The Directive on the Deployment of Alternative Fuels Infrastructure – An analysis of its effects on the market uptake of natural gas vehicles

Karl Törnmarck
The Directive on the Deployment of Alternative Fuels Infrastructure – An analysis of its effects on the market uptake of natural gas vehicles

Karl Törnmarck

Supervisor: Mikael Höök
Evaluator: Kjell Aleklett
The Directive on the Deployment of Alternative Fuels Infrastructure – An analysis of its effects on the market uptake of natural gas vehicles

KARL TÖRNMARCK


Scientific Abstract: The EU transport sector is currently extremely dependent on foreign oil and the import bill for this fuel was in 2011 approximately € 210 billion. The European Commission (EC) claims that this dependency will eventually affect the member states' economic security and mobility as oil is a finite resource. At the same time, the transport sector needs to reduce its CO₂ emissions with 60% until 2050. Therefore in 2013, the EC proposed the “Directive on the Deployment of Alternative Fuels Infrastructure”, which purpose is to create road fuel infrastructure for the alternative fuels electricity, hydrogen and, the main focus of this report, natural gas. The EC believes that infrastructure acts as a major barrier for the adoption of natural gas vehicles (NGV), which in the EU has been extremely limited. The scientific community agrees that infrastructure is an important barrier, but not the sole decider for the market penetration of NGV’s. Empirical evidence claims that in order for large-scale adoption to occur, natural gas needs to be priced at least 40% lower than conventional fuels (gasoline, diesel) and the payback period (the added investment cost of an NGV) must be lower than four years. Historical data shows that if these criteria are not met this will lead to market failure, even if the adequate infrastructure is in place. The two criteria are examined in this report in the four of the largest EU countries: Germany, UK, France and Spain whom together account for a majority of all vehicles registered in 2012. Italy was excluded as it has already has a well-developed NGV fleet.

Two car models from different price ranges in NGV, gasoline and diesel versions were studied: the Fiat Punto and the Audi A3 Sportback. Payback periods were calculated based on yearly average annual distances travelled per country, fuel prices, vehicle fuel efficiency and the added investment cost for an NGV compared to gasoline and diesel vehicles. In order to compare fuel prices default energy content values were used to convert CNG into gasoline and diesel equivalents. As the price of CNG is heavily dependent on favorable taxation one needs to question the economic sustainability, and therefore this study also analyses the future price difference between gas and the conventional fuels using a supply and demand model with oligopoly conditions. This model was complemented with the 4 A’s method, which are Availability, Accessibility, Affordability and Acceptability.

Results show that the conditions for NGV’s compared to diesel vehicles are optimal in Germany, UK and Spain, as they all have fuel price difference of minimum 40% and payback periods significantly below 4 years. As a majority of all new vehicles registered in the EU are diesel models this will have a strong positive impact on the NGV market.

The conditions for the gasoline comparisons are suboptimal, or slightly inconclusive as the payback periods in a few cases are above, or just below four years. As default values have been used during calculations the numbers are sensitive to change and simply too uncertain to draw any solid conclusions. The price differences between CNG and gasoline are within the criteria level of 40%.

The price difference analysis between oil and natural gas shows great uncertainty, as there are many factors involved, such as environmental and geopolitical. A potential factor that could decouple prices is “fracking” of domestic EU shale gas resources, but this seems unlikely to happen due to environmental, social and economical reasons. Imported US LNG could have a similar effect but it might be exported east in order to meet the increasing demand from countries in Asia pacific.

In conclusion, if the Directive on the Deployment of Alternative Fuels Infrastructure was implemented we would likely see a moderate to high market penetration of NGV’s, mostly due to their comparative advantage towards diesel vehicles. As gasoline meets the fuel price difference criteria this will also have a positive effect on the NGV market albeit limited by questionable payback periods.

Keywords: Sustainable Development, natural gas, transport, EU, microeconomics, policy, energy.

Karl Törnmarck, Department of Earth Sciences, Uppsala University, Villavägen 16, SE- 752 36 Uppsala, Sweden
The Directive on the Deployment of Alternative Fuels Infrastructure – An analysis of its effects on the market uptake of natural gas vehicles

KARL TÖRNMARCK


Popular Summary: The foundation of what today is known as the European Union (EU) was established in the aftermath of the second World War by the signing of the Coal and Steel Community (ECSC) in 1951. Today, the EU has evolved into a massive entity with 28 member states covering many different policy areas, for example transport and energy. The EU transport sector is heavily dependent on imported petroleum products which account for approximately 95% of its total energy consumption which led to a total import bill of € 210 billion in 2011. At the same time CO2 emissions from the transport sector need to be heavily reduced with 60% until 2050. In order to cope with these issues the European Commission (EC), the only EU institution with the power to propose legislation, has put forward the Directive on the Deployment of Alternative Fuels Infrastructure which purpose is to create road fueling infrastructure for the alternative fuels electricity, hydrogen and, the main focus of this report, natural gas in form of Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG). Natural gas has the environmental benefit (compared to oil) of CO2 savings up to 25%. It is much like oil, a fossil hydrocarbon, but of a more simple nature as it consists mainly of methane and therefore has very low sulfur and nitrogen dioxide emissions. The EC claims that infrastructure is a main barrier for large-scale adoption of natural gas vehicles (NGV’s) and that it will solve the “chicken and egg” situation of there being no demand as there is no infrastructure in place and vice versa. Peer-reviewed studies agree with this statement, but claim that infrastructure is not the sole decider for the market penetration of NGV’s. Empirical evidence claims that in order for large-scale adoption to occur, natural gas needs to be priced at least 40% lower than conventional fuels (gasoline, diesel) and the payback period (the added investment cost of an NGV) must be lower than four years. The purpose of this report is to analyze these criteria in order to assess the directive’s affect on the market uptake of NGV’s in Europe and also to make an assessment of the future price difference between oil and natural gas. Results show that the conditions for the NGV’s compared to diesel vehicles are optimal in Germany, UK and Spain which is of great importance as a majority of all new vehicles registered in the EU are diesel. The conditions for the gasoline comparisons are suboptimal, or slightly inconclusive. As default values have been used during calculations and the numbers are within a range of uncertainty it difficult to draw any solid conclusions for these vehicles.

The future price difference analysis between oil and natural gas shows great uncertainty, as there are many factors involved, such as the environment and geopolitics. A potential factor that could decouple prices is “fracking” of domestic EU shale gas resources, but this seems unlikely to happen due to environmental, social and economical reasons. Imported US LNG could have a similar effect but it might be exported east in order to meet the increasing demand from countries in Asia pacific.

In conclusion, if the Directive on the Deployment of Alternative Fuels Infrastructure was implemented we would likely see a moderate to high market penetration of NGV’s, mostly due to their comparative advantage towards diesel vehicles. As gasoline meets the fuel price difference criteria this will also have a positive effect on the NGV market but is limited by questionable payback periods.

Keywords: Sustainable Development, natural gas, transport, EU, microeconomics, policy, energy.

Karl Törnmarck, Department of Earth Sciences, Uppsala University, Villavägen 16, SE- 752 36 Uppsala, Sweden
Content
1. Introduction ............................................................................................................................1
  1.1 Aim of this study ..............................................................................................................1
  1.2 Data sources ...................................................................................................................2
  1.3 Delimitations ...................................................................................................................3
  1.4 Disposition ......................................................................................................................3
2. Background..........................................................................................................................4
  2.1. The functioning of the EU ..............................................................................................4
    2.1.1. EU Energy policy ......................................................................................................4
  2.2. EU energy usage .............................................................................................................5
  2.2.1. The European natural gas market ..............................................................................8
  2.2.2 Projected price difference natural gas and oil ............................................................10
  2.3. Projected global energy demand ..................................................................................11
  2.4. EU vehicle fleet ............................................................................................................12
3. Methodology .......................................................................................................................15
  3.1. Price difference between natural gas and conventional fuels (gasoline, diesel) ............15
    3.1.1. Future price difference natural gas and conventional fuels ....................................17
  3.2. Payback period ............................................................................................................17
4. Results ....................................................................................................................................19
  4.1. Fuel price comparison ...................................................................................................19
  4.1.1. Fuel price comparison by country ..............................................................................21
    4.1.1.1. Germany ...............................................................................................................21
    4.1.1.2. UK .........................................................................................................................21
    4.1.1.3. France ....................................................................................................................21
    4.1.1.4. Spain .....................................................................................................................22
    4.1.1.5. Subsidies ...............................................................................................................22
  4.1.2. Future price difference natural gas vs. oil .................................................................22
    4.1.2.1. EU domestic gas reserves and pipeline projects ..................................................22
    4.1.2.2. The role of LNG ...................................................................................................23
  4.3. Payback period .............................................................................................................24
    4.3.2 Payback period UK ..................................................................................................25
    4.3.3 Payback period France ..............................................................................................26
    4.3.4 Payback period Spain ...............................................................................................27
5. Discussion ...........................................................................................................................28
  5.1 Primary findings ..............................................................................................................28
  5.2 Validity of payback calculations .....................................................................................28
  5.3 Development of electric vehicles ...................................................................................29
  5.4 Sustainability ..................................................................................................................29
  5.5 Consumer awareness .....................................................................................................30
  5.6. Uncertainties ................................................................................................................30
6. Conclusions .........................................................................................................................31
7. Acknowledgements ............................................................................................................32
8. References ...........................................................................................................................33
Appendix ..................................................................................................................................39
  Payback period Germany ....................................................................................................39
  Payback period UK ..............................................................................................................39
  Payback period France .........................................................................................................40
  Payback period Spain ...........................................................................................................41
1. Introduction

The foundation of what today is known as the European Union (EU) was established in the aftermath of the Second World War by the signing of the “Treaty establishing the European Coal and Steel Community (ECSC) in 1951. Its function was originally to control the commodities necessary for warfare (coal and steel) through a customs union. Over time the original treaty became less important as Europe along with many other countries in the world became increasingly dependent on other fossil fuels, predominantly oil but also natural gas. In 1958, the “Treaty Establishing the European Atom Energy Community (Euratom)” came into effect, which became one of the first energy institutions in Europe. Its main purpose was originally to coordinate the member states peaceful use of nuclear energy, but has today evolved into providing other services on the matter, such as knowledge, infrastructure and funding (Langsdorf, 2011).

The road towards a common energy policy was not without complications as different energy mixes and geological conditions created a variety of priorities between the member states, in combination with a general resistance to give up political influence (Langsdorf, 2011). The EU was officially established in 1993 with the implementation of the “Maastricht treaty” (Maastricht, 1992). Its main functions was to strengthen the democratic legitimacy of the institutions, increase the efficiency within these institutions, create an economic and monetary union, develop the social dimension of the European community and create cohesive foreign and security policy. It was not until after an unofficial meeting in 2005 where the Council of the European Union pronounced that cohesive energy policy would be created for the union (EC, 2005). The results of this unofficial meeting were given legislative power by the Lisbon Treaty in 2007, which was implemented in 2009 and is specified in Article 194 of the Treaty on the Functioning of the European Union (Lisbon Treaty, 2007). EU energy policy is implemented by different market based tools such as subsidies, taxes and the CO2 emission-trading scheme. The EU has since 2008 been producing policy focused on achieving energy security and reducing the impact of global warming (DG Energy, n.d).

This is where natural gas comes into play, as it (to some extent) deals with the issues of energy security and climate change, being less sensitive to price fluctuations and in comparison to oil has potential CO2 savings of up to 25%. It is still a fossil hydrocarbon but of a more simple nature as it consists mainly of methane and therefore has very low sulfur and nitrogen dioxide emissions. (Energigas Sverige, 2014a) Therefore, natural gas has sometimes been used within the transport sector in order to improve air quality in major cities (Goyal & Sidhartha, 2003). It can be retrieved from conventional gas fields, unconventional gas fields (for example in the form of shale gas), obtained during the production of crude oil as well as recovered from coal-mines (IEA, 2013). Natural gas can be used in the form “compressed natural gas” (CNG) in an internal combustion engine in a natural gas vehicle (NGV), for heating, cooking or used to produce electricity in a gas turbine (Tekniska Verken, n.d.). It can also be transformed into liquefied natural gas (LNG), a process where the gas has been compressed at -163 Celsius, 1/600 of its original size making it suitable for long distance and heavy-duty road transport. LNG can also be used in as a maritime fuel. Natural gas has the benefit from an environmental standpoint that it can be interchangeable and mixed with biogas, an energy source that after it has been “upgraded” contains of mostly methane and small amounts of CO2. Biogas is produced during anaerobic digestion of biomass and in principle it has no CO2 emissions because it does not add any “new” CO2 into the atmosphere (Aga, 2012; Tekniska Verken, n.d.).
The EU transport sector is extremely dependent on oil and the IEA claims that the import bill for this fuel was in 2010 approximately €210 billion (EC, 2011). Approximately 95% of its total energy consumption is derived from petroleum (Statistical pocketbook, 2013). According to the transport whitepaper from 2011 his dependency will eventually affect the member states (MS) economic security and mobility as oil is becoming scarce and is a finite resource. At the same time, CO₂ emissions need to be heavily reduced over the coming 30 years in order to reach the transport sectors long-term reduction targets and therefore the EC are turning towards low carbon alternative alternatives (COM/2013/0017).

“The directive on the deployment of alternative fuels infrastructure” is the foundation of this thesis and its purpose is to increase the market uptake of alternative fuelled vehicles (AFV’s) in the EU through the build up of minimum infrastructure for electricity, hydrogen and natural gas, which were identified in the “alternative fuels strategy” (COM/2013/0018; COM/2013/0017). It was proposed in early 2013 and has been negotiated since that time. The EC claims that the directive will solve the “chicken and egg” situation of AFV’s, as car manufactures are not producing these vehicles due to lack of demand, as there is no or little infrastructure in place. This thesis will focus on a specific part of the proposed directive, namely the infrastructure for natural gas in form of CNG, a fuel suitable for light and medium duty vehicles (COM/2013/0018).

The scientific community agrees with the EC, that infrastructure is a barrier for large-scale adoption of NGV’s (Achtenicht, et al., 2012; MacLean et al. 2004), but that other factors such as a price difference of minimum 40% between natural gas and conventional fuels (diesel and gasoline) in combination with a payback period of less than four years is necessary, if not crucial to avoid market failure (Yeh, 2007). This is based on empirical evidence in countries where market penetration of NGV’s has occurred. New Zealand for example in the mid 1980’s had a NGV fleet of 10%, which eventually disappeared when the criteria’s mentioned above were no longer met (Yeh, 2007).

1.1 Aim of this study

The current energy situation described above brings out many new questions about the future situation of EU’s energy usage. Infrastructure has been asserted as a major barrier for market penetration of NGV’s, but empirical evidence claims it is not the sole decider for successful commercialization. Previous studies suggest that two economical factors, namely the “payback period” and the price difference between gasoline/diesel and natural gas, also come into play (Yeh, 2007).

The aim of this study is to determine if the current conditions for the “payback period” and the price difference between gasoline/diesel and natural gas are sufficient so that the directive on Deployment of alternative fuels infrastructure can potentially lead to a large scale market uptake of NGV’s in the EU. It will also through synthesis of a qualitative and quantitative assessment explore the future price difference between oil and natural gas.

As the directive is currently under negotiation, this thesis is extremely relevant and it will highlight current issues within the transport and energy sector. Its relevance is also a major downside as the directive is currently under negotiation and the eventual outcome might differ from the original proposal.

1.2 Data sources

Data for this report has been provided from a wide range of different sources. Current and historical energy data has been supplied from the oil and gas company BP (BP 2013). It is a free, frequently-used source recommended by scholars from Uppsala University and is often
referenced in different peer-reviewed articles and reports. Data from other trusted sources like the European statistical agency “Eurostat” and the International energy agency (IEA) has also been used but to a lesser extent.

A very important empirical study for this report is Sonia Yeh’s article from 2007 “An empirical analysis on the adoption of alternative fuel vehicles: the case of natural gas vehicles”. This article was encountered during the literature review for this report and was repeatedly referenced in peer-reviewed articles regarding natural gas vehicles. The study and its empirical findings were found trustworthy and applicable for this report.

While comparing fuel efficiencies between vehicles I have used data from the respective producer. Its trustworthiness can definitely be discussed but since this report does not compare vehicles from different companies this does not appear to be an issue, assuming that producer A has been consistent while testing fuel efficiency for the different models.

In order to make a broad assessment of the future price difference between oil and gas a mix of peer-reviewed sources and news articles were used. The news articles involved were mainly from Euractiv, a trusted source that covers and analyses the EU agenda. Also, the major news bureau Reuters and the Guardian were used as references, both of which can be considered trustworthy.

1.3 Delimitations

The cost of retrofit (conversion) has not been included in this report due to difficulties in retrieving accurate information, in combination with that I’m uncertain of what the fuel efficiency of a car would be after conversion making calculations on payback period difficult. I have not calculated a margin of error for the payback periods, but I am certain there is room for one as I have used default values for energy content and for converting kg of CNG into Nm³.

Due to time limitation it has not taken into account that the directive on alternative fuels infrastructure also proposes build up of LNG refueling that is more suitable for heavy-duty vehicles and ships that could increase the demand and also the price of natural gas.

1.4 Disposition

Depending on the academic background of the reader of this thesis it might be necessary to skip towards more detailed chapters of this thesis. If the reader has a good knowledge of the EU energy and transport sector then I would recommend moving directly to Chapter 3.

First of all, chapter 2 of this thesis project covers the main features of the EU and its main energy and transport strategies, followed a rather detailed description of EU’s energy usage, the main features of the EU natural gas markets. Chapter 3 describes the methodology used in this report with emphasis on the different criteria, which are necessary for the large-scale market uptake of NGV’s. Chapter 4 covers the results of the payback periods and the price differences in detail for each country studied and also an assessment of the future price differences of oil and gas in the EU. Chapter 5 includes discussion of the results and also the delimitations and uncertainties of this report followed by conclusions in chapter 6.
2. Background

2.1. The functioning of the EU

The EU has a very unique political system, and it is commonly known as “quasi-federal”. It’s three major legislative entities are: the European Commission (EC), the Council of the European Union and the European Parliament (EP) (EU Mep, n.d). The commission is divided into Directorates-General (DG) depending on area of responsibility; hence there is one for transport (MOVE), climate (CLIMA) and environment (ENVI) etc. The EC employs citizens from different parts of the EU and its purpose is to work for EU as a whole, not representing separate countries. The council on the other hand consists of representatives from the MS governments and work from a national standpoint. The only institution with a direct mandate from the EU people is the EP. The politicians are elected on a five-year basis and the numbers of representatives from each respective country vary depending on population size, where Germany being the largest has 98 members of parliament (MEP) and Sweden has only 20. Depending on ideology in their home country they join different political groups in the EP (EU Mep, n.d).

The EC is (almost) solely responsible for proposing legislation that will be implemented by the MS, and has been granted this right by “The Treaty on the Functioning of the European Union”. (The Lisbon treaty gave citizens of the EU the possibility to call directly on the EC to propose legislation, although for this to happen they require one million signatures in seven countries (Lisbon Treaty, 2007). In the beginning of a policy process, the EC releases green papers, which can be considered as consultation documents of policy proposals for stakeholders. They can result in white papers in form of roadmaps that describe the major challenges and outlines long-term objectives and guidelines for the specific policy area at hand (EU Legislation Summaries, n.d). Neither the white nor green paper hold any commitment to action or legislative power, although the whitepapers shows what regulation can be expected in the future, as the directives are normally motivated and derived from different whitepapers and strategies. After the EC has proposed a directive they are negotiated in the Council and (depending on subject) the appropriate EP committee whom might change or amend the directive. This is followed by a first reading in the plenary sessions (EU Legislation Summaries, n.d).

2.1.1. EU Transport policy

The cornerstone of current EU transport policy lies with the 2011 White Paper “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system” (COM/2011/0144). As described in the introduction, the dependency on oil is currently very severe and approximately 95% of fuel consumption in the EU comes from oil-derived products (Statistical pocketbook, 2013). The roadmap was created in order to increase economic stability and to cope with environmental challenges within the transport sector. A few ambitious targets have been set, for example by halving the use of “conventionally fuelled cars” (non hybrid internal combustion engines) for 2030 and to faze them out in cities for 2050 (EC, 2011). As for CO₂ emissions, the target is to cut them by 20% until 2030, and 60% for 2050 (EC, 2011). In order to limit CO₂ emissions for personal vehicles, the EP has approved that as of 2015, the average vehicle fleet emissions of all new cars sold cannot
exceed 130 grams of CO$_2$ per kilometer, and 95 gram per kilometer in 2021 (DG CLIMA, 2014).

“The directive on alternative fuels infrastructure” (COM/2013/0018), was released in January 2013 and goes in line with the 2011 whitepaper on transport (COM/2011/0144). Its main purpose is to increase the market uptake of alternative fuels within the EU, with the creation of fuelling and charging stations for alternative fuels; the main options being electricity, hydrogen, and natural gas in form of Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) or Gas-To-Liquid (GTL). The EC proposes a build up of sufficient minimum infrastructure for these fuels in order to allow full circulation of alternative vehicles within the EU along with technical standardization for vehicles and charging points, as the EC motivates that these factors have been hindering the development for alternative fuels. The minimum amount of electrical charging points vary from country to country, depending on current amount of electrical vehicles (EV’s) and long-term national targets and at least 10% of them need to be publically accessible. For example, Sweden would be required to have 145,000 charging points in total and 14,000 publically accessible, whereas for example Germany would be required to have 1,503,000 charging points, 150,000 of them publically accessible. For hydrogen vehicles, the minimum distance between charging stations would need to be 300 km in order for EU circulation to be possible (COM/2013/0018).

The main importance for this thesis, however, is that the proposed directive requires a rather substantial network favoring usage of natural gas. Applicable for short to medium distance journeys, an infrastructure for CNG would be constructed with a minimum distance between fuelling stations of 150km (Future Transport Fuels, 2011; COM/2013/0018). As for heavy duty vehicles and ships a sufficient number of LNG stations would be created, for the road sector at a minimum distance of 400 km between stations and for the maritime sector all ports within the Trans-European Transport (TEN-T) Core Network shall be equipped with LNG (COM/2013/0018).

2.1.2. EU Energy policy

The EC’s directorate-general for energy (DG Energy), describes natural gas as “critically important to the EU...in a time where European deposits are being depleted and consumer appetite continues to increase” (DG Energy, n.d). In the Energy Roadmap to 2050, the EC communicates the importance of natural gas in the short- and medium-term (2030-2035) as a substitute to oil and coal, in order to reduce CO2 emissions (DG Energy, 2011). If applied with Carbon Capture Storage (CCS) it could be seen as a long-term low carbon option, otherwise it would be preferred used as a back up supply to renewable energy sources. The commission also recognizes shale and other unconventional gasses as important sources of supply in Europe, referencing to the recent development in the US (DG Energy, 2011).

The EC’s short-term climate and energy targets includes the Europe 20-20-20 strategy, which include a 20% reduction of CO$_2$ compared to 1990 levels, raising the production of energy from renewable resources to 20% and a 20% improvement in energy efficiency until 2020 (EC, 2014). If other large-scale economies are committed to reducing their share of emissions the EC is willing to push the CO$_2$ reductions to 30% (EC, 2014). The policy’s main purpose is to combat climate change, increase EU’s energy security and competitiveness. The targets are implemented through a set of directives and measures; a reformation of the emission trading system, carbon captures storage, setting national targets for non-EU Emission Trading Scheme (ETS) and national renewable energy targets. Energy efficiency is regulated through the Energy Efficiency Plan and the Energy Efficiency Directive (EC, 2014; EC, 2014).
In order to control industrial pollution, the EP and the council in 2003 proposed a market-based mechanism for reducing CO₂ called ETS, which in principle means that company A would have the “right” to pollute up until a certain limit. Any greenhouse gasses released beyond that limit would need to be abated or company A would be in need to buy allowances from company B, if said company had cheaper abatement cost. This is done in order to ensure cost effectiveness. The allowances where divided through free allocation, but that will not be the case in the future as the EC is currently transforming the system. Companies will instead be allowed to purchase the rights at an auction (2003/87/EC).

Carbon capture and storage (CCS) is seen by the EC as an option for cleaning fossil fuel from CO₂ emissions from power plants and other point sources and it can be stored in oil and gas reservoirs and coal seams. The EC describes the rather high cost of CCS as a barrier for usage of this technology (DG CLIMA, 2014).

2.2. EU energy usage

EU’s energy sector is dependent on imported fossil fuels and the total import bill for oil and gas was in 2012 more than € 400 billion, approximately 3,1% of the unions GDP (Eurostat, 2010). Petroleum products have the largest share of the union’s energy mix at 35%, followed by natural gas at 24% (EC, 2013). In 2010, the EU consumed 1194 Million tons of oil equivalents (Mtoe) and 31,7% of this energy was used by the transport sector. The import dependency of solid fuels (e.g. coal, peat), petroleum and gas has in total risen by 25% between 1995-2011. This is due to an increase in energy consumption in combination with a decrease in EU energy production. As shown by figure 1, the import share of natural gas alone increased from 43,5 % to 67% between 1995-2011 (BP, 2013; Eurostat, 2010).

This can be expected to increase over the following years as EU production of fossil fuels is expected to decline further (BP, 2013). EU’s main import of natural gas is currently supplied by Russia (30%), followed by Norway (28%), Algeria (13%) and Quatar (11%) (DG ENERGY, 2013).
The usage of natural gas within the EU road transport sector has so far been very limited and there are currently only around one million road vehicles in use, including light, medium and heavy-duty vehicles, accounting for only 0.4% of the total amount of vehicles in the EU (Alamo, 2013). Figure 2 shows us that as of 2011, the EU transport sector consumes a large share of petroleum-derived products, and the EEA claims that 95% of the energy used comes from this source (Eurostat, 2013; EEA, 2013). The use of LNG within the maritime sector has also been quite limited but can be expected to rise as the sulfur directive comes into effect in 2015 (Energigas, 2014b). The directive is applicable to Sulfur Emission Control Areas (SECA) in Europe (Baltic Sea, English channel, North Sea) and limits sulfur emissions to 0.1% forcing the shipping industry to switch from the conventional “heavy fuel oil”, a low-grade residue from the distillation of petroleum, to cleaner alternative sources or cleaning techniques (McPhie & Caouette, 2007; 2012/33/EU).
When it comes to the future usage of natural gas within the EU transport sector the situation is quite unclear and projections tend to differ, although they are usually quite cohesive in the sense that they project an increase over the following 15 years (Eurogas, 2013; BP, 2013; European Gas Forum, 2012). The non-governmental interests group Natural Gas Vehicles Association (NGVA) believes that CNG/LNG vehicles can have a 9% market share in 2030 (NGVA, n.d). The credibility of these reports can definitely be discussed as potentially biased as they are written in association with several energy companies. However, peer-reviewed papers also support the notion of a potential increase, as the technology for these types of vehicles already exists and are well developed (Enger & Horn, 2009).

2.2.1. The European natural gas market

For this report, the price difference between oil and gas is very important, as it is a major factor when it comes to the uptake of NGV’s. Both oil and gas are finite resources and the price of them can be expected to rise as they are becoming more difficult to access (Aleklett, 2012).

One must keep in mind that oil and gas prices have a history of being closely coupled due to the fact if one analyses them from an economic standpoint, they are substitutes in terms of consumption and when it comes to production they act as complements, as well as rivals (Villar & Joutz, 2006). If the price for oil increases the consumer will switch over to natural gas hence causing an increase in price for gas while at the same time decreasing the price for oil due to less demand. They compete mainly in electricity generation and within the industrial sector. From the supply (production) side natural gas is found in two forms namely associated and non-associated. Associated gas exists in crude oil reserves either as free gas or
in solution with crude oil. Non-associated gas is not in contact with significant amounts of crude oil. Crude oil and natural gas production are therefore strongly interlinked as they can be extracted from the same resources (Villar & Joutz, 2006).

As shown by fig. 3 the prices between the resources in the EU are closely coupled (BP, 2013). With this information one would think that the current price relations, which are not naturally giving favor to natural gas as an automotive fuel being, would be kept in the future, but studies and projections suggest that this is not necessarily the fact, that future decoupling is possible. This is currently the case in the US (Nasdaq, 2014; Erdos, 2012).

The price for natural gas in the EU has been set through three different types of price formation mechanisms:

- Long-term contracts (LCT’s) with oil indexation
- Gas on gas competition (GOG)
- Regulated prices (EC, 2014)

LTC contracts with oil indexation are bilateral contracts between the gas producer and an importing utility that upon receiving the gas resells it to distribution companies and larger industrial consumers (EC, 2014). They are directly linked to the price of oil but newer indexation formulas have recently been updated to also include linkage to other commodities such as electricity and the value of hub priced gas (EC, 2014).

GOG is a market-based pricing system, simply based on supply and demand which is currently the method used in the US (Economist, 2012). Regulated prices are controlled by national agendas (EC, 2014).

In 2012, 45% of European gas trade was through GOG and 50% was traded with LTC’s (EC 2014). Since the oil and gas prices historically have been closely correlated, LTC’s make sense as they secure energy supply. The negative side however is when decoupling occurs and the price for oil rises while the gas price remains low, the importer is stuck with a contract that is priced higher than market price. This occurred in the aftermath of the financial crisis in 2008 when EU gas demand had decreased. Qatar had developed a major LNG supply meant for the US that was not needed due to the shale gas boom. Qatar, who then needed to find other buyers, turned to Europe, which led to an increased supply of gas and therefore lower

![Price-relation Crude Oil vs. Natural Gas](bp.com)

*fig. 3, price-relation crude oil vs. natural gas, 1996-2012 (BP, 2013)*

The price for natural gas in the EU has been set through three different types of price formation mechanisms:

- Long-term contracts (LCT’s) with oil indexation
- Gas on gas competition (GOG)
- Regulated prices (EC, 2014)
prices, which was very negative for importers stuck with LTC’s. It forced Gazprom and Statoil to include “spot prices” within the contracts, leading up to the higher percentage of GOG pricing in the EU that we have today (Economist, 2012). It is important to note that in 2005, GOG only accounted for 20% of European gas trade (EC, 2014). The EC has been trying to implement a domestic liberal energy market since 2000 through a set of directives, but according to the Economist, it was the increased supply of Qatari gas that made the real change and that future liberalization might be slow (Economist, 2012; EC, 2014).

2.2.2 Projected price difference natural gas and oil

The price projections in figure 4 describe the future price difference between oil and gas, which supports a notion of decoupling. This data however was supplied to the authors by the IEA, which data projections should be analyzed with some caution as their data has previously been criticized (Aleklett et. al, 2009). Even though the exact numbers might differ from reality, the general themes of these projections are acknowledged.

The US is a good example of a country that has experienced decoupling of natural gas and oil prices. It used to be heavily dependent on foreign oil but with the introduction of new technologies such as “fracking” and horizontal drilling the country has in recent years become increasingly reliant on domestic resources such as shale gas. It cannot be conceived as anything else than an energy “boom”, with shale-related production increasing with an astonishing 417% between 2007 – 2012, which is shown by figure 5 This led to a 20% total increase in natural gas production over the same period (BP, 2013).

Since the US did not export gas, overproduction led to a drastic price fall, as shown by fig. 6 (Nasdaq, 2013). As shale is a non-associated gas, meaning that it is not a bi-product of crude oil production, the prices where decoupled in the US due to a dramatic increase in production of a resource that was not related to oil which makes it necessary to investigate the potential supply of excess gas in Europe and elsewhere (BP, 2013).
2.3. Projected global energy demand

In order to understand the EU’s energy usage, one must look at global demand. These types of projections should be read with some caution, but the figure 7 and 8 supplied by BP’s “World Energy Outlook to 2035” gives us an idea of what we can expect when it comes to future energy consumption, with stagnation in OECD EU and little variation in the US. Emerging countries China and India stand for most of future demand (BP, 2014).
2.4. EU vehicle fleet

Gasoline and diesel are vehicles are dominating the EU road transport sector. Figure 9 illustrates that on average, diesel vehicles account for 55% of new registration whilst gasoline stands for 44%. For the countries that will be analyzed in this report diesel cars had a 48% market share in Germany, 51% in the UK, 73% in France and 69% in Spain. Hybrids, electrics, NGV’s and ethanol together account for only1% of total new registrations. Figure 10 shows us that with an exception of Italy, NGV’s account for very few of the vehicles in Europe (ICCT, 2012).
Figure 11 shows that in general, vehicles registrations in Europe are on a negative slope, which could serve as an indicator for changing behavior or possibly that cars produced in the last decade are of better quality. The ICCT claims the spike in 2009 that followed the financial crisis is due to financial stimulus and is not part of the general market trend. The five largest countries (and vehicle markets); Germany, UK, France, Italy and Spain together account for 75% of all new vehicle registrations (ICCT, 2012).
fig 11. Vehicles registrations in Europe (ICCT, 2012)
3. Methodology

The following section describes how this report will make an assessment of the two major criteria affecting the market uptake of NGV’s. Firstly, previous studies suggest that the price for natural gas needs to be approximately 40-50% less, in order to avoid market failure of NGV’s even if the appropriate infrastructure is in place (Yeh, 2007). Therefore, section 3.1 describes in detail how these prices will be compared, followed by section 3.1.1 which lists what methods that will be used to project the future price difference between oil and gas in section.

Secondly, previous studies suggest that customers prefer their investment payback within three to four years while choosing fuel economy, findings which are consistent with countries that have had successful NGV market penetration. To calculate this it is necessary to create a formula as shown by section 3.2.

3.1. Price difference between natural gas and conventional fuels (gasoline, diesel)

The prices will be compared based on average prices for gasoline/diesel and CNG gasoline/diesel equivalents converted from normal cubic meters (Nm³). The price of gasoline/diesel and natural gas data is collected from NGVA Europe and is based on a yearly average from 2013 (NGVA, 2013). The reason that the prices are compared after natural gas (in form of CNG) has been converted into gasoline/diesel equivalents, priced per liter, is due to the fact that it is the “comparable price” that needs to 40-50% lower, not the real price difference sold at fuelling stations. Depending on country, CNG is measured and sold in kilos or Nm³ which if not converted would be much more difficult to compare. For this report applies that: 1 kg CNG = 0,73 Nm³. The conversion factor varies depending on the normal density of gas in each country but it is in this case set to a default mean value. Gasoline, diesel and natural gas have different energy content so the default values that are needed in order to create comparable equivalents are:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CNG</th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy content/liter</td>
<td>0,0096 kWh/liter (9,6kWh/Nm³)</td>
<td>8,8 kWh/liter</td>
<td>9,85 kWh/liter</td>
</tr>
</tbody>
</table>

(NGVA Europe, 2013)

The numbers differ with an average of 0.5 kWh compared to another source (Biogasportalen, n.d), which has estimated higher energy content per each fuel. Both sources however estimate equal differences between the fuels in percent, and since this study is based on comparisons this is what matters.

3.1.1. Future price difference natural gas and conventional fuels

In order to analyze the future price difference of natural gas and oil I will use a supply and demand model (figure 12) under the conditions of an oligopolistic market (Holz, 2009). This means that there are few actors as certain barriers such as large start-up costs and geopolitical limitations make it difficult for other entities to join. Perfect competition is not in place and
producers are able to set marginal price much higher than marginal cost, hence making the consumers into price-takers. The suppliers set prices in relation to what the other actors are doing (Pindyck & Rubinfeld, 2013; Cigerli, 2012; Carlton & Perloff, 2005).

As shown in figure 12, the fundamentals of supply and demand tell us that a supplier will sell a certain amount of units to an increasing price (MIT, 2011). The customer on the other hand is willing to pay more for more units. If perfect information and competition is in place the price is set at the intersection of the two curves, called equilibrium where marginal cost is equal to marginal revenue. If there where to be an increase in supply the blue line would be pushed to the right leading to an equilibrium at a lower price. If on the other hand demand would increase this would mean an increasing willingness to pay pushing the red demand curve to the right meaning an increased price per unit (MIT, 2011).

The natural gas market is obviously not under perfect competition, where for example, the Russian gas exporter Gazprom controls 70% of Russia’s natural reserves and produces 78% of the countries gas (Nord Stream, n.d). However, empirical evidence points out that further LNG trade could increases the number of both importers and exporters bringing additional competition and supply to the natural gas market with lower gas prices and increased liberalization with more GOG competition as a result (Dorigoni et al. 2010). Also domestic shale gas reserves could have a similar impact as was seen in the US. This report will analyze the natural gas and oil prices with these empirical finding taken into account (Nasdaq, 2014; Dorigoni et al. 2010; Holz, 2009; Dorigoni & Portatadino, 2008).

![Supply and Demand Model](image)

The supply and demand model is very simplified and does not include a wider spectrum of factors such as environmental, social or political. Therefore, in order to make a better assessment of the natural gas and oil prices the analysis will include the 4 A’s method (Hughes, 2010) when discussing the supply of oil and gas, which are defined as followed:

- **Availability** indicates “the amount of supply of a given primary energy resource in terms of known reserves”
- **Accessibility** can be seen as a compliment to the first “A”, as sources can be available but non accessible due to technical, social, political and environmental elements.
- **Affordability** refers to the cost of fuel, infrastructure and the cost of energy services.
- **Acceptability** refers to Environmental awareness in combination of stricter regulation creates constraints towards fossil fuels do to CO2 and particle emissions.
These factors are normally used to study energy security but as they are adding another dimension to the simplified supply and demand model the analysis is able to give a much more clear and realistic picture of the situation.

3.2. Payback period

In order to calculate the payback period I have used a formula that includes the different economic parameters specified in Yeh (2007):

\[
I > Y \times \left( \frac{D \times F}{(P - PDif \times E)} \right)
\]

- \( I \) = Investment price difference between a NGV and a conventional vehicle (€)
- \( D \) = Average Distance Travelled (Kilometers/year)
- \( F \) = Fuel Efficiency/Kilometers
- \( P \) = Gasoline/diesel price (€)
- \( PDif \) = Price difference between gasoline/diesel and natural gas
- \( E \) = NGV fuel efficiency multiplier
- \( Y \) = Year until financial payback

Investment price (I) difference between a NGV and a conventional vehicle will be calculated on a case by case basis, as retail prices and potential tax breaks that affect the payback period differ to a great extent between countries and they are necessary in order to calculate the “total cost of ownership”, (TCO) The vehicles compared will be of the same or similar model in cases where there is no conventional equivalent, with a maximum difference of engine output of 20%. This is done in order to ensure validity of the report, as the payback period for a vehicle with more horsepower is not comparable due to the fact that the investment cost and fuel consumption can be assumed to be higher (Esaisson et al., 2007). This is also based on the assumption that the consumer’s preferences are the same when it comes to buying an NGV or a conventional vehicle, e.g. weight, engine output and quality. Average distance travelled (D) is based by national yearly estimates. In order to compare fuel efficiency (F), the average consumption of gas is converted from kilos (kg) or “normal cubic meters” (Nm³) into “gasoline/diesel equivalents”. The default values used for this are:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CNG</th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy content/liter</td>
<td>0,0096 kWh/liter (9,6kWh/Nm³)</td>
<td>8,8 kWh/liter</td>
<td>9,85 kWh/liter</td>
</tr>
</tbody>
</table>

(NGVA Europe, 2013)

The efficiency will be based on overall usage, as city and highway driving generate different fuel consumption patterns (Miljöfordon, 2014). NGV fuel efficiency multiplier (E) is simply the difference energy efficiency between the NGV and the conventional model represented by a multiplication factor. For example if the NGV is 10% more efficient than the conventional vehicle the multiplication factor will be 0,9 and if the NGV would be 10% less efficient the factor would be 1,1. The Fuel efficiency comparison is calculated based on difference between energy contents of the fuels using the default values described above.

Based on previous studies, the year until payback in this case needs to be less than four in order for the investment to be perceived as profitable (Yeh, 2007). For this project, a payback period of less than four years will be considered as favorable market conditions positively affecting the uptake of NGV’s. The numbers are based on current (or recent) retail...
prices, which will serve as an indicator of how the directive on Deployment of alternative fuels infrastructure will affect the market uptake of NGV’s if it was implemented today. Ideally, payback periods would be calculated based on 2020 projections when the directive is implemented, but since subsidies and tax cuts can change rapidly depending on government, I have chosen to work with current numbers. This is due to the fact that subsidies and tax cuts have an adverse effect on years until financial return.

Due to time limitation I will focus on comparing two NGV’s with two gasoline/diesel models; the Fiat Punto and the Audi Sportback. I will then investigate the cost for these vehicles in the four largest (by population) EU countries that has not had successful market penetration namely Germany, United Kingdom, France, and Spain. As described earlier, the five larges countries account for roughly 75% of the new registrations of vehicles within the EU (ICCT, 2012). Italy has been excluded as they have the largest NGV vehicle fleet in the EU (NGVA, 2013). I am acknowledging that the value of an NGV and a conventional car might have different discount rates but do to the time limit of my report this will not be included in the calculations. Also, the service interval of an NGV is very similar to a conventional vehicle and does not in the short-term affect the total cost of ownership (Biogas, n.d).
4. Results

In this section, the tables presented below are price differences between CNG, gasoline and diesel in the EU from 2013. First of all table 13 and 14 show us the prices of CNG equivalents compared to the gasoline and diesel, followed by figure 15 and 16 which in percent show how much lower CNG is compared to the two fuels.

4.1. Fuel price comparison

The prices shown below in figure 13 and 14 are price comparisons for CNG with the conventional fuels gasoline and diesel. As described in the methods section due to energy content, the CNG equivalents becomes different depending on what fuel it is set in comparison with. As diesel has higher energy content than CNG (Nm$^3$), it has a higher real value whereas the opposite applies for gasoline. For example, the cost for 1 Nm$^3$ of natural gas in Austria was 0,74 € which converts into 0,66 € of gasoline equivalents and 0,76 € of diesel equivalents.

\[ \text{Cost for 1 Nm}^3 \text{ of natural gas in Austria: } 0.74 \text{ €} \]

\[ \text{Converted to gasoline: } 0.66 \text{ €} \]

\[ \text{Converted to diesel: } 0.76 \text{ €} \]

**fig. 13, CNG (gasoline) equivalents and gasoline prices in the EU 2013. **"\ast\" signifies real price difference. (NGYA, 2013).
Figure 15 describes the difference in percent between CNG equivalents compared to gasoline prices. For example in Lithuania one could purchase 1 liter of CNG equivalent for 40% less than the price 1 liter of gasoline, whereas in Latvia CNG was 74% cheaper. The criteria for favorable market conditions for NGV’s described by previous studies suggest that CNG prices needed to be 40-50% lower (Yeh, 2007). This is true for almost all cases in the EU besides Sweden, Denmark and Portugal (39%) (Sweden still has a rather substantial NGV fleet of 44,321 vehicles but the Swedish government has chosen to subsidize the vehicles directly instead of the fuel) (NGVA, 2013). The main subjects for this study are all well above the criteria line, with Germany at 56%, France at 46%, the UK at 53% and Spain at 50%.
Figure 16 shows that the price difference in Germany, UK and Spain is within the criteria of 40% in comparison to diesel. France on the other does not qualify with only a 28% price difference.

![CNG eqv. price difference % / Diesel 2013](image)

*Fig. 16, CNG equivalents (gasoline) as percent (%) lower price than diesel in the EU (NGVA, 2013)*

### 4.1.1. Fuel price comparison by country

#### 4.1.1.1. Germany

With a rather substantial price difference between gasoline and CNG equivalents at 56% Germany has a quite developed NGV fleet of 96,349 vehicles. However, considering that Germany has 587 cars per 1000 human population and in total has a population of over 81 million, the total share of NGV’s is very low. The price difference between the two fuels is due to the fact that CNG has a reduced tax of 13,90 €/MWh, applicable until 2018. When it comes to the comparison of CNG and diesel the price difference is less significant than compared to gasoline, but at 43% lower it still reaches the criteria for favorable market conditions for NGV’s *(NGVA, 2013)*.

#### 4.1.1.2. UK

The UK has had a very limited market penetration of NGV’s, and as of 2013 they are only 559. The country fills the criteria for price difference, where CNG is priced 53% lower than gasoline and 49% lower than diesel due to favorable taxation for CNG. The limited number of CNG vehicles can be attributed to the very low number of refilling stations in the country that are only 9 *(NGVA, 2013)*.

#### 4.1.1.3. France

France meets the price difference criteria with 46% when comparing CNG to gasoline. The case for diesel is different where CNG is only 29% lower than diesel and therefore not meeting the criteria of minimum 40%. The significant price difference between gasoline and diesel has on the other hand contributed to a large uptake of diesel vehicles in France, and in 2012 over 70% of new cars sold were diesel fuelled *(Lucchese, 2012)*.
4.1.1.4. Spain

The price difference of CNG compared to gasoline is 50%, which meets the criteria for significant price difference. In comparison to diesel CNG is sold at a 40% lower price, providing favorable market conditions for CNG in Spain. The price difference is due to lower taxes on CNG as vehicle fuel of 0.414 €/kWh, which is 6.5 times lower than the tax on diesel (NGVA, 2013).

4.1.1.5. Subsidies

The countries that are described above are all in need of subsidies in order for the price difference criteria of minimum 40% to be true. If removed, CNG would not be considered as an attractive option, especially in relation to diesel where the margins are rather slim. Unfortunately, projecting the future implementation of subsidies or difference in taxation would be extremely difficult as it differs between governments in the respective countries.

4.1.2. Future price difference natural gas vs. oil

4.1.2.1. EU domestic gas reserves and pipeline projects

**Availability/Accessibility/Affordability/Acceptability**

On a global scale the EU member states hold very little of the world’s natural gas reserves (BP, 2013). At the end of 2012, proven reserves were 1.6 trillion cubic meters (tcm), which is roughly 1% of the total supply, and both domestic reserves and production are in decline. Russia on the other hand has 17.6% of the world’s proven reserves, Turkmenistan 9.3% and Norway with 1.1% (BP, 2013).

Large-scale extraction of shale gas in the EU would lower the prices and promote the usage of this energy source within the transport sector but the conditions for this to occur do not look promising given the evidence presented below. Experts estimate the total amount of technically recoverable shale gas resources in Europe to be approximately 18 Tcm, with France, Poland and Romania having the largest shares (Papatulica, 2013). In total, Europe’s shale gas resources account for only 4% of the world’s total shale gas reserves of 425 Tcm. 33% of these reserves are located in North America and 36% in Russia (DOE/EIA, 2011).

The profitability and therefore also the frequency of extracting resources are correlated with the market price of the resource at stake, as shown in figure 17. Ruud Weijermars from Delft University has written an economic analysis of the internal rates of return (IRR) and net present values of four wells in Europe and one in Turkey (Weijermars, 2013). The article shows uncertainty in how profitable a number of shale wells actually are. In this case, the Polish and Austrian wells were considered profitable while the Swedish, German and Turkish were not (Weijermars, 2013). Another study points out that the main reasons that shale wells are less likely to become profitable in Europe compared to the US are geological differences, the fact that the EU gas is located at much larger depths making it more difficult and expensive to extract. Also, many countries in Europe have much higher population density than the US and as shale gas extraction or “fracking” can have negative environmental effects this will in turn affect more people creating public concern. (Papatulica, 2013) The latter is actually a great issue for the natural gas companies as public protest has made it necessary to discontinue extraction, for example in Romania (Reuters, 2013). It has also been banned in countries such as France, Bulgaria and a major Dutch bank Rabobank has stopped.
financing any type of shale gas activity (Euractiv, 2014b; Dutchnews, 2013). The EC’s Joint Research Centre (JRC) agrees with the claims stated above, and that shale gas will have a rather limited impact on EU’s energy dependency, as resources are not large enough and difficult to extract. At best it will replace the decline in domestic EU conventional gas production (Pearson et. al, 2012; NewScientist 2012).

In order to decrease dependency on Russian gas the EU has set out plans to retrieve gas from the Shah Deniz II gas field in Azerbaijan. This will be done through the Trans-Adriatic-Pipeline (TAP), which is planned to run from the boarder between Turkey and Greece, forward through Albania across the Adriatic Sea and into Italy and Western Europe. (Trans-Adriatic-Pipeline, 2014; Euractiv 2013a) On the 17th of December 2013 EC president Barroso signed an investment decision in the gas field Shah Deniz II, the TAP and also the pipeline connecting the two, namely the Trans-Anatolian-Pipeline from the Turkish-Georgian boarder to the Turkish-European boarder (Euractiv, 2013a). The plan is to supply the EU with gas starting 2019 with 10 bcm of Azerbaijani gas and 6 bcm Turkish gas per year (Euractiv, 2013a). This can diversify supply from Russia, but it is important to know that the trade is done through signing of long-term oil indexed contracts, which may not further decouple the prices between oil and gas in Europe (E.ON, 2013; Enerdata, 2013; BP Global 2013).

Another pipeline project might be able to bring additional gas to the EU market, namely the Trans-Caspian-Pipeline that would go from Turkmenistan and then connecting to the Azerbaijani TAP bringing gas into Europe (Eurasianet, 2013). Turkmenistan however has signed a deal for substantial amounts of gas to China whom is a prime investor in a major gas field. Depending on negotiations with China and further developments of Turkmenistan’s resources there might be gas available to the EU through the TAP. Azerbaijan however might be reluctant in providing access for the Turkmen gas as it would increase competition and the transportation fees might not cover the losses in gas sales. (Natural gas Europe, 2013) What is important for these projects is that the EU is unlikely to become dependent on solely high-risk pipelines due to geopolitical issues and conflicts along the way. Wood writes that: “The dilemma for the EU is that it must invest large amounts of capital in both new pipeline and LNG supply chains” (Wood, 2012).

4.1.2.2. The role of LNG

Availability/Accessibility/ Affordability/Acceptability
Potential US LNG exports to Europe would increase natural gas supply as US suppliers are expected to peg prices to the US Henry Hub, (gas on gas competition) rather than to oil indexation, which could decouple oil and gas prices in Europe (Deloitte, 2013). As supply increases and the EU market is more liberalized natural gas prices could become even less expensive than oil, which could increase the uptake of natural gas within the transport sector. Empirical evidence also points out the US LNG would have a competitive advantage from current Russian pipelines (Moryadee et. al, 2014). The question is however if LNG will be supplied to the EU in the future or if it will be lost to the growing Asian demand. The US has been considered as a future LNG exporter to the EU and the UK gas company Centrica struck a deal in 2013 with an US producer Cheniere to start the import of LNG (Euractiv, 2013c). During 2013, the US energy department issued six permits and political opinion wants to speed up the process of LNG export permits (Rascoe, 2014). In line with this, during the recent developments of the Crimea crisis, the “Visegrad 4” countries Poland, the Czech Republic, Hungary and Slovakia has recently asked the US congress to simplify the exporting process in order for the US gas to reach the shores of Europe at an earlier stage (Euractiv, 2014a). US Energy secretary Moniz says that an LNG export project will commence in 2015 and that six more will be available at the end of the decade. A very important note is that Moniz also explains that there is no certainty where these shipments will go (Euractiv, 2014c). At a later stage Council president Rompuy and EC president Barroso requested the same thing from president Obama, whom stressed the urgency of the EU to facilitate its own shale gas reserves (Traynor, 2014). The EU and the US are currently working on a free trade agreement, something that could also hasten the access to American gas (Traynor, 2014). The uncertainty lies in that the increasing demand of energy in Asia might displace US LNG exports to the east. This in combination with a potential decrease in natural gas consumption in Europe could cause an increasing price difference between the EU and Asian markets, which would make Asia into a more profitable importer (Massy & Vukanmovic, 2014). Also, as shown by fig. 17 the depressed gas prices in the US has led to a decreased gas rig counts and well completions which brings concerns regarding the future security of shale gas output (Weijermars, 2014).

4.3. Payback period

For this report I have chosen two different car models in different price ranges in order to get an understanding of the payback period for NGV’s. The costs for the vehicles have been retrieved from the different car manufactures websites depending on country. In some cases it is the retail price that is listed which include VAT and in some countries it is a “on the road price” which include registration plates, half tank of gas etc. I have been very diligent in making sure that when comparing prices a NGV Punto “on the road price” is compared with a gasoline Punto “on the road price”, as to guaranty reliability.

In the table below, I have presented the fuel-efficiency data for CNG, gasoline and diesel versions of the Fiat Punto and the Audi A3 Sportback, as well as the NGV fuel-efficiency multiplier which is necessary in order to calculate the payback period using the formula presented in chapter 3.2. All technical data on the vehicles is retrieved from the car manufactures websites (Fiat, nd; Audi, n.d).

<table>
<thead>
<tr>
<th>Model</th>
<th>Fiat Punto (CNG) 1.4 (.77/70)</th>
<th>Fiat Punto (Gasoline) 1.4. (77) Start/StopTM</th>
<th>Fiat Punto (Diesel) 1.3MultiJet85c hStart/StopTM 90g (85)</th>
<th>Audi A3 Sportback (CNG) 1.4 TFSI (110)</th>
<th>Audi A3 Sportback (Gasoline) 1.2 TFSI (105)</th>
<th>Audi A3 Sportback (Diesel) 1.6 TDI (105)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Vehicle fuel efficiency multiplier

<table>
<thead>
<tr>
<th></th>
<th>Fiat Punto Gasoline</th>
<th>Fiat Punto Diesel</th>
<th>Audi Sportback Gasoline</th>
<th>Audi Sportback Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.995</td>
<td>1.45</td>
<td>1.0063</td>
<td>1.159</td>
</tr>
</tbody>
</table>

In the following sections, information is provided on vehicle price, fuel prices, fuel price difference multiplier, and average annual distance travelled, which is then used to calculate the payback period according to equation presented in chapter 3.2. (Calculations are found in the Appendix.)

4.3.1 Payback period Germany

<table>
<thead>
<tr>
<th></th>
<th>Fiat Punto CNG</th>
<th>Fiat Punto Gasoline</th>
<th>Fiat Punto Diesel</th>
<th>Audi Sportback CNG</th>
<th>Audi Sportback Gasoline</th>
<th>Audi Sportback Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Fiat Punto 1.4</td>
<td>Audi A3 Sportback 1.4 TFSI</td>
<td>Fiat Punto 1.4 Start/StopTM (77)</td>
<td>Audi A3 Sportback 1.2 TFSI (105)</td>
<td>Fiat Punto 1.3 MultiJet85chStart/St opTM 90g (85)</td>
<td>Audi A3 Sportback 1.6 TDI (105)</td>
</tr>
<tr>
<td></td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td>Price €</td>
<td>15890</td>
<td>25900</td>
<td>13390</td>
<td>22800</td>
<td>15790</td>
<td>25700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>Fuel price difference multiplier (gasoline vs. CNG)</th>
<th>Fuel price difference multiplier (diesel vs. CNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.6</td>
<td>1.4</td>
<td>0.44</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Payback periods CNG

<table>
<thead>
<tr>
<th></th>
<th>Gasoline comparisons</th>
<th>Diesel comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiat Punto Gasoline</td>
<td>3.48</td>
<td>0.83</td>
</tr>
<tr>
<td>Audi Sportback</td>
<td>5.07</td>
<td>0.786</td>
</tr>
</tbody>
</table>

4.3.2 Payback period UK

<table>
<thead>
<tr>
<th></th>
<th>Fiat Punto CNG</th>
<th>Fiat Punto Gasoline</th>
<th>Fiat Punto Diesel</th>
<th>Audi Sportback CNG</th>
<th>Audi Sportback Gasoline</th>
<th>Audi Sportback Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Fiat Punto 1.4</td>
<td>Audi A3 Sportback 1.4 TFSI</td>
<td>Fiat Punto 1.4 Start/StopTM (77)</td>
<td>Audi A3 Sportback 1.2 TFSI (105)</td>
<td>Fiat Punto 1.3 MultiJet85chStart/St opTM 90g (85)</td>
<td>Audi A3 Sportback 1.6 TDI (105)</td>
</tr>
<tr>
<td></td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td></td>
<td>22862</td>
<td></td>
</tr>
</tbody>
</table>
Prices have been converted from pounds to euro using a currency exchange website. (valuta.se, 2014) The Fiat Punto CNG is currently not for sale in the UK due to an extremely underdeveloped NGV market. Therefore a default potential value has been calculated based on the price differences for the vehicles in Germany. The price relation between the gasoline and diesel versions of the Punto where almost identical in the UK and, therefore such an estimate can be considered reliable.

4.3.3 Payback period France

France
Average Annual Distance Travelled: km 12090 km (La sécurité routière, 2012)

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>CNG</th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Fiat Punto 1.4 (77/70)</td>
<td>Audi A3 Sportback 1.4 TFSI (110)</td>
<td>Fiat Punto 1.4, Start/StopTM (77)</td>
</tr>
<tr>
<td>Price €</td>
<td>17050</td>
<td>26380</td>
<td>13750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gasoline price €/L</th>
<th>Diesel Price €/L</th>
<th>Fuel price difference multiplier (gasoline vs. CNG)</th>
<th>Fuel price difference multiplier (diesel vs. CNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.53</td>
<td>1.33</td>
<td>0.54</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Payback periods CNG

<table>
<thead>
<tr>
<th></th>
<th>Gasoline comparisons</th>
<th>Diesel comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiat Punto Gasoline</td>
<td>4.34</td>
<td>1.1</td>
</tr>
<tr>
<td>Audi Sportback Gasoline</td>
<td>5.64</td>
<td>0.58</td>
</tr>
</tbody>
</table>

For the diesel comparisons CNG is only 29% cheaper which, in combination with the fuel efficiency advantage of the diesel Fiat Punto, gives us a negative payback period of -6 which of course is an inconclusive number and simply means that even though the CNG Fiat Punto has a very low added investment cost, you will never get your investment returned through fuel savings. The correct value is therefore not -6, it should rather be infinity.
### 4.3.4 Payback period Spain

**Spain**

Average Annual Distance Travelled: km 12000 km *(Arrojoaudi, 2012)*

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>CNG</th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Fiat Punto 1.4 (77/70)</td>
<td>Audi A3 Sportback 1.4 TFSI (110)</td>
<td>Fiat Punto 1.4 Start/StopTM (77)</td>
</tr>
<tr>
<td>Price €</td>
<td>13550</td>
<td>25850</td>
<td>11750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gasoline price €/L</th>
<th>Diesel Price €/L</th>
<th>Fuel price difference multiplier (gasoline vs. CNG)</th>
<th>Fuel price difference multiplier (diesel vs. CNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.43</td>
<td>1.33</td>
<td>0.50</td>
<td>0.60</td>
</tr>
</tbody>
</table>

**Payback periods CNG**

<table>
<thead>
<tr>
<th>Gasoline comparisons</th>
<th>Diesel comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiat Punto Gasoline</td>
<td>Audi Sportback Gasoline</td>
</tr>
<tr>
<td>3.66</td>
<td>4.62</td>
</tr>
<tr>
<td>Fiat Punto Diesel</td>
<td>Audi Sportback Diesel</td>
</tr>
<tr>
<td>1.38</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Figure 18 below shows us the comparative advantage in term of payback periods for the diesel comparisons. They are all well below 4 years, whereas the gasoline comparisons are greater than 4 years and more uncertain.

![Payback period CNG vs. Gasoline and Diesel](image)

*fig. 18, Payback period NGV in comparison to gasoline and diesel vehicles*
5. Discussion

5.1 Primary findings

The results of the study, summarized in table 1, indicate mixed findings. The conditions for the price differences between the vehicle fuels are almost optimal except for France where diesel fuel is only priced 29% lower than CNG, which is not within the criteria. The price differences between diesel and CNG are in a few cases very sensitive as both Spain (40%) and Germany (43%) are very close to the criteria of minimum 40%. In summary, the conditions for the diesel comparisons (both payback periods and fuel price differences) are very positive and Germany, UK and Spain all have optimal conditions. The little added investment cost for an NGV compared to diesel keep the payback periods all below two years, well within the four-year criteria. This is of great importance as diesel vehicles currently have a very strong position on the EU vehicle market (55% of new registrations).

Table 1: Summary: Payback periods and fuel price differences

<table>
<thead>
<tr>
<th>Criteria/Countries</th>
<th>Germany</th>
<th>UK</th>
<th>France</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline Price dif.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Diesel Price dif.</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Gasoline Fiat</td>
<td>✓</td>
<td></td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Gasoline Audi</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Diesel Fiat</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Diesel Audi</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ = Criteria met blank = Criteria not met

In the gasoline payback period comparisons, conditions are sub-optimal for the market penetration of NGV’s in the EU. When analyzing the payback periods one notices that it is only in two cases, the Fiat Punto in Germany and Spain, which are within the criteria range. There are some vehicles, which are close to the four-year criteria line; the French Audi Sportback (4.34 years) and the UK Fiat Punto (4.23 years).

5.2 Validity of payback calculations

The NGV’s in comparison to gasoline cars do not have a solid case in this analysis, as you only need a slight variation in annual distance travelled, fuel price differentials in order for them to be above, or below the criteria line. The diesel comparisons make a much more convincing case as they are all well below the four year limit. An important note is that the diesel comparisons are in comparison to the NGV’s very energy efficient hence making them sensitive to price changes. For example in Spain an increased investment cost of 500€ for an NGV Fiat Punto compared to the diesel equivalent brings the payback period way above the criteria limit. Even if the numbers in this report are solid and within a statistical margin of
error it becomes evident that price positioning for NGV’s is very important in order to maintain beneficial market conditions.

The inclusion of additional car models would have made a more solid analysis but conclusions and generalizations can still be made from my results, as the IEA claims the average increased production cost compared to gasoline vehicles is between 1450€ to 2020€ depending on vehicle size which goes in line with the numbers used in my calculations (IEA, 2010). An important note is also that the payback periods are strongly correlated with the price difference between the different fuels and as a large majority of EU countries (as shown by chapter 5.1) fill the criteria for both diesel we can most likely expect favorable market conditions also for the diesel compared payback periods in other parts of Europe.

This report has gathered empirical data analyzing the probability of market penetration for NGV’s in Europe, but there are many uncertainties as well as factors that could rapidly change the current conditions. If the infrastructure was in place it could send positive signals towards car manufactures to produce more NGV’s. If this then would lead to large-scale production the costs could potentially decrease causing the added investment of a NGV to decrease hence shortening payback periods below the reference year.

5.3 Development of electric vehicles

Other questions that arise that affect payback periods are annual distances travelled. Will EU drivers continue to drive the same distances in the future or will it be displaced by other modes of transport? If you look at the distance travelled by cars in France it has been a decreasing trend during the last 10 ten years (La Sécurité Routière, 2012). In 2000, the average car travelled 13670 km per year compared to only 12090 km in 2012. If this trend continues the payback periods for vehicles will increase as less driving means less annual savings on fuel. What alternative options are there to cars? As 75% of the EU population live in urban areas this makes 25% of all trips travelled less than 15km. These types of trips can be expected to increase substantially over the next 20 years, which could create an increased demand of vehicles suitable for short trips for example electric cars, vehicles that in general have very limited driving ranges of approximately 150-200 km, excluding high end Tesla vehicles (ManagEnergy, n.d; Miljöfordon, 2014). Also, as urban areas become more populated governments might feel inclined to give incentives to low carbon and particle options. An electric car has 0% CO2 tailpipe emissions per kilometer compared to the NGV Fiat Punto, which has 115 g/km, tailpipe emissions. (Tailpipe emissions are the direct emissions from the vehicle.) For example, concerns of air quality in Paris made it necessary for the local government to create a short-term limit of cars on the road (Schofield, 2014). The electric car has much lower noise levels, which is an attractive attribute for cars in urban areas. As described earlier in this report the commission has set a 60% CO2 reduction target for 2050 within the transport sector which might give stronger incentives to subsidies electric vehicles and public transport rather than NGV’s, with their limited reduced impact on CO2 emissions.

5.4 Sustainability

The question is if the cost of natural gas infrastructure outweighs the social and environmental gains of increased air quality and decreased climate impact. Critics to the cost of infrastructure claim that natural gas will never be a bridge fuel towards sustainable transportation, as it is merely another fossil fuel (T&E, 2013). This argument makes a lot of
sense if the EC takes the advice to inject bio-methane into the natural gas grid instead of using it directly as vehicle fuel. If one was to maximize the potential of bio-methane through large-scale anaerobic digestion of biomass all over Europe and then used it for the transport sector, NGV’s could be seen as a sustainable from an environmental standpoint. It can neither be considered sustainable from an economic standpoint as it would like many other options at this stage need to be subsidized in order for any large scale vehicle uptake to occur as shown by chapter 4.1.1.5 (Subsidies). In the countries studied natural gas enjoys favorable taxation compared to gasoline and diesel. In order to ensure market penetration it will also be necessary to subsidies the vehicles directly.

5.5 Consumer awareness

A final interesting note on the discussion is the flexibility of payback periods and price difference criteria. It is important to recognize that consumers might have different preferences when it comes to purchasing a NGV, which can be considered as an environmentally beneficial option. Some might accept a longer payback period than 4 years due to environmental concerns whilst some might not be willing to invest any additional money at all. With increasing environmental awareness it is possible that the criteria could become less strict and including a larger group of potential buyers but this is very difficult to quantify and draw any major conclusions from. Also, the general idea is still that the maximum of 4 years for payback periods and 40% price difference is meant to create “large-scale” adoption, assuming that many (or most) consumers are driven by financial incentives.

5.6. Uncertainties

This report has focused on the market uptake of NGV’s in relation to the directive on Deployment of alternative fuels infrastructure, which seeks to create CNG refueling stations in Europe. CNG itself is not suitable for long distance and heavy vehicles as the average distance of light and medium weight vehicles is only around 300km. (This applies if one only refills the NGV with CNG. All vehicles in this report come with an additional gasoline tank to increase driving range)

The semi qualitative assessment of the future natural gas prices does come with some uncertainty, as there are so many factors that come into play. The 4 A’s method acts as a compliment to the supply and demand model with mixed oligopoly but this is not the strongest part of this report. In the wake of the Crimea crisis the energy situation in Europe is a bit unstable. Not to say that it would be in Russia’s interest to cut off the power supply, there is simply too much at stake, but it says something about that one might need to think about current political relations. An important question is how big a part politics will play when it comes to future trade of oil and gas. Of course, the political stability between different future associated pipeline countries such as Turkmenistan, Azerbaijan and Turkey is very important but how much politics will be involved in global LNG trade, a potential game changer in energy trade? For the US it has been a political decision to allow export of natural gas, but as US Energy secretary Moniz said (Euractive 2014a), the US cannot guarantee where the countries recourses will go. The US (both Republicans and Democrats) is known for having a strong belief in the free market, which would make it difficult to intervene in the exporting companys’ decisions of to whom to sell the gas, as it would normally go to the highest bidder, which in this case could mean China and its surroundings. Politics are involved however when it comes to monetary support of LNG infrastructure as it has been proposed in the EU, simplifying LNG trade. The role of politics in projecting natural gas prices cannot be understated, but it needs to be covered by further research.
6. Conclusions

After completion of this analysis, we can conclude a number of things based on the implementation of the deployment of alternative fuels infrastructure. First of all, countries with a high market uptake of diesel vehicles will have a higher ratio of NGV’s, as the payback comparisons in these cases are very low. Conditions to switch over from diesel to an NGV are optimal in Germany, UK and Spain. As these vehicle markets together account for 49% of all new vehicles registrations in the EU (2012) in combination with high diesel uptake, this could have a very positive effect on the NGV market. France’s conditions are suboptimal as the price difference between diesel and CNG is too low whilst the payback periods are still optimal. Therefore we can expect a lesser market penetration of NGV’s although it might be compensated by the high percentage of new registrations of diesel vehicles.

As for the gasoline comparisons, the results can be considered suboptimal or even inconclusive due to the fact that some of the payback periods are within a margin of error around 4 years and sensitive to change.

The current fuel prices and payback periods are sustained though differences in taxation and cannot at the current stage be considered economically sustainable. EU shale gas will most likely not in any foreseeable future lead to an increased price gap between natural gas and conventional fuels, as these resources will not be extracted in large amounts. US LNG could potentially decouple the pricing of fuels but there are too many factors involved such as political, environmental and economical in order to draw any major conclusions.

In summary, at this stage we can see a “noticeable” positive effect for the NGV market in Europe. However it will not reach its full potential due to suboptimal conditions for gasoline comparisons.
7. Acknowledgements

I would like to thank my supervisor Mikael Höök at Uppsala University for his insight and guidance throughout the writing of this thesis. Also I would like to thank Ruud Weijermars at TU Delft for sharing his insight within the oil and gas sector and Matthias Maedge, Javier Lebrato from the Natural Gas Vehicle Association Europe for supplying information regarding NGV policy.
8. References


European Commission (COM/2014/15) “A policy framework for climate and energy in the period from 2020 to 2030”.


European Commission (COM(2005) 645 final; COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT; “Interim report on the follow up to the informal meeting of Heads of State and Government at Hampton Court”


European Gas Forum (2012) “Reducing CO2 emissions in the EU Transportation Sector to 2050; An alternative pathway to reach 2050 abatement targets with lower costs”.


European Commission. (COM/2011/144) “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system”.


Appendix

Payback period Germany

\[
\text{Paybackperiod }_{\text{fiatpunto CNG vs Gasoline}} = \frac{15890 - 13390}{((14000 \times 0.057) \times (1.6 - (1.6 \times 0.44 \times 0.995)))} = 3.48
\]
Criteria < 4 years
3.48 < 4

\[
\text{Paybackperiod }_{\text{audi sportback CNG vs Gasoline}} = \frac{25900 - 22800}{((14000 \times 0.049) \times (1.6 - (1.6 \times 0.44 \times 1.0063)))} = 5.07
\]
Criteria < 4 years
5.07 > 4

\[
\text{Paybackperiod }_{\text{fiatpunto CNG vs Diesel}} = \frac{15890 - 15790}{((14000 \times 0.035) \times (1.41 - (1.41 \times 0.57 \times 1.45)))} = 0.83
\]
Criteria < 4 years
0.83 < 4

\[
\text{Paybackperiod }_{\text{audi sportback CNG vs Diesel}} = \frac{25900 - 25700}{((14000 \times 0.038) \times (1.41 - (1.41 \times 0.57 \times 1.159)))} = 0.786
\]
Criteria < 4 years
0.786 < 4

Payback period UK
<table>
<thead>
<tr>
<th>Model</th>
<th>Fuel Comparison</th>
<th>Payback Period Calculation</th>
<th>Criteria</th>
<th>Result</th>
</tr>
</thead>
</table>
| Fiat Punto           | CNG vs. Gasoline      | \[
\frac{(17455 - 14709)}{((13196*0.057)*(1.58 - (1.58\times 0.47\times 0.995)))} = 4.34
\]                                                                                    | < 4 years | 4.34 > 4 |
|                      |                       |                                                                                           |          |        |
|                      | CNG vs. Diesel        | \[
\frac{(17455 - 17238)}{((13196*0.035)*(1.64 - (1.64\times 0.51\times 1.45)))} = 1.1
\]                                                                                    | < 4 years | 1.1 < 4 |
|                      |                       |                                                                                           |          |        |
|                      | CNG vs. Gasoline      | \[
\frac{(25900 - 22862)}{((13196*0.049)*(1.58 - (1.58\times 0.47\times 1.0063)))} = 5.64
\]                                                                                    | < 4 years | 5.64 > 4 |
|                      |                       |                                                                                           |          |        |
|                      | CNG vs. Diesel        | \[
\frac{(25900 - 25705)}{((13196*0.038)*(1.64 - (1.64\times 0.51\times 1.159)))} = 0.58
\]                                                                                    | < 4 years | 0.58 < 4 |
|                      |                       |                                                                                           |          |        |
| Payback period France|                       | \[
\frac{(17050 - 13750)}{((12090*0.057)*(1.53 - (1.53\times 0.54\times 1.995)))} = 6.76
\]                                                                                    | < 4 years | 6.76 > 4 |
\[
\text{Payback period Audi Sportback CNG vs. Gasoline} = \frac{(26380 - 24630)}{(12090 \times 0.049 \times (1.53 - (1.53 \times 0.54 \times 1.0063)))} = 4.23
\]
Criteria < 4 years
4.23 < 4

\[
\text{Payback period Fiat Punto CNG vs. Diesel} = \frac{(17050 - 16950)}{(12090 \times 0.035 \times (1.33 - (1.33 \times 0.71 \times 1.45)))} = -6
\]
Criteria < 4 years
-6 = inconclusive

\[
\text{Payback period Audi Sportback CNG vs. Diesel} = \frac{(26380 - 26180)}{(12090 \times 0.038 \times (1.33 - (1.33 \times 0.71 \times 1.159)))} = 1.85
\]
Criteria < 4 years
1.85 < 4

Payback period Spain

\[
\text{Payback period Fiat Punto CNG vs. Gasoline} = \frac{(13550 - 11750)}{(12000 \times 0.057 \times (1.43 - (1.43 \times 0.5 \times 0.995)))} = 3.66
\]
Criteria < 4 years
3.66 < 4

\[
\text{Payback period Audi Sportback CNG vs. Gasoline} = \frac{(25850 - 23920)}{(12000 \times 0.049 \times (1.43 - (1.43 \times 0.5 \times 1.0063)))} = 4.62
\]
Criteria < 4 years
4.62 < 4
\[
\text{Paybackperiod. fiatpunto } CNG \text{ vs. Diesel} = \frac{(13550 - 13450)}{((12000 * 0,035) * (1,33 - (1,33 * 0,6 * 1,45)))} = 1.38
\]
Criteria < 4 years
1.38 < 4

\[
\text{Paybackperiod. audi sportback } CNG \text{ vs. Diesel} = \frac{(25850 - 25650)}{((12000 * 0,038) * (1,33 - (1,33 * 0,6 * 1,159)))} = 1.08
\]
Criteria < 4 years
1.08 < 4