MSc Program
Renewable Energy in Central and Eastern Europe

SUSTAINABLE MOBILITY
Comparison of alternative automotive technologies from Environmental and Economic point of view

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **Stefan Bogdanović**, hereby declare

1. that I am the sole author of the present Master Thesis, "Sustainable Mobility - Comparison of alternative automotive technologies from Environmental and Economic point of view", 110 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, ________________ ____________________________

Date Signature

Abstract

The core objective of this work is to create comprehensive comparison, research and evaluation of most significant models of sustainable mobility, Hydrogen, Biodiesel and Electric energy as road transportation fuel sources looked over three most important aspects: Ecology and Environment, Technology and Economy.

A core question stems from the objective statement: Will it make any sense to proceed with further research and development of these fuels and technologies despite higher costs, and what is the cost of our damaged environment? In order to answer this question along with numerous side questions which emerged during my research on this topic, numerous available data, previous studies and expert and professional literature as well as couple personal technology tests and evaluations have been used.

Finally, it was concluded that even the smallest step in the direction of sustainable mobility has a significant impact on our environment and our future. Further developments of advanced, more sustainable technologies as well as alternative fuels are major points for future. Legal regulations and smart filling and charging station networks are shown to be equally important towards mass acceptance of such sustainable mobility concepts.

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List of Abbreviations

ANL	Argonne National Laboratory
BD	Biodiesel
CEP	Clean energy Partnership
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CTG	Cradle to Grave
EC	European Commission
EGVI	European Green Vehicles Initiative
EPOSS	European Technology Platform on Smart Systems Integration
ERTRAC	European Road Transport research Advisory Council
EU	European Union
EUCAR	European Council for Automotive Research and Development
EUR	Euro Currency
EV	Electric Vehicle
EVI	Electric Vehicles Initiative
FAME	Fatty Acid Methyl Esters
FCEV	Fuel Cell Electric Vehicle
GEA	Global Energy Assessment
GHG	Greenhouse Gasses
GREET	Greenhouse gases, Regulated Emissions and Energy use in Transportation
H_2	Hydrogen
HEV	Hybrid Electric Vehicle
HP	Horsepower (BHP - Break Horsepower)
HRS	Hydrogen Refuelling Stations
IC	Internal Combustion
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IPTS	Institute for Prospective Technological Studies
JRC	Joint Research Centre
KOH	Potassium hydroxide
kWh	Kilowatt Hour
LCA	Life Cycle Analysis
LDV	Light Duty Vehicles

N_aOH	Sodium hydroxide
NG	Natural Gas
NOx	Nitrogen Oxides
PEM	Polymer Electrolyte membrane
PHEV	Plugin Hybrid Vehicle
PV	Photovoltaic
R&D	Research and Development
RE	Renewable energy
RES	Renewable Energy Resources
UCO	Used Cooking Oil
WTT	Well to Tank
WTP	Well to Pump
PTW	Pump to Wheels
WTW	Well to Wheels

1 INTRODUCTION

Since the early beginning of the automotive history (19th century), sustainable, cost effective, efficient and simple mobility has been a delicate question and significant drive of human civilization development.

Beside many difficulties and unsolved issues, the sustainable concepts of transportation are still hot spots for further technology researches and development. They represent one of the most significant approaches towards sustainable and renewable future, especially in regard to lowering the CO_2 and GHG emissions in order to provide cleaner and bearable future. Significance of this thesis lies in this environmental status overview and analysis of how far or close we are from sustainable mobile solutions, which, without any further debate, is crucial, international topic in last couple of decades.

Main, core motivation for research on this topic and thesis is previously acquired experience working in the international oil company, responsible for development of filling station networks on the global level as well as gained knowledge on the RES Master program, about renewable solutions which would be able, under certain circumstances, to replace partially or completely the fossil fuels in the near future. Special interest was related to further development of technology, mainly vehicle related, necessary to support renewable solutions utilization. As overall motivation, I have to mention the environment end ecology as crucial starting and ending point of all our further steps towards renewable and sustainable transportation future.

Described motivation and personal belief, that the sustainable solutions in passenger car - road transportation are far from satisfying and utilized in desirable manner, will lead to defining the essence of this thesis and core objectives and questions related to research of possible scenario issues and results when using these solutions in mass produced, commercial way.

1.1 Core objectives and questions

Core objectives and questions in this thesis are mainly related to Sustainable Transportation models. This term represents selection of technological and fuel sources (Hydrogen, Biodiesel and Electricity) used by alternative and conventional passenger vehicles.

First objective of this thesis is to conclude what is direct and what is indirect influence on the environment from selected sustainable transportation models.
In this context, model means exact combination of selected vehicle and fuel technology. Furthermore these models will be represented by hydrogen powered fuel cell vehicles, conventional vehicles powered by biodiesel blends and electricity powered vehicles in combination with infrastructure and networks issues.

Second objective is to assess which transportation models have the positive economic appraisals regarding the current European market situation.
The most sustainable solutions are ones that have acceptable economic result as well as major impact on reduction of emissions. According the results of these analysis, through this objective, I will be able to determent the most useful technology in this context.

Third objective is to make a prediction of what technologies are most promising for the further development towards sustainable road transportation and how to achieve that.
Considering all technology aspects, with significant environmental and economic influences it has to be evaluated and assessed, and as a result provided the most sustainable solution for further development.

In order to assess selected sustainable road transportation models and core objectives of this thesis, following segments and defined questions will be analyzed and answered in detail:

Overall automotive market

- What is the current automotive situation worldwide, alternative vs. conventional?

Environment and ecology

- What are the most important ecological aspects of the modern road transportation (passenger car transport related)?

- What is the most significant sustainable model related to environment protection?

Technology and network development

- What are the mostly used renewable/alternative technologies currently in the field of transportation?
- How do selected "green" technologies differ from conventional ones?
- What are the main issues for mass development of "green" vehicles and sustainable filling/charging stations and how to overcome them?

Sustainable Economy

- What are the main economical parameters influencing the development of sustainable technology models including fuels from renewable and conventional resources?
- What can we expect in the future - technology cost related forecasts?

Legal regulatory and Frameworks

- What is the regulatory perspective on sustainable mobility concepts?
- What are the positive examples towards utilization of green energy and technology?

The expected result of this thesis is to confirm that every step we make in the field of renewable energy concerning our environment, is worth of trying and needed. I expect to find that existing policies and regulations are not sufficient and that current economic situation in these fields is still a major drawback for some large-scale investments and technological breakthroughs. Also, thesis itself should confirm that investment in new, more effective, optimal "green" technology is worthy and has more positive aspects than the continuance of pure fossil fuels utilization. Finally, I should have confirmed that electric vehicles should have the most important role and the most promising future among selected mobility models, as it is also the wide spread opinion of the professionals in this field of research.

1.2 Method of approach

General method of approach

The aim of this thesis is to recognize everyday issues related to sustainable mobility topic, including automotive industry outlook, technological, economic and environmental appraisal, so historiographical, theoretical and methodological research approach was applied. Detailed analysis, calculation and comparison between selected models will be conducted for both, economic and environmental assessment. In these and other segments of the work common ground for testing and comparison will be defined and strictly used. This common ground (sustainable mobility models) is related to exact technologies (vehicles and infrastructure) and fuel resource (hydrogen, biodiesel and electricity) used.

Models definition

For the purpose of this thesis, terms (synonyms): "Model", "Sustainable Model" or "Transportation Model" are defined and used. Model in this shape includes:

- Hydrogen vehicles technology
- Biodiesel vehicles technology
- Electric vehicles technology

Hydrogen vehicles used here are based on Fuel cell powered electric vehicles technology. Biodiesel vehicles are related to vehicles which use blends of biodiesel in range from 5 to 20% (B5-B20) based on internal combustion engine technology (ICE). Defined Electricity vehicles (EV/BEV) are those based on pure electricity technology, combination of battery (lithium-ion) and electric motors.

Selected transportation models in this thesis consider technology and environment as the most important aspects for each model as well as economic approach to every evaluated solution. As exact testing vehicle for all of these technologies, the Mercedes-Benz B Class is used. This model will allow to compare all of these technologies using same vehicle platform. This means that this chosen vehicle exist in all of these variations (hydrogen, electricity, biodiesel and conventional diesel powered). This would be of great importance in order to compare these technologies and their separate impacts on a same way.

Primary literature sources

In order to answer defined questions in understandable manner, I will use analysis of the already existing literature and researches of scientific journals such as:

- European Commission reports and papers (Legislative, initiatives and general frameworks and projections in Europe)
- Eurostat statistical data (European price and general statistics)
- European Environment Agency (GHG emissions and trend projections in Europe)
- Available data from manufacturing companies (Vehicles R&D companies - Tesla motors, Mercedes Benz, BMW)
- OMV AG and Shell (Energy related case studies)
- Various data from consulting companies (Rocky Mountain Consulting, GEP AFTP, Element Energy, GBEP, Pure Energy Centre, etc.).

All these data and data found during research of the scientific literature, are firstly presented and described, and, afterwards, they were compared and discussed in regard to Environmental, Technological and Economic fields.

Economic calculations and sensitivity analysis

Supporting calculations, in this theses, are used in purpose of easier comparison of economic models and emissions figures in correspondent chapters. Calculation and comparison in Chapter 5, will be done by calculating deferent transportation cost scenarios as well as all major depending figures (depending of vehicle type and used fuels). In order to calculate these costs following segments were defined:

- Overall Transportation costs
- Energy costs
- Vehicle costs including operational and maintenance costs

These costs are presented in Eur/km driven and calculated using following formulas (Ajanovic and Haas, 2012):

$$C_{transport} = C_{energy} + C_{vehicle} + C_{o\&m}$$

$$\mathbf{C}t = \mathrm{FI} * \mathrm{P}f + \frac{(\mathrm{IC} * \alpha)}{skm} + \mathrm{C}o\&m$$

In addition to calculated costs, using these figures furtherer sensitivity analysis is conducted concerning change of overall transportation costs over investment and energy cost changes. Investment and Energy costs are assumed to be changed in range from -50% to +50%, with steps of 5%. Resulted analysis presented graphically as "Line charts". Complete calculated tables are presented in Addendum 3.

Environmental calculations

Calculation of GHG emissions will be done using already existing software and predefined parameters as a starting points. For this segment of calculations, I have used GREET Excel tool, created by Argonne National Laboratory (ANL). Main purpose of this calculation is overview of GHG, Emissions, and general Energy Use in Transportation Models, presented in gCO_2/km. As most important results, considered are only those which directly influence these segments:

- WTP (Well to Pump)
- PTW (Pump to Wheels)
- WTW (Well to Wheels)

Those three segments were used also in the overall comparison and assessment. In addition to these segments I have used one more analysis approach CTG (Cradle to Grave). This final approach is used in order to create complete picture of all most important emissions which are in the scope of this thesis and in order to calculate the averaged overall emission amounts for complete technology life cycle.

Detailed calculation tables and default parameters are available in Addendum 2.

1.3 Structure of work

This Master thesis consists of seven major sections (chapters). First chapter consists of Introduction and core objectives of the work, as well as method of approach.

In order to thoroughly conduct this research, chapters related to general Sustainable mobility, Environmental and Ecology, Technology and network infrastructure, Economics and Legal Regulatory and Frameworks Outlook were introduced as a connected apprehensive analysis sets, which also could be viewed as completely separate ones.

In section Sustainable Mobility (Chapter 2), general overview of road transportation models (passenger vehicles) will be given as well as setting up all necessary definitions and parameters used in the thesis further on. Here will be given historical overview and definition of core models used in this work (Chapters 3, 4 and 5).

In Environmental and Ecology section (Chapter 3), comprehensive analysis and overview of defined models from Chapter 2, will be given in regard to impacts on environment and emissions. In this chapter, focus will be on CO_2 and GHG emissions.

Technology and network infrastructure section (Chapter 4) will provide all relevant technology descriptions and analysis. There will be conducted research and comparison on technologies which are correspondent to selected fuel sources and therefore both, fuel technology and vehicle technology will be taken into the consideration. Beside these two segments, special concern related to networks infrastructure will be presented and analyzed.

In Economic section (Chapter 5), defined models from Chapter 2 will be considered as starting points for calculation of transportation, energy and vehicles costs which will provide us with all general figures I need for final comparison in order to conclude if some solution is more or less feasible in context of this work.

Legal Regulatory and frameworks outlook is the Chapter 6. In this section some of the most significant policies and regulations will be presented and discussed, as well as most interesting examples related to this topic from some selected European countries.

Final, Chapter 7, will have all conclusions and answers to previously defined questions and core objectives, defined in Chapter 1.

2 SUSTAINABLE MOBILITY

Sustainable mobility can be explained as a term which includes large variety of transportation models that enables movement with constant environment impact reductions, technology improvement while retaining highest possible convenience rate. In this thesis I will define custom selection of sustainable mobility models and try to analyze on the comprehensive level. Purpose of next two chapters will be introduction and definition of sustainable mobility and related concepts which are used in this thesis.

Sustainable mobility, in the context of this thesis and in the context of overall road transportation, will mostly cover light duty, passenger vehicles seen through the prism of renewable fuel solutions and feasible network developments in Europe. In order to define and analyze sustainable mobility, it is necessary to first define strict models which could be, at the end, compared.

Sustainable mobility models in this thesis are defined trough three major fields of research: Vehicles, Fuels and Networks (infrastructure and filling station networks). This means that a comprehensive analysis of these three fields in regard of three selected renewable fuel solutions - Hydrogen, Biodiesel and Electricity will be conducted. Detailed elaboration of selected elements will be conducted in the following chapters.

In order to be sustainable in reality, it is necessary that all three points of defined models are feasible, competitive and comparable to fossil fuel solutions. To do so, it is of most importance to analyze Technology, Environmental, Economic and Legal situation and perspectives for these models.

Even if we could agree that sustainable mobility leads to sustainable future and that there is a necessity for positive changes in automotive sector concerning environment, it cannot be forgotten that beside this, we have to have feasible solutions in meaning of economics, as it is one of the most important drives of the modern civilization. Doing so, we might have a chance to partially correct the damage we have caused to the environment and thus reduce further ones.

2.1 Mobility and overall transportation, tendencies and key indicators

According to the data from European Vehicle Market Statistics from 2013, the largest part of vehicles in Europe is still running on conventional fossil fuels (gasoline 42% or diesel 55%). As the math is simple - in Europe, we had roughly about 267 million vehicles in year 2010 (Figure 2-1). The rest of it, about 3% (or 8 million vehicles), belongs to all other "more sustainable" fuels altogether. So, in this category we have natural gas and ethanol vehicles and all sorts of hybrid vehicles (hydrogen, electric or natural gas hybrids), as well as standalone electric and hydrogen cars. Taking a look at a bigger picture than Europe, interesting fact is that in, for instance, US, Japan and China, countries with high people and vehicle density, the majority of vehicles use conventional gasoline with no significant part of diesel in use.

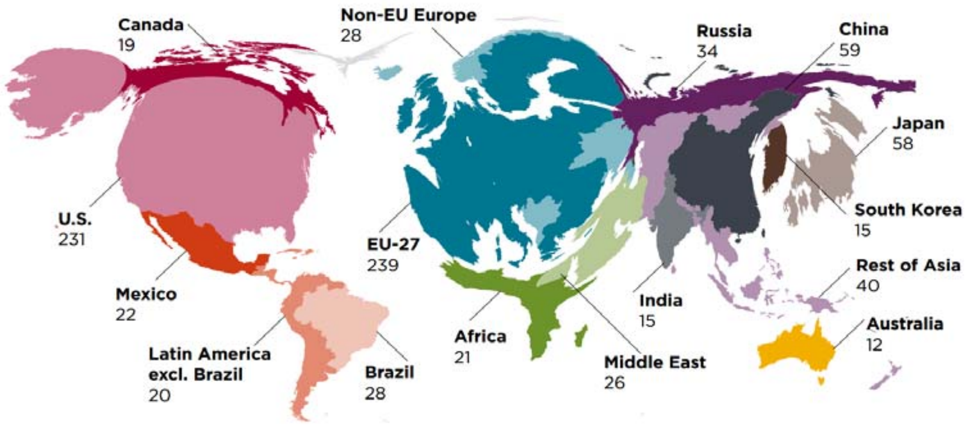

Figure 2-1: 2010 Light duty vehicles stock in millions (Source: ICCT 2013)

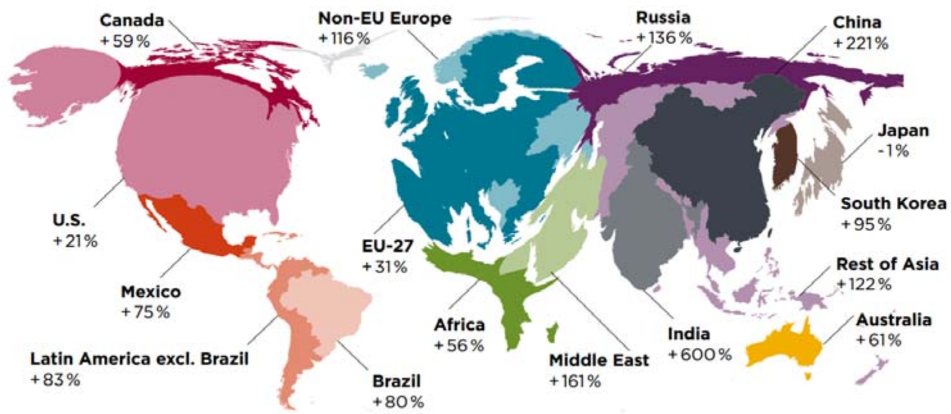

Figure 2-2: Light duty vehicles stock Variation between 2010 and 2030 predictions (source: ICCT 2013)

The world transportation sector is responsible for near 28% of the global energy demand. Road transportation takes a significant, largest part or more than 70%. Almost all (95%) of the energy for transportation comes from conventional fossil fuels. According to available predictions, shown on Figure 2-2 we can see that in EU only, we will, most probably, have increment of 31% in sector of light vehicles and additionally 116% increment in rest of the Europe. These are very important figures which indicates necessity to proceed with development and changes. According to GEA report in 2012 these figures can be confronted in the future but that would require a serious improvement of vehicle designs and technology, infrastructure, fuel optimization and safety improvements in order to reduce their environment influence. This would most certainly be possible if serious and strict rules related to technology production (especially conventional ones) and final purchase of green solutions would be conducted on a large scale, not only partially (defined country by country). These issues will be discussed and analysis in detail in Chapter 6.

2.2 Passenger car transportation models overview

In this thesis, as it is already stated, the passenger car road transportation models will be used in order to compare them and assess their impacts on environment, technology development, economy and legal aspects of our lives. Passenger car transportation has been selected as it is clear that significant increase in this segment is present in last decade (Eurostat, 2014a) in Europe as well as worldwide, as elaborated in Chapter 2.1. It is crucial for this research to compare the impacts on environment and economy, and to see what are the most important issues, pros and cons of the existing and developing technologies and existing legal and general frameworks.

Selected transportation models in this thesis consider technology and environment as the most important aspects for each model as well as economic approach to every evaluated solution. This means that following models will be assessed in detail trough the Environmental, Economic and Technological aspect:

- Hydrogen vehicles technology (Hydrogen powered Fuel cell vehicles)
- Biodiesel vehicles technology (Biodiesel blends B5-B20 powered vehicles)
- Electric vehicles technology (Electricity powered battery vehicles)

Every model has to be analyzed as combination of vehicle technology, fuel technology and network infrastructure in order to define common issues and common ground for comparison. These three segments are of crucial significance for any transportation model in order to be considered as everyday solutions which could eventually replace conventional and most convenient existing models which are mainly based on fossil fuel and hybrid powered transportation.

Fuels and technologies which are not in the scope of this thesis and research are other biofuels and hybrid solutions. Other biofuels like Bioethanol is not used in this research as the main focus of this thesis is EU were we have slightly higher use of biodiesel and as biodiesel represents more interesting choice as it involves fossil and renewable energy into one mix. Hybrid technology, although has important influence in the future technology development, will not be covered in this thesis, as we have already selected biodiesel as fuel/technology which involves fossil and renewable energy. Some basic comparison and review of these technologies will be conducted where needed.

In order to make a qualitative analysis, a comparison with conventional fuels and vehicles will be conducted where possible. Also, for this purpose it was necessary to define the common testing ground. In this manner, for the testing vehicle, the Mercedes-Benz B-Class models were selected, because this was the common and ideal platform for all three models as well as conventional fuel model.

The selected vehicle manufacturer has the following models which were used for this research:

- B-Class F-Cell, as a hydrogen powered vehicle
- B-Class Electric Drive, as an electric vehicle
- B-Class Diesel, as biodiesel and conventional diesel vehicle

Another important reason for choosing these vehicles is their segment. This vehicle model is the recognized representative of the middle segment of the light vehicle market (mainly medium size family vehicles, or combination of B and C segment according to official automotive classifications) and on the other hand seems to be a good choice if we want to find the golden middle in terms of average passenger vehicles in Europe (Figure 2-3).

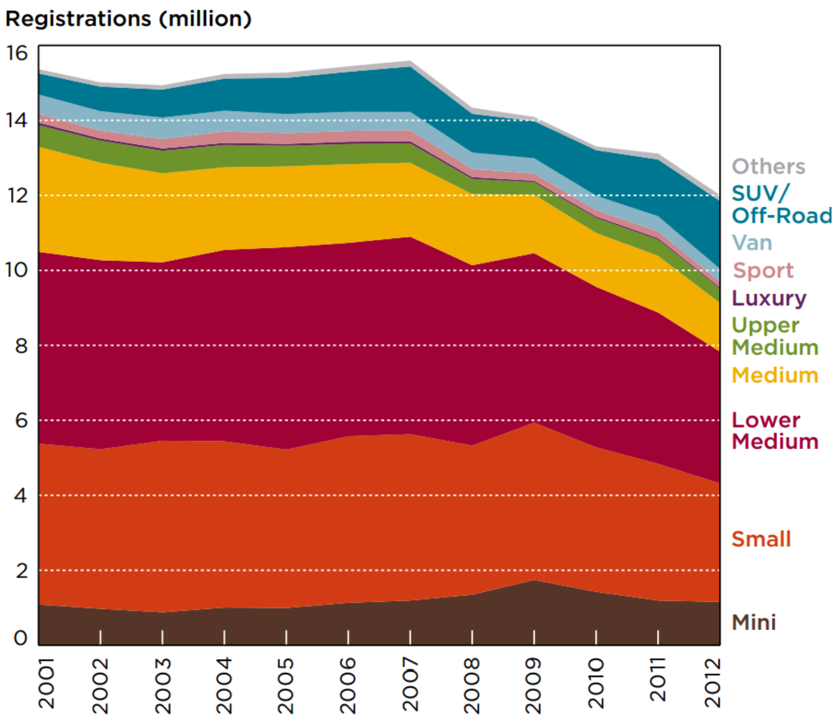

Figure 2-3: Passenger cars vehicle segment, EU-27 (source: ICCT 2013)

This trend shows us that beside the general slight decline number of new vehicle registrations in all segments, this part from lower to upper medium segment is the most significant one and has the lowest decline. Therefore it will be used as a starting point for this research trough the following chapters.

In addition to the selected vehicles, one more vehicle will be used in calculations and comparisons. It is Tesla Motors Company and their representative Model S vehicle. Introducing this vehicle, even slightly above selected vehicle segment in the luxury segment), is very important when assessing the economic and convenient aspects of sustainable mobility models because of their interesting network development suggestions (network models) and high efficiency and high performance vehicles.

3 ENVIRONMENTAL AND ECOLOGY PERSPECTIVE

Environmental and Ecological perspective method of approach and appraisal in this thesis will be done using the comparison of existing data, mainly official emissions data from technology and manufactory companies as well from oil and related consulting companies, on this topic and research of points defined as the most important ones for all three alternative fuel solutions: Hydrogen, Biodiesel and Electricity, as well as comparing the results with conventional fuel values. It is assumed that CO_2 as well as GHG emissions are the most important pollution sources and they will be discussed in detail in meaning of fuel production, vehicle and parts production as well as end fuel combustion.
In following chapters, emission influence and significance will be evaluated and compared using tool for definition of GHG emissions in transportation, based on WTP, PTW and WTW analysis, the GREET analysis tool (ANL) as well as analysis based on the cradle to grave concept (CTG). Detailed calculations are provided in Addendum 2.

Finally in Chapter 3.4, overall comparison of evaluated emissions figures will be conducted and compared to fossil fuel (conventional fuels) emissions. This final comparison will show what the real differences between selected models are and, widely used, conventional models as well the most important segments of GHG emissions and their impact on overall results.

Comparing the results we should be able to conclude what are the possible paths for future development, main downsides of all selected technologies and how green those solutions are in a real life usage.

The importance and overall impact of road transportation on environment is well known and has been analyzed for a long period of time. Now, we can, without any doubt, say that transportation segment, especially road transportation is among the most important pollutant sources in the world, especially if manufacturing of vehicles and fuel technology is taken into consideration (Figure 3-1).

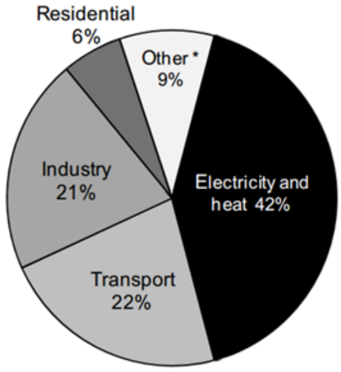

Figure 3-1: Amount of World CO2 emissions by segment in 2011
(source: IEA, 2013)

On the other hand, the situation in Europe is even more pronounced, as we can see it on the following Figure 3-2, GHG emission. Data resented here is for range from 1990 to 2011. Years shown afterwards (towards 2015 and 2020) are only predictions. On this graph we can notice the firm raise of GHG transport related emissions until 2007. In the following years we can see basically sold holding of strongly defined values. Year 2007 in this graph shows this peak in transportation which may be explained if we compare it with Figure 2-3 from Chapter 2.2, where this year represents also peak in new registered vehicles in all segments.

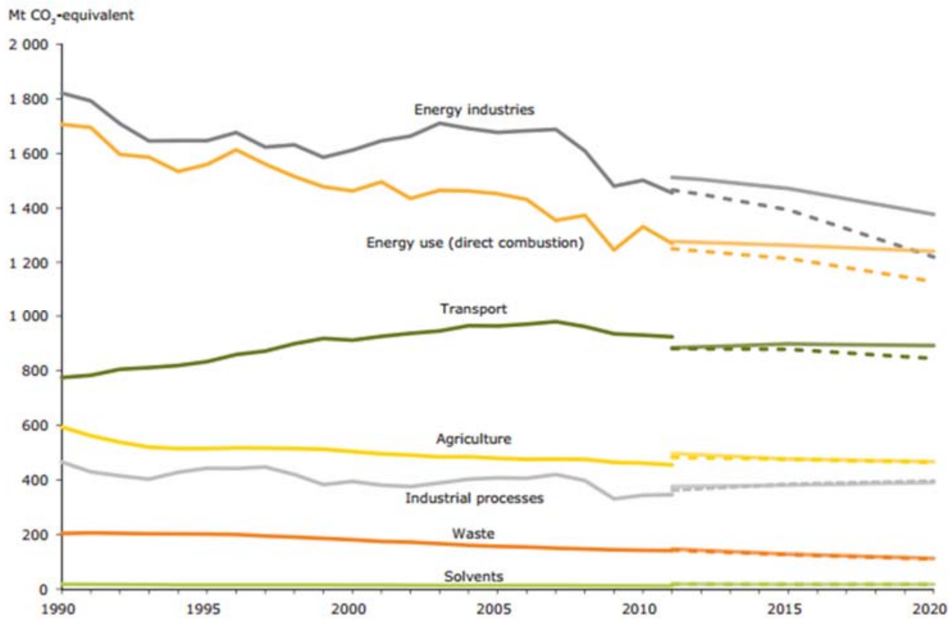

Figure 3-2: GHG Emissions overview and predictions
(source: EEA, 2012)

As this research will be conducted on the medium vehicle segment it is important to define some overall marginal values related to the emissions presented by this vehicle segment. Figure 3-3 shows us that researched data indicate that this segment has significantly higher emissions then the average, but also we can see that the positive trend, in context of lowering emissions, is noticeable from year 2007 and that trend is kept (ICCT 2013). This, on the other hand, could also be connected to figures presented in Chapter 2.2 and milestone year 2007. Beside this influencer (decline of new registration numbers) we should be aware one additional, very important aspect which is technology improvement, related to fuels and vehicles production. Combining these two aspects it is clear that they are responsible for such drastic reduction of the average CO_2 emissions in passenger vehicle segment.

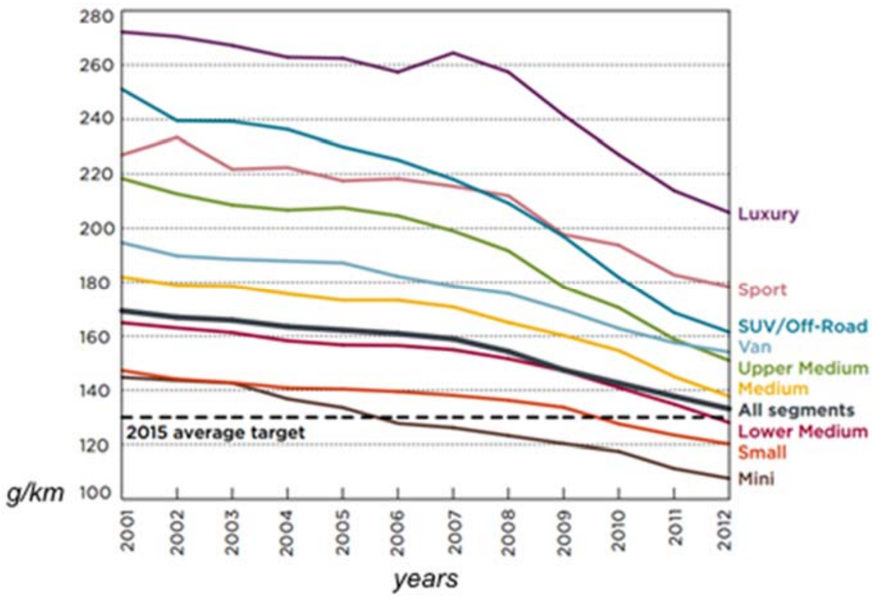

Figure 3-3: Average CO2 emissions by passenger vehicle segment (source: ICCT 2013)

As it is a clear fact that the current energy systems based mainly on usage of the fossil fuel resources are not friendly to environment and ecology, they cannot be sustainable in any manner. The primary concern that the amount of the available fossil resources will not be sufficient for the mankind even in near future, becomes one less important issue in comparison to the influence it has on the environment when transformed into useful energy. Even this resource is very limited and significantly reduced every year, as the demand is rising every single day, so more important issue is how to protect environment in the most economical and efficient way. A great damage has already been done to the Earths ecology and it cannot be so easily fixed, some inflected damages will remain as a permanent problem. What we can do and what is the main topic these days is how to proceed. New, renewable related technology has become more and more available, standardized and efficient so it can be utilized in such a way that we can consider it in order to partially or even completely replace the fossil fuel resources in some segments of our everyday life. First two steps in this direction would certainly be replacing fossil fuels in our everyday life, in our houses and in the way we consider everyday transportation.

As a direct method of evaluation, when analyzing the environmental and ecological aspects of fossil and renewable resources in transportation we will take a look and define two main pollution segments in fuel life cycle:

- Upstream
- Downstream

The most important parts of the Upstream segments are: Exploration, Extraction and Production. On the other side, in Downstream segment we have: Distribution, Storage and Usage (utilization or combustion). All of these segments are very important for definition and analysis of potential and actual pollution problems and issues (Zütel, A. et al., 2008).

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2011, CO_2 accounted for about 84% of all U.S. greenhouse gas emissions from human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle, both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere. While CO2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution.
The main human activity that emits CO_2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation, although certain industrial processes and land-use changes also emit CO_2.

In this thesis I will analyze the influence of both segments of fuel resources production and distribution on our environment and overall ecology. As previously defined, Hydrogen, Biodiesel and Electricity influences will be highlighted, but in order to compare it, the current situation with fossil fuels has to be established and presented. The most important figures which will be compared in this thesis will be the CO_2 and other significant GHG elements (N_2O, CF_4, SF_6, HFCs) because of planned limits of global temperature increase to be less than 2ºC in comparison to the pre-industrial level. This means that serious reduction of CO_2 has to be introduced in the near future (GEA, 2012).

Analyzing the conventional fossil fuels production through these segments led us to the following results. In both, the upstream and downstream segment, we have to pay attention to the following issues:

- **Exploration:** Researching in the field as well as preliminary drilling means significant pollution in manner of GHG. These processes are more and more complex and more and more pollution demanding over the years of development. As we can see in Figure 3-4, the emissions from E&P processes are of an unchanging trend with significant amounts.
- **Extraction:** After establishing the positions and setting up the processes for extraction we are introduced to new problems and possible hazards. It is very import to keep in mind and also to take it into the consideration that beside the obvious CO_2 emissions and other GHG, a huge problem is the constant danger related to possible oil spills in oceans or soil, depending of extraction locations. Even it is not certain that it will happen, the constant threat exists and the risk in case we neglect this possibility is way too high.
- **Production:** In order to produce fossil fuels certain amount of gasses are released into the environment as well as usage of large amount of hazardous chemicals which could lead to soul contamination.
- **Distribution and Storage:** Distributing the fuels on-site is an important element as it introduces the indirect problem of transportation pollution, possible risks of accidental spilling and similar issues. In Figure 3-5, a number of spills as well as quantities is presented. We can see that on the total number of spills, South America stands with highest values, far from any other continent. On the other side, quantities related, we can see that Africa is even higher rated then South America, comparing to Europe.
- **Usage:** Using fossil fuels and its combustion is the most important issue as it produces the direct damage to the environment. In the combustion process the most significant pollutants created in this way are Sulfur oxides, nitrogen oxides, organic carbons, carbon monoxide and carbon dioxide (Zütel, A. et al., 2008).

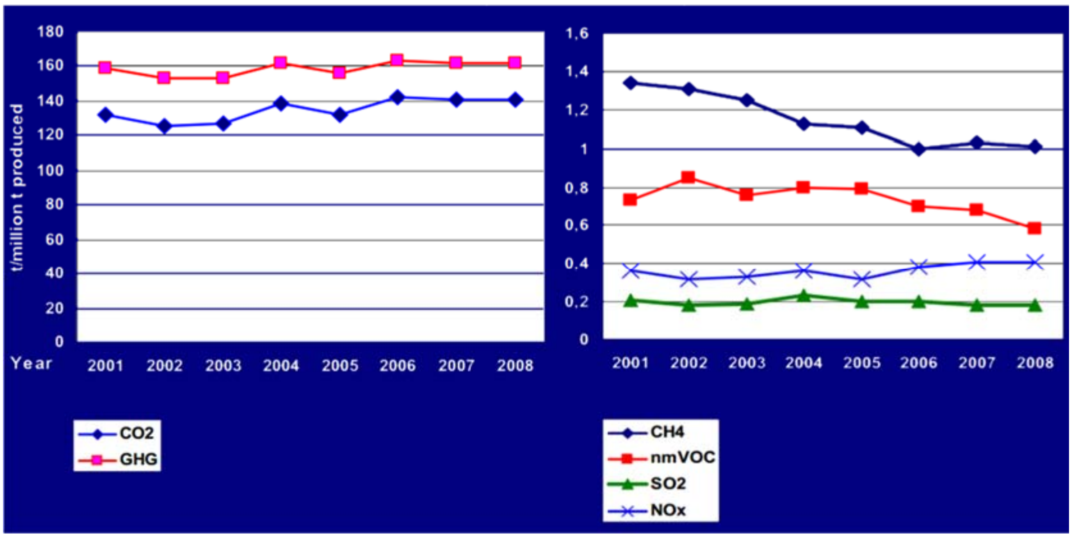

Figure 3-4: Emissions to air from E&P activities (source: Garland E, 2010)

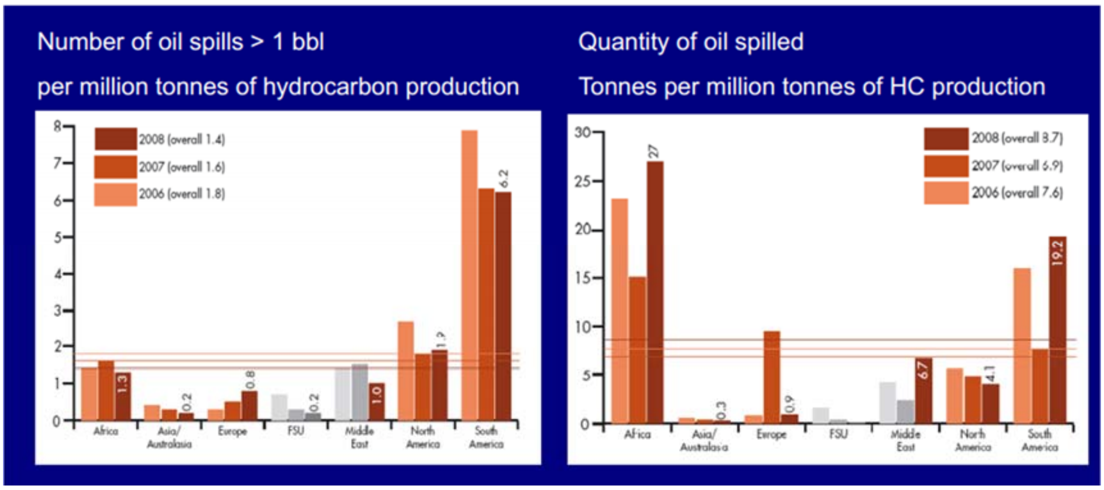

Figure 3-5: Number of spills and quantities (source: Garland E, 2010)

As discussed in before, we can conclude that it is clear that fuel exploration, production and transportation represents, on the large scale, significant source of pollutions before reaching its end-use (combustion or utilization process).

From the fuel utilization point of view the most important and already implemented direct strategies and legislations (European Union legislation) in order to instantly reduce the GHG, are the legislations related to car manufacturers meaning that it is very important to optimize engines, lower fuel consumption and CO_2 emissions. In order to fulfil these requirements, the basic targets have been set. The CO_2 reduction until the year 2021 is set to 95g of CO_2/Km and the fuel consumption from 4.1 to 3.6l/100Km for petrol and diesel engines respectively. The current situation shows us and that the CO_2 emissions are limited around 130 grams of CO_2 per km for passenger cars.

3.1 Hydrogen fuel cells and vehicles environmental impacts

Hydrogen as an energy carrier represents CO_2 free fuel when utilized in vehicles. The only end-product of its utilization in vehicles is pure water. So taking this into the consideration we can conclude that hydrogen represents a very good basis for further development in car industries. On the other hand we have to consider the other side, the production of hydrogen and its transportation and storage. Basically there are two possibilities for hydrogen production, one is using fossil fuels and the other is using renewable energy resources. In this thesis I will mainly consider hydrogen creating by electrolysis using the RES, as this would have most sense, in opposite to the energy or resource used for H_2 production, could be used as a fuel itself, directly. In this case we would also have problem with combustion, CO_2 and GHG emissions. In detail, CO2 and GHG emissions will be analyzed trough the WTP (Well To Pump), PTW (Pump To Wheels) and summered WTW (Well to Wheels) cycles provided by GREET.

The hydrogen fuel cell is acutely an electromechanical converter of energy. In this converter the chemical reaction between hydrogen and oxygen occurs. As a result we have a generation of power and heat without end-combustion and CO_2 emissions. The only product of this reaction beside the energy is pure water.

If we analyze possibilities for transportation of produced hydrogen and its storage we can recognize the following possibilities. One is the transportation of hydrogen fuel in pressured tanks and delivery on site by Lorries (Züttel, A. et al., 2008). Beside this, it is possible to produce H_2 on site using renewable energy resources where applicable. The pipeline solution for distribution of hydrogen is also possible but taking into the consideration costs of implementation it does not represent a feasible solution so far as, mainly, there are no existing suitable infrastructures which could support this kind of supply. This will be analyzed in detail in this thesis later on in Chapter 4 and 5.

Taking everything into the consideration, it is clear that if produced from renewable, emissions free resources, hydrogen as an energy carrier represents almost emissions free solution. The only drawback in this sense, on the environment side, would be the problem of transportation and the emissions thus produced. The possibility of producing hydrogen on site (filling stations) makes this a very interesting future possibility regarding emissions reduction path.

Also, the idea of using hydrogen as an energy backup method of unused renewable energy is very important. This means that if, for instance demand for wind power is lower than energy generated, we could, using some of clean methods, create hydrogen directly and store it until needed.

Using GREET tool (ANL) for overall calculation of GHG emissions for Hydrogen model we get following assumptions on Table 3-1. In scope of these generated figures were different sources of hydrogen as well as different types of distribution, as distribution of hydrogen itself represents important segment of total emissions and they are presented in gCO_2e/km. I have included distribution of hydrogen from natural gas, pure electrolysis and electrolysis from renewables as well as central production from natural gas, coal and biomass.

Table 3-1: GHG Emissions overall results for Hydrogen
(source: GREET tool)

H2	Distributed from NG	Distributed Electrolysis	Distributed Electrolysis from Renewable	Central production from NG	Central production from Coal	Central production from Biomass
WTP	165	356	2	159	279	56
PTW	0	0	0	0	0	0
WTW	165	356	2	159	279	56
	gCO2e/km					

Results in Table 3-1 and Figure 3-6, creates clear picture of cleanest solutions related to hydrogen emissions issues. Firstly, we have to repeat once again that PTW or end product of usage of produced hydrogen fuel emits zero CO_2 emissions so they have no effect on WTW end result. Secondly, we can see that lowest emissions comes from distribution of hydrogen produced from renewables. After this we have central production of hydrogen from biomass. Highest emissions, according to this table, originated from central production of hydrogen from coal and distribution of hydrogen produced by non-renewable electrolysis, which was expected.

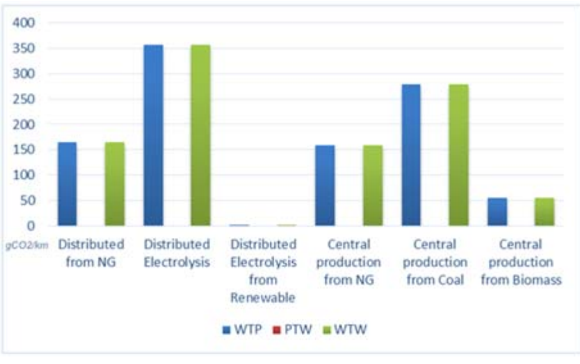

Figure 3-6: Graphical representation of overall GHG emissions for hydrogen based on generated data
(source: GREET tool)

3.2 Biodiesel fuel and technology environmental impacts

Ecological point of view of biodiesel can be elaborated in two directions. Analyzing the exact combustion of biofuels, on one hand, will give us the result that it can be considered as CO_2 neutral because the amount of released CO_2 in the atmosphere is almost the same as it is previously been accumulated by the plants.

On the other hand, it would be necessary to take a look at the big picture and analyze the detailed life cycle of biofuel. Taking this into the consideration we would observe the whole life of biofuel and end-use, from the cultivation of the selected biomass source, its processing, (production of vehicles is more or less equal for all selected fuel types) and, at the end, the end usage. The result of this evaluation will be that biofuels are not completely CO_2 neutral as it would appear taking into the consideration only the combustion process. Also, a slight increase in nitrogen oxides is present within biodiesel lifecycle.

In this chapter, GREET (ANL) tool will be used for definition of overall GHG emission figures as in previous Chapter 3.1 in order to obtain most important emission segments: WTP, PTW and WTW

It is very important to emphasize that even if we look only at the detailed lifecycle results, the released CO_2 is significantly less than in case of standard diesel or gasoline cars. The overall greenhouse gas emissions figures can be described by Figure 3-7, below. It shows us the comparison between Fossil fuels, Methane, Ethanol and Biodiesel at the end presenting level of environmental impacts to eco systems, human health and resources, in regard to referent value "Petrol, CH-mix". As a sources for gating the biodiesel here we have soy, rape, jatropha and oil palms. These sources will be also discussed in detail later on in this chapter.

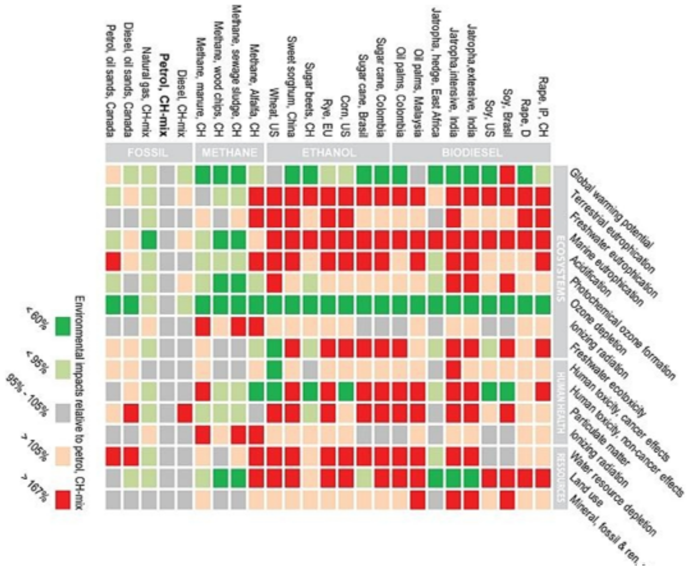

Figure 3-7: Diversity overview of environmental effects
(Source: EMPA, 2012.)

A very important aspect of biodiesel positive and negative environment sides is considering the different blends. Even if it is not emissions free fuel, it can significantly influence overall pollutions and represent the most plausible solution for the nearest future of fuel development. Involving higher percentage of biodiesel into conventional fossil fuel would significantly reduce the CO_2 and GHG emissions.

According to studies conducted (Enguidanos M. et al., 2002.) the following figures (Table 3-2) and pollutants can be highlighted analysed:

- **Carbon dioxide:** Biodiesel ton burnt has about 2.4 tons of CO_2. With current, proven knowledge we can say that this amount of CO_2 would be completely nullified in one year just by growing crops in fields and producing more vegetable oils, and also absorbed through the following carbon cycle. This is why we could say that biodiesel carbon dioxide emissions are almost equal to zero (Enguidanos, M. et al., 2002.).

- **Nitrogen oxides:** In case of pure biodiesel, the NO emissions can be rather high but taking into the consideration that the biodiesel has no significant amount of sulfur, it is possible to use some of the controlling functions which could reduce the NO content, which, on the other side cannot be used in conventional fuels. This means that nitrogen oxides could also be considered as a minor polluting issue in pure biodiesel. In case of the blends, it is clear that it would represent a problem because of conventional diesel part and lack of control and reduction possibility.

- **Carbon Monoxide:** As biodiesel contains additional 11% of the oxygen molecules, it represents an important fact for fuel efficiency itself but also it restricts monoxides production and lowers the emissions up to 40%.

- **Particulate matter:** Breathing particulates from the exhaust emissions represent a very important, direct human health issue. Biodiesel has approximately 40% lower overall particulate matter emissions than conventional diesel fuel.

- **Bio-degradability:** In case of accidental spill and environment hazard, both, conventional diesel and biodiesel would represent important direct pollution threat. Knowing that conventional diesel would only degrade 50% in period of 21 days, biodiesel represents significantly safer fuel as it would degrade up to 98% in the same period.

Table 3-2: Biodiesel combustion emissions in comparison to conventional fossil diesel (source: Enguidanos, M. et al., 2002)

EMISSIONS TYPE	BIODIESEL BLEND	
	B100	B20
Total unburned Hydrocarbons	-93%	-30%
Carbon monoxide	-43.2%	-12.6%
Hydrocarbons	-56.3%	-11.0%
Particulates	-55.4%	-18.0%
Nitrous oxides	+5.8%	+1.2%
Air toxics	-60% / -90%	-12% / -20%
Mutagenicity	-80% / -90%	-20%

A more complicated and complex issue is related to biodiesel production segment or indirect emissions. Those emissions are mainly related to land use and changes consequences. According to the existing researches (Hiederer, R. et al., 2010.) a very important issue could be provoked in case of "bad management", if the production of biodiesel is not properly defined and organized it could lead to larger GHG emissions, if changing the land used for food to biodiesel resource purpose or dislocating it.

As the resulting figures for GHG emission related to biodiesel production and utilization, following Table 3-3 is generated by GREET (ANL) tool. As a starting point and definition of the biodiesel WTW analysis, I have set 5 most common sources for biodiesel production (Soybean, Palm, Rapeseed, Jatropha and Algae). These five sources are afterwards evaluated trough WTP, PTW and WTW frame.

Table 3-3: Resulting table for GHG emissions related to production and utilization of Biodiesel (source: GREET tool)

BD	Soybean	Palm	Rapeseed	Jatropha	Algae
WTP	17	18	28	28	34
PTW	187	187	187	187	187
WTW	204	205	215	215	221
	gCO2e/km				

As shown in Table 3-3 and Figure 3-8, we can see that lowest amount of emissions came from WTP cycle or production. Significantly higher amounts came from combustion process. Also, we can note that lowest WTP values are from Soybean and Palm. Other three are with more than 50% higher emissions. Keeping in mind that combustion of the end-fuel biodiesel is so high comparing to production, we can assume that further development, related to biodiesel, should go in direction of ICE technology optimization and improvements.

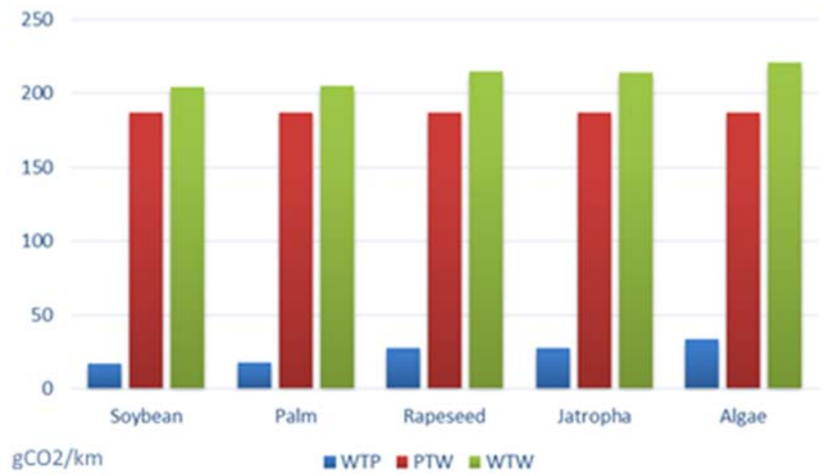

Figure 3-8: Graphical representation of overall GHG emissions for biodiesel based on generated data (source: GREET tool)

3.3 Electricity in road transportation environment impacts

Speaking about electric vehicles, similar issues and conclusions could be proven as in case of hydrogen powered cars. Electric powered cars do not emit any emissions and represent a very important aspect of sustainable and cleanest mobility solution.

If we consider that electricity used for this kind of vehicles is produced from renewable energy sources (Wind, Solar, Hydro…) only, it is clear that this technology is the most promising one and the most suitable for planet safety. On the other hand, even if electricity used in this way is produced from non-renewable sources, we would have a significant impact on the CO_2 and GHG emissions reduction (EC, 2010). It is also a fact that in some cases production of electric vehicles could be more critical for the environment that production of conventional fuel powered cars but overall reduction of emissions is still lower.

In this chapter, I will use comparison and analysis of figures generated by GREET too (ANL), as it was done in previous Chapter 3.2 and 3.1 in order to analyze WTP, PTW and overall WTW emission values.

Also, the noise issue, present with conventional vehicles, biodiesel and most of the hybrid vehicles in this case would not be the problem. Noise does not impact Earths environment directly but certainly influence the overall human health and life quality.

On the other, negative, side, beside production pollution we have to highlight the importance of buttery environment issues. Batteries used in modern electric vehicles (lithium-ions) can be of great danger taking into consideration its production as well as their disposal. If not done correctly it could have a significant polluting effect on environment, especially if we consider a large scale usage of these batteries worldwide.

In order to maximize the reduction of emissions produced by light vehicles it would be ideal to have a network developed in such a manner that it would have the satisfactory coverage of an area or even country and that it receives its "fuel" (electricity) by renewable resources where possible, by direct production on-site. The most important example of such network and idea behind it is the developed network of Tesla Motors

Company which, beside electric vehicles production, offers its customers the smart network, developed in such a way that it covers all main roads and all needed energy for charging these vehicles by renewable sources, usually solar on charging station canopy. Furthermore, all buyers of these vehicles can use this "filling stations" or Supercharger stations completely free of charge (in US and in some European countries as well). This, of course, represents the original and well-designed economic model of this company, which, besides the obvious, pushes the limits for other companies and certainly helps Electric vehicles and Sustainable stations to be more and more represented in an active, everyday use (http://www.teslamotors.com/supercharger).

This example represents the stand alone solution for electric vehicle charging and in this case it is important to recognize that having this solution, we have overridden a possibility to have hazardous and accidental oils spills on spot and in process of fuel transportation, also eliminating the emissions related to fuel transportation. Also, the same as in case of hydrogen powered vehicles, it is possible and maybe more convenient to have it along existing filling station for conventional fuels. In this case, this technology would be popularized and owners of these vehicles would have other facilities available for their needs, such as restaurants, cafes, shopping malls etc.

Some studies and researches (EC, 2012a) indicate that the reduction of Carbon emissions by the 2050 could be almost 474 million metric tons, in case of switching to only electric engine solutions.

If we, once again, generate data from GREET tool (ANL) for electric vehicle and electricity as a power source we will get following figures in Table 3-4 and Figure 3-9. As most interesting sources for electricity generation, I have selected coal, biomass, geothermal sources as well as general (other) renewable sources like wind and photovoltaic.

Table 3-4: Resulting table for GHG emissions related to production and utilization of Electricity (source: GREET tool)

EV	Coal	Biomass	Geothermal	Other Renewable
WTP	260	19	24	1
PTW	0	0	0	0
WTW	260	19	24	1
	gCO2e/km			

First and most important is to once again highlight that in case of EV there are no PTW emissions or "combustion emissions", which is same as it was case with Hydrogen models explained in chapter 3.1. This fact leaves us only with WTP emissions. As it was clear and expected, highest emissions comes from coal as an electricity resource. If we take a closer look we can see that rough difference between coal and other resources is over than 16 times. Furthermore, Very interesting is the value for "Other renewable" mostly referred to wind and PV. This indicates clear path for the further development of electricity source for these kind of vehicles. Combining this value with zero exhaust emissions we can be sure that electric vehicles in combination with electricity produced by wind and sun provides the most sustainable solution in regard of GHG emissions, considering previously elaborated emissions in Chapters 3.1 and 3.2.

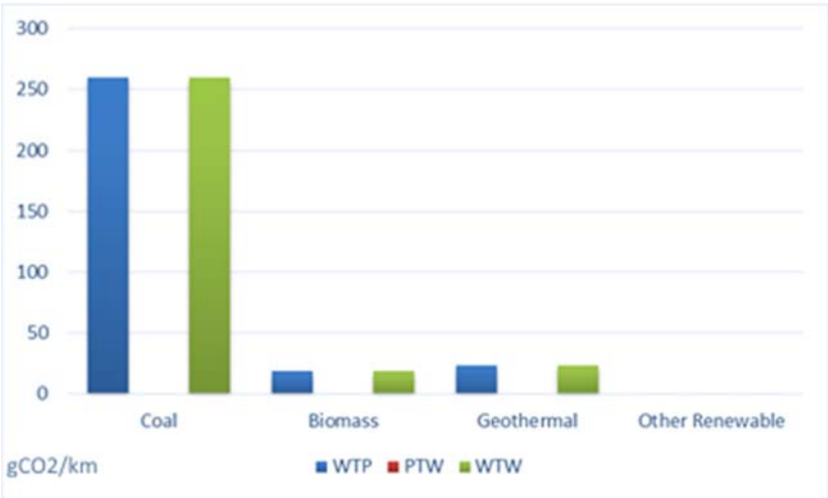

Figure 3-9: Graphical representation of overall GHG emissions for electricity, based on generated data (source: GREET tool)

3.4 Overall environment impacts comparison

In order to create the overall comparison and qualitative analysis in this chapter, it is necessary to introduce the one more emission segment, the vehicle production emissions. Previously analyses and collected data in Chapter 3.1, 3.2 and 3.3 will be compared and conclusion will be provided. As a main result in this chapter, I should be able to recognize the most environment friendly model and elaborate it in context of sustainable mobility.
Among compared figures, I will use WTP, TPW and WTW figures for hydrogen, biodiesel, electric and conventional models.

In order to continue with precisely defined models, I will use these vehicle models as a representatives, in order to have a common ground for further research and comparisons in chapters afterwards.

Beside the selected and defined vehicles, one more electric powered vehicle is included into the comparison, the Tesla "Model S" as it represents the significant step forward considering performance, usability and luxury.

Following Table 3-5 presents the overall results and figures already collected through the evaluation in previous chapters. In this table, beside basic information about models, resources they use and calculated emissions, we have also included data from vehicle production emissions and segments which concerns the conventional fossil fuel vehicles. In part of the table related to emissions, only most related figures (resources) were presented. As the core of this thesis is sustainable mobility, for core defined models, only renewable resource related figures are used and presented in a range form.

Table 3-5: Emissions by fuel source and utilization segment (source: AUDI AG 2014, Tesla Motors 2014b, GREET, Sullivan J. et al. 2010)

VEHICLE	FUEL	FUEL RESOURCE	WTP	TPW	WTW	VEHICLE PRODUCTION EMISSIONS
H2 Mercedes Benz F-Cell	Hydrogen	RES	2-95	0	2-95	814-2282
BD Mercedes Bez B-Class	Biodiesel	RES	17-34	187	204-221	723-2113
EV Mercedes Benz Electric	Electricity	RES	1-19	0	1-19	913-2194
EV Tesla Model S	Electricity	RES	1-19	0	1-19	750-2000
Diesel Mercedes Benz B-Class D	Diesel	FOSSIL	52	187	239	723-2113
			gCO2e/km			kgCO2e/car

Analyzing the results, firstly we can see the obvious comparison with conventional model (fossil diesel solution). All other defined models represents sustainable and low emissions solutions versus conventional one. This difference, in most cases is significant in every group of data even if we take the worst case scenarios (upper limits) into consideration.

Well to Wheels analysis showed us that overall emissions produced from renewable resources and utilized in green vehicles represents significant reduction and improvement in comparison to fossil fuel solutions and that our mutual tendency towards clean and sustainable mobility is on the right path with plenty of room for further development considering the environment effects. Secondly, vehicle production figures presented in Table 3-5 are also useful and interesting because they indicates that technology for all of these examples is more or less in some mutual range and that it has been confronted with a certain barriers and limitations which are hard to get through. In this field also, most certainly exist small space for improvement and further reduction.

If we go deeper into the calculations and further analysis we can calculate the average GHG emissions footprint which is related to one vehicle in one year or in defined life period of 10 years. According to already explained emissions data and defined inputs (average 12,000 km/year over 10 years of lifetime), we can calculate that in average (considering WTW and vehicle production emissions only), one hydrogen vehicle should be responsible for roughly 7,3 tonCO_2 emissions trough period of 10 years. With same calculation we will recognize about 2,5 tonCO_2 emissions for electric vehicles and finally approximately from 27 to 30 tons of CO_2 emissions for biodiesel and conventional diesel vehicle, respectively. Calculating the best possible scenarios (considering lowest presented emission values) we can found that hydrogen vehicle would be responsible for 1,1, electric vehicle for 0,9 and biodiesel and diesel from 25 and 29 tons of CO_2 emissions in defined life period.
These rough figures, from this kind of calculation approach (Cradle to Grave) also confirms presented level of emission reductions by certain renewable solutions, considering electricity model as best possible choice in regard of environmental approach.

4 TECHNOLOGY AND NETWORK INFRASTRUCTURE PERSPECTIVE

In previous Chapter 3, I have analyzed some of the most important emissions emitted by different solutions and technologies. In this chapter idea is to create a comprehensive analysis between currently available technologies in sustainable mobility sector as well as to give an overview on possible future developments. Vehicle manufacturing technologies as well as alternative fuels production methods will be appraised and compared. Also, an important aspect will be comparison of the tested and researched performance figures of the real, existing examples of selected and predefined sustainable mobility models which directly influence our lives. Different technologies will be evaluated and assessed according to efficiency, performance and technology and infrastructure availability.

According to this, method of approach for sustainable technology and network and infrastructure development perspective segment of this thesis will be researching of available data and previous analysis conducted as well as personal testing of accessible sustainable mobility models.

4.1 Hydrogen fuel cells technology

Although hydrogen and fuel cells are present in automotive industry for quite some time now, they still have not been massively present on the worldwide market. There is a couple of reasons for this. After introducing hydrogen as a possible energy carrier, a question of security arises, in part due to political reasons and lobbying situation in decision makers' circles. Keeping these points aside, we have to keep in mind that hydrogen as a fuel resource has the highest possible efficiency rate as well as that it could be produced in variety of ways and from variety of sources, and as most importantly, it could be produced from water using electricity from renewable sources and in its final use, produce no CO_2 at all as we discussed and proved in Chapter 3.1.

Technology itself is simple in general. The hydrogen fuel cell is divided in half with the Polymer Electrolyte Membrane or PEM, which is on both sides coated with catalyzer and electrode which is gas permeable. In this setup, both hydrogen and oxygen can travel from one side to the other trough the existing gas channels. Hydrogen is then being divided on electrons and protons by the catalyzer. This way, protons which are positively charged can go through PEM and negative electrons cannot, and electricity is then generated. In case of connected electrodes, the direct current flow is produced (Züttel, A. et al., 2008. and Al Hallaj, S., Kiszynski, K., 2011.). This process is clearly presented on the following Figure 4-1.

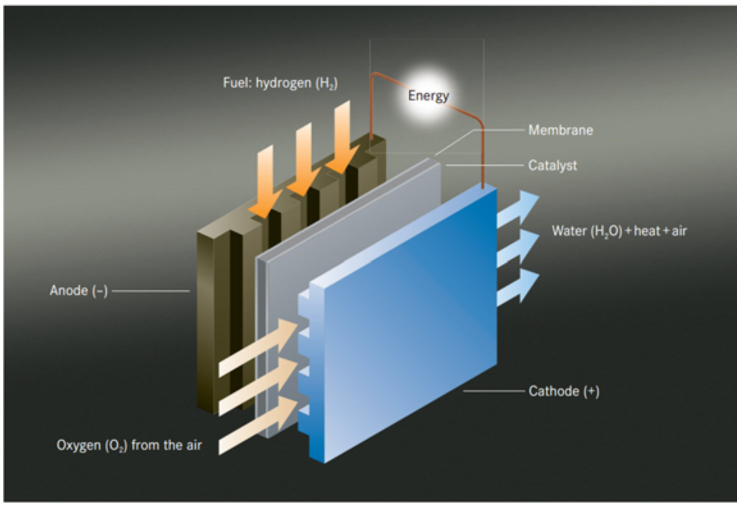

Figure 4-1: Hydrogen fuel cell scheme
(source: http://www.mbusa.com/vcm/MB/DigitalAssets/pdfmb/fcell/248x168_b-klasse_f-cell_NP11_EN_DS_low2.pdf)

The basic principles of fuel cells technology were also demonstrated by British physicist William Grove in year 1839. He discovered that four cells containing oxygen and hydrogen could produce electrical energy (Gross, J. 2002.). Even this was long time ago and taking into the consideration that there were some descriptions and thesis in early 17th century, the serious development of fuel cells began during the last years of the 20th century.

Two main types of hydrogen to useful energy conversion methods for road transportation are:

- Electrochemical reaction of hydrogen and oxygen in fuel cell, producing the electrical energy.
- Direct combustion with air in conventional engines (internal combustion engine, steam engines or turbines).

With Fuel cells in hydrogen technology, the controlled reaction is achieved, there are no emissions, the traditional combustion is removed and instead, the electrons exchange is introduced and power is created in a pure chemical reaction between oxygen and hydrogen.

The idea behind the presented and tested vehicle, as behind the complete hydrogen fuel cell concept, is to have an emission free vehicle which creates its own electricity on spot. If we take a look at Figure 4-2, we can see the major parts of such H2 mobility system. All parts for energy production and conservation are located beneath the car and in the engine compartment. The room for passengers as well for baggage is not affected by this setup.

Figure 4-2: Hydrogen fuel cell powered vehicle scheme (source: http://www.mbusa.com/vcm/MB/DigitalAssets/pdfmb/fcell/248x168_b-klasse_f-cell_NP11_EN_DS_low2.pdf)

Figure 4-2 presents the following main parts of a fuel cell powered vehicle:

1. Fuel cells (stack): The fuel cells are stacked together because of better autonomy and efficiency.
2. Fuel tank system: Compressed hydrogen gas tank with pressure of ~700bar.
3. Battery: Battery used in this vehicle is lithium-ion battery and its main purpose is to store electricity generated by braking and to provide that same electricity when needed, during intensive acceleration as additional boost.
4. Electric motor: The motor used to power the front wheels in this car is a high torque electric motor and it is powered by fuel stack and battery.

Oxygen is taken from the environment and hydrogen from the pressured tank. After their reaction in the fuel cell stack, electricity is generated and delivered to the electric motor when throttle pedal is pressed by the driver. In the fuel stack, the most important part is the proton conducting synthetic membrane which has the platinum coating on both sides and it is responsible for separation of hydrogen and oxygen gases. It has the important role in braking down hydrogen into positively charged protons, which flow through the membrane to oxygen (forming water), and negatively charged electrons. As negatively charged electrons cannot go through the membrane, they will stay and create the surplus of electrons on the hydrogen side and an electron deficiency on the other, oxygen side, will occur. This forms positive and negative pole, cathode and anode, respectively. As they are connected, they produce the current flow and give power to the electric motor.

In addition, in case of excessive braking or driving down-hill, the lithium-ion battery (1,4kWh capacity on the tested model) is automatically charged by kinetic energy and that additional energy is stored until needed for the electric motor during acceleration periods. This process is combustion free and produces no emissions whatsoever. Also, the noise is reduced to the minimum, as it is the case with all electricity powered vehicles, and depends mainly on driving conditions and vehicle setup (road, weather, tires, etc.).

As well as it is important to have pollution and efficiency in mind it is also very important to consider vehicle performance outputs and that must not be neglected. As described in the production specifications of the vehicle tested model, torque is equal to 290Nm, which is more than enough for this class of passenger vehicle and certainly more than equal to B-Class conventional fuel powered version (between 200-250 Nm). As it is the case with almost all electric powered engines this one also has the instant reaction time as well as satisfying performances. Another side of the vehicle output and performance is range issues. These figures depend on the manufacturer but are in the neighborhood of the 300-500km.

Safety issues regard the hydrogen and fuel cells technologies are very important from every single point of view. Analyzing the current production methods and vehicle manufacturers as well, this issue, nowadays, is not present more than in any other conventional or renewable sources powered vehicle. One of the most important questions are related to flammability and end use safety.

In order to achieve the safe use of these technologies, some rules were established. They are more or less similar to fossil fuel technology safety rules. Introducing the codes and standards for most sensitive aspects was only the first step. In this manner the most important questions standardized were facilities and tank designs and protection, earthing and lighting protection and the recommended safety distances – a distance between other sensitive and hazardous equipment and installations (electric components, power lines, other fuels, etc.). Also, the same as in case of fossil fuels equipment, it is strictly defined what materials and components can be used in the hydrogen production and utilization systems setting up. Finally we have also the end-users safety equipment which means standardized dispensers and its nozzles and relevant end-users education (HIE RE, 2006).

The hydrogen storage represents one of important issues of this technology. Currently mostly used method is high-pressure storage as hydrogen has low density and storage using normal pressure would not make any sense as it would require large amounts of space or tanks/containers. This is the main reason for compression and liquidation of hydrogen prior to storing it as hydrogen volume could be reduced for almost 100% in this process. This also leads to the conclusion that currently the best solution when speaking about hydrogen in mobility is liquid hydrogen. In order to do so, hydrogen temperature should be lowered below -250ºC. This is, at the same time, a complicated side of this process as it usually has the significant energy but also sophisticated technology demand. In order to hold such low temperatures, the materials used in this kind of systems must be reliable and be able to prevent warming up of hydrogen (CEP, 2014). Warming up of hydrogen in this system would mean a huge problem because of high pressure increase. This is the reason why storage systems, both in vehicles and at filling stations should be well designed and constructed. Adequate storage should be able to keep safe liquid hydrogen on temperatures below -250ºC and in case of gas state of hydrogen it usually has to be able to keep it pressured up to 1,000 bar or up to 700bar in vehicles.

Taking short overview in the future research and development plans related to hydrogen storage (HIE RE, 2006), beside high pressurized storage, three more methods are currently in the experimental phase and both represent the solid state hydrogen storage:

- Metal hydride storage
- Chemical hydrogen storage
- Carbon hydrogen tanks

In the following Table 4-1, the summary of all available storage technologies and methods is presented.

Table 4-1: Hydrogen storage type overview
(source: HIE RE, 2006)

H2 STORAGE TYPE	STORAGE TECHNOLOGY	ENERGY DENSITY	PROS	CONS
Copressed Hydrogen	Steel/Carbon fiber cylinders (200/350/700 bar)	0.5/1.9/1.6 kWh/kg	Widely used storage model, easy to implement. Low-cost with high energy density.	Heavy and large storage model, not used on large scale.
Liquid Hydrogen	Low temperature storage	1.7 kWh/kg	Easier large scale transportation and delivery.	Still not widely used/accepted as a small tanks storage. Costly liquefecation process.
Metal Hydride	Light metals (Magnesium, Boron, Lithium, Sodium)	0.8 kWh/kg	Developing technology with high potential. Safest solution as it exclude the high preasure tanks.	High costs.
Chemical Hydride	Hydrates reactive with wather/alcohol	1.4 kWh/kg	Developing technology with high potential. Excluding the high preasure tanks.	Still not developed enough.

First process is actually the process of absorption. In this process, metals which have high affinity for hydrogen (usually light metals such as lithium, sodium, aluminum, magnesium, etc.) are used as a temporary storage. Absorbing of hydrogen by these materials releases certain amount of heat. The idea beside this process is to have hydrogen absorbed by these metals and when needed, it could be released using the waste heat from the fuel cell (reverse process). There are a couple of advantages in this approach. First, this would be a safer method of storage as high pressured tanks would not be used and also there is a potential of high energy density. Chemical storage method represents the process of chemical bound between hydrogen and some other solid materials. In order to release it again, a chemical reaction has to be used. Carbon hydrogen tanks are newly developed tanks, made from carbon fibers. The main positive side of these tanks is that they could hold hydrogen with pressure higher than 700 bars. Also, this is a significantly lighter solution, comparing to conventional, steel tanks.

4.2 Biodiesel technology

Biodiesel is a type of biofuel and it can be produced from various vegetable oils (soybean, rape seed, etc.). Today it is commonly used as a diesel additive or even a substitute for conventional fossil diesel fuel. Biodiesel is available and used in various different mixtures defined with its content. In this manner, we have a pure blend of biodiesel also known as pure biodiesel or B100 and other blends with content of biodiesel in range of 5% (means that it has 95% of fossil diesel and 5% biodiesel content) named B5, B30 with 30% of biodiesel content and so on. Vehicle related aspect of biodiesel in this thesis consider the same vehicle as it used for utilization of pure fossil diesel, selected Mercedes Benz B Class Diesel. This vehicle does not include any engine or vehicle modifications at all.

The biodiesel production process converts oils and fats into chemicals called long-chain mono alkyl esters, or biodiesel. These chemicals are also referred to as fatty acid methyl esters (FAME) and the process is referred to as transesterification. See process diagram in Figure 4-3.

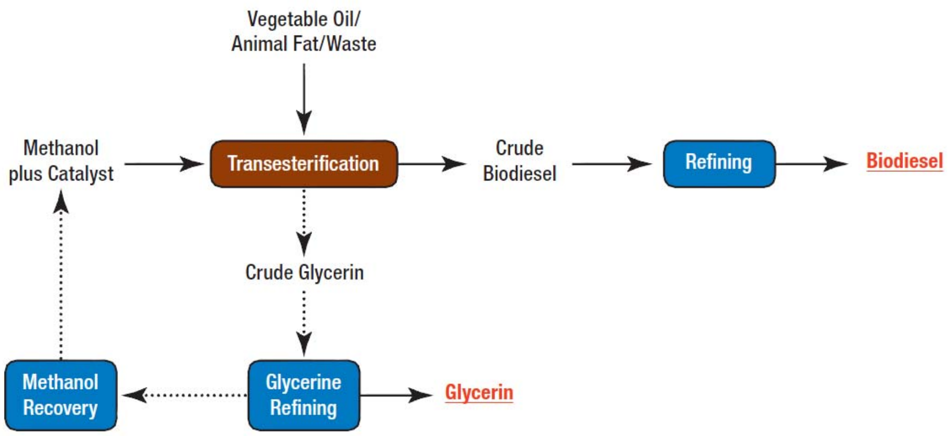

Figure 4-3: Transesterification process scheme
(source: own depiction)

Raw or refined plant oil, or recycled greases that have not been processed into biodiesel, are not biodiesel and should be avoided. Research shows that plant oils or greases used in combustion engines at concentrations as low as 10% to 20% can cause long-term engine deposits, ring sticking, lube oil gelling and other maintenance problems and can reduce engine life (NREL, 2006). These problems are caused mostly by greater viscosity, or thickness, of raw oils (around 40 mm2/s) compared to that of diesel fuel, for which the engines and injectors were designed (1.3 to 4.1

mm2/s). Through the process of converting plant oils or greases to biodiesel by transesterification, the viscosity of the fuel is reduced to values similar to conventional diesel fuel (biodiesel values are typically 4 to 5 mm^2/s).

Conventional biodiesel is produced from raw vegetable oils derived from soybean, canola, oil palm or sunflower, as well as animal fats and used cooking oil. Oils and fats which came from these sources are converted to biodiesel using either methanol or ethanol. It is also possible to use vegetable oils as untreated raw oils. In that case, it is very important to take into the consideration a large risk of engine and system damages. The main side products from biodiesel production are mainly protein meal and glycerin, and they are very important to the overall economic appraisal of the production process. It is very important to highlight that the conventional biodiesel production is also very sensitive to feedstock market prices.

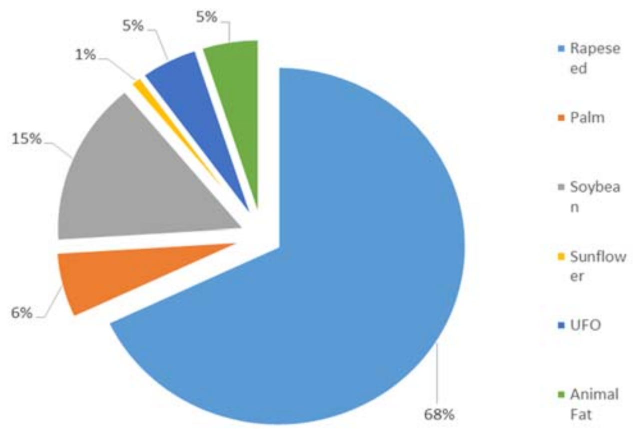

Figure 4-4: Estimated share of raw material sources for Biodiesel production worldwide (source: Mittelbach M, 2012)

Figure 4-4 shows us estimated share of feedstock in biodiesel production on worldwide basis which are also defined and explained as sources in Chapter 3.2. Largest portion (68%) comes from UFO or UCO (used frying or cooking oil). Second one is soybean with 15%. Lowest portion comes from Sunflower. In Table 4-2, short comparison between single and multi-feedstock is presented.

Table 4-2: Single feedstock vs. Multi feedstock

SINGLE FEEDSTOCK	MULTI FEEDSTOCK
Completely refined vegetable oil	Diferent kinds of oils, fats, waste oils and fats, fatty accids
Sodium methylate, NaOH, KOH catalysts	H2SO4, NaOH, KOH catalysts
Continuous process	Semi continuous or batch type transesterification
Purification of biodiesel without destillation	Purification of biodiesel by destillation
Glycerol is either cruder or pharmaceutical grade	

There are several processes which aim to produce fuels with properties very similar to diesel and kerosene and may be called as advanced biodiesel. These processes are still in a development phase and may not be available commercially. There will be a possibility of blending these fuels with fossil fuels in any proportion. Also they can use the same infrastructure and should be fully compatible with engines in heavy duty working vehicles.

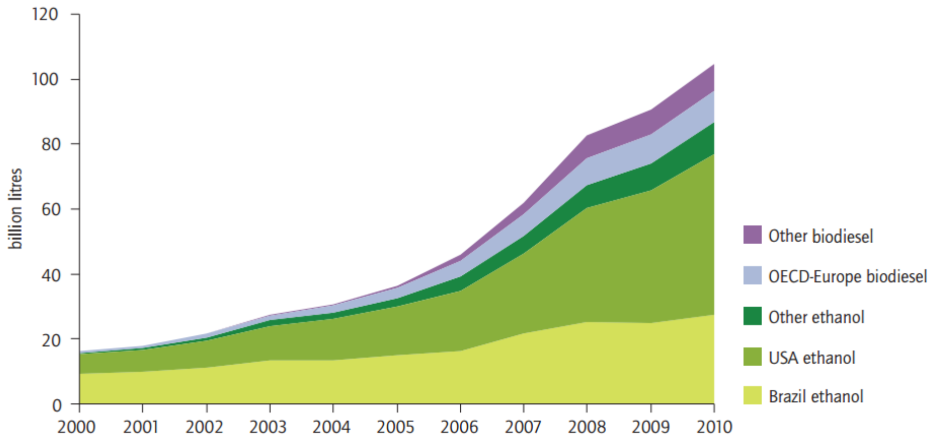

Figure 4-5: Biofuel production on global scale from 2000 to 2010.
(Source: IEA, 2010.)

In Figure 4-5, the relation between biofuels ethanol and biodiesel is presented, from year 2000 until 2010 and the figures shown are defined in billions of litters of biofuel. From this, we can clearly see the main tendencies in the production which is in constant growth.

In general, the production methods of biodiesel can be divided in to three main types regarding its production capacities (Mittelbach M, 2012). They are Small, Medium and Industrial size production. Short overview follows.

- **Small size production**
  - 500 - 5.000 t/a
  - Batch process
  - KOH
  - Various feedstocks
  - Limited quality control

- **Medium size production**
  - 5.000 - 50.000 t/a
  - Batch, semi continuous process
  - KOH, NaOH
  - Sufficient quality control

- **Industrial size production**
  - 100.000 - 250.000 t/a
  - Continuous process
  - Sodium methylate
  - Fully refined vegetable oils
  - Sufficient control

According to the research (Enguidanos, M. et al., 2002), using only biodiesel as a fuel source (B100) would have major impacts. First, it would impact the consumption, which means that in this case vehicles would use 10% more fuel or 1,1 liters of biodiesel instead of 1 litter of conventional diesel fuel. Second, it would also influence the performance around 10%. Other important issues are also the long term storage, corrosion of some materials and vehicle maintenance complexity. It is also proven that these losses are not linear and it means that in case of other blends, for instance of B20 or lower percentage, has the same consumption and performance as it would be the case with the conventional diesel fuel in the same test vehicle. Despite the fact that pure B100 could have some negative impacts on the engine lifetime and functionality, the lower blends, on the other side, have the beneficial impact on the engine as they would provide higher lubricity, keeping engine safe and in the top performance range.

In order to keep biofuels a significant part of the sustainable mobility and in order to fight with the question known as "food or fuel" issue and the fact that some countries has been introducing legal limitations for biofuels production from food resources (China example), a new generation of biofuels has been developed. An interesting example might be the OMV's second generation biofuels, where diesel fuel is produced from the chopped wood pellets using "BioCrack" chemical process. The idea behind this rather complex process is conversion of solid carbon into liquid hydrocarbon or converting solid biomass into liquid fuel (Figure 4-6). Beside wood the following target is to use agricultural waste as corn residue and straw.

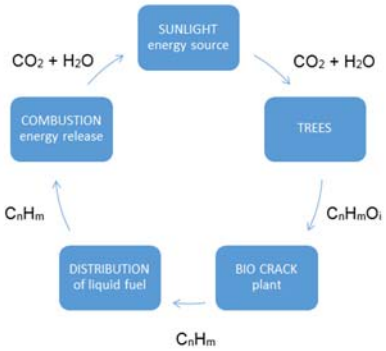

Figure 4-6: Liquid hydrocarbon, part of the Carbon cycle (source: OMV R&M, 2014)

4.3 Electricity technology in passenger car mobility

Despite the fact that hydrogen fuel cell vehicles are still not in mass production, electric vehicles has been available for a long time now. Their research, development and production are in focus of all major players in the automotive market. Many of these vehicles are currently in use worldwide. In Europe, this value is below 1% of total registered vehicles (ICCT 2013).

In an electric vehicle, instead of the combustion engine, there are one or more electric motors powering the wheels. The power source for these motors is a set of connected batteries. This process or schema is very similar to one described in the hydrogen and fuel cell technology. The only difference is that in case of EV there is no hydrogen tank and fuel cells. Charged electricity is immediately stored in high capacity batteries and directly delivered to electric motors when needed (Figure 4-7). It is clear that the main and most important part of an EV is a battery. In early models, lead-acid batteries were used but during the long period of adjustments, research and development the lithium-ion (Li-Ion) batteries appear to be currently the best possible solution. Other "experimental" battery types were proven to have plenty of safety issues and concerns, like overheating which could lead to serious problems. Currently, the lithium-ion batteries are providing the highest power and energy density (150 Wh/kg) levels. Average fossil fuel powered engine has around 12kWh/kg energy density, much more than in EV's. This difference becomes smaller if we take into consideration a conventional vehicle and its components weight and energy demand. Raising this value to 200 Wh/kg would be some short term target in order to significantly improve electric vehicle characteristics, especially the most problematic part which is the range (EC, 2010). Following Table 4-3 describes some of the present EVs on the market. Also, the comparison between the most important vehicle parameters (range, top speed acceleration, etc.) is given. As previously defined and used we also have Mercedes Benz Electric Drive based on B Class. According to presented figures usage of this model in this thesis is once again justified as it represents comparable average which was the idea behind this vehicle selection.

Table 4-3: EV market short overview
(source: Tesla Motors 2014b, VW 2014, Mercedes-Benz 2014b, BMW 2014 and Honda 2014)

BRAND	MODEL	VEHICLE CLASS	BATTERY CAPACITY (kWh)	VEHICLE RANGE (km)	HP	TOP SPEED (km/h)	ACCELERATION (0-100)/s
TESLA	MODEL S	Upper	85	425	362	200	5.4
VW	GOLF E	Middle	24.2	190	115	140	10.4
Mercedes Benz	B-Class Electric Drive	Middle	36	135	177	160	7.9
BMW	i3	Middle	22	130	170	150	6.5
Honda	Fit EV	Lower	20	85	123	150	8.7

On the other hand and unfortunately this is not quite enough for the overall purpose of electric vehicles. This represents the major problem at the same time. These types of batteries, at the beginning were designed not for powering vehicles but for small electric devices. On the large scale, the main concerns, still existing, are the lifetime periods, production and recycling costs and safety. Usually this kind of batteries used in small electric devices had a lifetime of approximately 3 years which is not even close to needed 10-15 years for the car industry.

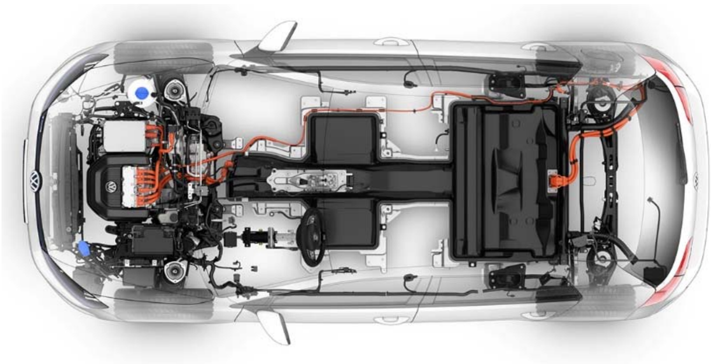

Figure 4-7: Electric vehicle scheme
(source: VW AG 2014)

When speaking about problems concerning the EV's and their batteries, a very big issue is the charging periods. While an average passenger vehicle needs approximately up to 4 minutes to fill the tank completely, in case of an electric vehicle this period could be much longer. For charging this kind of vehicle, it would take from half an hour to over 8 hours, depending if charging takes place in the household charging unit, standard or supercharged "filling" stations. Adding to this periods the waiting times on stations, could also mean a lot of problems for passengers.

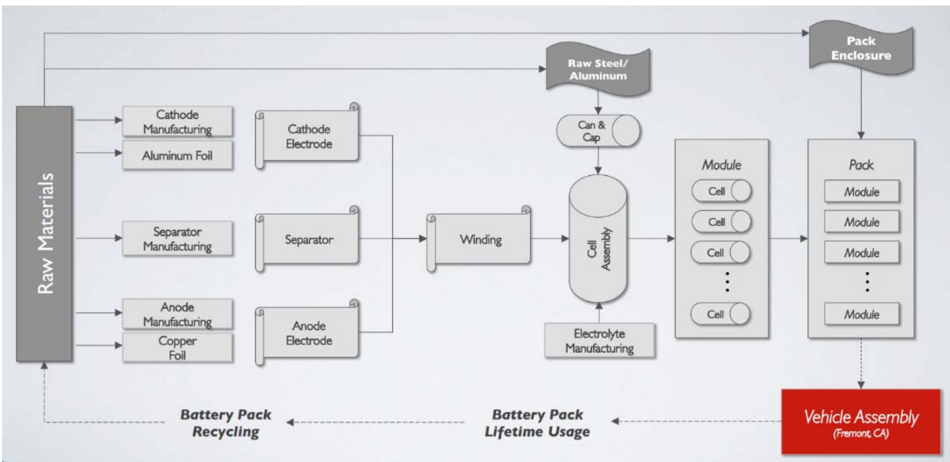

Figure 4-8: Electric battery and electric vehicle manufacturing process flow
(source: Tesla Motors 2014b)

Some car companies are trying to solve these problems by introducing the possibility of swapping/changing the batteries. As this seems to be rather a complicated process, Tesla Motors companies managed to create some pilot batteries swapping stations. They managed to swap batteries on one car, in completely automated process, in 90 seconds, which is significantly less than filling up the tank in an average conventional vehicle. Even the fact that this solution requires a high end engineering and process planning, this represents significant breakthrough in EV charging technology.
On the other, conventional side of charging electric vehicles, we have standard or supercharging stations. Once again, an excellent example for this kind of technology in use is Tesla Motors Company. At their supercharger stations, it is possible to completely charge the electric vehicle (85kWh models) in 75 minutes, 80% for 40 minutes and 50% in just 20 minutes. For comparison purpose, an average electric vehicle charging time at a regular charging station can take even 16 times more time than on the supercharged one (Tesla Motors 2014). In the following diagram (Figure 4-9), average charging periods of electric vehicles versus conventional fuel vehicles are compared. Into this comparison, I have included one more category, the battery swapping and Tesla supercharging solution. As a conclusion, we can see that average charging periods for electric vehicles are far from convenient levels which are in range of 5-10 minutes maximum. Having included Tesla models, we can see that there is a potential for further development in this direction and certainly that there is a significant room for improvement. If done correctly and fast enough charging the electric vehicle in the future might be as fast as filling up the conventional fuel vehicle.

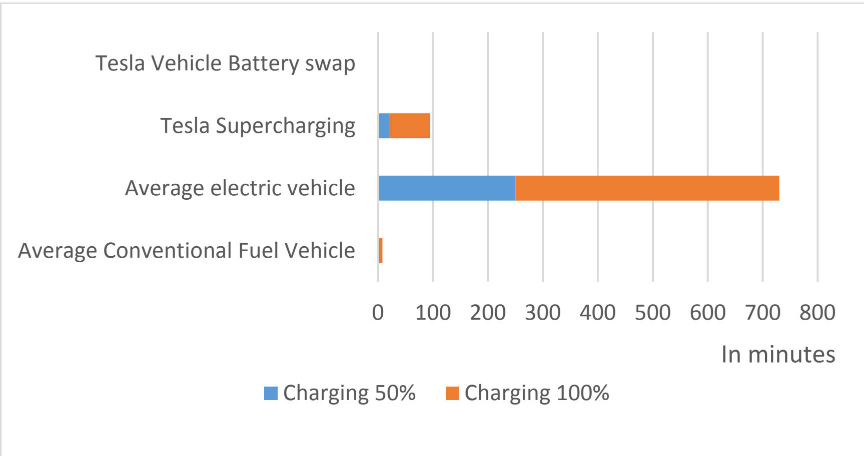

Figure 4-9: Charging periods - EV vs. Tesla vs. Conventional Vehicles (source: Tesla Motors 2014)

Besides charging time point of view, a very important aspect is also the source of electric energy provided for charging this kind of vehicles. In previously stated example, some of the charging stations were equipped with solar panel on the canopy so the electric energy is generated on spot and additional, if needed, is taken from the grid. This is also the main principle for the EV fuel source generation. The electric energy could be generated directly on site, near or even on a charging station, using photovoltaic or wind turbines combined with the grid provided electricity. Any of these, represents a cleaner solution then conventional fuel usage, especially keeping in mind that there are no direct CO_2 and any other GHG emissions using electric vehicles, as proven in Chapter 3.3.

Other significant technological breakthrough is related to term Supercapacitors. They already exist and are in use in some electric and hybrid vehicles even more and they represents very useful, storage devices. The main difference or main advantage to lithium-ion batteries is a possibility of supercapacitors to store/collect and release energy very fast. These advantages are currently used in EV and HEV as side systems meant for collecting energy created during intensive braking or driving downhill and also for providing this same energy for instant acceleration when needed. This is a very important part of the overall vehicle power system as, in this way, the life of the main battery is prolonged and performance, both range and acceleration related, is significantly higher. There are many researches in the field of supercapacitors which are trying to improve its usability so they could be used on a larger scale or even as a substitute for main lithium-ion batteries.

In the following Table 4-4 the main comparison between supercapacitors and lithium-ion battery is presented. The most important differences are charging time and life cycle. As a negative side we can recognize the costs, which are currently extremely high, even 20 times higher than price of lithium-ion batteries.

Table 4-4: Figures comparison between Supercapacitors and Lithium-ion batteries (source: Battery University 2014)

DESCRIPTION	SUPERCAPACITOR	LITHIUM-ION
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	Over 500
Cell voltage	2.3 to 2.75V	3.6 to 3.7V
Specific energy	5 Wh/kg	100–200 Wh/kg
Specific power	Up to 10,000 W/kg	1,000 to 3,000 W/kg
Cost	$20/Wh	$0.50-$1.00/Wh
Service life (in vehicle)	10 to 15 years	5 to 10 years
Charge temperature	–40 to 65°C	0 to 45°C
Discharge temperature	–40 to 65°C	–20 to 60°C

Other side which also makes the electric vehicle story more complicated is the fact that during the decades of development of the car industry, light vehicles (and most of the types) become a part of our everyday life and in that manner they have a large scale of commodities which require additional energy. The most of light vehicles currently in use in Europe are now equipped with lots of devices and comfort components like air-conditioning, entertainment and navigation systems, advanced board computers, mobile device charging stations, etc. It is not possible to imagine a normal usage of modern vehicle without them. It is a fact that all of these components are seeking for additional energy, which, in conventional fuel powered vehicle, is based on the energy from combustion engine. This is why the EV manufacturing companies have a very difficult task to solve, it is important to keep all necessary commodities and functionalities but also, not to affect too much the end-performance on the vehicle, especially range. There are several possible solutions for this problem, one is usage of high powered supercapacitors which will obtain its energy during driving and store it until needed for some component or even combine it with small scale solar cells from the roof of vehicles (EC, 2010). Those, and more advanced solutions are still in research and development phase.

4.4 Network Infrastructure development

The most important element in sustainable environment of road transportation is network development. Technology in vehicles and in efficient production and fuel distribution has to be developed in parallel. This is the only way how new sustainable and green technologies could be utilized on large scale in the shortest possible time.

In order to analyze current situation in Europe I will discussed network possibilities and known issues related to hydrogen and electricity technology. Biodiesel will not be analyzed in regard of the network development as its distribution could and relies on existing infrastructures and networks based on conventional fossil fuel products.

The current situation in hydrogen mobility segment is a bit complicated. Existing networks are certainly not sufficient for potential users and vehicle manufactures have slow down exploration and production plans. Mainly because of current high demand of conventional vehicles and exploration of other, currently more popular vehicle types (electric vehicles and hybrids).

When speaking about network development in regard of hydrogen fuels and electricity, there are three major possible choices:

- New, separate, network development;
- Add-on for existing filling station networks;
- Home charging stations.

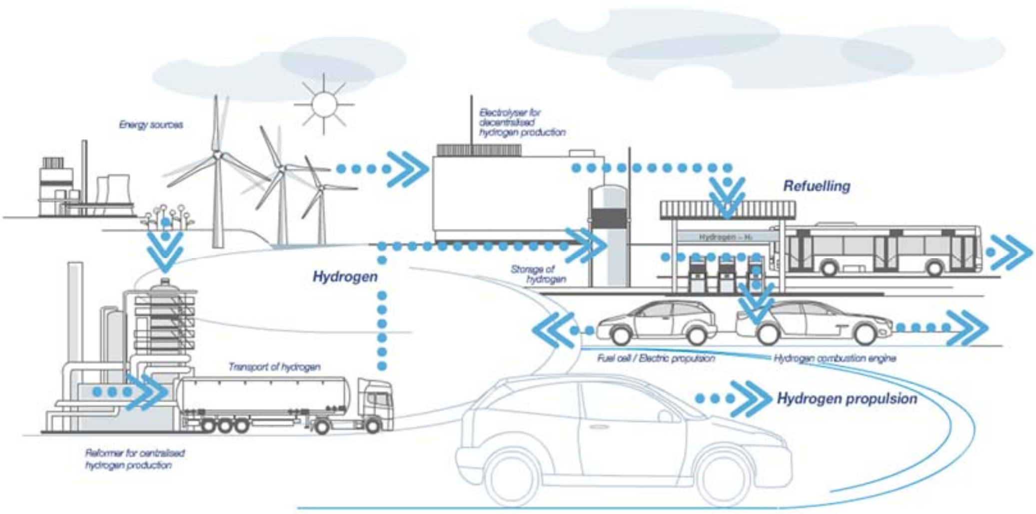

Figure 4-10: Hydrogen production, distribution and utilization (source: http://www.cleanenergypartnership.de/tech)

New networks development (Figure 4-10) certainly represents the most expensive and technologically dependent choice but also provides a possibility to have an independent alternative fuel filling system. Currently, in Europe only around 72 standalone filling hydrogen stations exist. Most of them are the add-on to existing conventional filling stations. The capacity of the standalone systems is usually above 50 vehicles per day or above 200 kg of hydrogen fuel. These figures depend on the scale of the station itself as well as of the hydrogen production/delivery method. The most problematic issue according to the author is the complexity of the smart network development. It means that many countries have too rigid laws and regulations where filling stations can be positioned along the roads and, on the other hand, the most important points on the most frequent roads and highways are already very well covered with conventional fuel filling stations.

There is also a possibility of an addition to the existing filling station or even mobile charging units which could be the best solution for some inaccessible places with lower demand. The addition to the existing filling station networks has a couple of advantages. Firstly, this is an already developed network and in most cases, stations are wide spread over the most important country roads and highways. This also reduces the implementation costs and the problem of constant electricity demand (if no green energy is available, it could be easily connected to filling station grid electricity or fossil fuel network). On the other hand, seeing it through the eyes of retail network holders, this would not be a problem regarding the competition because, it would be an additional offer as well as it would keep the existing customers who decide to switch to green vehicle solutions. This point is very important when we speak about every sustainable mobility concept too. In Figure 4-12, hydrogen filling stations in Europe are presented on the map. There are over 20.000 (Figure 4-11 and 4-13) electric vehicle charging stations all over Europe or over 50.000 charging slots (http://chargemap.com/stats).

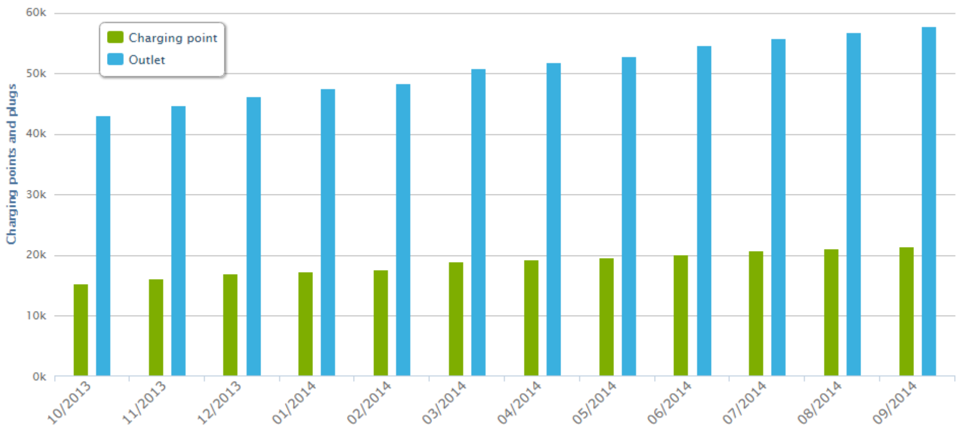

Figure 4-11: EV Charging points and slots statistics (source: http://chargemap.com/stats)

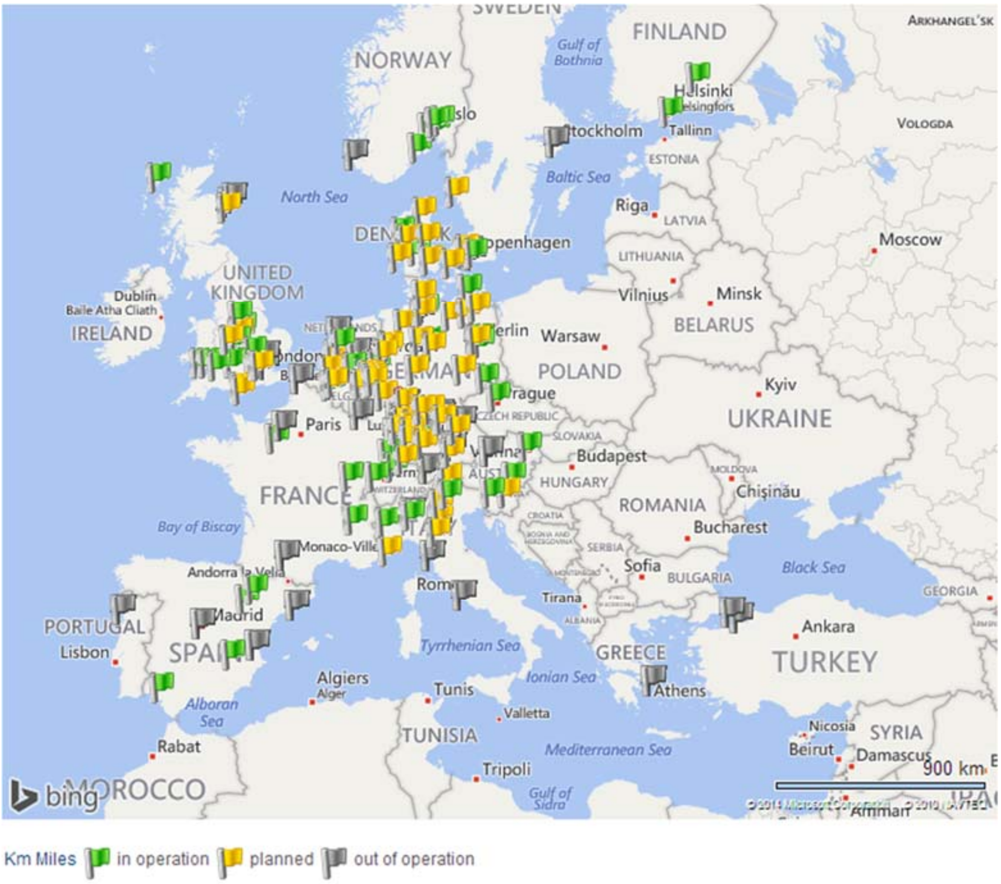

Figure 4-12: Hydrogen filling station network in Europe
(source: http://www.netinform.net/H2/H2Stations/H2Stations.aspx?Continent=EU&StationID=-1)

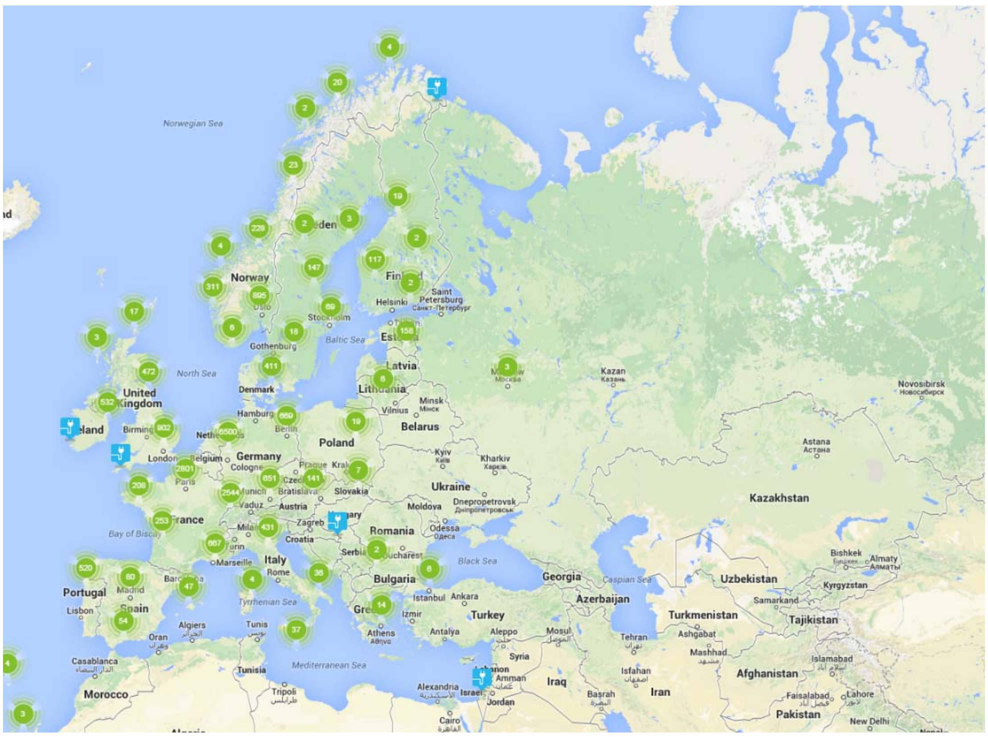

Figure 4-13: EV Charging points in Europe
(source: http://chargemap.com/)

In the Addendum, Figure A-1, the distribution of charging points per location type and per country is presented in detail.

A very important player in the European market is also Tesla Motors Company with their charging solutions and interesting coverage. As it can be seen in the following Figures 4-14 and 4-15, Tesla charging stations network is counting 63 in Europe and they are planning to significantly widen their network in following years.

Figure 4-14: Tesla Motors charging stations currently open (source: Tesla Motors 2014)

Figure 4-15: Tesla motors charging station planed until 2015 (source: Tesla Motors 2015)

Analyzing previous EV charging point's maps and coverage, we can conclude that current coverage is very promising and functional in reality. The only problem would be shorter routes and everyday traveling distances. Beside a very good coverage, it has to be much better in order to fulfil our everyday needs, and not only long journeys. In addition, planning of routes and every day trips, in order to follow the most economic and reasonable trips can be very exhausting and time demanding, so this solution certainly is not the most convenient one.

Home charging stations seem to be a promising idea for both, hydrogen and electric vehicles. There are plenty already developed technologies and solutions for home charging purpose, made by BMW, Honda, Toyota, Tesla, etc... This will be very important segment in the future when these vehicles become real and equal market choice for potential buyers. Taking relatively low vehicle range into consideration, in comparison to conventional vehicles, this possibility would significantly improve the usability of these cars. Technology for home charging stations is similar to standalone stations, only on smaller scale. The process remains the same and includes the same elements, electricity choice (grid electricity or home renewable energy production), the water electrolyser, compressor, high pressure hydrogen tanks (storage) in case of hydrogen (Figure 4-16) and storage batteries and filling dispensers (nozzle) for electric powered vehicles. In order to achieve zero emissions and CO_2 free road transportation concept, it would be necessary to use the renewable energy production, either by small wind generators or solar cells.

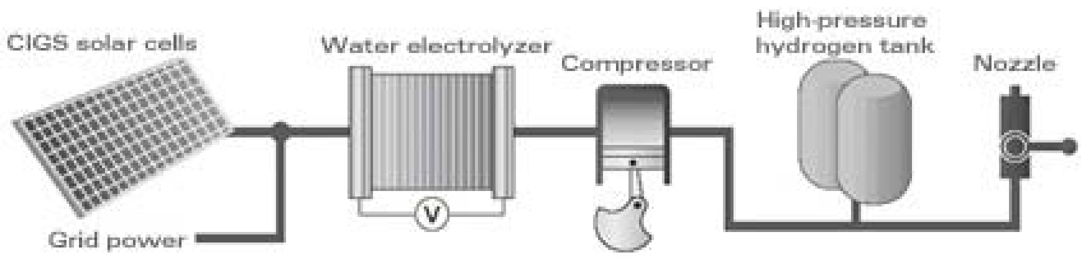

Figure 4-16: Hydrogen home charging scheme (source: http://world.honda.com/FuelCell/SolarHydrogenStation/)

In case of hydrogen and three filling/charging scenarios, following fuel distribution choices are available:

- Connection to the existing hydrogen pipelines;
- Delivery and storage on site (Figure 4-17);
- On-site hydrogen production and storage (Figure 4-18).

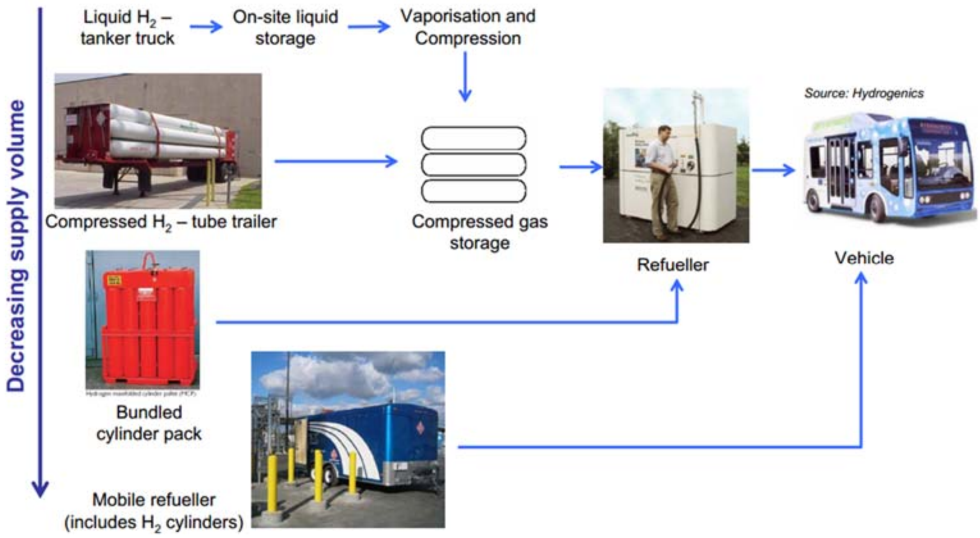

Figure 4-17: Hydrogen delivery and storage on site (source: HIE RE, 2006)

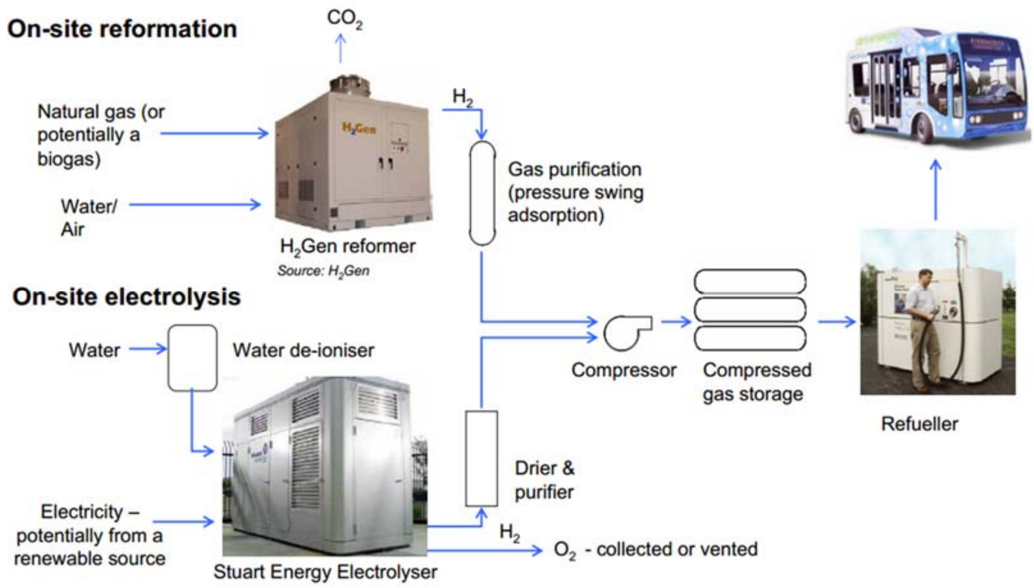

Figure 4-18: Hydrogen on-site production (source: HIE RE, 2006)

A problem which also arises from previous researches indicates that large scale production and use of hydrogen and electric vehicles could, beside positive environment effects, also have a negative impact on the electricity grid, in case of extensive grid usage and in case of low renewables usage for obtaining clean electricity. According to the research, done by European Commission and ERTRAC and EPoSS, in case that a million EV's going roughly about 10.000 km per year, we would need one terawatt of energy (TWh) (EC, 2010). As this amount is just a small part of the globally produced energy in Europe this is not creating a major problem for future but looking in short terms this could be a significant problem for the electricity grids and their stability. In light of this information, it would be necessary to create or to develop the smart electricity grids which would be able to automatically take care of these problematic stations (numerous simultaneous charging). This should be a very important step of mass implementation of electric and also hydrogen powered vehicles.

4.5 Overall technology in road transportation comparison

In this chapter I will summarize and compare collected data from previous, technology oriented, chapters. As a result I will have defined and discussed most sustainable and most promising passenger car sustainable mobility model.

Motor vehicles and their engines require a high energy content and best possible fuel efficiency. For purpose of comparison we should compare hydrogen with a fossil fuel diesel/biodiesel as well as with electric vehicles. According to data provided by OMV R&M in 2012, fossil fuel diesel has 11 kWh/kg and the hydrogen can go up to 33 kWh/kg. This difference is clearly significant and goes in favor of hydrogen. The research indicates that an average passenger car can be filled up in approximately 3 minutes (in range of 2-5, depending on vehicle capacities). This figure is more than competitive with filling time of conventional fuels and specially comparing the time needed for charging an electric vehicle, if we put aside swapping battery possibility. In this period of 3 minutes, the 4 kg of H2 is filled in a hydrogen powered car and it could provide around 400km of driving range.

Table 4-5: Overall technical comparison of Hydrogen, Electric and Diesel/Biodiesel vehicles (source: manufacturers official data/websites)

BRAND	MODEL	FUEL	BATTERY/TANK CAPACITY	VEHICLE RANGE (km)	HP	TOP SPEED (km/h)	ACCELERATION (0-100)/s
TESLA	MODEL S	Electricity	85 kWh	425	362	200	5.4
Mercedes Benz	B-Class Electric Drive	Electricity	36 kWh	135	177	160	7.9
Mercedes Benz	B-Class F-Cell	Hydrogen	4 kg	400	134	170	11.4
Mercedes Benz	B-Class Diesel	Diesel/Biodiesl	56 L	1244	120	190	10.4

All the figures (Table 4-5) stated here are both from the manufacturer side/specifications and from the personal test methods proven to be correct with minimal differences, most probably because of not ideal and same testing environment.

Important information, regarding this particular mobility examples are the efficiency facts. This car version had a torque of 290 Nm, which is more than enough for this class of the passenger vehicle and certainly more than equal B-Class conventional fuel powered version (between 200-250 Nm). As it is the case with almost all electric powered engines, this one also had the instant reaction time as well as satisfied performances. The capacity or range of this particular vehicle was approximately 400 km (Table 4-5). This means that this vehicle consumes 1kg of hydrogen on 100km and that tank capacity is 4 kilograms. As stated by the manufacturer this car would be reliable in the extreme cold weather occasions, even up to -25 °C.

Beside the Mercedes-Benz, there are also other players in this "closed" market. Among other, in the hydrogen story, the Honda, Toyota and BMW are also involved. The Mercedes B class F-Cell vehicle is selected because this vehicle was available for real time test purpose to the author and other car manufacturers had almost the same performance figures as selected or less attractive for this purpose (BMW).

Four major problems were noticed and highlighted in this part of the study. In the utilization of hydrogen and usage of fuel cells in general, following problems occur:

- Utilization costs including undeveloped networks
- Safety issues - bad image and real concerns
- Range limitations
- Availability

Firstly and most importantly is to highlight that the actual and real market of hydrogen fuel cell cars does not exist, as these vehicles are still not in mass production (except some large scale pilot projects for civil road transportation models) and it is not possible to buy them regularly. These vehicles are still in a kind of a network test phase so they can be obtained based on the research requests or special invitations and buying requests. This is a real problem which should influence further analysis and compilation of this fuel type but having in mind that many short and long term plans consider the mass production of this kind of vehicles from year 2015. Because of this, hydrogen and fuel cells concept will be treated as almost equal with other fuel sources which are parts of this comprehensive analysis.

Further on, a very important issue is range. Comparing it to the others, it is clear that hydrogen vehicle has less than a double or even triple range of a diesel or petrol vehicle. This can be a very big problem taking into the consideration that large scale of the consumer population, especially in Europe, is used to have a great autonomy and not to be chained to a filling station. All other technical aspects of this technology and vehicles indicate that no other performance is lacking behind conventional fuels and there are some even better figures.

Safety issues are basically related to old events or event which happened a very long time ago and it is related to the Hindenburg airship (Zeppelin) disaster. There is also the concept of hydrogen bomb which certainly gives some wrong ideas to mass population. The negative public reception regarding Hindenburg zeppelin was dated back in 1937. Hindenburg was a German passenger airship which, in that time, caught on fire during ending of current flight and unfortunately was completely destroyed in flames together with 97 people on board. Most probably, using mass media at that time, lobbying groups and politics, it was presented to the population in order to understand that the main reason why this airship was destroyed was hydrogen itself. Hydrogen was used as a navigability resource on that airship and according to numerous investigations there is no solid evidence that hydrogen was responsible for this disaster (Corbo, P. et al., 2011).

Even decades later, there is a still existing safety issue which goes along with hydrogen technology even there have been many successful and certified analysis and testing. I do not believe that this would represent any serious threats in the future, also regarding the further development of this technology.

When speaking solely about electric vehicles, one additional concern arises. It is a question regarding the lithium-ion batteries. We have to consider the limitations of the main source for manufacturing these batteries, which are the only used solution in modern and mass produced electric vehicles. The main component of these batteries is lithium, a soft and light metal which belongs to alkali metal group of chemical elements. Many studies before have stated some concerns if the world lithium reserves would be enough for future electric, hybrid or fuel cell vehicle production demand. As lithium worldwide production (Figure 4-19) is rising every year for 25% it certainly raises this question on the top shelf of possible future issues related to electric vehicles. Even some additional studies have shown that current lithium reserves can fulfil demand for 1 billion of 40 kWh batteries and this also represents a limiting factor and limiting resource.

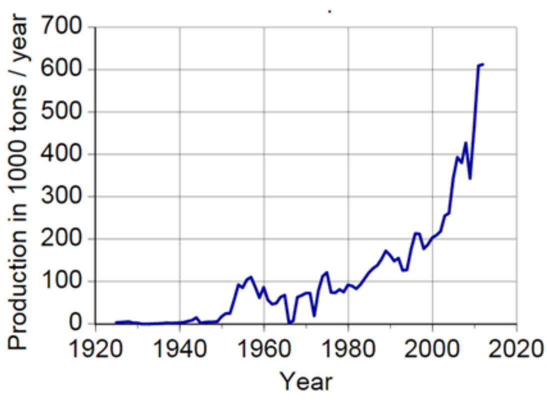

Figure 4-19: World production of lithium
(source: http://en.wikipedia.org/wiki/Lithium)

After analyzing and comparing the whole set of data, we can notice some of the most important patterns. As expected, the most interesting were electric vehicles but not only because of their performances but also because of the shown possibility for further development and improvement. Comparing them to fossil fuel vehicles, there is not much left to do in order to achieve more efficiency with less pollution. In this manner the author's opinion is that besides introducing higher blends of biodiesel and achieving defined limits of CO2 emissions there is no large room for additional improvements and optimizations. It seems that fossil fuels are on their maximum of the optimization levels. Keeping in mind that car manufacturers are not so interested in adjusting their engines regarding usage of higher biodiesel blends and providing warranty for their vehicles in this context, we can conclude that alternative fuels scene is highly highlighted in the years to come. If comparing electric vehicles with hydrogen powered ones, there is a complete new set of issues. As previously described, hydrogen technology is still not in satisfying development phase. It is still in some pilot project stage and it is developing slowly. Beside the positive sides, I believe that even with significant emission values lower than conventional fuels ones and interesting travel ranges, this technology is still waiting for some significant breakthrough in the future as well as cost intensive distribution systems.

In addition to this conclusion, I have to mention the very presence of Hybrid vehicles. Even they are not in the scope of this thesis, it is significant to mention their importance, especially as they represents an ideal transition model from conventional fossil fuels towards emissions free, sustainable vehicle solutions.

We are all aware that hybrid vehicles have been present in the current car market for some time now and their number is rising every year. The reason of its success certainly lies in the fact that, besides conventional way of using our vehicles, we have opportunity to be partially emissions aware while getting all the benefits of it. Using hybrid vehicles, customers are getting improved performance with improved ranges. The only negative side, from customers point of view is that the overall vehicle mass is increased and that the room for luggage is significantly reduced because of the battery storage.

If we do a bit deeper analysis we can notice the additional interesting fact. Usually the hybrid vehicles have electric motors as addition to already existing standard engines from the manufacturer pallet. This means that, for instance, the large SUV which uses 3.000ccm V6 or even larger V8 engines with more than 4.000ccm, which are producing tremendous amounts of CO2 and have serious fuel consumption, are having the additional electro motors which are used for additional boost of energy when needed and for small segments of city driving. Even with this solution we will notice significant CO_2 reductions but the main point seems to be missed out. According to author's opinion, hybrid vehicles should have electric motors and battery sets only as combination with lowered, low consumption and polluting vehicle engines. We have excellent example coming from the BMW Company, which, in this year, introduced the vehicle market with their brand new i8 hybrid model of a luxury sports car. What they did is to develop a low fuel consuming and low polluting engine of only 1.500ccm which, in combination with electric motor can free excellent performance and low consumption of the conventional fuel while emitting lowest possible amounts of CO_2. This has a lot more sense when speaking about ultimate sustainable mobility solutions.

5 ECONOMIC PERSPECTIVE

The Economic appraisal of selected sustainable mobility models will be conducted through cost and benefits analysis of the existing and researched data. The overall comparison has to include vehicle or investment costs, cost of energy needed and fuel prices, in order to calculate general transportation costs. Comparing resulted data will indicate the most feasible solution for passenger vehicles - road transportation models. Also, using sensitivity analysis and tracking changes of Transportation costs over investment and energy costs we will create clear picture of major milestones and directions towards which we have to strive.

Main Transportation costs (Eur/km) will be calculated using following formulas:

$C_{transport} = C_{energy} + C_{vehicle} + C_{o\&m}$

Or, in detail:

$$\mathbf{C}t = \mathrm{FI} * \mathrm{P}f + \frac{(\mathrm{IC} * \alpha)}{skm} + \mathrm{C}o\&m$$

This summarize all energy and vehicle related costs including operation and maintenance. Following formulas will define these costs:

$$\mathrm{C}e = \mathrm{FI} * \mathrm{P}f$$

$$\mathrm{C}v = \frac{\mathrm{IC} * \alpha}{skm}$$

$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

Where FI represents Fuel Intensity, P_{fuel} - price of the selected fuel including taxes, IC the investment costs and skm - yearly average kilometers driven by one vehicle. The "α", "n" and "z" represent capital recovery factor, depreciation periods and Interest rates, respectively. $C_{o\&m}$ are operation and maintenance costs and they are defined over skm or at the end they will be calculated as Eur/km. Fuel prices used here were selected as an average prices for the end use. This means that this figures are actual figures available on the filling/charging stations across the Europe. Fuel production source is not taken into the consideration, even it could have some price influence, because, for this calculation we have to analyze the transportation cost for the end users and therefore only the average price is considered. It is important to highlight that used fuel prices have already included all the taxes.

As an average of number of kilometers one vehicle is traveling for one year I have set 12.000 km. For all vehicles, depreciated period and interest rates are set to 10 years and 5%, respectively (AAT, 1995). Depreciation period seemed to be right as it would be time in which these cars will be most efficient including some average electric battery life and the fact that drivers will usually change their vehicles after 120.000 km driven and certainly before they are 10 years old. In order of comparison this figure is same for all vehicles as they are analyzed as equal solutions. For the fuel and energy prices I have used averaged official figures in Europe obtained from filling stations and charging points as these figures are actual prices which end consumers would be using. It is assumed that price of energy should be also used based on the price coming from charging stations and not from price generated depending on different energy sources (Fossil, PV, Wind, Ng, Etc.). This assumption will also be apprised during sensitivity analyses were we can see how important and which influence, variation of energy price would have on the end result - Overall Transportation cos.

Vehicle models for comparison and input parameters will remain the same as in the previous chapters of this thesis, including two Tesla Motors examples.

In following calculations, in next four chapters, collected data from official production companies and external sources will be used. Tables with these figures as well as results are described in the following chapters. As a conclusion we should create a clear picture of relations between selected models in regard of economic approach and should be able to define most important models towards sustainable transportation future.

Detailed calculation tables are provided in Addendum 3.

5.1 Economic perspective on Hydrogen network and fuel cells usage

Despite the fact that hydrogen vehicles are still not in mass production and represent smallest part of the sustainable mobility, hydrogen delivery and filling station are well known, but also in a developing, pilot stage.

In this chapter overall analysis of economic segments of highest importance regarding the hydrogen mass usage will be conducted. All major aspects, from network development, production and transportation will be considered and discussed. Finally basic calculation of transportation costs will be done using already defined formulas and previously collected data. At the end, with Sensitivity analysis will round up this mobility model and be able to conclude what are the main cost influences and in which direction this model have feasible path.

According to the obtained data in previous chapters we can once again divide hydrogen economic approach in two main parts on site production and hydrogen delivery. In case of delivery at filling stations, we have the easiest solution but with plenty of downside issues. Firstly, we have to acknowledge that transportation of hydrogen to the end users has its own costs and certainly has an issue with emissions caused by transportation vehicles. Secondly, these solutions (filling stations) are usually small scale solutions. Even the fact that 10 vehicles per day seems ok for the current number of hydrogen vehicles on roads, this is a very small capacity and it cannot be sufficient for any serious large scale popularization of this kind of vehicles. Some rough calculations (HIE RE, 2006), show that for this kind of small scale stations the investment costs would be around 250.000 euros. Scaling this up to a serious filling station without on-site hydrogen production, would easily go above half a million euros.

On the other side, we have the hydrogen filling station with on-site fuel production. These solutions are demanding in meaning of technical complexity, filling station location and size of the location itself. As a rough example we can take the small scale, 20 vehicles per day, station with the investment costs around and above one million euros (HIE RE, 2006). Scaling these figures up, in order to improve the maximal number of cars per day, we would have investment costs larger then it is the case with conventional fossil fuels filling stations. As the hydrogen production process is rather complex it can produce usually up to 1kg of hydrogen in one hour, which is not a serious figure if this approach for large scale scenario of hydrogen vehicles is considered. In addition, the current technologies for on-site hydrogen production are capable of delivering low pressure hydrogen after production. This means that additional compression methods should be introduced, which would at the end influence the process complexity and end-price of hydrogen fuel.

The positive side of this approach would be a cheaper end-price of hydrogen fuel, comparing to the delivered one.

Price components of these two models are price of the electricity itself (if hydrogen is produced using grid electricity) and price of delivered hydrogen in case of delivery model. According to some estimations (HIE RE, 2006), price of hydrogen could be in a range between 6 to 11 euro/kg H_2 in case of grid electrolysis and in range of 7 to 22 euro/kg H_2 in case of delivery schemes. According to this sensitivity issue, it is clear that the most feasible solution will be highly depended on the local energy prices and secondly, it could depend on the delivering price of hydrogen.

Detailed hydrogen price component (for final consumers), based on technology used, is shown in the following graph (Figure 5-1). As we can see, in all presented categories, production costs are far highest in comparison to other components.

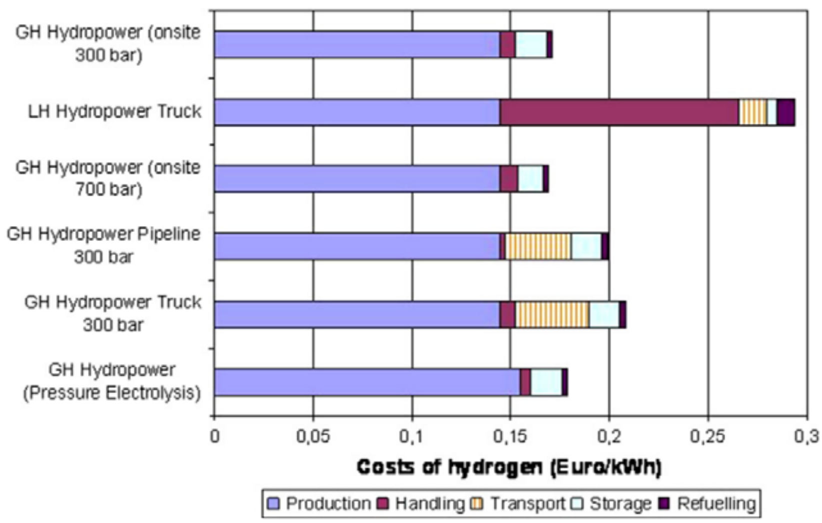

Figure 5-1: Hydrogen price components, LH- Liquid H2, GH- Gaseous H2 (source: Ajanovic A, 2008)

Summing up all together including the common inputs from previous chapter, Table 5-1 is created. According to the requested figures the table has all the data inputs for the purpose of an easier comparison. Fuel costs are defined into three categories, based on the resource used for production. Hydrogen fuel price was difficult to define, mostly because many of the suppliers are currently offering it as a "free" solution in promotional period or, in case of some suppliers (Mercedes-Benz, Toyota, etc.) fuel also comes free of charge in case customers are using their financing schemes and programs. For this purpose, referent hydrogen fuel price is taken from running filling station in Europe (OMV Shuttleworthstrasse station in Vienna, Austria) and defined as 9 Eur/kg. Operation and maintenance costs were defined as a sum of all major vehicle related costs in period of one year or defined kilometers per year. Defined figure of 0.055 Eur/km consist of Registration and Insurance, regular maintenance, expected small repairs and tyre changes, includes all the taxes applicable and it is based on existing researches (IEA, 2010).

Table 5-1: Hydrogen powered vehicles - Cost inputs overview (source: AFDC 2014, Mercedes-Benz 2014a, Toyota 2014)

TRANSPORTATION COSTS SEGMENTS - HYDROGEN							
Vehicle Technology	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km
	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (P_f)	O&M Cost
FCV H2 Fuel Cell Vehicle	50,000	0.97	12,000	10	5	9	0.055

For Fuel cell vehicle it was very difficult to obtain the most precise investment costs, mainly because this technology is still not used in mass production and it is not publically available as well as predicted prices usually depends on many different optimistic assumptions. Investment cost in this case is set to 50.000 Eur including the taxes. This cost was established according to official available data (Energy, 2012 and Fuel Cell 2000, 2011) as well as the comparison with other known sources of economic approach to fuel cell vehicles and available technologies like Toyota, 2014. Manufacturer (Mercedes-Benz) has defined leasing option for this vehicle (B Class, F-Cell) and set it to around 600 Eur/month. This price includes vehicle price, registration and taxes and service, complete O&M costs.

Taking everything in consideration, as well as depreciation period, we can define stated rough figure for purpose of further calculation. As these kind of vehicles are still not in mass production and it is very difficult to buy them, and obtain the correct investment value, we have compared it with the expected purchase price of the Toyota Fuel Cell Sedan planned to be sold, in limited number in 2015, for 52.000 Euro (Toyota, 2014). Comparing these two figures and including the difference in price elements of both vehicles we can assume that defined vehicle price for analyzed vehicle is justified and acceptable.

If we use formulas defined in previous chapter and apply define figures, following calculations and results are created:

$$\boldsymbol{\alpha} = 0.12$$

$$\mathbf{C}t = \mathrm{FI} * \mathrm{P}f + \frac{(\mathrm{IC} \ * \ \alpha)}{skm} + \ Co\&m = 0.642\,\frac{Eur}{km}$$

The results, with separate energy, vehicle and overall transportation costs are also presented in the Table 5-2 below. These figures will be analyzed further more in chapter 5.4 when they will be compared with other selected models.

Table 5-2: Hydrogen powered vehicles Transportation, energy and vehicle cost results (source: own calculation)

TRANSPORTATION COSTS RESULTS FOR HYDROGEN			
Vehicle Technology	EUR/km		
	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
FCV H2 Fuel Cell Vehicle	0.642	0.087	0.555

In order to consider potential scenarios in the future, following Sensitivity chart is created (Figure 5-2).

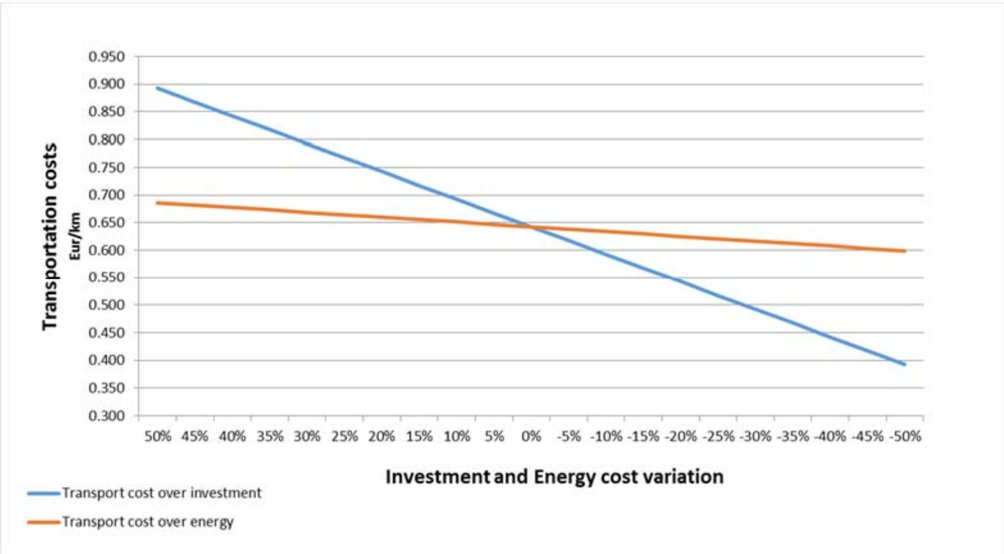

Figure 5-2: Sensitivity of the Hydrogen powered Transportation costs over Investment and energy costs variation.

As we can see on this graph, sensitivity of Transportation cost is observed over change of investment and energy (fuel) costs. I have set sensitivity in range from -50% to +50%. As expected, biggest influence on the overall Transportation cost will have change of the vehicle or the investment itself. It seems to be highly possible to see this scenario as future possibility rather than one influenced with energy cost, as technology development is advancing in positive direction towards more availability and price reductions. From this point of view, most important investment target would be aiming to 30% vehicle price reduction, in order to have competitive, acceptable price within the standard medium segment vehicles. Energy or fuel costs sensitivity shows us only small room for price reduction. Other figures included into Transportation cost calculations were not used in sensitivity analysis as they have only minor influence and even less room for reduction.

5.2 Economic perspective on Biodiesel usage

Biodiesel as a fuel solution obviously does not have a bright future if considered as 100% or B100 - partially because of price of production, partially because of lack of interest in development of customized vehicles for this purpose. Finally there is also the issue of using food sources as main resource for production. On the other hand, smaller blends seem to have a better chance to be widely used. As an already present solution in meaning of B5, B10 and B20 blends, it represents a smart choice considering lowering the emissions and prolonging the working period of a conventional fuel engine.

In this chapter, biodiesel economics will be discussed over major segments such as biodiesel production and infrastructure and final calculation will be done together, in parallel with conventional diesel solution. Once again Transportation costs will be calculated and further on used in next chapters for final comparison. At the end, using calculated values, sensitivity analysis will be conducted and presented. In order to keep the same framework in this Economic chapter, I will show influences of investment and energy costs variations on the overall transportation costs.
When discussing the economics on the biodiesel or biofuels solutions, we have to consider several points. We have direct and indirect cost components which will influence the overall end-product prices.
The main cost components (Duncan J, 2003) of any biofuel solution could be generalized and divided on:

- Feedstock related costs
- Production/Conversion/Transportation related costs
- Taxation of the end-energy product

For the Feedstock we could assume that it accounts for 85% of the biofuel end-cost (Hitchcock G, 2008).

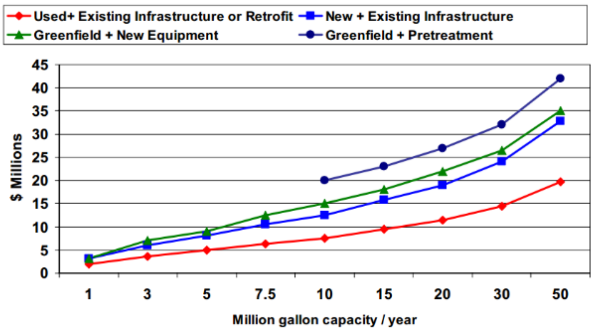

Figure 5-3: Biodiesel plant capital costs variations (source: Tyson S, 2006)

The production costs for the second generation biofuels production are estimated to be in range of 0.16-0.26 Eur/Lit of biodiesel in comparison to the first generation costs in range of 0.05-0.20 Eur/Lit, mainly depending on the production scale (Hitchcock G, 2008). The capital costs for biodiesel production (Tyson S, 2006) mainly depend on the plant scale too, but also depend on the fact whether the existing infrastructure is used, if there are some pre-treatment methods included and if it would be a Greenfield investment (Figure 5-3). Even these exact figures are not used in following calculations, it is very important to have them described because on some further solution feasibility analysis they has to be included and considered among most important ones. For the transportation costs we can assume that they are the same or lower than conventional fossil fuel ones.

Taxation of the biofuels is also very important and has a significant influence on final fuel price. Depending on the country, tax reduction can be partial or even up to 100%.

The same as for hydrogen powered vehicles, the following Table 5-3 is created with inputs for biodiesel and conventional diesel vehicles. The investment cost is set to 25.000 Euro including taxes according to Mercedes-Benz official price listings. Value is the same for both vehicles as we have considered the same vehicles. Diesel fuel price was defined according Europe average price in 2012 and 2013 (1.43 Eur/Lit) according to GIZ, 2014 and current average price (1.45 Eur/Lit from OMV R&M filling stations - OMV FS 2014), to 1.44 Eur/Lit. Fuel price of biodiesel (B20) was very difficult to obtain as it may vary in large scale depending on different taxes and transportation costs across the Europe. Price for this purpose is set to 0.76 Eur/Lit according to averaged prices from GSI, 2013 report and AFDC, 2014. Operation and maintenance costs (O&M) were set to 0.07 and 0.075 Eur/km for BD and ICE example respectively, according to researched and testing data as well as according to official figures from Mercedes-Benz, 2014b.

Table 5-3: Biodiesel/Conventional Diesel powered vehicles - Cost inputs overview (source: Mercedes-Benz 2014b, GIZ 2014, GSI 2013, AFDC 2014, OMV FS 2014)

TRANSPORTATION COSTS SEGMENTS - BD/Diesel							
Vehicle Technology	EUR/Vehicle	Lit/100km	km	year	%	Eur/Lit	Eur/km
	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (P_f)	O&M Cost
BD B20 Biodiesel blend B20	25,000	4.7	12,000	10	5	0.76	0.070
ICE D Internal Combustion Engine Diesel	25,000	4.7	12,000	10	5	1.44	0.075

Using the figures from previous Table 5-3 we can create the following formulas and calculations for biodiesel model:

$$\boldsymbol{\alpha} = 0.12$$

$$\mathbf{C}t = \mathrm{FI} * \mathrm{P}f + \frac{(\mathrm{IC} \ * \ \alpha)}{skm} + \ \mathrm{C}o\&m = 0.356\frac{Eur}{km}$$

And following for conventional diesel vehicle:

$$\mathbf{C}t = 0.393\frac{Eur}{km}$$

In resulting Table 5-4, we can see that despite the fact that biodiesel has a lower end-price than conventional diesel and that vehicles have the same purchase price, the end difference is not so great. On the other side we have to consider the CO_2 reduction with biodiesel blends and as stated like that, it is obvious that biodiesel vehicles even with lower blends like B5, B10 or B20 have important and competitive role in the current fuel market.

Table 5-4: Biodiesel/Conventional Diesel powered vehicles transportation, energy and vehicle cost results (source: own calculation)

TRANSPORTATION COSTS RESULTS FOR BD/DIESEL			
Vehicle Technology	EUR/km		
	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
BD B20 Biodiesel blend B20	0.356	0.036	0.320
ICE D Internal Combustion Engine Diesel	0.393	0.068	0.325

If we analyze the correlation between overall Transportation cost and investment and energy costs variations, for both diesel and biodiesel solutions we have following sensitivity chart presented on the Figure 5-4.

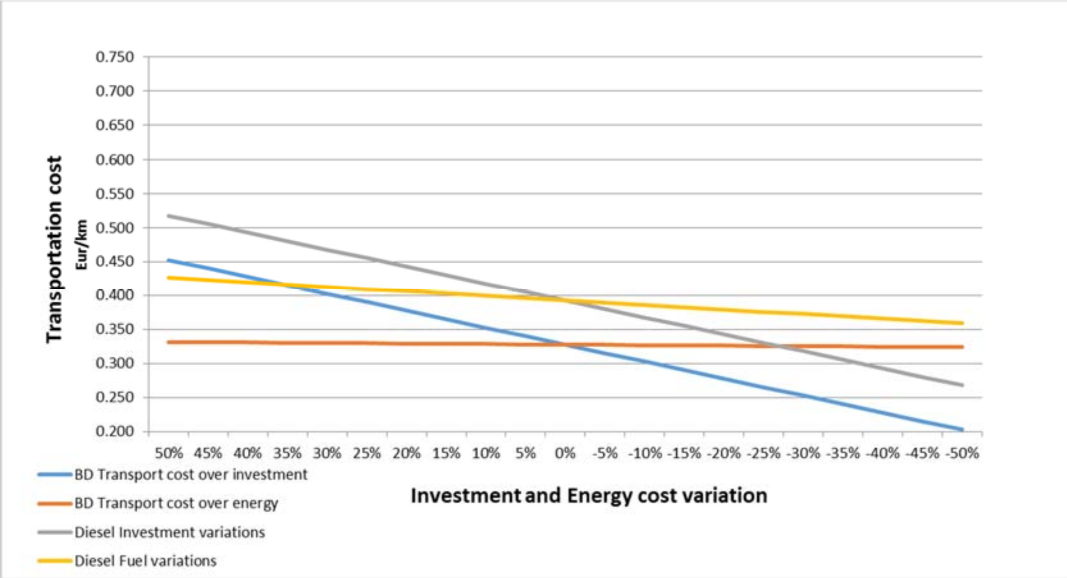

Figure 5-4: Sensitivity of the Biodiesel and Conventional diesel powered Transportation costs over Investment and energy costs variation (source: own graph)

We can see that comparing these two solutions, fuel price reduction has significantly higher impact in the case of conventional diesel vehicle. On the other hand, opposite to this founding we can see that investment costs reduction are coming with higher impacts on transportation costs in case of biodiesel vehicle model. It has also been proven that, same as in case of hydrogen model (Chapter 5.1), investment cost or cost of the vehicle itself caries the most significant cost reductions possibility.

5.3 Economic perspective on Electricity in road transportation usage

For the electric vehicles market the most significant economic issues are related to the cost of production and end vehicles price. The reasons for, still very high, vehicle prices, which are going from 30.000 euros to over 100.000 euros including taxes, are mainly due to lack of previous research and development. We have to keep in mind that, even the fact that alternative automotive solutions are existing almost simultaneously with conventional vehicles, they have not been developed with the same capacities and as we can see did not have enough media room for themselves until couple of years ago when we all started to be more green taking care about our footprints.

The popularization of Electric vehicles, on the other side, has forced the certain vehicle manufacturers and entrepreneurs to start with high speed research and development and even production, in just couple of years span. This development speed has to have a greater impact on the vehicles end price. On the other side, as electric vehicles have very delicate and sensitive issues all around, regarding the construction, energy utilization inside the vehicle, battery quality, consumption and comfort as well, they demand a new way of thinking and engineering. Manufacturers had to develop some completely new way of thinking and approach in a short period of time, in order to solve these issues and prove to customers the existence of all main and additional conveniences they were used to in their conventional vehicles. As these are new and briefly researched solutions, they are also costly at the moment.

If looking outside the box, we should acknowledge a couple more cost aspects. The first important one is electricity price and its source. For electric vehicles and green path following, it is of substantial importance to have as clean as possible, both fuels and vehicles using them. Considering the best possible scenario, we have concluded that on-site generation of electricity using renewable resources would be the ideal. Afterwards there is a possibility of using electric energy generated on remote site and finally there is an option of using grid electricity which has its own share of renewable and conventional fossil fuels. The second major aspect is cost of an electric vehicle itself and finally, the third aspect would be charging network development.

The author believes that in the following 5-10 years, the development of these vehicles will be on much firmer ground and these costs would be significantly lower than they are now.

Table 5-5: Electric vehicles - Cost inputs overview (source: AFDC 2014, Tesla Motors 2014b, Eurostat 2014, Mercedes-Benz 2014b)

TRANSPORTATION COSTS SEGMENTS - ELECTRIC							
Vehicle Technology	EUR/Vehicle	kWh/100km	km	year	%	Eur/kWH	Eur/km
	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (P_f)	O&M Cost
EV Electric Vehicle	35,000	25.63	12,000	10	5	0.16	0.050
EV Tesla Model S 85kWh	65000	18.1	12,000	10	5	0.16	0.240
EV Tesla Model S 85kWh	65,000	18.1	12,000	10	5	0	0.024

In Table 5-5, inputs for calculation of transportation costs for electric vehicles are provided. Beside already explained figures in previous chapters, here we have defined the fuel price or electricity price and set it to 0.16 Eur/kWh. These figure represents the averaged value for last three years in Europe for both, industrial and household charging solutions (EC - Eurostat, 2014 and AFDC, 2014). The main reason for this is because these kind of vehicles are charged on commercial large scale charging stations and home charging ports as well. So in this case it is important to find the gold middle too. Sources of the electricity were not considered directly in this calculation as at the end, the end-user is obliged to use existing charging stations/solutions nevertheless of the energy source awe need the real-time transportation costs picture in the Europe today. Also, it is very important to mention variety of electric vehicles charging solutions in regard of costs and payment methods. Currently we have three main possibilities. It is possible to use stations free of charge completely (explained further on), fixed monthly cost and payment per single charging. This last possibility can be paid based on charging duration, electricity used and charging session.

As presented in the table, there are three sets of data. The first is an average electric vehicle based on the selected model of the car at the beginning of this thesis (Mercedes Benz B-Class Electric Drive). Other two models represent Tesla Motors electric vehicle. The reason for this lies in the fact that this company has created a significant breakthrough in technology and performance related to electric vehicles and that is the reason why this would be a very interesting comparison point. The third part is the same Tesla vehicle but considering that electricity price for charging of this vehicle is 0 Eur/kWh. The reason for this statement is that this company provides their customers with completely free charging of Tesla vehicles at their charging stations.

Investment costs are official data provided by car manufacturers Tesla Motors and Mercedes Benz. Operation and maintenance costs are according to Tesla motors company official data set to 0.024 Eur/km. For standard electric vehicle this value is set to 0.050 Eur/km according to personal research and IEA, 2010.

Following formulas and calculations were defined based on previously defined values for selected models (Table 5-5).

EV:

$\boldsymbol{\alpha} = 0.12$

$$\mathbf{C}t = \mathrm{FI} * \mathrm{P}f + \frac{(\mathrm{IC} * \alpha)}{skm} + \mathrm{C}o\&m = 0.441\,\frac{Eur}{km}$$

Tesla Example I and Example II:

$$\mathbf{C}t = 0.703\,\frac{Eur}{km} \quad and \quad \mathbf{C}t = 0.674\,\frac{Eur}{km}$$

As a final comparison and result, Table 5-6 is created. As the first highlight, it is clear that beside best efforts of Tesla Motors company, as explained in Chapters 4.3 and 4.4 is far away from standard family electric vehicle. Only reason is obvious, the investment cost itself as this vehicle has almost double the price comparing to the standard electric vehicle (Mercedes Benz B-Class E-Drive). Even if we consider this limited possibility provided by Tesla, to use charging stations for free (to eliminate all energy costs), it is still extremely high in any comparison. We can confirm this on sensitivity analysis conducted only on example of Tesla, on Figure 5-7, were we can clearly see how small influence of the energy price is, in comparison to high investment costs. Keeping all of this in mind, we can consider Tesla Model S vehicle as a luxurious vehicle and in this segment it might have a chance to justify its high purchase price.

Table 5-6: Electric vehicles - transportation, energy and vehicle cost results (in Eur/km) (source: own calculation)

TRANSPORTATION COSTS RESULTS FOR ELECTRIC			
Vehicle Technology	EUR/km		
	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
EV Electric Vehicle	0.441	0.041	0.400
EV Tesla Model S 85kWh	0.703	0.029	0.674
EV Tesla Model S 85kWh	0.674	0.000	0.674

If we conduct the sensitivity analysis as it was done with previous two mobility models we will get following charts (Figure 5-5 and Figure 5-6). In the first case energy price reduction (variation) has almost none influence on the overall Transportation cost. Investment cost remain with the same significance to Transportation costs as it was with previous two models described in Chapter 5.1 and 5.2.

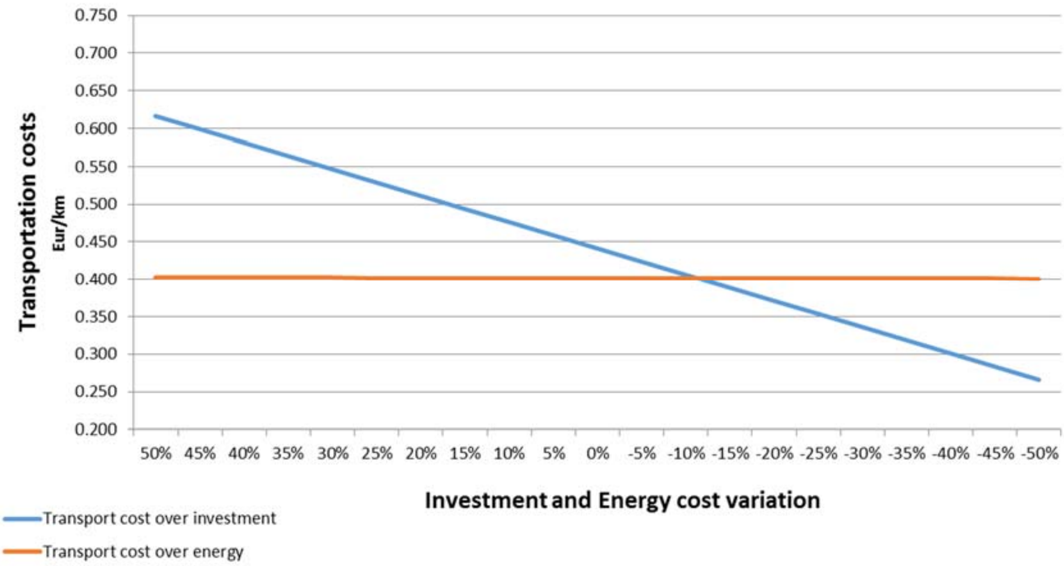

Figure 5-5: Sensitivity of the EV Transportation costs (Eur/km) over Investment and energy costs variation (source: own graph)

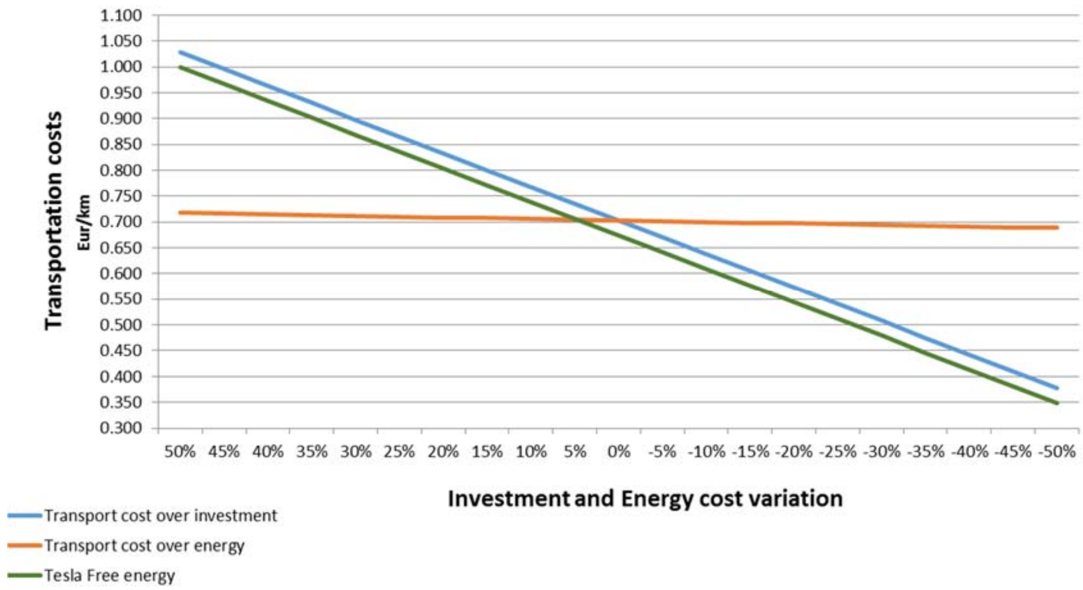

Figure 5-6: Sensitivity of the Tesla EV powered Transportation costs over Investment and energy costs variation (own: graph)

5.4 Overall economic comparison of defined models

In this chapter, all analyzed models will be compared and main differences will be highlighted and discussed. Costs calculated in Chapters 5.1, 5.2 and 5.3 will be core comparison elements.

Summing all results together, following Table 5-7 is created. As we can see, the most economic mobility model is resulted to be the Biodiesel solution (B20 mix), following with standard diesel vehicle model. This, connected first and second place, was expected as they share the most intensive cost influencer, the investment cost (Figure 5-7). Significant difference was noticed in energy prices for these two models, but as it was conducted in sensitivity analysis in previous chapters and in this case especially in Chapter 5.2, these costs has lower influence rate than the investment itself. If we continue with results analysis, all other models turns to be placed as expected. Electric vehicle (standard) will be second sustainable choice and fuel cell the least economic. All of these ranking positions are justified with exact model investment cost, especially last two examples of Tesla Motors Company were high investment costs turns to be so important that even defined free energy concepts turns to be completely useless. As we can see, all presented energy costs for these models are more or less in the range of conventional fuels prices, to be precise only hydrogen energy costs are little over this range but all other, are lower up to double then conventional fuels solutions.

Table 5-7: Overall comparison of mobility costs calculated in Chapters 5.1, 5.2, 5.3 (source: own calculation)

TRANSPORTATION COSTS OVERALL RESULTS			
Vehicle Technology	EUR/km		
	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
BD B20 Biodiesel blend B20	0.356	0.036	0.320
ICE D Internal Combustion Engine Diesel	0.393	0.068	0.325
EV Electric Vehicle	0.441	0.041	0.400
FCV H2 Fuel Cell Vehicle	0.642	0.087	0.555
EV Zero Cenergy Tesla Model S 85kWh	0.674	0.000	0.674
EV Tesla Model S 85kWh	0.703	0.029	0.674

Based on everything stated in this and previous chapters, we can create clearer picture of sustainable transportation and its correlation to conventional models. It is very important to recognize two major milestones for current as well for future sustainable transportation development.

First, we have to understand necessity of the transitional steps which includes all sorts of hybrid vehicles including Biodiesel solutions as they are not completely sustainable and, as it appears, according to discussed technology issues in Chapter 4.2. They will, most probably, stay in current status for quite a while as majority of vehicle manufacturers are mostly interested in electric vehicles research and development, except the Audi example were certain Biofuels solutions are also recognized as a possibility for the future development path. Biodiesel, as well as variety of hybrid vehicles, represent the reasonable solutions towards future where majority of vehicles will be powered by renewable and emissions free solutions. This, on the large scale, influence mass population and lead them towards sustainable solutions and on the small scale, shows us that there exists cleaner and more economical way of transportation with minimal influence on commodities we are all used to.

As a second milestone in sustainable development future path, I have recognized and concluded that Electric vehicle models would have large significance if not the complete primacy in automotive industry. In favor of this conclusion we have the fact that all large manufacturing companies with significant market shares in automotive industry and also smaller companies are going into this direction, investing serious time and many in research, development and in last couple of years in production too. If we compare hydrogen solution with everything stated, we have to understand that even with some medium costs reductions, we would still and up with vehicles which are based on the electricity. On the other hand hydrogen powered mobility, as we concluded in Chapter 4.1 will have high significance in case of usage of the stored, surpass, energy, especially on remote, hardly accessible locations.

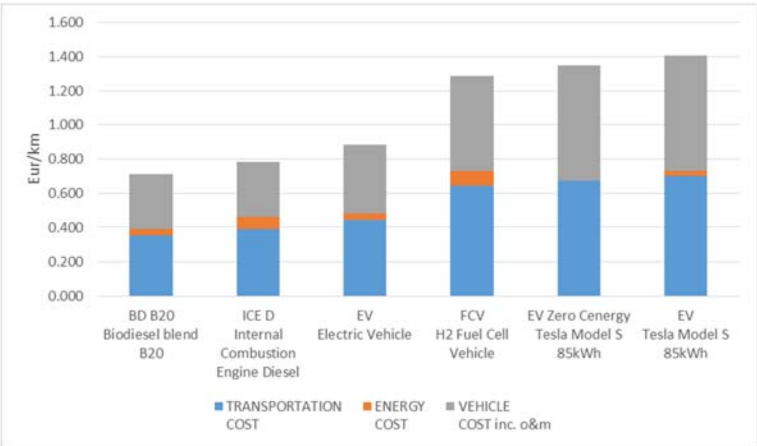

Figure 5-7: Comparison results, ratio between energy and vehicle costs and overall transportation costs (source: own graph)

6 LEGAL REGULATORY AND FRAMEWORKS OUTLOOK

6.1 Importance of regulations and policy frameworks

Legal regulatory, policies, laws and frameworks in sustainable mobility are as equally important as technology development. If regulations, policies and targets are not developed according to our changing environment situation, technological changes and modern civilization trends, we will not be able to save and prolong life on our planet and smartly and responsibly use the limited resources available.

When speaking about policies, we have to highlight some of the basic approaches towards sustainable mobility. The main purpose of global and local policies is to, eventually, during the time, we end complete dependence on fossil fuels in transportation sector. As it is clear, best possible directed goes towards renewable fuel sources and new technologies developments. Thus, it is necessary to include numerous industry (large scale) but also the small scale subsidies and regulations in this field.
For electric, hydrogen and hybrid vehicles, policies are going in two directions: promotion and improvement and Facilitating deployment of new rising technologies (FIA, 2011). These two points are covering placement on the existing market, evaluation and presentation of power generation in comparison to conventional fuels, taking lead in development of the improved network infrastructures and working on standardization issues. For biofuels, most important to highlight, beside already defined steps is the existence of renewable energy directives which will be explained in detail in following paragraphs.

Beside the fact that all available RE regulations are more or less directly or indirectly influencing this topic, only the most important will be analyzed and discussed. There are a few important starting points regarding emissions limitations and fuel utilization, the Directive 2009/30, Regulative 443/2009, European Commission strategy from 2007 and EU Fuel Quality Directive. Rough, overview pathway towards year 2050 is presented on the Figure 6-1, were we can see emissions reduction scenario for transportation sector, among other sector's. In next couple of paragraphs, selected directives, regulations and pathways will be analyzed.

Directive 2009/30/EC, among other segments, is related to fuel quality and mechanisms for monitoring of fossil fuels and reduction of GHG emissions. According to this directive, until end of the 2020, greenhouse gasses emissions should be reduced from 6% up to 10% per unit of energy from fuel supplied comparing to values measured in the year 2010 or 30% against levels from 1990. This reduction should be obtained using alternative fuel solutions and biofuels as well as reducing emissions on fuel production sites. Furthermore, additional 2% reduction should be obtained through the use/purchase of the electric or emissions free vehicles. On the other hand, this directive does not encourage destruction of biodiversity, arable land and resources in favor of biofuels production. Higher content of biofuels in the fossil diesel blends is advisable while the values are under defined limits. In this manner, setting up of the B10 blend standardization is one of the major priorities for biofuels in this directive.

Regulation 443/2009 has the main object of setting standards for emissions related to light vehicles. The European Union has already set clear limitations in order to reduce the vehicles GHG emissions on a large scale. If we take a look at year 2007, we can see that, in average, passenger cars were responsible for emitting about 160g CO_2/km. A couple of years ago, in 2012, we had to accomplish limitations of 120g CO_2/km. In the period from 2012 until 2015, 100% of new produced vehicles should comply with this limitation. Afterwards, from 2020, emissions from this source will most probably be lowered under 90-100g of CO_2/km. (EC, 2010). These "limitations" are very important for the goal of reaching green and sustainable transportation concept in near future as well as for pushing manufacturers and engineers towards seeking new, cleaner and emissions free solutions.

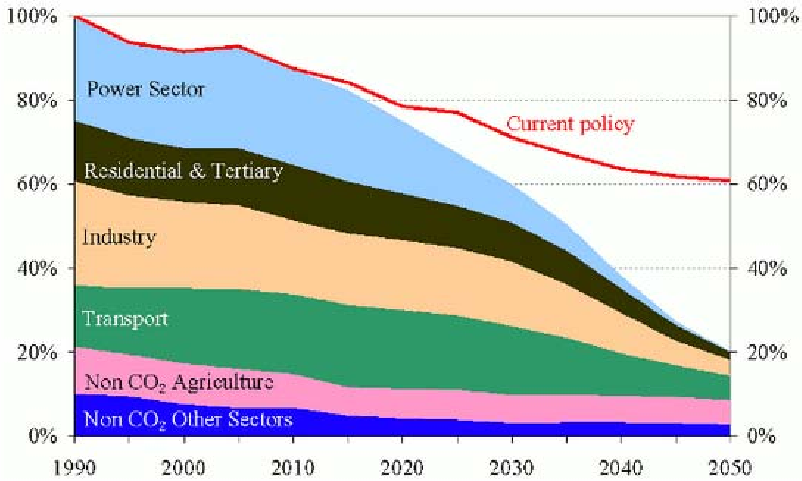

Figure 6-1: Emissions reduction roadmap per sector. (Source: Europa 2014)

Other positive impact from these legislations is related to fuel consumption. The defined target for fuel consumption of light duty vehicles in 2017 is equal to 6.6 and 7.5 l/100km, for diesel and petrol fuels, respectively. The target for 2020 is significantly higher and it is set to 5.5 and 6.3 l/100km for these two fuels. Until the end of year 2015, it is expected that clear and fixed targets beyond 2021 are defined.

Furthermore, in order to help drivers when buying a new vehicle, an additional normative for vehicle sellers has been set by the European Union. According to this, "CO_2 Cars Labelling", the special label describing the ecological and emissions data and tax influence of the emissions for certain vehicle, is necessary to be clearly placed on or near the selling car. To be precise, the mandatory data are CO_2 emissions group (from A to G, where A represents lowest possible emissions), fuel usage and costs as well as taxes and registration information and Vehicle fuel consumption depending to drive cycle and basic engine information.

In the following picture (Figure 6-2), example for this kind of CO_2 labelling is presented.

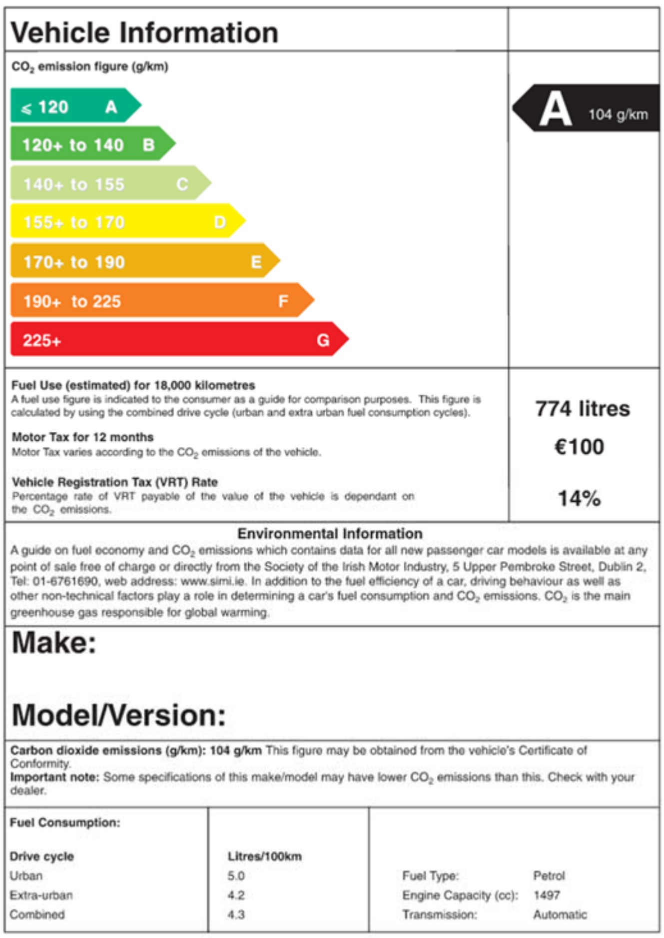

Figure 6-2: CO2 Vehicle labelling
(source: http://upload.wikimedia.org/wikipedia/commons/6/67/Irish_Car_CO2_Label.svg)

If we put aside the vehicles positive limitations, we can take a look at fuels influence and regulations directly. The reduction of fuel's GHG intensity (used in vehicles), set by European Union's Fuel Quality Directive to 10%, makes significant difference to overall emissions amount produced by every vehicle. This segment of this directive is also known as a Low Carbon Fuel Standard.

Defined 10% are valid for all fuel types, including the biofuels and gasoil. This percentage contains three separate segments. The first concerns the fuels directly (6%), the second one (2%) is related to new technology R&D and the third (2%) concerns clean development mechanisms (Europe 2014). The most important thing regarding this reduction is that it is influences the complete fuel life cycle, from exploration and production over processing and transportation.

Biofuels are also influenced by this directive. In order for biofuels to become a substitution for fossil fuels, they have to be with minimum 35% lower emissions and, the biofuel source cannot be from high biodiversity land (Europa 2014).

6.2 Overall example regulatory rules and policies in Europe

In this chapter, most important positive and negative legal sides related to renewable energy and sustainable mobility are discussed and few of them will be explained in detail.

The same as previously, we can consider two sides or in this case two supporting schemes. One related to vehicles, and one concerning fuels. Following Table 6-1 summarizes some of the most interesting examples from some European countries, of this topic. Here we can see some of the selected examples which covers already discussed problems in road sustainable mobility sector (passenger car part).

Table 6-1: Comparison of different support schemes
(Source: http://www.res-legal.eu/comparison-tool/)

COUNTRY	SCHEME	DESCRIPTION
Norway	Taxes reduction	Tax (VAT) savings, 4,500Eur for an EV
Netherlands	Taxes reduction	Annual tax savings 380Eur for EV
Estonia	Subsidy - Grant for EV purchase	The grant up to 35-50% (not more than 19.000 Eur) of the purchase price of an EV is available.
Germany	Tax reduction	Annual circulation tax exemption for 5 years after registering EV
Denmark	Tax reduction	Onetime and registration tax savings 14,000Eur for EV
Sweden	Subsidy, Tax reduction	25% Vehicle price reduction; Tax reduction
Estonia	Subsidy - Grant for EV charger	The grant up to 1000 Eur for purchase of an EV home charging station.
Austria	Oil Tax reduction	Petrol, Diesel and Mineral oil containing biogenic materials and lower sulphur values has reduced Mineral Oil Tax from 0.028 to 0.515 Eur/litre of produced fuel.
Belgium	Excise reduction	Biofuels from rapeseed oil are exempt from excise duty by the amount of fuel they replaces.
Portugal	Tax reduction, subsidy	Income tax reduction 30%; VAT 20% exemption;

		Subsidy up to 750-1,000Eur for green vehicle (below 130g/CO_2)
HR, CZ, MT	Excise exemption	Biofuels are exempt from excise duty
Ireland	Tax exemption	VRT tax exemption for EV and 2500E rebate for PHEV
Latvia	Tax reduction	Fuel blending with biofuels, tax reduction: Pure 100% biofuel- 0.33 Eur/Liter Blend 70-85% biofuel - 0.23 Eur/Liter Over 30% biofuel - 0.12 eur/Liter
Lithuania	Tax reduction	Amount of tax reduction depends on the biofuel percentage over the mandatory limits.

One of the most important country based examples certainly is Norway. This country could be observed among most important electric vehicle promotion pioneers. They have introduced indicative schemes related to EV in early 90's. Since them they are the leading country in this scope, not only in Europe bat also on a world scale. (Hannisdahl O. et al. 2013). This is one of the main reasons why Norway have more than 6,1% of passenger car market share in EV and HEV together in 2013 (ICCT, 2014). Which is almost the double then it was in 2012, as we can see on Figure 6.3. Very important comparison, provided on this figure, is also in relation to US figures including California, which is considered as an important market for alternative vehicles. Completely opposite situation then Norway, we can also see in case of Netherland were ration of EV and HEV are going in favor of hybrid vehicles.

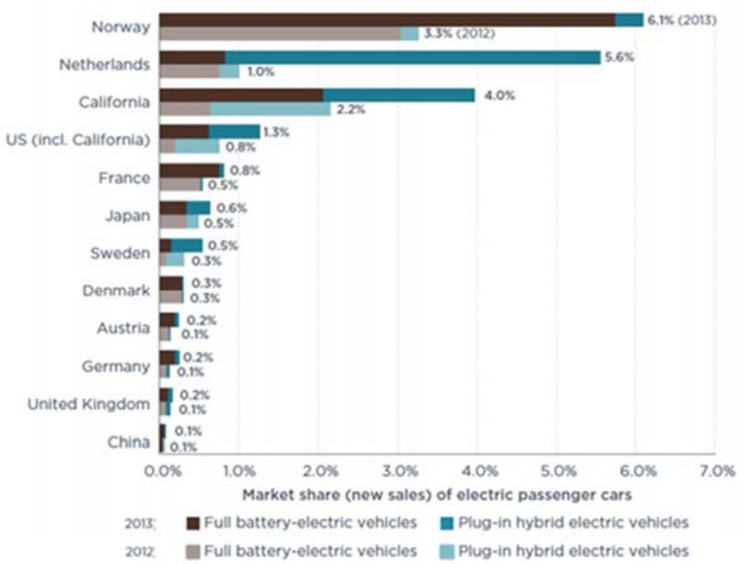

Figure 6-3: Market share of EV and HEV vehicles in 2012 and 2013 (source: ICCT, 2014)

According to presented figures we can conclude that Norway is going towards 10% of market share until 2020. If we take a closer look in Norway scenario and why they are in this position we can see that main reason may lay in fact that Norway is a country with very high taxes on internal combustion engines. Basically this taxation can be divided in two parts. Firstly vehicles are being taxed upon import and this tax depends on vehicle weight, motor, CO_2 and NO_X emissions. Afterwards, as a second step they have regular VAT tax of 25% (Hannisdahl O. et al. 2013). On the other side, electric and fuel cell vehicles are completely excluded from this taxations, both import and VAT. Beside these most important points, in Norway as in many other countries, also exist some additional benefits for the EV and FCEV owners, like free public parking, parking reservation places with charging points. We should not also neglect the fact that Norway Government ha invest over 6.5 Million Euros in 2009 in construction and acceleration of charging points construction. This resulted over 3700 charging points in Norway until 2013.

Other significant pioneer in this field certainly is Denmark. They have introduced promotion incentives of the electric vehicles in the early 1984. This way, EV were exempt from existing registration tax. Modified version of this initiative is still in order (until 2015) and it is related exclusively to EV. It is important to explain the simple logic behind tax exemption in case of these vehicles. They are using logic that tax should be related to emissions produced by the vehicle itself, so the more CO_2 emissions the higher the taxes are. With this logic they established that 0 emissions should be awarded with 0 taxes. In addition, Denmark in order to continue popularization of emission free vehicles has created public charging stations which enables customers to charge their vehicles free of charge.

These kind of support would make some of the currently economically non-feasible solutions, such as Tesla vehicles, to become closer to the bearable choice. Standard electric vehicles with these kind of reductions would be even more feasible and currently would have, financially looking, the equal figures as conventional vehicles or even more economic.

As a negative side or non-covered possibilities, we can highlight some countries which are completely opposite to the previous case, making it even harder to be emissions aware and responsible. Serbia could be taken as an excellent example of this. In this country, the main problem, which a potential buyer of an electric or hydrogen vehicle will be confronted with, is a lack of possibility to even register this kind of vehicle.

There have been some attempts toward the possible solution but at the end the result is the same situation as it was before. This is a good example of how not-awareness of the country itself and lack of regulative could be a serious obstacle towards sustainable mobility concepts, which, as we have concluded several times in this thesis, are substantial for the future.

7 SUMMARY AND CONCLUSIONS

Sustainable mobility is an obvious path towards sustainable society and future perspective. Achieving higher goals in regard to fuel, vehicles and technology in general, we can make overall emissions stabilization and even reduction in certain amounts.

In this thesis we have summarized, concluded and proven several points as planned and defined in Chapter 1.1. Three core objectives were defined:

First objective of this thesis is to conclude what is direct and what is indirect influence on the environment from selected sustainable transportation models. As environment and ecology are two of the most important, if not the only two relevant, driving aspects of the sustainable mobility concept, comprehensive analysis has been conducted. One of the major questions raised from this part of the research was, if the biodiesel solution still represented the countable and equally comparable to other two selected. The main reason for this doubt was the fact that we usually have to consider only blends of biodiesel and conventional fossil diesel fuel, in ratios of B5, B10 or B20 in best case. The reason for this is of technological nature. After going deeper into this problem, it was shown that even it was only a partially renewable solution (B20) it still had significant emissions advantages versus pure fossil fuels. After conducting the analysis, biodiesel solutions turns to be significantly cleaner then fossil ones, even concerning the isolated combustion process. Other impacts from biodiesel solutions like noise level produced during the utilization is rather the same as it is case with conventional diesel vehicles. Biodiesel technology, as well as some hybrid technologies, is representing the ideal starting point of modern transformation in transportation sector. Analysis of hydrogen and electricity in road transportation showed that their purity and zero emissions setup highly depend and can be shaded by two aspects: technology used and source of energy used for generation of these alternative fuels and distribution methods. If not organized properly, distribution and wrong energy sources could lead these near zero emissions drivers into equal pollutants as fossil fuel solutions. As assumed, if renewable energy is used for electrolysis process of hydrogen production, we could obtain almost zero emissions model according to WTW, analysis. Same is concluded for Electric vehicles which also was expected as these technologies share certain amount of technology and both are based on electric motors and batteries in vehicles. As it was shown, PTW emissions in both cases are equal to zero so only environmental impact comes from vehicle and fuel production process. In this segment I have concluded that even high emissions emitted during technology production (vehicle and related parts) are not influencing end-comparison as it is in the same range for all defined models. During research of direct and indirect influence of selected models in this thesis, I have proven that lowest negative impact, in this manner, on the environment and ecology would have Electric technology concept.

Second objective is to assess which transportation models has the positive economic appraisals regarding the current European market situation.

Analyzing the current automotive markets, both in Europe and worldwide, I have noticed a general pattern regarding the sustainable road transportation. As a common side, we are witnessing an overall concern regarding the CO_2 and GHG emissions, from oil companies over vehicle manufacturers to end users. This necessity for cleaner solutions has become a common target. Despite the fact that every of these three sides of the story have different approaches, the end result is the same - cleaner energy and technology. Oil companies are manly driven by price reductions and taxations and their profit margins, vehicle manufacturers driven by technological curiosity, market demand for alternative solutions and legal regulations as well and the end users of both segments which are driven by environmental awareness, necessity to start changing the world from their selves and seeking for the sustainable and cheaper transportation. All these points currently look positive enough, beside high technology prices, towards sustainable future in road transportation.

Economical appraisal showed us that highest economic impact for all selected models was technology related costs or investment costs in vehicles. I have concluded that in this segment the most cost reductions could be made in the future, especially as vehicle costs for some technologies like Fuel-cell Vehicles are significantly higher than others. Comparing defined models in this part of the research I have proven that most economical solution is biodiesel as it has both the lowest investment and energy related costs. Excluding the conventional fuel model, on the second place is electric transportation model. As biodiesel could be observed partially as a hybrid model of transportation, these two first models should share the most economic place. If fossil fuel solutions are included than we have the biodiesel as the most economic once again, before ICE models. Lowering technology costs and considering variety of tax exemptions and subsidies, alternative solutions could be comparable and competitive with conventional fuel solutions.

Third objective is to make a prediction of what technologies are most promising for the further development towards sustainable road transportation and how to achieve that.

Analyzing the technological aspect of selected models and comparing them with conventional solutions, a couple of uncertainties developed. Firstly, there was an performance issue, or better to say fear, whether new emerging technologies with zero emissions and clean energy would be up to existing high performance - high comfort solutions. Secondly, there were plenty of security and health issues addressed to hydrogen and EV mobility. Once again, with comprehensive analysis and testing, I have concluded that, similar to conventional vehicles, quality and performance would go with a certain, higher, price. Even the range became an issue which can be solved in numerous ways, which was the most problematic issue of all. One question remains - does our environment have a price and in which moment do, the high prices, become less problematic issue? It was also concluded that safety issues regarding the hydrogen electricity models were mainly historical fears which have survived until today. Even occasionally some problems with battery overheating and flammability of the hydrogen occur, these issues are still lower rate than ones present with conventional fuels, especially if we consider side effects of both solutions. As expected, a very large problem, technology related, are filling or charging stations and networks (infrastructure). Even there are some possibilities to create add-ons on existing, well organized and planned conventional filling stations, or setting up the home charging solutions, this still represents one of the major technological drawbacks. To be precise, network development and charging stations offer will determine the convenience of EV and Hydrogen vehicle utilization, even more they will indirectly influence the ranges. The main conclusion regarding the technological and network segment for the future development, in this thesis, is that electric and hydrogen vehicles will have no significant market share and bright future, even the EV is the most promising one, unless a serious network of filling stations is developed across the whole continent (rather than in few countries), even before mass production of these vehicles occurs. In order to achieve the mass production and utilization of electric vehicles in Europe, higher influence of legal regulations and promotions, manly trough the subsidies and country support, is necessary as well as going towards development of sustainable, smart infrastructures and networks of charging stations. This, finally leads us to conclusion which technology is most promising for the future. According to everything stated it has to be Electric vehicle technology mostly because of rapid R&D in this field and positive attitude towards "new green technology". In order to fulfil this prediction, further development of infrastructure and charging networks should be primary goal. Meanwhile, models like biodiesel or hybrid, will be excellent transitional solutions as they provides relatively green technologies and lower energy demand with competitive investment costs.

According to all previously stated and appraisals conducted, it is concluded that every step, no matter how small or costly it would be, is worth trying and needed for our environment. It can also be concluded that even with high costs, selected sustainable mobility concepts can be feasible and competitive with fossil fuels. Although the overall transportation costs were showed to be higher than expected, they still stayed in range of marginal acceptance. Precisely speaking electric model is proven to be the with lowest environment influences and beside biodiesel or even some hybrid solutions (which are ideal transition models towards future sustainability), it represents most promising model for the future of the sustainable mobility. Main drawback related to this technology currently are investment costs which already have tendency of general decline. Also, network development for these sustainable models turns to be one of important drives of change and mass acceptance by end-customers. Author believes that if this tendency related to investment costs and infrastructure would be fulfilled, the Electricity model could, significantly, replace conventional fossil oriented models, especially if right regulations and legislatives would be defined and properly used in whole Europe like it was done in some individual countries.

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ADDENDUMS

Addendum 1 - Distribution of EV Charging stations worldwide

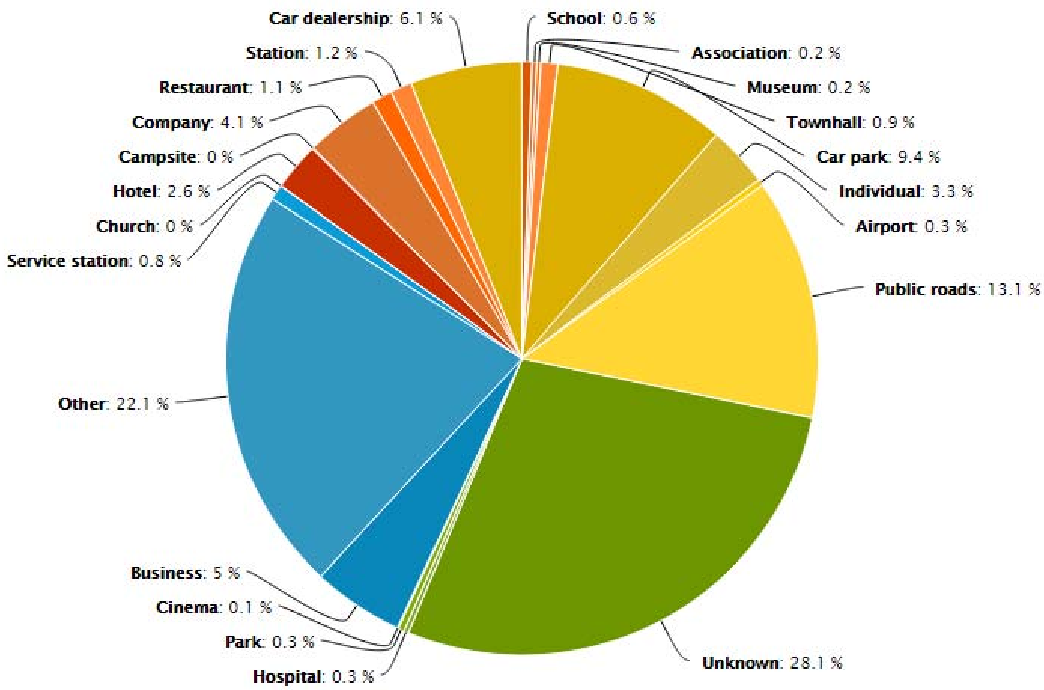

Figure A- 1: Distribution of charging stations per location type (source: http://chargemap.com/stats)

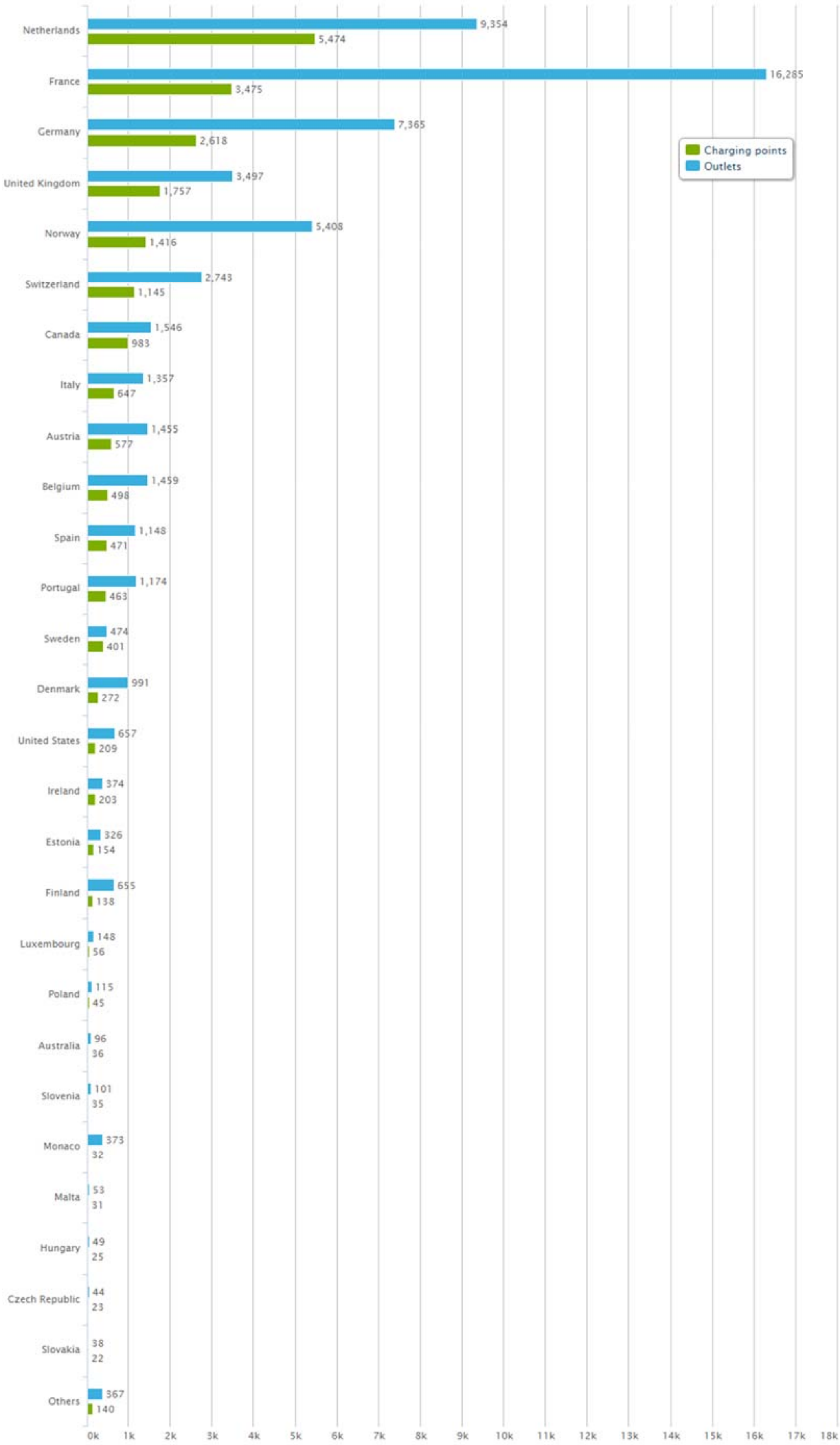

Figure A- 2: EV Charge points and outlets per country (source: http://chargemap.com/stats)

Addendum 2 - Environmental and Ecological impacts

Table A- 1: Calculation table for GHG emissions (source: GREET, ANL)

Results created by ANL on 10/25/2013 using GREET1_2013 version, October 2013 release

Energy use results in this tab are provided in units of kJ per km of vehicle's travelled distance, and in units of grams per km of vehicle's travelled distance for emissions

Fuel		Gasoline	G. H2									Diesel	BD 20					Electricity			
Vehicle		ICE	FCV									ICE	ICE					EV			
Feedstock		Conventional ICE Vehicle	Distributed NG SMR	Distributed Electrolysis: U.S. Mix	Distributed Electrolysis: CA Mix	Distributed Electrolysis: Renewable	Central NG SMR	Central LFG SMR	Central Coal w/o CCS	Central Coal w/ CCS	Central Biomass	Conventional ICE Vehicle	Soybean	Palm	Rapeseed	Jatropha	Algae	Coal	Biomass	Geothermal	Other Renewable
Total Energy	WTP	933	1,135	3,575	3,352	989	1,138	-937	1,821	1,771	2,256	592	868	646	805	749	1,648	1,775	3,496	61	61
[kJ/km]	PTW	2,965	1,412	1,412	1,412	1,412	1,412	1,412	1,412	1,412	1,412	2,471	2,471	2,471	2,471	2,471	2,471	872	872	872	872
	WTW	3,898	2,547	4,986	4,764	2,401	2,550	474	3,233	3,182	3,668	3,063	3,338	3,117	3,275	3,220	4,118	2,647	4,368	933	933
Fossil Energy	WTP	761	1,067	2,983	3,350	0	1,060	399	1,751	1,672	634	575	588	589	648	666	772	1,773	147	0	0
[kJ/km]	PTW	2,767	1,412	1,167	1,412	0	1,412	0	1,412	1,412	0	2,471	2,007	2,007	2,007	2,007	2,007	872	0	0	0
	WTW	3,528	2,479	4,150	4,762	0	2,471	399	3,163	3,084	634	3,046	2,596	2,596	2,655	2,673	2,779	2,645	147	0	0
Coal	WTP	80	219	1,907	8	0	252	250	1,584	1,460	276	56	70	54	59	57	158	1,724	3	0	0
[kJ/km]	PTW	0	0	789	0	0	0	0	1,412	1,412	0	0	0	0	0	0	0	872	0	0	0
	WTW	80	219	2,696	8	0	252	250	2,996	2,872	276	56	70	54	59	57	158	2,596	3	0	0
NG	WTP	447	833	1,002	3,324	0	792	141	120	166	259	324	329	339	389	384	405	8	16	0	0
[kJ/km]	PTW	0	1,412	368	1,412	0	1,412	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WTW	447	2,245	1,370	4,736	0	2,203	141	120	166	259	324	329	339	389	384	405	8	16	0	0
Petroleum	WTP	234	15	75	18	0	16	8	47	46	100	195	190	195	200	224	208	42	129	0	0
[kJ/km]	PTW	2,767	0	9	0	0	0	0	0	0	0	2,471	2,007	2,007	2,007	2,007	2,007	0	0	0	0
	WTW	3,001	15	84	18	0	16	8	47	46	100	2,666	2,197	2,202	2,207	2,231	2,216	42	129	0	0
GHG	WTP	57	165	356	294	2	159	53	279	76	56	52	17	18	28	28	34	260	19	24	1
[gCO2e/km]	PTW	217	0	0	0	0	0	0	0	0	0	187	187	187	187	187	187	0	0	0	0
	WTW	274	165	356	294	2	159	53	279	76	56	238	204	205	215	215	221	260	19	24	1

Note

- Nerm term future: Target year 2015 or Vehicle model year 2010
- Average gasoline/diesel mix: 91.9% of conventional crude and 8.1% of oil sand
- Pyrolysis gasoline and diesel: See [1] for details
- Corn ethanol: Industry average mix between wet and dry mills (88.6% of dry mill and 11.4% of wet mill)
- Cellulosic ethanol: See [2,3] for details.
- Average conventional NG/Shale gas mix: 63.2% of conventional NG and 36.8% of shale gas
  + Conventional NG and shale gas: See [4] for details
  + Manure-based AD gas: See [5] for details
- Central Coal-to-G.H2 w / CCS
  + CCS rate: 90%
  + Electricity consumption for CCS: 250kWh/ton of C captured
- Central COG-to-G.H2: COG is treated as a co-product. Energy use and CO2 emissions from coking process are allocated between coke and COG.
- FTD, Coal-to-Liquid w / CCS
  + CCS rate: 89%
  + Electricity consumption for CCS: 335.6kWh/ton of C captured
- FTD, Coal/Biomass-to-Liquid: 20% biomass per dry mass basis
- BD and RD: Uese system level energy allocation method to handle co-product credits
  + Palm, rapeseed, jatropha: See [6] for details
  + Camelina: See [7] for details
  + Algae: See [8,9] for details
- Renewable diesel: Based on UOP's renewable disel technology
- Power plant generation efficiencies, technology shares and transmission losses: See [10] for details
- PHEV and EV charger efficiency: 85%
- Fuel economy of conventional gasoline vehicle: 24.8 mpg
- Fuel economy ratio of alternative vehicles relative to the conventional gasoline vehicle
  + Gasoline HEV: 140%
  + E85 FFV: 100%
  + CNGV, LNGV: 103%
  + G.H2 FC HEV: 243%
  + Conventional Diesel Vehicle: 120%
  + Electric Vehicle: 400% (without battery charger efficiency
- Fuel economy and electricity consumption of PHEVs: See [11] for details

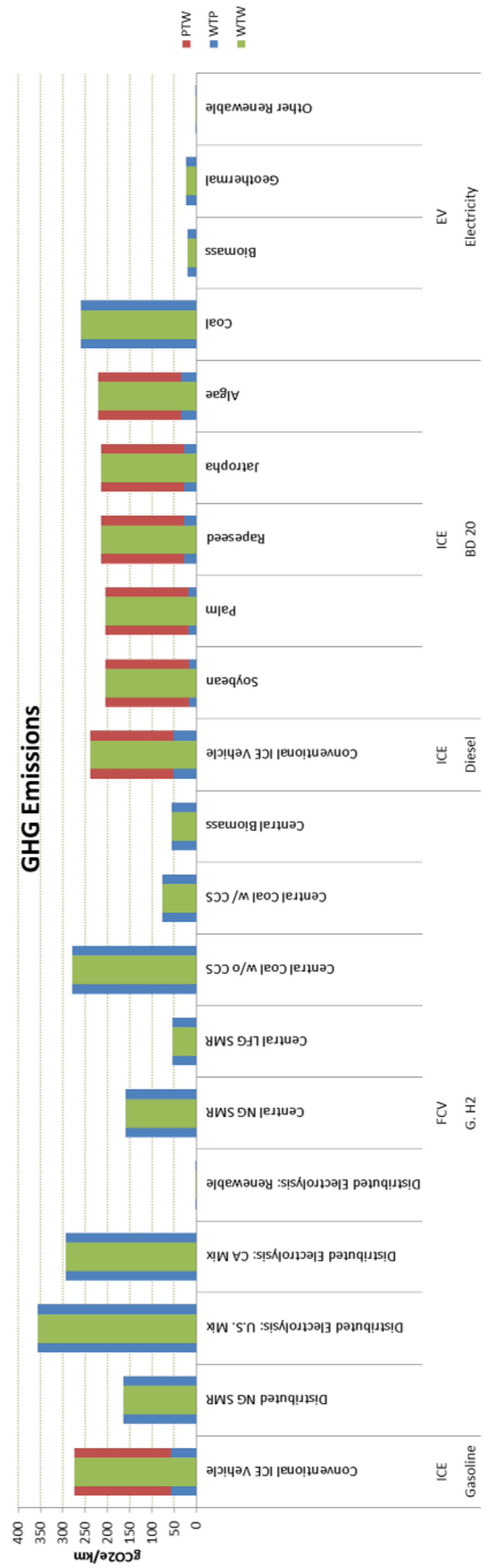

Figure A- 3: GHG Emissions overview chart (source: GREET, ANL)

Addendum 3 - Economical calculations

Table A- 2: Hydrogen powered F-Cell vehicle economic calculations with variables - Investment costs and Fuel Costs (source: own depiction)

H2	Investment Cost (IC) EUR/Vehicle	Fuel Intensity (FI) kg/100km	Kilometers per year (skm) km	Depreciation period (n) year	Interest rate (z) %	Fuel Cost (Pf) Eur/kg	O&M Cost Eur/km	TRANSPORTATION COST (RESULTS: EUR/km)	ENERGY COST (RESULTS: EUR/km)	VEHICLE COST inc. o&m (RESULTS: EUR/km)
50%	75,000	0.97	12,000	10	5	9	0.055	0.892	0.087	0.805
45%	72,500	0.97	12,000	10	5	9	0.055	0.867	0.087	0.780
40%	70,000	0.97	12,000	10	5	9	0.055	0.842	0.087	0.755
35%	67,500	0.97	12,000	10	5	9	0.055	0.817	0.087	0.730
30%	65,000	0.97	12,000	10	5	9	0.055	0.792	0.087	0.705
25%	62,500	0.97	12,000	10	5	9	0.055	0.767	0.087	0.680
20%	60,000	0.97	12,000	10	5	9	0.055	0.742	0.087	0.655
15%	57,500	0.97	12,000	10	5	9	0.055	0.717	0.087	0.630
10%	55,000	0.97	12,000	10	5	9	0.055	0.692	0.087	0.605
5%	52,500	0.97	12,000	10	5	9	0.055	0.667	0.087	0.580
0%	50,000	0.97	12,000	10	5	9	0.055	0.642	0.087	0.555
-5%	47,500	0.97	12,000	10	5	9	0.055	0.617	0.087	0.530
-10%	45,000	0.97	12,000	10	5	9	0.055	0.592	0.087	0.505
-15%	42,500	0.97	12,000	10	5	9	0.055	0.567	0.087	0.480
-20%	40,000	0.97	12,000	10	5	9	0.055	0.542	0.087	0.455
-25%	37,500	0.97	12,000	10	5	9	0.055	0.517	0.087	0.430
-30%	35,000	0.97	12,000	10	5	9	0.055	0.492	0.087	0.405
-35%	32,500	0.97	12,000	10	5	9	0.055	0.467	0.087	0.380
-40%	30,000	0.97	12,000	10	5	9	0.055	0.442	0.087	0.355
-45%	27,500	0.97	12,000	10	5	9	0.055	0.417	0.087	0.330
-50%	25,000	0.97	12,000	10	5	9	0.055	0.392	0.087	0.305

H2	Investment Cost (IC) EUR/Vehicle	Fuel Intensity (FI) kg/100km	Kilometers per year (skm) km	Depreciation period (n) year	Interest rate (z) %	Fuel Cost (Pf) Eur/kg	O&M Cost Eur/km	TRANSPORTATION COST (RESULTS: EUR/km)	ENERGY COST (RESULTS: EUR/km)	VEHICLE COST inc. o&m (RESULTS: EUR/km)
50%	50,000	0.97	12,000	10	5	13.5	0.055	0.686	0.131	0.555
45%	50,000	0.97	12,000	10	5	13.05	0.055	0.682	0.127	0.555
40%	50,000	0.97	12,000	10	5	12.6	0.055	0.677	0.122	0.555
35%	50,000	0.97	12,000	10	5	12.15	0.055	0.673	0.118	0.555
30%	50,000	0.97	12,000	10	5	11.7	0.055	0.668	0.113	0.555
25%	50,000	0.97	12,000	10	5	11.25	0.055	0.664	0.109	0.555
20%	50,000	0.97	12,000	10	5	10.8	0.055	0.660	0.105	0.555
15%	50,000	0.97	12,000	10	5	10.35	0.055	0.655	0.100	0.555
10%	50,000	0.97	12,000	10	5	9.9	0.055	0.651	0.096	0.555
5%	50,000	0.97	12,000	10	5	9.45	0.055	0.647	0.092	0.555
0%	50,000	0.97	12,000	10	5	9	0.055	0.642	0.087	0.555
-5%	50,000	0.97	12,000	10	5	8.55	0.055	0.638	0.083	0.555
-10%	50,000	0.97	12,000	10	5	8.1	0.055	0.634	0.079	0.555
-15%	50,000	0.97	12,000	10	5	7.65	0.055	0.629	0.074	0.555
-20%	50,000	0.97	12,000	10	5	7.2	0.055	0.625	0.070	0.555
-25%	50,000	0.97	12,000	10	5	6.75	0.055	0.620	0.065	0.555
-30%	50,000	0.97	12,000	10	5	6.3	0.055	0.616	0.061	0.555
-35%	50,000	0.97	12,000	10	5	5.85	0.055	0.612	0.057	0.555
-40%	50,000	0.97	12,000	10	5	5.4	0.055	0.607	0.052	0.555
-45%	50,000	0.97	12,000	10	5	4.95	0.055	0.603	0.048	0.555
-50%	50,000	0.97	12,000	10	5	4.5	0.055	0.599	0.044	0.555

Table A- 3: Biodiesel powered vehicle economic calculations with variables - Investment costs and Fuel Costs (source: own depiction)

BD	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
50%	37,500	4.70	12,000	10	5	0.16	0.07	0.453	0.008	0.445
45%	36,250	4.70	12,000	10	5	0.16	0.07	0.440	0.008	0.433
40%	35,000	4.70	12,000	10	5	0.16	0.07	0.428	0.008	0.420
35%	33,750	4.70	12,000	10	5	0.16	0.07	0.415	0.008	0.408
30%	32,500	4.70	12,000	10	5	0.16	0.07	0.403	0.008	0.395
25%	31,250	4.70	12,000	10	5	0.16	0.07	0.390	0.008	0.383
20%	30,000	4.70	12,000	10	5	0.16	0.07	0.378	0.008	0.370
15%	28,750	4.70	12,000	10	5	0.16	0.07	0.365	0.008	0.358
10%	27,500	4.70	12,000	10	5	0.16	0.07	0.353	0.008	0.345
5%	26,250	4.70	12,000	10	5	0.16	0.07	0.340	0.008	0.333
0%	25,000	4.70	12,000	10	5	0.16	0.07	0.328	0.008	0.320
-5%	23,750	4.70	12,000	10	5	0.16	0.07	0.315	0.008	0.308
-10%	22,500	4.70	12,000	10	5	0.16	0.07	0.303	0.008	0.295
-15%	21,250	4.70	12,000	10	5	0.16	0.07	0.290	0.008	0.283
-20%	20,000	4.70	12,000	10	5	0.16	0.07	0.278	0.008	0.270
-25%	18,750	4.70	12,000	10	5	0.16	0.07	0.265	0.008	0.258
-30%	17,500	4.70	12,000	10	5	0.16	0.07	0.253	0.008	0.245
-35%	16,250	4.70	12,000	10	5	0.16	0.07	0.240	0.008	0.233
-40%	15,000	4.70	12,000	10	5	0.16	0.07	0.228	0.008	0.220
-45%	13,750	4.70	12,000	10	5	0.16	0.07	0.215	0.008	0.208
-50%	12,500	4.70	12,000	10	5	0.16	0.07	0.203	0.008	0.195

BD	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
50%	25,000	4.70	12,000	10	5	0.240	0.07	0.331	0.011	0.320
45%	25,000	4.70	12,000	10	5	0.232	0.07	0.331	0.011	0.320
40%	25,000	4.70	12,000	10	5	0.224	0.07	0.331	0.011	0.320
35%	25,000	4.70	12,000	10	5	0.216	0.07	0.330	0.010	0.320
30%	25,000	4.70	12,000	10	5	0.208	0.07	0.330	0.010	0.320
25%	25,000	4.70	12,000	10	5	0.200	0.07	0.329	0.009	0.320
20%	25,000	4.70	12,000	10	5	0.192	0.07	0.329	0.009	0.320
15%	25,000	4.70	12,000	10	5	0.184	0.07	0.329	0.009	0.320
10%	25,000	4.70	12,000	10	5	0.176	0.07	0.328	0.008	0.320
5%	25,000	4.70	12,000	10	5	0.168	0.07	0.328	0.008	0.320
0%	25,000	4.70	12,000	10	5	0.160	0.07	0.328	0.008	0.320
-5%	25,000	4.70	12,000	10	5	0.152	0.07	0.327	0.007	0.320
-10%	25,000	4.70	12,000	10	5	0.144	0.07	0.327	0.007	0.320
-15%	25,000	4.70	12,000	10	5	0.136	0.07	0.326	0.006	0.320
-20%	25,000	4.70	12,000	10	5	0.128	0.07	0.326	0.006	0.320
-25%	25,000	4.70	12,000	10	5	0.120	0.07	0.326	0.006	0.320
-30%	25,000	4.70	12,000	10	5	0.112	0.07	0.325	0.005	0.320
-35%	25,000	4.70	12,000	10	5	0.104	0.07	0.325	0.005	0.320
-40%	25,000	4.70	12,000	10	5	0.096	0.07	0.325	0.005	0.320
-45%	25,000	4.70	12,000	10	5	0.088	0.07	0.324	0.004	0.320
-50%	25,000	4.70	12,000	10	5	0.080	0.07	0.324	0.004	0.320

Table A- 4: Diesel powered vehicle economic calculations with variables - Investment costs and Fuel Costs (source: own depiction)

D-I	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
50%	37,500	4.70	12,000	10	5	1.44	0.075	0.518	0.068	0.450
45%	36,250	4.70	12,000	10	5	1.44	0.075	0.505	0.068	0.438
40%	35,000	4.70	12,000	10	5	1.44	0.075	0.493	0.068	0.425
35%	33,750	4.70	12,000	10	5	1.44	0.075	0.480	0.068	0.413
30%	32,500	4.70	12,000	10	5	1.44	0.075	0.468	0.068	0.400
25%	31,250	4.70	12,000	10	5	1.44	0.075	0.455	0.068	0.388
20%	30,000	4.70	12,000	10	5	1.44	0.075	0.443	0.068	0.375
15%	28,750	4.70	12,000	10	5	1.44	0.075	0.430	0.068	0.363
10%	27,500	4.70	12,000	10	5	1.44	0.075	0.418	0.068	0.350
5%	26,250	4.70	12,000	10	5	1.44	0.075	0.405	0.068	0.338
0%	25,000	4.70	12,000	10	5	1.44	0.075	0.393	0.068	0.325
-5%	23,750	4.70	12,000	10	5	1.44	0.075	0.380	0.068	0.313
-10%	22,500	4.70	12,000	10	5	1.44	0.075	0.368	0.068	0.300
-15%	21,250	4.70	12,000	10	5	1.44	0.075	0.355	0.068	0.288
-20%	20,000	4.70	12,000	10	5	1.44	0.075	0.343	0.068	0.275
-25%	18,750	4.70	12,000	10	5	1.44	0.075	0.330	0.068	0.263
-30%	17,500	4.70	12,000	10	5	1.44	0.075	0.318	0.068	0.250
-35%	16,250	4.70	12,000	10	5	1.44	0.075	0.305	0.068	0.238
-40%	15,000	4.70	12,000	10	5	1.44	0.075	0.293	0.068	0.225
-45%	13,750	4.70	12,000	10	5	1.44	0.075	0.280	0.068	0.213
-50%	12,500	4.70	12,000	10	5	1.44	0.075	0.268	0.068	0.200

D-II	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
50%	25,000	4.70	12,000	10	5	2.16	0.075	0.427	0.102	0.325
45%	25,000	4.70	12,000	10	5	2.088	0.075	0.423	0.098	0.325
40%	25,000	4.70	12,000	10	5	2.016	0.075	0.420	0.095	0.325
35%	25,000	4.70	12,000	10	5	1.944	0.075	0.416	0.091	0.325
30%	25,000	4.70	12,000	10	5	1.872	0.075	0.413	0.088	0.325
25%	25,000	4.70	12,000	10	5	1.8	0.075	0.410	0.085	0.325
20%	25,000	4.70	12,000	10	5	1.728	0.075	0.406	0.081	0.325
15%	25,000	4.70	12,000	10	5	1.656	0.075	0.403	0.078	0.325
10%	25,000	4.70	12,000	10	5	1.584	0.075	0.399	0.074	0.325
5%	25,000	4.70	12,000	10	5	1.512	0.075	0.396	0.071	0.325
0%	25,000	4.70	12,000	10	5	1.44	0.075	0.393	0.068	0.325
-5%	25,000	4.70	12,000	10	5	1.368	0.075	0.389	0.064	0.325
-10%	25,000	4.70	12,000	10	5	1.296	0.075	0.386	0.061	0.325
-15%	25,000	4.70	12,000	10	5	1.224	0.075	0.383	0.058	0.325
-20%	25,000	4.70	12,000	10	5	1.152	0.075	0.379	0.054	0.325
-25%	25,000	4.70	12,000	10	5	1.08	0.075	0.376	0.051	0.325
-30%	25,000	4.70	12,000	10	5	1.008	0.075	0.372	0.047	0.325
-35%	25,000	4.70	12,000	10	5	0.936	0.075	0.369	0.044	0.325
-40%	25,000	4.70	12,000	10	5	0.864	0.075	0.366	0.041	0.325
-45%	25,000	4.70	12,000	10	5	0.792	0.075	0.362	0.037	0.325
-50%	25,000	4.70	12,000	10	5	0.72	0.075	0.359	0.034	0.325

Table A- 5: Electricity powered vehicle economic calculations with variables - Investment costs and Fuel Costs (source: own depiction)

E	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
50%	52,500	25.63	12,000	10	5	0.16	0.05	0.616	0.041	0.575
45%	50,750	25.63	12,000	10	5	0.16	0.05	0.599	0.041	0.558
40%	49,000	25.63	12,000	10	5	0.16	0.05	0.581	0.041	0.540
35%	47,250	25.63	12,000	10	5	0.16	0.05	0.564	0.041	0.523
30%	45,500	25.63	12,000	10	5	0.16	0.05	0.546	0.041	0.505
25%	43,750	25.63	12,000	10	5	0.16	0.05	0.529	0.041	0.488
20%	42,000	25.63	12,000	10	5	0.16	0.05	0.511	0.041	0.470
15%	40,250	25.63	12,000	10	5	0.16	0.05	0.494	0.041	0.453
10%	38,500	25.63	12,000	10	5	0.16	0.05	0.476	0.041	0.435
5%	36,750	25.63	12,000	10	5	0.16	0.05	0.459	0.041	0.418
0%	35,000	25.63	12,000	10	5	0.16	0.05	0.441	0.041	0.400
-5%	33,250	25.63	12,000	10	5	0.16	0.05	0.424	0.041	0.383
-10%	31,500	25.63	12,000	10	5	0.16	0.05	0.406	0.041	0.365
-15%	29,750	25.63	12,000	10	5	0.16	0.05	0.389	0.041	0.348
-20%	28,000	25.63	12,000	10	5	0.16	0.05	0.371	0.041	0.330
-25%	26,250	25.63	12,000	10	5	0.16	0.05	0.354	0.041	0.313
-30%	24,500	25.63	12,000	10	5	0.16	0.05	0.336	0.041	0.295
-35%	22,750	25.63	12,000	10	5	0.16	0.05	0.319	0.041	0.278
-40%	21,000	25.63	12,000	10	5	0.16	0.05	0.301	0.041	0.260
-45%	19,250	25.63	12,000	10	5	0.16	0.05	0.284	0.041	0.243
-50%	17,500	25.63	12,000	10	5	0.16	0.05	0.266	0.041	0.225

E	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
50%	35,000	0.97	12,000	10	5	0.24	0.05	0.402	0.002	0.400
45%	35,000	0.97	12,000	10	5	0.232	0.05	0.402	0.002	0.400
40%	35,000	0.97	12,000	10	5	0.224	0.05	0.402	0.002	0.400
35%	35,000	0.97	12,000	10	5	0.216	0.05	0.402	0.002	0.400
30%	35,000	0.97	12,000	10	5	0.208	0.05	0.402	0.002	0.400
25%	35,000	0.97	12,000	10	5	0.2	0.05	0.402	0.002	0.400
20%	35,000	0.97	12,000	10	5	0.192	0.05	0.402	0.002	0.400
15%	35,000	0.97	12,000	10	5	0.184	0.05	0.402	0.002	0.400
10%	35,000	0.97	12,000	10	5	0.176	0.05	0.402	0.002	0.400
5%	35,000	0.97	12,000	10	5	0.168	0.05	0.402	0.002	0.400
0%	35,000	0.97	12,000	10	5	0.16	0.05	0.402	0.002	0.400
-5%	35,000	0.97	12,000	10	5	0.152	0.05	0.401	0.001	0.400
-10%	35,000	0.97	12,000	10	5	0.144	0.05	0.401	0.001	0.400
-15%	35,000	0.97	12,000	10	5	0.136	0.05	0.401	0.001	0.400
-20%	35,000	0.97	12,000	10	5	0.128	0.05	0.401	0.001	0.400
-25%	35,000	0.97	12,000	10	5	0.12	0.05	0.401	0.001	0.400
-30%	35,000	0.97	12,000	10	5	0.112	0.05	0.401	0.001	0.400
-35%	35,000	0.97	12,000	10	5	0.104	0.05	0.401	0.001	0.400
-40%	35,000	0.97	12,000	10	5	0.096	0.05	0.401	0.001	0.400
-45%	35,000	0.97	12,000	10	5	0.088	0.05	0.401	0.001	0.400
-50%	35,000	0.97	12,000	10	5	0.08	0.05	0.401	0.001	0.400

Table A- 6: Electricity powered Tesla vehicle economic calculations with variables - Investment costs and Fuel Costs (source: own depiction)

TESLA	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
50%	97,500	18.10	12,000	10	5	0.16	0.024	1.028	0.029	0.999
45%	94,250	18.10	12,000	10	5	0.16	0.024	0.995	0.029	0.967
40%	91,000	18.10	12,000	10	5	0.16	0.024	0.963	0.029	0.934
35%	87,750	18.10	12,000	10	5	0.16	0.024	0.930	0.029	0.902
30%	84,500	18.10	12,000	10	5	0.16	0.024	0.898	0.029	0.869
25%	81,250	18.10	12,000	10	5	0.16	0.024	0.865	0.029	0.837
20%	78,000	18.10	12,000	10	5	0.16	0.024	0.833	0.029	0.804
15%	74,750	18.10	12,000	10	5	0.16	0.024	0.800	0.029	0.772
10%	71,500	18.10	12,000	10	5	0.16	0.024	0.768	0.029	0.739
5%	68,250	18.10	12,000	10	5	0.16	0.024	0.735	0.029	0.707
0%	65,000	18.10	12,000	10	5	0.16	0.024	0.703	0.029	0.674
-5%	61,750	18.10	12,000	10	5	0.16	0.024	0.670	0.029	0.642
-10%	58,500	18.10	12,000	10	5	0.16	0.024	0.638	0.029	0.609
-15%	55,250	18.10	12,000	10	5	0.16	0.024	0.605	0.029	0.577
-20%	52,000	18.10	12,000	10	5	0.16	0.024	0.573	0.029	0.544
-25%	48,750	18.10	12,000	10	5	0.16	0.024	0.540	0.029	0.512
-30%	45,500	18.10	12,000	10	5	0.16	0.024	0.508	0.029	0.479
-35%	42,250	18.10	12,000	10	5	0.16	0.024	0.475	0.029	0.447
-40%	39,000	18.10	12,000	10	5	0.16	0.024	0.443	0.029	0.414
-45%	35,750	18.10	12,000	10	5	0.16	0.024	0.410	0.029	0.382
-50%	32,500	18.10	12,000	10	5	0.16	0.024	0.378	0.029	0.349

TESLA	Investment Cost (IC)	Fuel Intensity (FI)	Kilometers per year (skm)	Depreciation period (n)	Interest rate (z)	Fuel Cost (Pf)	O&M Cost	TRANSPORTATION COST	ENERGY COST	VEHICLE COST inc. o&m
	EUR/Vehicle	kg/100km	km	year	%	Eur/kg	Eur/km	RESULTS: EUR/km		
50%	65,000	18.10	12,000	10	5	0.24	0.024	0.717	0.043	0.674
45%	65,000	18.10	12,000	10	5	0.232	0.024	0.716	0.042	0.674
40%	65,000	18.10	12,000	10	5	0.224	0.024	0.715	0.041	0.674
35%	65,000	18.10	12,000	10	5	0.216	0.024	0.713	0.039	0.674
30%	65,000	18.10	12,000	10	5	0.208	0.024	0.712	0.038	0.674
25%	65,000	18.10	12,000	10	5	0.2	0.024	0.710	0.036	0.674
20%	65,000	18.10	12,000	10	5	0.192	0.024	0.709	0.035	0.674
15%	65,000	18.10	12,000	10	5	0.184	0.024	0.707	0.033	0.674
10%	65,000	18.10	12,000	10	5	0.176	0.024	0.706	0.032	0.674
5%	65,000	18.10	12,000	10	5	0.168	0.024	0.704	0.030	0.674
0%	65,000	18.10	12,000	10	5	0.16	0.024	0.703	0.029	0.674
-5%	65,000	18.10	12,000	10	5	0.152	0.024	0.702	0.028	0.674
-10%	65,000	18.10	12,000	10	5	0.144	0.024	0.700	0.026	0.674
-15%	65,000	18.10	12,000	10	5	0.136	0.024	0.699	0.025	0.674
-20%	65,000	18.10	12,000	10	5	0.128	0.024	0.697	0.023	0.674
-25%	65,000	18.10	12,000	10	5	0.12	0.024	0.696	0.022	0.674
-30%	65,000	18.10	12,000	10	5	0.112	0.024	0.694	0.020	0.674
-35%	65,000	18.10	12,000	10	5	0.104	0.024	0.693	0.019	0.674
-40%	65,000	18.10	12,000	10	5	0.096	0.024	0.691	0.017	0.674
-45%	65,000	18.10	12,000	10	5	0.088	0.024	0.690	0.016	0.674
-50%	65,000	18.10	12,000	10	5	0.08	0.024	0.688	0.014	0.674