627	303638	325998	350619
Scenario D	2713159		166260	179139	193126	208060	223970	241075	259329	278315	299257	320686	343942

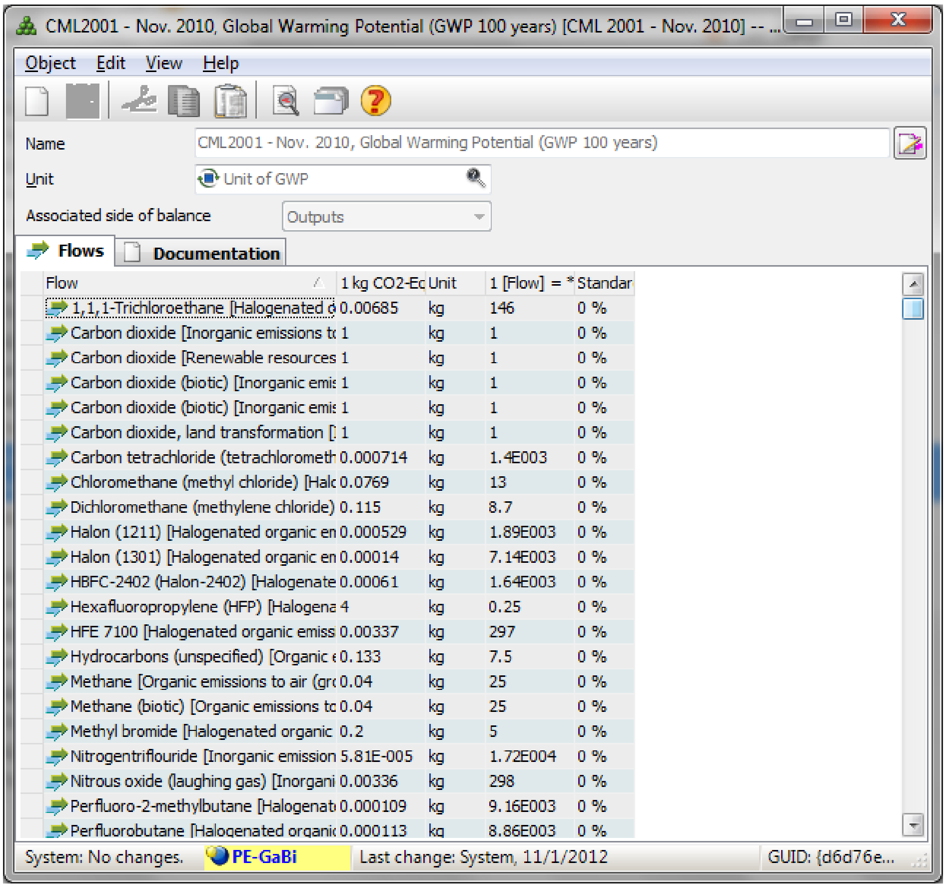


Figure 4.2. Global warming potential equivalency factors (Gabi 6.0, CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years)).

Climate change is defined as the impact on the atmosphere heat radiation absorption. And it has indirect impacts on the ecosystem and human health. GHG emissions to air directly affect climate change.

In CML 2001 methodology, the contribution of emissions to the global warming potential is given for the 20, 100, 500 time horizons, as specified by Intergovernmental Panel on Climate Change (IPCC). In this study 100 years horizon is selected because the most common time horizon used in similar studies is 100.

The life cycle inventory data have multiple metrics. In order to calculate the LCIA results for the global warming impact category, the GHG emissions are multiplied with the specified factors, which are kg CO_2 equivalent per kg GHG emission. The results of characterization for global warming potential are expressed with kg CO_2 equivalent as the common metric (Goedkoop et al., 2008).

The total and year by year global warming potential (kg CO_2 equiv.) of GHG emissions to air and recourse consumption are shown in Table 4.4 for all scenarios.

All scenarios' GaBi charts for global warming potential of GHG emissions to air and resource consumptions are available in APPENDIX B.

GWP is selected as impact category of this study and the total GWP for each scenario are listed as follow:

- Scenario A: 279,767 million kg CO_2 equiv. Scenario A is the base scenario.
- Scenario B: 276,989 million kg CO_2 equiv. 1.0% better than scenario A.
- Scenario C: 271,894 million kg CO_2 equiv. 2.8% better than scenario A.
- Scenario D: 270,341 million kg CO_2 equiv. 3.4% better than scenario A.

The GWP of all scenarios is mostly caused by inorganic emissions to air. For Scenario A, 95.81% of the GWP is caused by carbon dioxide, followed by 3.05% of GWP because of methane and 1.4% of GWP because of nitrous oxide.

The GWP reductions achieved by Scenario A with respect to other scenarios are given in the below table.

Table 4.3. GWP comparisons (Scenario B, C & D compared to Scenario A).

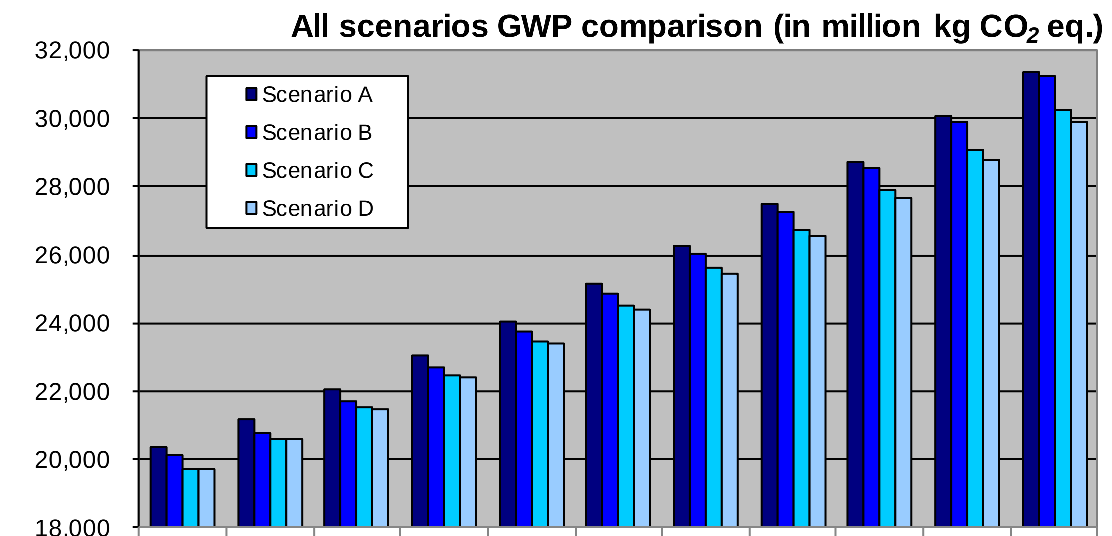
	GWP of Scenario B-C-D (%) compared to Scenario A		
	B	**C**	**D**
Emissions to air	**99.3**	**97.8**	**97.2**
Inorganic emissions to air	99.3	97.7	97.2
Carbon dioxide	99.3	97.8	97.2
Nitrous oxide (laughing gas)	102.1	101.1	99.9
Organic emissions to air (group VOC)	98.5	96.6	96.3
Methane	98.5	96.6	96.3

Table 4.4. The total and year by year GWP (kg CO_2 equiv.) of GHG emissions to air and recourse consumption for all scenarios.

in million kg CO_2 eq	**Total (2013-2023)**		**Year**										
Resources			**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Scenario A	(8836)		(587)	(619)	(655)	(695)	(739)	(785)	(836)	(890)	(948)	(1010)	(1072)
Scenario B	(9212)		(605)	(655)	(692)	(732)	(775)	(822)	(872)	(926)	(983)	(1045)	(1106)
Scenario C	(9292)		(596)	(631)	(671)	(716)	(765)	(819)	(878)	(940)	(1013)	(1088)	(1177)
Scenario D	(9459)		(598)	(634)	(675)	(721)	(773)	(830)	(893)	(959)	(1038)	(1120)	(1217)
Emissions to Air			**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Scenario A	288603		20917	21790	22729	23734	24801	25930	27122	28376	29692	31065	32446
Scenario B	286201		20710	21414	22395	23439	24542	25704	26927	28210	29553	30951	32355
Scenario C	281186		20307	21218	22176	23188	24239	25332	26478	27703	28908	30187	31450
Scenario D	279801		20287	21194	22143	23141	24170	25234	26347	27543	28696	29926	31121

Figure 4.3 shows the global warming potential year by year comparison of all scenarios in single graph format. It clearly shows all ELVs regulations reduce the global warming potential. Scenario D results the highest global warming potential reduction as the ELVs regulation in scenario D is permanent and more electrical passenger cars are stimulated.

The global warming potential reduction in scenario B starts with 1.1% and then increase and follow by a decrease and ends with 0.4% in 2023. This is because the major impact of ELVs regulation in scenario B is effective in 2013 & 2014. The global warming potential reductions in scenario C and D are increasing year by year as the ELVs regulations are permanent and scenario D is more effective in reducing global warming potential due to promoting more electrical passenger cars.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Scenario A	20,331	21,171	22,074	23,039	24,063	25,145	26,286	27,486	28,744	30,054	31,374
Scenario B	20,105	20,759	21,704	22,707	23,767	24,883	26,055	27,285	28,570	29,906	31,249
Scenario C	19,711	20,587	21,504	22,472	23,474	24,513	25,600	26,763	27,896	29,099	30,274
Scenario D	19,689	20,560	21,468	22,420	23,397	24,404	25,454	26,584	27,658	28,806	29,904

Figure 4.3. Year by year GWP comparison for all scenarios.

As we move from Scenario A to Scenario D, each step decreases the GWP. In scenario A, there is no ELVs regulation hence it is the base scenario. In scenario B, older engine technology based passenger cars are voluntarily replaced with new technology passenger cars over two years, which yields 1.0% reduction in GWP. In Scenario C, the replacement of older engine technology based cars is not voluntary, which decreases older engine technology based passenger cars in traffic drastically and additional 1.8% reduction in GWP is achieved. Finally in scenario D, not only older engine technology based passenger cars are replaced with new technology cars, but also electrical cars are incentivized. The electrical car count increase in traffic yields additional 0.6% reduction in GWP. The total reduction achieved in scenario D, compared to scenario A, reached 3.4%.

The emissions of electric passenger cars are sensitive to the assumptions made about the electricity grid (Howey et al., 2011). 20-50% GHG reduction can be possible according to production type of electricity, and also if renewable energy uses for electricity production, approximately 60% reduction would be possible (Ou et al., 2010; Granovski et al., 2006; Howey et al., 2011).

Figure 4.4, Figure 4.5 and Figure 4.6 compares the major GHG (CO_2, CH_4 and N_2O) emissions reduction for all scenarios.

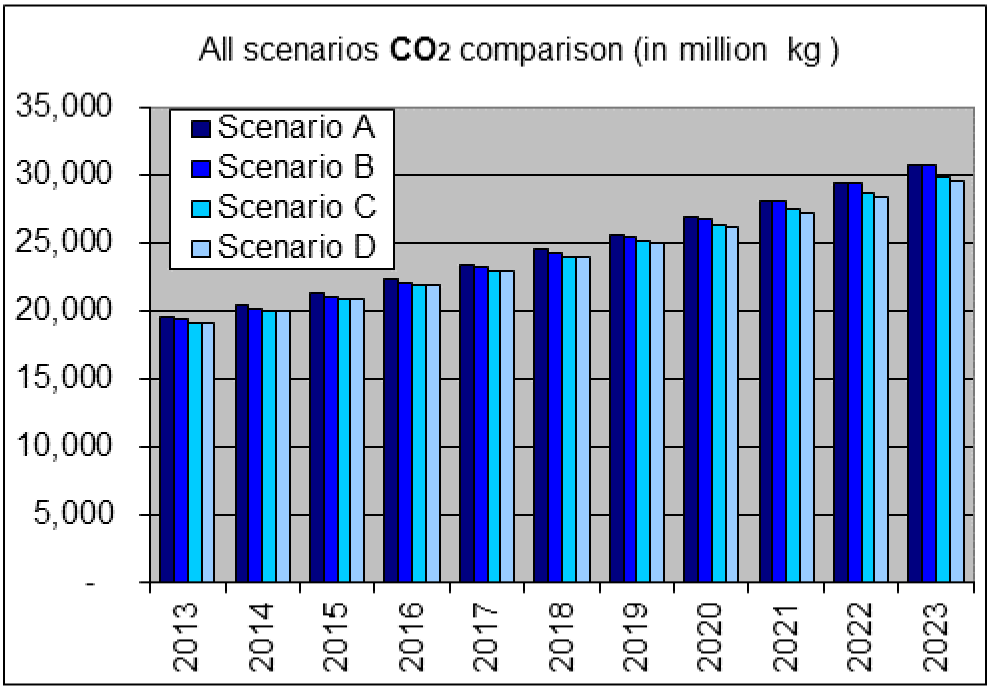


Figure 4.4. Year by year comparison of CO_2 for all scenarios.

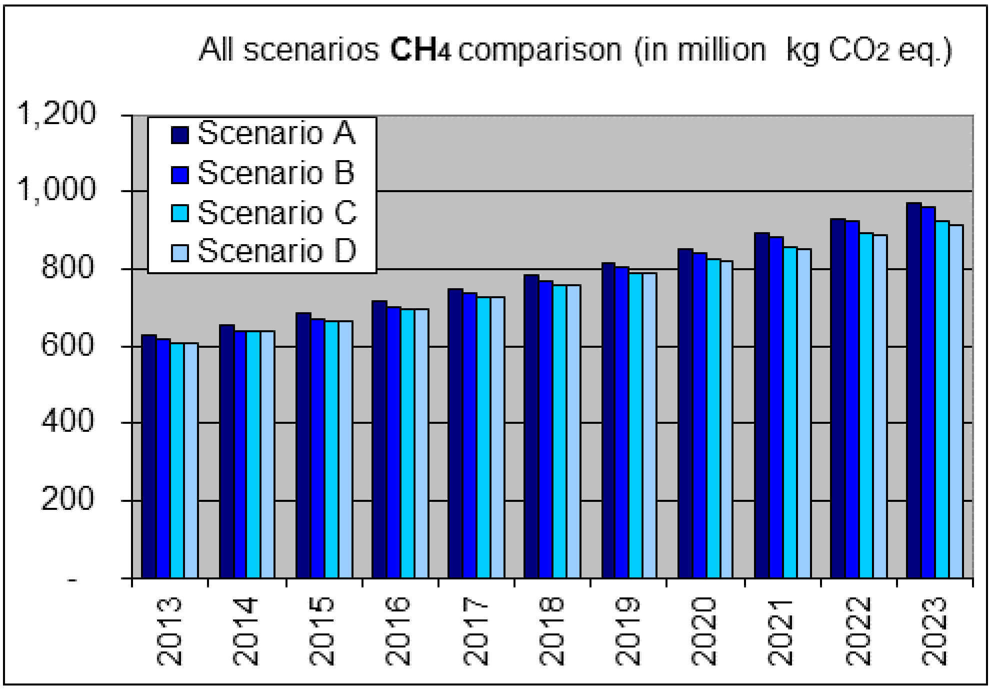


Figure 4.5. Year by year comparison of CH_4 for all scenarios.

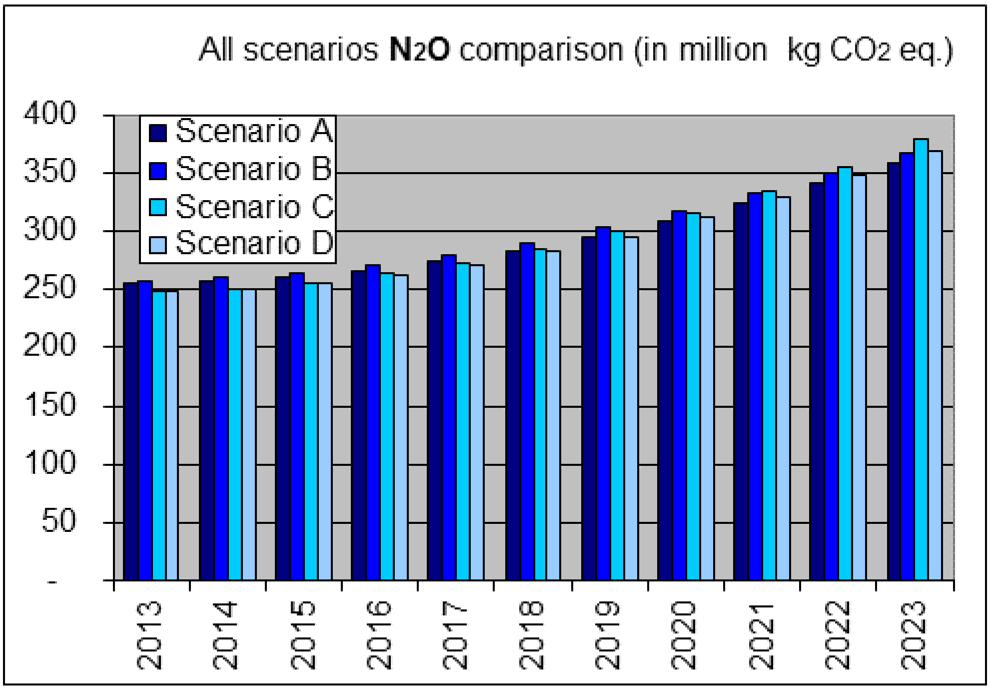


Figure 4.6. Year by year comparison of N_2O for all scenarios.

4.2. Sensitivity Analysis

Sensitivity analysis is conducted at the end of this study to evaluate the robustness of the model. There model results obtained based on certain assumptions and changes in assumptions have impacts on outputs.

In this section of the study, key assumptions are selected and changes those assumptions on outputs are evaluated:

- The count of new passenger car addition is assumed to start with 550,000. 10% increase in the initial year assumption impacts the number of passenger cars at 2023 by 4%. So, model sensitivity to initial year new passenger car addition count is not major.

- New passenger car addition is assumed to grow 4% every year. 10% increase in the growth rate assumption impacts the number of passenger cars at 2023 by less than 1%. So, model sensitivity to new passenger cars addition growth rate is not major.

- The removal of passenger cars and gasoline to LPG conversions are based on last 5 years' averages. These might impact the results, however as all scenarios work on the same 5 year average assumption, these does not impact the comparison of scenarios.

- Each passenger car is assumed to travel 10,000 km every year. This assumption has direct impact on absolute figures; however it has no impact on relative comparison of scenarios. A 10% increase in average travel distance will increase GHG emissions 10% in all scenarios, so the relatively there is no change.

- Fuel type distribution of passenger cars impacts the results directly as different fuel type cars have different emission factors. The comparison between Scenario C and scenario D shows that increasing contribution of electrical passenger cars in traffic yields better GHG emissions reduction. It can be achieved to lower the emissions reduction drastically by making contribution of electrical cars very high, however an assumption beyond 5% is not reasonable, as per the forecasts across the world.

- It is assumed that EURO 5 will be the latest emission technology for passenger cars. Of course, technological improvements will further improve the reductions for all scenarios.

It can be concluded from the sensitivity analysis of the key assumptions that the model is robust. Technological improvements (such as EURO 6 or better emission technology availability before 2023), social and economic changes (such as population dynamics, economic crisis or bubbles) and consumer behaviors (such as buying tendencies) may impact the outcomes.

5. CONCLUSIONS

Along with the population increase and economical demand advancement in Turkey, the importance of road transportation has been steadily rising; however, consequently air pollution has been evenly effected. Air pollution is also anticipated to keep on growing, which reveals the necessity of taking precautions in accordance with Turkey's commitments and plans.

This study aimed to evaluate the potential reduction in GHG emissions from passenger cars operations through implementing three different ELVs regulations as precautions.

The GHG emissions from passenger cars in Turkey will keep on increasing till the end of 2023 as the number of passenger cars is expected to increase steadily year by year, following the recent years trend. The GHG emissions from passenger cars operations are expected to increase from 20,331 million kg CO_2 eq. in 2013 to 31,364 million kg CO_2 eq. in 2023 without implementing any ELVs regulation.

The analysis results show that all three proposed ELVs regulations in scenarios B, C and D will result in lower GHG emissions and consequently lower global warming potential. In all scenarios, it is expected to have immediate effect, because all proposed ELVs regulations are targeting to remove passenger cars with older engine technology from traffic. Since there is a stock of older passenger cars – 19% of total passenger cars are more than 20 years old and 5% of total passenger cars are more than 30 years old – implementing ELVs regulations will slow down the GHG emissions increase starting from first year.

Even though all three proposed ELVs regulations implementation will achieve slowing down the GHG emission increase; scenario D, in which the ELVs regulation is perpetual and more electrical passenger cars are incentivized to be in traffic, has the best overall and ongoing results.

In scenario B, which proposes the similar ELVs regulation applied in 2003, the reduction impact is immediate, however, the reduction magnitude is starting to slow down because the ELVs regulation will be applied for limited time period, two years. The total global warming potential reduction from passenger cars till the end of 2023 will be 1.0% in scenario B, however the yearly reduction will drop from 1.1% in 2013 to 0.4% in 2023.

In the scenario C and D, the global warming potential reduction is also immediate in initial years but also the reduction magnitude will be continuous because of the fact that the ELVs regulations implemented in these scenarios are permanent. In both scenarios, the yearly reduction of global warming potential increases till the end of 2023. In scenario C, the reduction of global warming potential starts with 3.0% in 2013 and climbs to 3.5% in 2023; and in scenario D, it starts from 3.2% and climbs to 4.7%. This is an expected result because in scenario D, the older passenger cars are encouraged to be replaced with more electrical passenger cars.

The total global warming potential reduction till the end of 2023 is 1.0% for scenario B, 2.8% for scenario C and 3.4% for scenario D compared to benchmark scenario, A.

In summary, it can be concluded that implementing ELVs regulations will contribute to lower the GHG emissions, and, as a result, lower global warming potential of passenger cars operations in Turkey, compared to not implementing any ELVs regulation. ELVs regulations remove passenger cars with older engine technology from traffic and hence more passenger cars with newer emission technologies or with alternative fuel/energy types are added in traffic. In long term, electrical passenger cars should be incentivized, hence the magnitude of ELVs regulations’ impact will be amplified and the impact will be more sustainable.

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APPENDIX

APPENDIX A

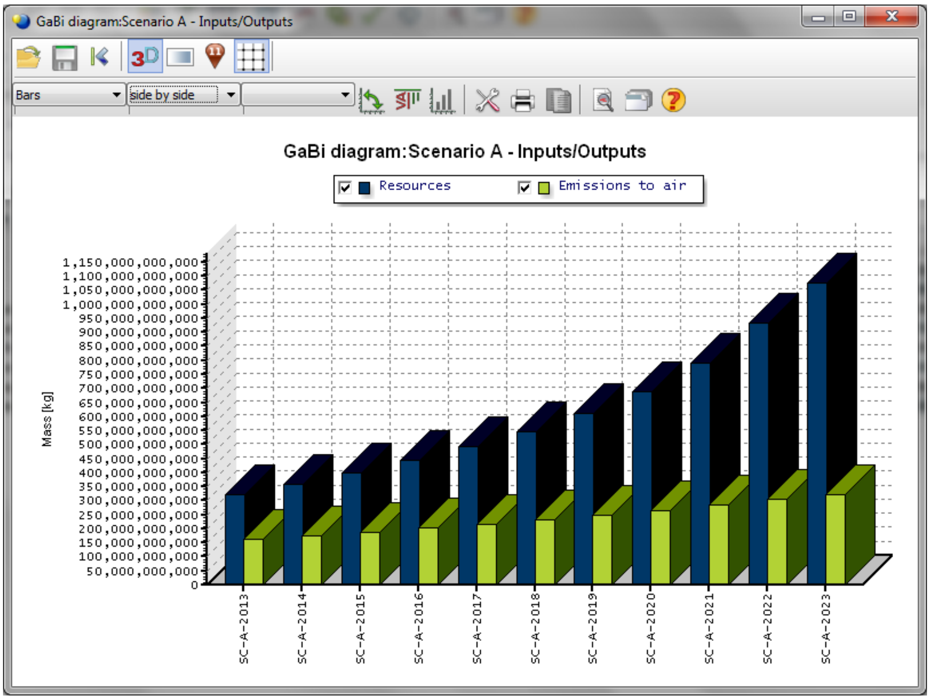

Figure A.1. Year by year GHG emissions to air and resource consumption for scenario A.

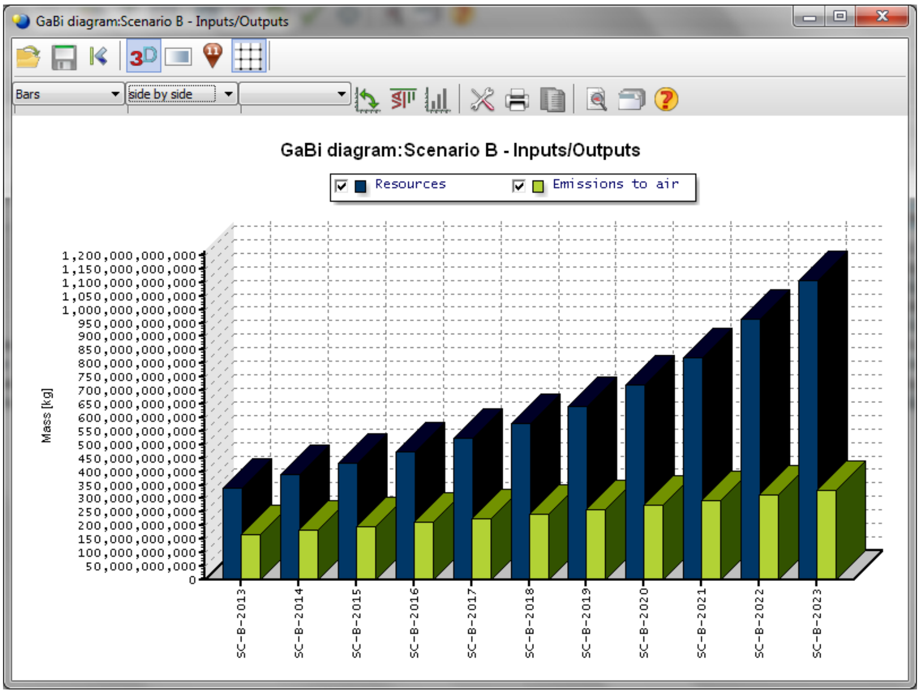

Figure A.2. Year by year GHG emissions to air and resource consumption for scenario B.

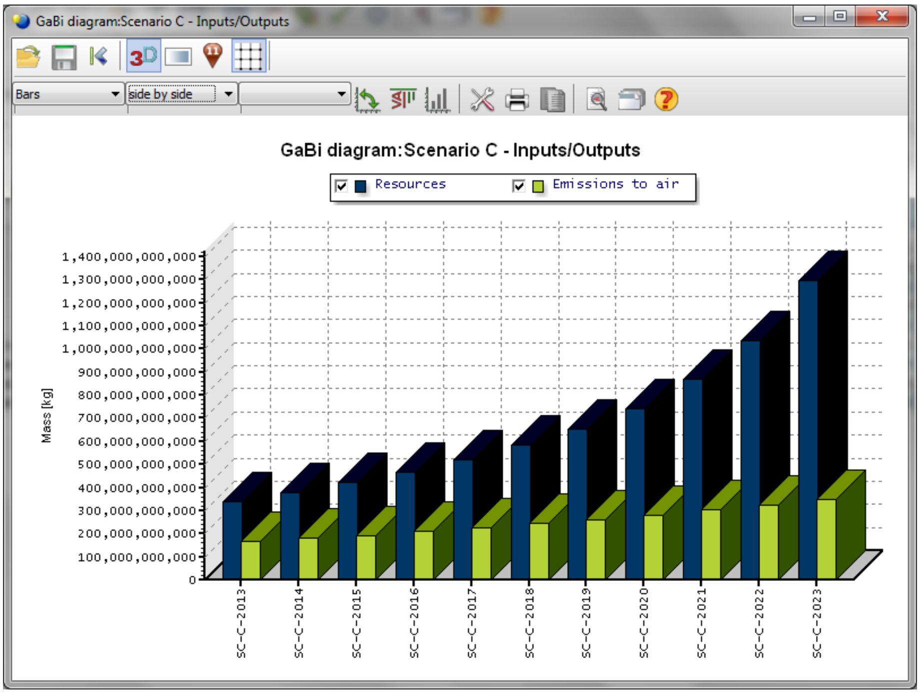

Figure A.3. Year by year GHG emissions to air and resource consumption for scenario C.

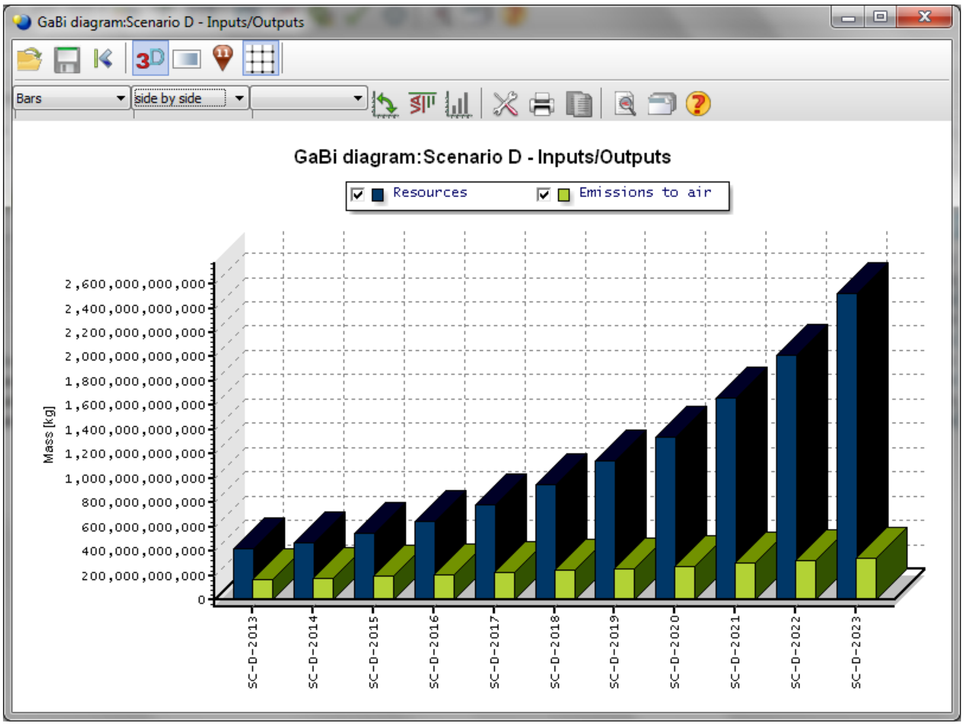

Figure A.4. Year by year GHG emissions to air and resource consumption for scenario D.

APPENDIX B

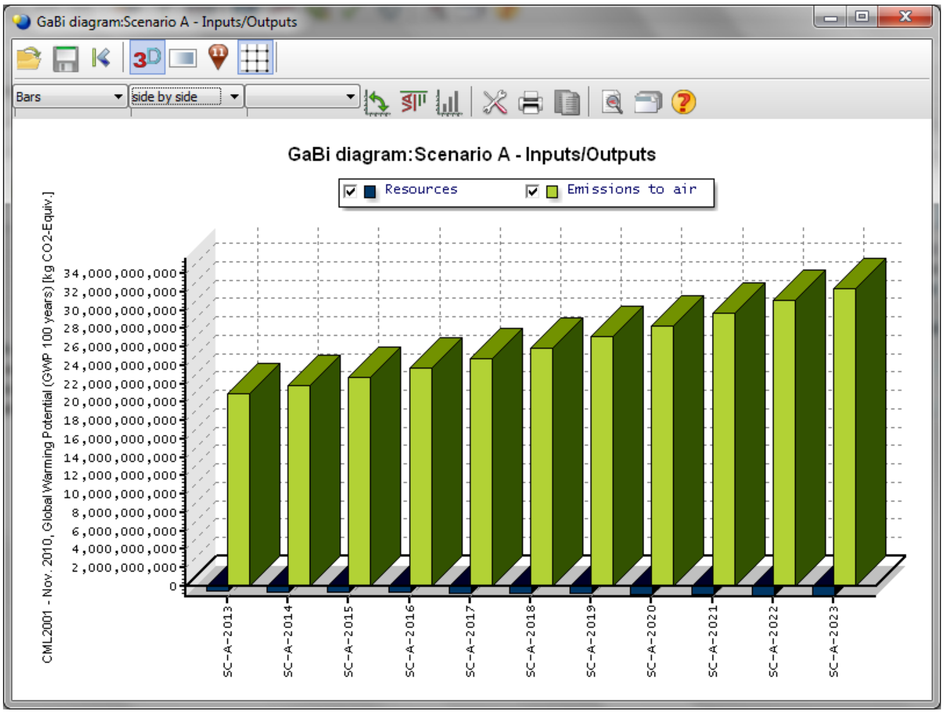

Figure B.1. Year by year GWP for scenario A.

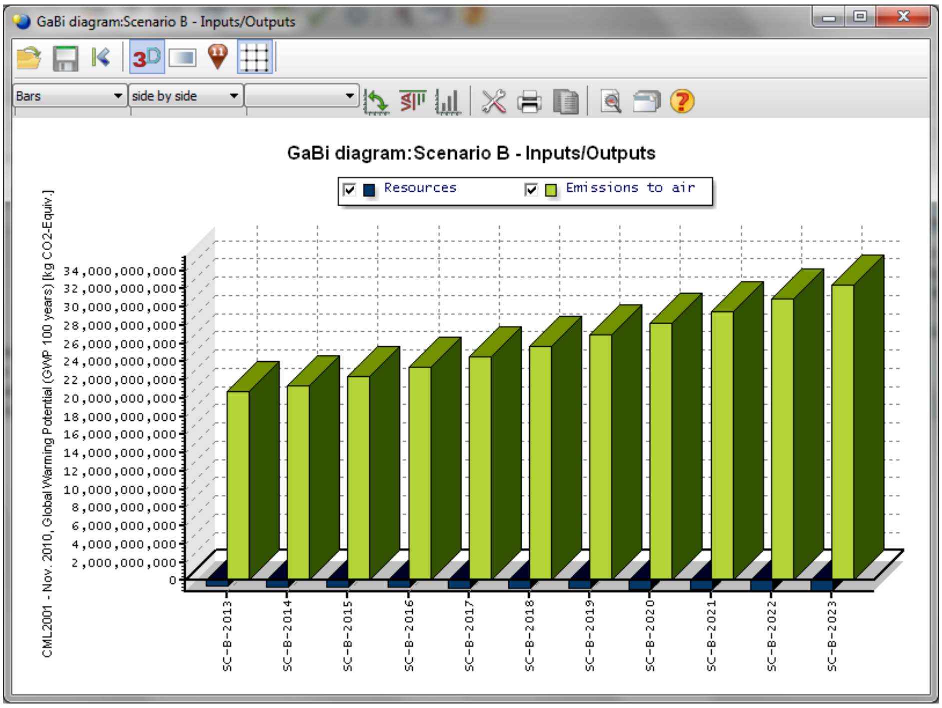

Figure B.2. Year by year GWP for scenario B.

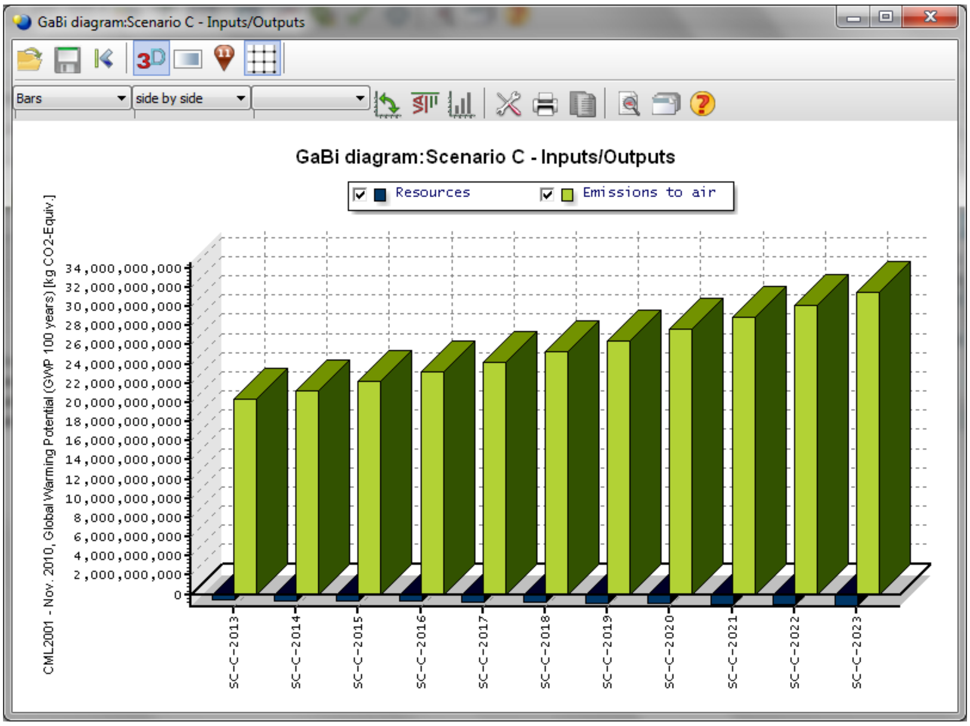

Figure B.3. Year by year GWP for scenario C.

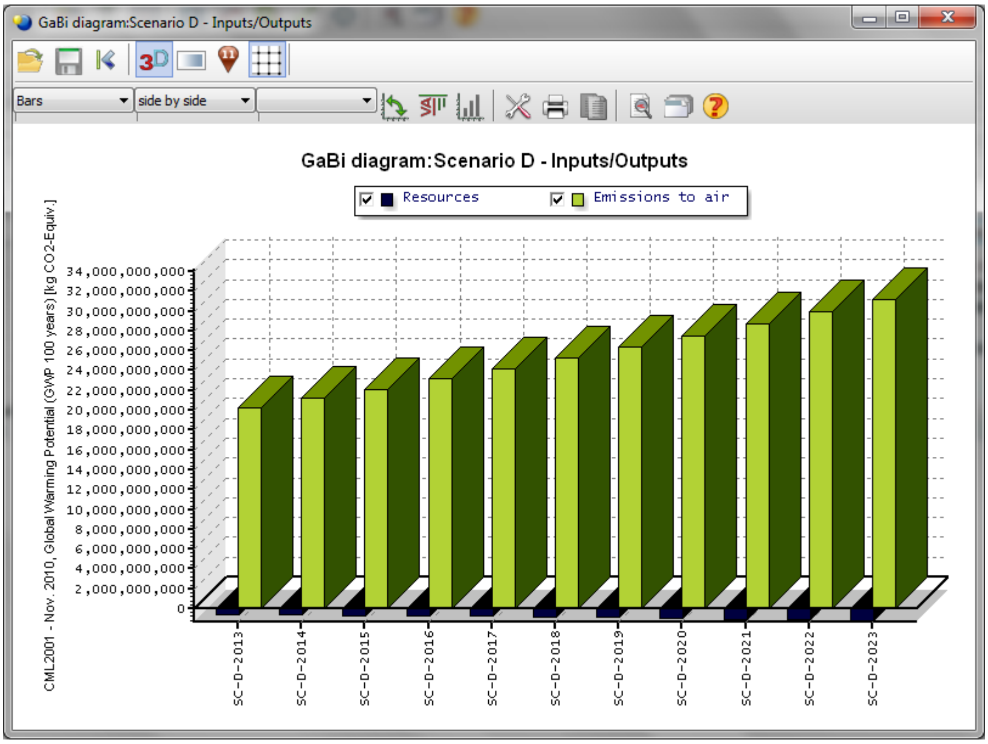

Figure B.4. Year by year GWP for scenario D.