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A model estimation of the potential demand for alternative fuel technologies in transportation

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‘ It doesn't matter how sensitive you are or how damn smart and educated you are, if you're not both at the same time, if your heart and your brain aren't connected, aren't working together harmoniously, well, you're just hopping through life on one leg. You may think you're walking, you may think you're running a damn marathon, but you're only on a hop trip. The connections gotta be maintained.’

Tom Robbins, Villa Incognito

Abstract

Road remains the biggest pollution source in transport sector, accounted for more than 70% of greenhouse gas emissions (EEA, 2018). Road transport is a source of harmful air pollutants such as nitrogen oxide (NOx) and particulate matter (PM), strongly linked to a variety of problems including premature death and respiratory issues. To improve air quality and minimize the impact on citizens' health and well-being, European Commission has put into force measures to support the swift in the type of energy, fuels and powertrains, to deploy efficient and advance alternative fuel technologies and to facilitate the change in mobility behaviour.

Several alternative fuel technologies like natural gas, electricity, and fuel-cell, have been identified as having a significant potential to reduce overall pollutants and gradually substitute the use of fossil fuels. As opposed to electric and fuel cell technologies which are still facing technical and economic challenges, Compressed Natural Gas (CNG) technology could be the leading fuel in the transition period towards low emissions era, because of the availability of the resources, the environmental performance of the vehicles, and the feasible conversion of diesel and gasoline engines to double-fuel. While cost and performance characteristics of natural gas vehicles (NGVs) are improved, there is unexploited market potential and many barriers to overcome including consumer acceptance, legal and financial challenges as well as legislative and regulatory issues.

The complexity of these market uptake barriers requires a multidisciplinary approach. This thesis attempts to methodically answer each of the main issues described above and broaden our current knowledge on the uneven innovation performance of Member States in terms of alternative fuel deployment. This study aims to analyse consumer behaviour in order to design and propose policies that will efficiently increase the uptake of cleaner technologies.

As a first step, a national survey was conducted to reveal private car owners' mobility habits, needs and expectations, and to define the major criteria regarding the adoption of alternative fuel technologies. A discrete choice experiment has been designed to elicit upon the values that consumers place when purchasing a car. The choice experiment includes four types of car/fuel combinations: natural gas, gasoline, diesel and liquefied petroleum gas, attributes related their technical characteristics, environmental performance, cost efficiency and safety and a list of monetary and non-monetary measures. A cluster analysis of the sample helped identify consumer groups with similar characteristics and patterns in purchase behaviour and reveal different types of drivers' profile that are more likely to invest in natural gas technologies. For each consumers' group a multinomial logit model (MNL) was developed, indicating that the increase of the refuelling infrastructure density, the fuel price, and the existence of financial ad policy incentives, could lead to a higher market penetration of natural gas vehicles.

Few researchers have dealt with the adoption of alternative fuel technologies in commercial vehicles used in city logistics. Our knowledge of how city logistics operators make decisions is based on very limited data. The aim of the thesis was thus to broaden our knowledge and to understand the various factors that affect the successful diffusion of alternative fuels by analysing both drivers' and fleet owners' response towards the use of CNG under different market scenarios. This thesis aims at identifying attitudes and perceptions of fleet owners and logistics companies, operating in Athens, with regards to a potential conversion of their fleets into bi-fuel. The results of the pilot survey underscore two main factors that affect alternative fuel technology adoption. The first refers to the importance of the type of the organizational structure that each company follows, and the second to the mistrust of the fleet owners to the stability of national policy strategies related to a low-emission mobility.

The contribution and innovation of this research covers several topics. We conducted two types of surveys targeting different market sections: private car owners and logistics operators. To our knowledge, this is the first time that both revealed preference and stated preference data has been collected for natural gas technology covering freight and passenger transport in Greece. The questionnaire was designed based on an extended literature review covering the majority of the factors that have been identified, including: actual and perceived vehicle attributes, vehicle use characteristics (tax incentives, fuel consumption etc), sociodemographic factors, attitudinal psychological factors and interpersonal influence on the adoption of an alternative fuel vehicle. The design of the questionnaire was reviewed not only by transport economists and engineers, but it also included constructive feedback from the Directors of the Public Gas Provider, and the opinions of several professional transport operators and professional drivers, regarding issues that matters the most on adopting an innovative technology. Finally, the interpretation of the results of the multinomial logit model were translated into a policy measures that could influence the car choice. The Integrated Policy Plan proposed as the final outcome of this survey includes the implementation of soft and hard policy actions in a step-by-step policy design, to enhance the use of natural gas based not only on the technical advantage of CNG, but also the key elements of the behavioural change.

Key words: Road Transport, Alternative fuels, Compressed Natural Gas, Transport Policy, Multinomial Logit Model, Urban freight

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List of abbreviations

AFV	Alternative Fuel Vehicle
BEV	Battery Electric Vehicles
CNG	Compressed Natural Gas
EC	European Commission
EU	European Union
GHG	Greenhouse Gas Emissions
H/C	Hydrocarbons
LPG	Liquified Petroleum Gas
MNL	Multinomial Logit
NGV	Natural Gas Vehicle
NOx	nitrogen oxide
NPF	National Policy Framework
PM	Particulate Matter
RP	Revealed Preference
SME	Small Medium Enterprise
SP	Stated Preference

Chapter 1

Introduction

1.1 The broader context

Even though the technological advantages of new vehicle powertrains have achieved lower levels of pollutants, transportation is one of the few sectors in Europe that faces an increase in CO_2 emissions. According to Annual European Union greenhouse gas inventory (EEA, 2018) greenhouse gas emissions (GHG) have shown a decrease in various sectors from 1990, except for transport sector. In fact, road transport remains the biggest pollution source, accounted for more than 70% of all GHG emissions in transport (EC, 2018). Moreover, cars are responsible for around 12% of the total European Union's emissions of carbon dioxide (CO_2) which is the main greenhouse gas. Road transport is also a source of other harmful air pollutants such as nitrogen oxide (NOx) and particulate matter (PM) (EEA, 2016). Externalities generated by transportation are strongly linked with health issues such as asthma, lung diseases, bronchitis as well as insomnia, anxiety, lack of concentration and high heart pressure due to increased noise levels in the city centres (Öhrström, 2004); (Gidlöf-Gunnarsson & Öhrström, 2007). The European Commission's (EC) answer to the challenge of emissions reduction is an irreversible shift to low-emission mobility. By 2030 overall greenhouse gas emissions should be 55% below 1990 levels (EC, 2020), and by mid-century transport emissions should be 60% lower than 1990. (EC, 2017). For the new cars, European Union's legislation sets mandatory emission reduction target value of 95 grams of CO_2, by 2021.

Alternative fuel technologies offer considerable opportunities to reduce air pollution, to improve well-being of urban residents and to contribute to oil independence of the transport sector. Public concern about climate change has intensified the research in areas of alternative fuel technologies and accelerated their adoption. There are several alternative vehicle technologies that are expected to increase more in the next decades, such as electricity, hydrogen, biomethane and other renewable sources that could contribute to greenhouse-gas emissions decrease and contribute in sustainability.

Currently in Europe, 2.8% of the passenger cars run on Compressed Natural Gas (CNG) or Liquified Petroleum Gas (LPG), whereas the share of petrol and diesel is 54% and 50% respectively. The share of electric and hybrid electric passenger vehicles accounts for 1%, with significant variations among Member States. In Greece, only 0,1% of the passenger cars run on LPG or CNG and almost 93% run on gasoline and the rest on diesel. The share of hybrid electric cars reaches 0.4% (ACEA, 2019).

In 2014, the EC in order to accelerate the roll-out of alternative fuel technologies, published the Directive on the Deployment of Alternative Fuels Infrastructure which requires Member States to develop National Policy Frameworks for the development of alternative fuel markets (electricity, CNG, LNG, hydrogen) and their respective infrastructure. However, the heterogeneity in ambitions and targets of each Member State encumbers the market uptake and discourage the investments in AFVs and refuelling infrastructure.

The difference in every country's market commercialisation is highly related to each country's long-standing legacy of alternative fuel usage, the implementation of promoting policies and the degree of public acceptance. The increase of the global alternative fuel fleet is not equally distributed and there are significant differences among countries not only regarding the different time periods of steep growth, but also the composition of alternative fuel preferred.

Based on the assessment of the National Policy Plans for the deployment of Alternative Fuel Infrastructure, 9 Member States and UK (Austria, Denmark, France, Finland, Sweden, Germany, Netherlands, Ireland, and Luxembourg) clearly prioritise electromobility. Only 3 Member States (Italy, Hungary and Czech Republic) have ambitious goals for the roll-out of natural gas vehicles. The National plans indicate that the development of a market for electric vehicles in the EU is likely to occur in three distinct waves. The first wave includes the uptake in Western Europe and Nordics countries; the South Mediterranean countries are likely to have the transition phase towards electricity in a second deployment stage with sales picking up appreciably in the mid-2020's. As for the Baltics, Central and Eastern European countries, the transition phase is more likely to occur in the late 2020's early 2030's- although there could be an earlier conversion second-hand market. (Transport&Environment, 2018).

Electricity indeed offers the possibility to substitute oil, to ensure energy supply and reduce CO_2 emissions and it has been widely supported by the EC which increased the appetite of private investors. As Europe tries to reduce greenhouse-gas emissions, policy makers have pinned hopes in electric cars whose previous limitations in range and life of battery are constantly improving. Although they provide a clear climate benefit, the power generation for charging these vehicles is still heavily based on coal. The electricity generated from renewables is increasing in some European countries (e.g. Norway), however, this is not the case for the majority of Member States.

In Greece, the largest share in the generated electricity belongs to lignite plants, while the share of petroleum products remains high due to their use in remote islands. According to the annual report of Institute of Energy for South Eastern Europe (IENE, 2019), the electrification of transport would require additional measures related to the decarbonisation of the energy power supply in order to meet climate objectives.

Natural gas, on the other hand, has become an important fuel in Greece, increasing its share in electricity generation and in total primary energy supply, doubling its share of total final consumption over the last decade. According to the National Policy Framework, Greece aspires to further expand the use of natural gas as a transport fuel and has already established appropriate refuelling infrastructure targets that reflect the CNG vehicle projections of the next decades. The wide portfolio of measures includes among others administrative, legislative and regulatory type of targets to facilitate the installation and operation of the alternative fuel infrastructure. The demand for natural gas is steadily rising, and a gradual increase in new CNG supply infrastructure is expected in the years to come, reaching 25 public and private supply points in 2020, 41 in 2025 and 65 in 2030.

The technology transition of Greece follows a slower pace than most Western European countries mainly due to lack of adequate monetary funds, techno-social momentum and overall market acceptance. In order to identify the root cause of slow pace of innovation, this thesis provides an overview of the current market status of alternative fuel technologies and the factors that hampers the market penetration and it analyses the perceptions and attitudes of the drivers towards the use of natural gas, through a Revealed and Stated Preference survey. The results of this survey are translated into policy actions and their impact on the acceleration of natural gas use is assessed and presented within an integrated policy plan.

1.2 Background

The following sections provides an overview of the status, trends and barriers of alternative fuels in transportation, including also the importance of central political actions and the need for a paradigm shift in individual mobility.

The contribution of individual mobility to a sustainable transport system and the shift towards alternative fuel technologies has been stressed in numerous research works (Barr & Prillwitz J, 2012) (Rabl & de Nazelle, 2012). The core of this approach for sustainable mobility, includes actions and measures to diminish the need for car use. To achieve this, sustainable transport paradigm is based upon:

- the reduction of the need for everyday trips, with the extended use of information and communication technology systems (ICT),
- the enhancement of car sharing and modal shift for urban commuting (public transport, cycling etc),
- and the achievement of a more efficient transport system with applicable vehicle technology innovation (Banister, 2008); (Grieco & Urry, 2016).

The role of alternative fuel technologies is included in the third dimension of the sustainable transport paradigm. Alternative fuel vehicles (AFVs) are vehicles that can be fuelled partially or fully by alternatives to fossil gasoline and diesel.

Currently, there are a lot of AFVs available in the automotive market running on natural gas, liquified petroleum gas, electricity, other biofuels, and recently on hydrogen. However, AFVs have not gained substantial market share, regardless the significant fuel economy and the environmental benefits they offer.

There is a wide range of research studies aiming at identifying the major factors that influence the demand of AFVs worldwide. Vehicle characteristics, fuel technology, policy actions and the density of alternative fuel infrastructure have been examined, to define under which circumstances the potential use of AFVs could gain a substantial share in urban mobility (Ewing & Sarigöllü, 1998); (Flynn, 2002). According to Romm (2006), AFVs and their respective fuels face two main core problems: firstly, their misplacement in the market cannot compete the trustworthy conventional vehicles that dominate the market for more than a century. Secondly, the high purchase price of the vehicle and the insufficient refuelling network do not counterbalance the accumulated reduction of operational cost and the environmental benefits they offer. That being the case, promotion strategies should be reinforced with policy incentives and/or mandates for both the infrastructure and the vehicles, at least at the early stages of the market adoption.

Browne et al. (2012) attempted to clarify the barriers that hinder the diffusion of AFVs, by categorising them according to their nature: financial, technical or commercial, institutional, legal, policy, public denial and physical barriers. With this prioritisation, the study aimed at developing corresponding policies to eliminate each barrier, with the participation of stakeholders at the initial phase of introducing a new technology in the market. Other studies focusing on the complexity of behavioural patterns, highlighted that the promotion of AFVs is strongly dependent not only on vehicle characteristics and purchase cost, but also on the exposure of the consumers on positive feedback (Jansson, Pettersson, Mannberg, Brännlund, & Lindgren, 2017) and marketing campaigns that can raise awareness and enhance their attractiveness. (Struben & Sterman, 2008). There has been an extended discussion over the development of sustainable mobility and the policy actions that have been implemented throughout the years at national or European level, and yet, without yielding fruitful results. According to Banister (2008) the key to a successful implementation of a change in the transport system is the citizen involvement in public policy formulation. Only if the public understands the rationale behind a policy action, a change in a current transport system will occur. The acceptability of a new policy package depends heavily on the collaboration of the key stakeholders, as well as the involvement of society members in the formulation of policy actions.

To achieve the change towards sustainable mobility financial, legislative, political, technical, and cultural barriers must be identified and overcome. The lifestyle is changing over time just as new technological changes and mobility solutions are emerging and quickly altering individuals' habits. But the adoption of new vehicles with alternative fuels requires public awareness and change of values, which can be achieved by educating the consumers in this respect.

Given that the problem related to the diffusion of an innovative technology does not only call for technological performance, but also for social acceptance, the behavioural dimension should also be further analysed for achieving the energy shift towards a zero-carbon transport future. The “neighbour effect”, can positively impact the adoption of AFV, as people tend to be influenced by the shared experiences of their social circle (Jansson, Pettersson, Mannberg, Brännlund, & Lindgren, 2017). The faster the positive feedback to drivers, the more visible the benefits will be (Mau, Eyzaguirre, Jaccard, Collins-Dodd, & Tiedemann, 2008). In the literature, that is developing with the purpose of better understanding the dynamics of consumers’ behaviour, there are several studies highlighting the importance of vehicles characteristics and incentives. However, a detailed understanding of interpersonal influence on the adoption decision is still lacking. The evaluation of attitudes, perceptions, behavioural factors, and the role of social norms are central for the appraisal of a future transport policy and must be investigated in a greater detail.

During the last decades, the estimation of the demand of alternative fuel technologies by researchers was not easily obtained, because alternative fuel technologies were still non-existing in the automotive market or they remained in an experimental phase, or they only corresponded to niche markets with low investing momentum. Therefore, many researchers used discrete choice Revealed Preference (RP) and Stated Preference (SP) surveys, asking participants to uncover their preference over hypothetical alternatives that would be available in the near future, because of technology innovation, development of the respective infrastructure and implementation of promotion policy actions (Calfee, 1985); (Achtnicht, Bühler, & Hermeling, 2012); (Axsen, Mountain, & Jaccard, 2009). The participants are exposed to hypothetical scenarios and asked to express preferences for products with specific attributes that may or may not be available in the market, thus the real market situation cannot be reflected with certainty (Beggs, Cardell, & Hausman, 1981); (Bunch, Bradley, Golob, & Kitamura, 1993); (Dagsvik, Wennemo, Wetterwald, & R, 2002).

The use of Compressed Natural Gas (CNG) in cars demonstrates a high environmental performance and significant cost savings, comparatively to existing conventional ones and could be considered as a turnkey solution for the medium-term transition to reduce the externalities generated by the transport sector. Although CNG has significant environmental advantage compared to gasoline and diesel, it is still a fossil fuel. However, Renewable Natural Gas, the so called Biomethane which is produced from various biomass sources, is a clean, sustainable and carbon neutral fuel and it works in the same way as natural gas. It is fully interchangeable with conventional natural gas and can be used in existing natural gas vehicles (Alternative Fuel Data Centre, 2020).

While the use of CNG in conventional vehicles (double-fuel) is already widely mastered and can be further improved, the use of electric vehicles (EVs) is until recently most promoted by the policy makers and gain the attraction of private infrastructure investors who invest heavily in the deployment of charging stations in main Northwest European cities. However, there are substantial doubts on when electric cars will surmount the technical and economic challenges they face: limited driving range, low energy density, high cost of batteries, limited number of charging stations and interoperability issues considering lack of standardisation between vehicles and charging points (EEA, 2016); (Engerer & Horn, 2010). Other issues relating to the lack of a functioning market for end-of-first-life batteries and the gaps in circular economy strategy for distribution and sale of the batteries, remain unanswered (Bonsu, 2020).

Many studies focus on the fact that Battery Electric Vehicles (BEV) have no tailpipe emissions and therefore is the optimal route towards sustainability, without considering the significant environmental damage by the CO_2 emissions generated for the construction of vehicle batteries (Pascoli, Femia, & Luzzati, 2001), or electricity generation which in many European countries is still mostly based on coal. The growing demand of electric cars, without careful consideration could contribute to a new environmental damage and social problems due to mining processes *'as some of the rare earth materials for electronic components and fuel cells, lithium for batteries are subject to supply restrictions and concentrated in a few geographical areas'* (EC, 2011).

Despite their remarkable environmental performance, the value added of the companies in the EU is still under dispute, as the origin of production of the batteries remain uncertain and their components could be massively imported. The report published from European Automobile Manufacturers' Association also underlines the negative impact of increasing electrification on job creation as BEVs are less labour-intensive than internal combustion engines (ICE) (ACEA, 2017).

It is imperative that all alternative fuels will play a significant role in the energy transition. While it is important to set long-term objectives, policy makers should consider solutions that are already available, cost-effective, and commercially viable to positively contribute to the decarbonisation of the transport sector.

A European strategy that will emanate from the current needs for transport decarbonisation and go towards the market, falls under the category of a push strategy. Funds and research programs are currently available for the development and proposal of alternative fuel technologies that are destined to find the end consumers. A closer look in the Horizon Energy Projects reveals the future trends in technologies that will possibly gain a significant market share and attract public and private investments. More than 100 million euros are available for Energy projects focusing on: solar energy industrial use, carbon capture and utilisation, and development of next generation of biofuel and alternative renewable technologies in aviation and shipping.

The focus on renewable sources is also illustrated in the pull strategy of commercial and investment banks that provide funding and financing of projects that are stimulated by the market needs as a response to the pull action of demand. Particularly, the EC provides €200 million for sustainable and efficient transport and simplifies access to financing for transport projects. In June 2018, the European Commission, as part of proposals for the next long-term budget (2021-2027), proposed the adaption of the CEF program[1] to support investment in Europe's transport, energy, and digital infrastructure networks with the following priorities:

- Advance work on the European transport network, while helping the EU transition towards connected, sustainable, inclusive, safe, and secure mobility.

[1] https://ec.europa.eu/transport/themes/infrastructure/cef_en

- Decarbonise transport, e.g. by creating a European network of charging infrastructure for alternative fuels and by prioritising environmentally friendly transport modes.

The CEF blending contribution, that will be applied according to specified exclusion and cost eligibility criteria, prioritize the AFVs and the respective stations especially when the fuel is generated by renewable sources. In this regard, CNG technology has a window of opportunity to gain substantial share in the energy game since the conversion of conventional vehicles into bi-fuels is a low-cost feasible process, the distribution of renewable gas in the future, will not require change in the infrastructure or in the vehicles' engines and the existing pipelines transferring gas can also be mixed with hydrogen (up to a certain amount) and be distributed in the existing network.

1.3 Research objectives

This study aims at developing a model that estimates the potential demand for AFVs to be used as a policy tool that compares and evaluates different policy plans in order to enhance the use of alternative fuels in transportation. To do so, the model includes variables that influence the fuel/vehicle choice of the individuals, their technical awareness, the technical characteristics of the vehicles, and a variety of policy and financial measures. Based on the results of the multinomial logit model (MNL), and the qualitative analysis of the transcripts of the interviews with urban logistics companies, a detailed policy framework was articulated and adjusted in Greek market, to be used as a tool from policy makers to build up the diffusion of natural gas in Greece.

The research objectives can be summarised as follows:

1. An in-depth literature review on alternative fuel technology in transport, major market barriers, innovation theory, consumers behaviour theory and a review of best applications and practices worldwide.
2. The design and application of a Multinomial Logit Model that analyses the consumers fuel/vehicle preferences under different monetary and non-monetary scenarios.
3. The analysis of complexity of urban logistics and the role of greener vehicles in the faster decarbonisation of the sector. A qualitative analysis of the interviews with major urban logistics companies and the identification of the main factors that influence the use of alternative fuels.
4. The development of different policy packages based on the results of the MNL that will be used to evaluate and compare the different scenarios and policy actions.
5. The development of an integrated policy package that includes soft and hard policy actions in a step-by-step policy design, to enhance the use of natural gas based not only on the technical advantage of CNG, but also the key elements of the behavioural change.

For this purpose, a Revealed and Stated Preference Survey was designed to assess the hypotheses that:

- well-informed people regarding new technologies are more likely to choose an AFV,
- that high purchase cost of a vehicle and the insufficient refuelling infrastructure are the greatest deterrent factors in a fuel/vehicle choice and
- that being a pro-CNG is not enough to choose an NG vehicle if it is not accompanied with subsidies and other incentives.

This research delves into variables that influence the fuel/vehicle choice of the individual. The analysis focuses on the technical characteristics of the vehicles, the technical awareness of the participants and their pro-environmental behaviour. Based on the results of the multinomial logit model (MNL), a detailed policy framework is developed and adjusted in Greek reality, to be used as a tool from policy makers to enhance the diffusion of natural gas. The results of this survey can be transferrable, and the skeleton of the policy plan could be adjusted to other countries based on their respective market characteristics.

It is not the objective of the study to go into the technical characteristics of every alternative fuel technology available in the European market, but to point out that a significant change in policy measures and public awareness, can create a significant market share for alternative fuel technologies with an ongoing momentum. That is why the development of the choice set for Greece included existing models of natural gas vehicles to be compared with the dominant conventional fuel vehicles running on gasoline, diesel and liquified petroleum gas. The alternative of electric vehicles was deliberately excluded from the survey. Having as an alternative the option of an electric vehicle would be incompatible regarding the time horizon schedule of this survey and would lead to misleading results.

The development of the hypothetical scenarios for this survey, is based on the premise that overall political stability concerning energy security issues is guaranteed.

1.4 Motivation for this thesis

Four main issues have motivated this thesis:

1. **Natural gas as a bridging technology in passenger cars and commercial fleets**

   Currently, transport is a minor consumer of gas in the EU totalling in 1% of total demand, whereas it accounts for one third of overall energy consumption relying on liquid fossil fuels. The EC undermarks that the decarbonisation of the transport sector cannot be achieved with one single solution, but with the involvement of multiple alternative fuels for each transport mode, like hydrogen and renewable methane (Cătuţi, Egenhofer, & Elkerbout, 2019). While numerous studies have investigated the potential of electrifying passenger transport, the gas-based solutions such as CNG, is overlooked in some scenarios due to the lack of substantial number of studies proving the technological development and price competitiveness. Despite the significant environmental benefits related to natural gas and biomethane, and the increased availability of CNG vehicles in the European market, the market share is still low, now making up 1.4 million gas vehicles (NGVA, 2019). The gradual substitution of natural gas by renewable sources like biomethane can contribute to oil dependency reduction and strengthen the diversification of energy security supply of the EU. Furthermore, the existing pipelines distributing natural gas could also accommodate future fuel technologies like biomethane/hydrogen blends.

2. Inconsistency of Member States in meeting the targets for reduction of externalities

The final Directive for the Deployment of Alternative Fuel Infrastructure requires Member States to develop National Policy Frameworks (NPFs) to provide specific objectives and policies for the market development of alternative fuel infrastructure to accommodate the use of AFVs (Compressed Natural Gas, Liquified Natural Gas, electricity and hydrogen). However, each Member State have set different policy actions to meet the EU objectives, depending on the current level of market uptake of each alternative fuel technologies, the availability of natural resources and the bilateral agreements with import countries. In the majority of NPFs, more emphasis has been placed on the expansion of the charging networks in urban and suburban areas by incentives and supporting tools with tax incentives and purchase subsidies for electric vehicles. The long-term solution of biomethane and hydrogen blends by using the existing infrastructure system has been less investigated. Alternative fuel network in Greece is still at its infancy, however Greek National Policy Framework sets specific goals regarding the deployment of CNG infrastructure: until 2020 CNG vehicles could circulate at least in densely populated urban and suburban areas, while until 2030 Heavy-Duty Vehicles, could circulate along the TEN-T Network. The National Public Gas Provider of Greece have entered into long-term pipeline natural gas and LNG supply contracts, enhancing the supply sufficiency not only of Greece, but also Europe. These projects fulfil the proposals of the COM (2014)330[2] for diversification of supply sources, it minimizes political as it involves primarily private company commercial assessment. These long-term contracts generate significant opportunities for a successful market penetration of alternative fuel technologies in Greek market.

[2] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL European Energy Security Strategy

3. **Greece as a case study**

   Forecasting the changes in the demand for natural gas when applying different policy and financial incentives, is used to develop an effective policy mix adjusted to the market needs, that could contribute to the gradual decarbonisation of the transport sector. To investigate why the diffusion of natural gas is still dealt with doubt and unbelief, it is crucial to identify the main diffusion barriers in several countries and examine the factors that affect its adoption. Greek natural gas market is still in a "seed stage" concerning the use of CNG as a transport fuel, whereas other countries have been leading the market for decades.

4. **Former collaboration with National Gas Provider of Greece**

   The idea of the present research is based on the primary results of a pilot survey taken place in Athens metropolitan area during the summer of 2012, on behalf of DEPA S.A., the National Provider of Natural Gas in Greece. This pilot survey focused on the investigation of attitude and perception of city logistics operators towards the conversion of their current fleet to bi-fuel (conventional fuel-CNG). The results of this survey are presented in following chapter. Identifying the needs of a niche market increased the motivation of conducting an in-depth investigation of the potential adoption of alternative fuels by Greek drivers.

1.5 Methodological Framework

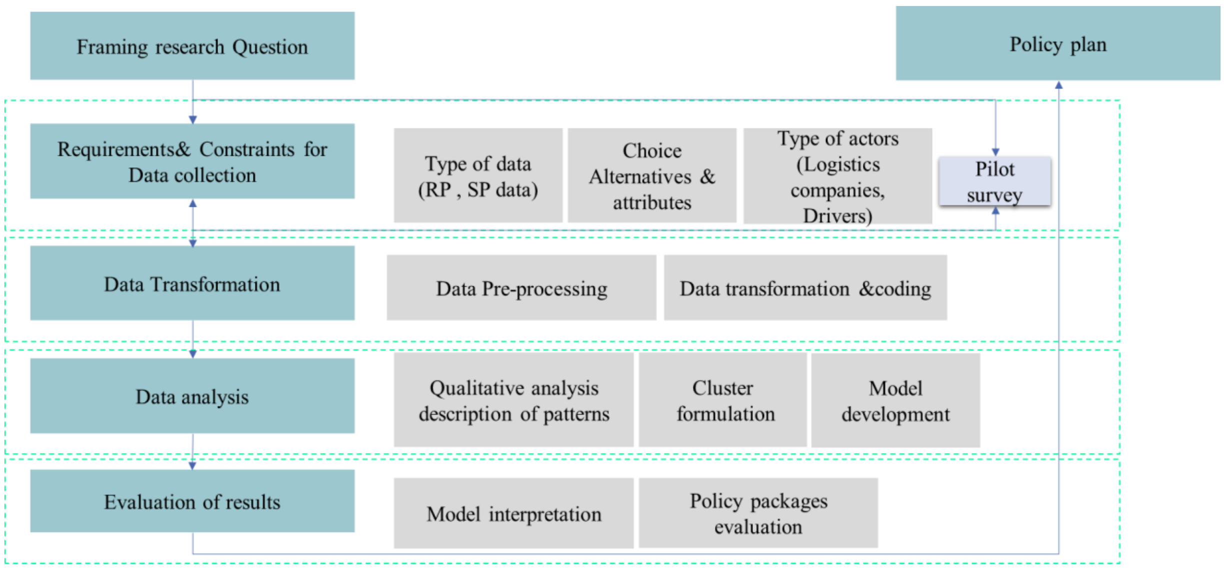
The development of an integrated policy plan requires an in-depth literature review on alternative fuel technology technical characteristics, innovation theory for the diffusion of an unknown technology in the market, decision-making patterns of the potential consumers based on sociology and psychology studies, to reveal all the possible factors that may affect their behaviour.

Two surveys were conducted:

- The first survey focused on identifying the major factors that affect drivers to purchase a natural gas vehicle.
- The second survey was in the form of semi-structured surveys with the aim to capture the attitudes and perceptions of logistics operators towards the use of natural gas and to identify their willingness to convert their fleet into double-fuel vehicles.

Based on the results of logit model that is estimated based on the first survey, an integrated policy plan is developed for promoting the use of natural gas, improving environmental conditions and informing the public for the benefits of new technologies in transport. The methodological framework is presented in the following figure.

Figure 1–Methodological Framework



1.5.2 Case Study

The surveys were conducted in Greece. The main survey regarding the Greek drivers was conducted during the summer of 2016. The web-based questionnaire was available on the official site of Greek National Gas Provider (DEPA S.A) and forwarded to official university sites all over the country, to special websites, car magazines, social media etc. The second survey concerning the logistics operators took place in 2016, during the Conversion Subsidy program from the National Gas Provider of Greece.

1.6 Structure of the thesis

This thesis is divided in 7 Chapters and is organised as follows.

Chapter 1: Introduction

This chapter introduces the topic and the main scope of this thesis, the motivation, the research questions, and the contribution.

Chapter 2: Competition of alternative fuel technologies: current situation

This chapter begins by examining what is known from previous studies about technical characteristics of natural gas as a fuel and its environmental performance. It provides an overview of the current situation in terms of number of vehicles and stations globally. The policy frameworks regarding the promotion of use of CNG as a fuel is also discussed.

Chapter 3: Market potential and diffusion barriers of alternative fuels: literature review results

In this chapter it is reviewed what is known from previous studies about the main factors that affect the market uptake of alternative fuel technologies, and the role of policy and financial incentives on the diffusion of alternative fuels throughout the years. This chapter also presents the findings from past studies focusing on individual specific factors that hamper the adoption of CNG.

Chapter 4: Implementation of surveys and model development

The fourth chapter is the core chapter of this thesis where the methodology of the study is presented. It continues with the data collection analysis and the survey design and it addresses the question regarding the fuel/vehicle choice of the participants, and it provides insight on the main criteria for the purchase of a new car. In this chapter, the structure and the results of the multinomial logit model are presented.

Chapter 5: From model estimation to transport policy suggestions

In this chapter, based on the results of the model, five policy packages were developed. The policies were articulated according to the most significant factors that affect the consumers, drawn by the results of the multinomial logit model. The five policy packages were used as the base for the development of the Integrated Policy Plan.

Chapter 6: Alternative fuels in city logistics: actors' perceptions

This chapter addresses the question research regarding the perception of urban logistics operators towards AFVs, it describes the survey design, the data collection process and discusses the main factors and beliefs that affect logistics operators in choosing an AFV.

Chapter 7: Conclusions

This chapter concludes the thesis providing a summary of the results. Recommendations for further research based on the challenges encountered during the writing of the thesis are also provided in the concluding chapter.

1.7 Contributions to the state of art and innovation of the Thesis

This PhD thesis aims at combining different perspectives of the literature on behavioural, organisational and innovation theory, to shed light on the ways consumers purchase green vehicles and interpret the results of the survey into a feasible policy plan. Despite the growing literature on alternative fuel technologies, this study challenges the norm of electromobility and formulates the assumption that Member States are not moving at the same pace in the energy transition and are having significant discrepancies in terms of ambitions and target setting.

Considering that Greece is still in embryonic stage, policy makers should consider the economic and market variations of each country, while at the same time they could achieve the targets of alternative fuel deployment as per Directive requirements. Since the differences among Member States hamper the market uptake of alternative fuels, the replicability of best practices is questionable.

This thesis focuses on understanding where these differences are coming from, analyse market dynamics and reveal the consumers behaviors. Having Greece as a case study helps us validate our assumptions on innovation pace and create a policy plan that will meet the needs of the market, will attract private investments, and help policy makers to contribute in sustainable mobility.

To do so, this study incorporates intermediate findings of previous smaller studies conducted in 2012 and 2015 when natural gas as a transport fuel was still not used. The questionnaire survey was developed in collaboration with the Directors of the Public Gas Provider of Greece (DEPA S.A) and feedback from members of official freight association of Greece. The finalisation of the included attributes was based on realistic scenarios and policy actions that the Natural Gas Provider would consider implementing in the next years and wanted to test their efficiency. To our knowledge, this is the first time that both RP and SP data have been collected for natural gas technology in Greece.

The survey targeted not only drivers but also urban logistics companies. The significance of including the potential use of CNG in urban freight distribution deliveries relies on the fact that they represent about 90% of the total urban good transport flows, and 18% of the total urban transport flows. Despite their different nature, they share the same infrastructure for both running and parking, contributing to congestion and pollution. But environmental benefits from the use of natural gas is more likely to increase if it is first adopted by commercial fleets.

The set of questions in the surveys did not solely focus on technical vehicle characteristics, but also on policy and financial incentives related to a new natural gas vehicle, and on the conversion of their current vehicle into bi-fuel. The sample was divided into 4 clusters based on similar characteristics and behavioral patterns and four Multinomial Logit Models were developed to estimate the utilities of each vehicle/fuel for each cluster. The model interpretation offers crucial information on how potential buyers would react in front of different vehicle/fuel options and financial incentives and allowed for a market segmentation. The results of the models were translated into a proposal of a Policy Plan. The integrated Policy Plan includes the implementation of soft and hard policy actions in a step-by-step policy design, to enhance the use of natural gas based not only on the technical advantage of CNG, but also the key elements of the behavioural change.

Finally, the insights from this study and the knowledge of the researcher regarding the dynamics of the alternative fuel market, provided the background for developing a methodology for the EC and the European Investment Bank (EIB), to foster the deployment of future projects on alternative fuel infrastructure under the CEF Transport Blending Facility[3] an innovative financial instrument to support projects contributing to the environmental sustainability and efficiency of the transport sector in Europe.

This thesis contributes to the research in alternative fuel technologies and the impact of policy and financial incentives during the "seed stage" of an innovative technology. The investigation of the Greek drivers' travel behaviour and commercial fleet owners could be helpful to the Ministry of Transport regarding the nature of policy measures that could successfully affect the use of natural gas as a transport fuel. The automotive industry and car dealers could also gain insight on the type of vehicle models with the higher potential demand and therefore, expand their market share. Public Gas Provider could use the different policy packages to evaluate and compare the different scenarios and policy actions. Further initiatives include the design of communication campaigns, promotion policies and purchase subsidies, as well as the collaborations with car engineers to expand their market share in the vehicle conversion market.

The results of this study and the issues highlighted can be used by the several stakeholders, summarized in the figure below.

Figure 2-Stakeholders

Stakeholders			
Automotive industry Original Equipment Manufacturers Authorised Repair shops	Private car drivers Logistics operators Fleet owners in general (school buses, taxi drivers etc)	Infrastructure operators Infrastructure owners (Governments) Refuelling Station Operators	Local authorities Ministries Public Gas Provider

[3] https://ec.europa.eu/transport/themes/infrastructure/news/2019-03-28-investment_en

Chapter 2

Competition of alternative fuel technologies: current situation

2.1 Natural Gas characteristics

Natural gas is a gaseous hydrocarbon fuel located in underground sources. It is a mixture mainly of methane (CH_4) and amounts of ethane (C_2H_6) and propane (C_3H_8). It also includes nitrogen (N_2), and carbon dioxide (CO_2) and some impurities in minor quantities such as sulphur (H_2S) and mercury (Hg).

There are several technological characteristics of natural gas as a road fuel that should be thoroughly examined for the diffusion of natural gas in the market. Findings from the Handbook of Natural Gas Transmission and Processing (2006) can be summarized below:

- Natural gas is colorless, odorless, tasteless and lighter than air. It is transformed in gas at any temperature over -1620C.
- The main substance of natural gas is methane which has the least number of carbon atoms per hydrogen atom in a molecule of all hydrocarbons, therefore, natural gas exhibits the highest Hydrogen to Carbon ratio (H/C) of all the fossil fuels. Fossil fuels contribute to the energy content with carbon and hydrogen; if the combustion is performed in the most efficient way, namely with the correct quantity of oxygen, hydrogen leads to water vapor and carbon to carbon dioxide. Water has the lowest environmental impact; therefore, a high H/C is preferred.
- Natural gas contains less contaminants than fuel oil. The secondary emissions of natural gas, benzene, lead, nitrogen oxides, carbon oxide are significantly lower in comparison to gasoline.
- In order for natural gas to be used as transport fuel, a process of compression (CNG) or liquefaction (Liquified Natural Gas) is required, because of the low energy density at atmospheric pressure and temperature comparing to liquid fuels. Natural gas distribution network is geographically widespread since the distribution occurs using pipelines.
- The number of octanes (130) proves than natural gas has high detonation resistance. It offers higher compression ratios, it limits the engine noise, it reduces the need for toxic additives such as aromatic hydrocarbons which in case of gasoline are usually used to improve the number of octanes. The high number of octanes requires ignition by spark

plugs or injection in a spark ignited engine or, in a compression ignition engine, the low octane number makes it require a pilot fuel for ignition;
- The air in the cylinder which leads to engine power loss is replaced by fuel vapor;
- Since it is lighter than air, in the event of a spill, it disperses quickly when released;
- High ignition temperature required along with the low flammability range make is an inherently safe fossil fuel;
- It is explosive only in a range of 5% to 15% mixture by volume with air.

Natural gas is stored in a tank within the vehicle and provide a range of 300-800km depending on the car model, in accordance with New European Driving Cycle (NEDC). Most NGVs available in the market, are bi-fuel vehicles, namely they run either on natural gas or on gasoline. In that case, the cumulative CNG and gasoline autonomy could reach between 600 and 1,360 km, depending on the model (CREG, 2018).

Regarding the fuel price, in comparison to other available fuels, natural gas is relatively cheap. In Greece, according to official statistics from Greek Ministry of transport for 2019:

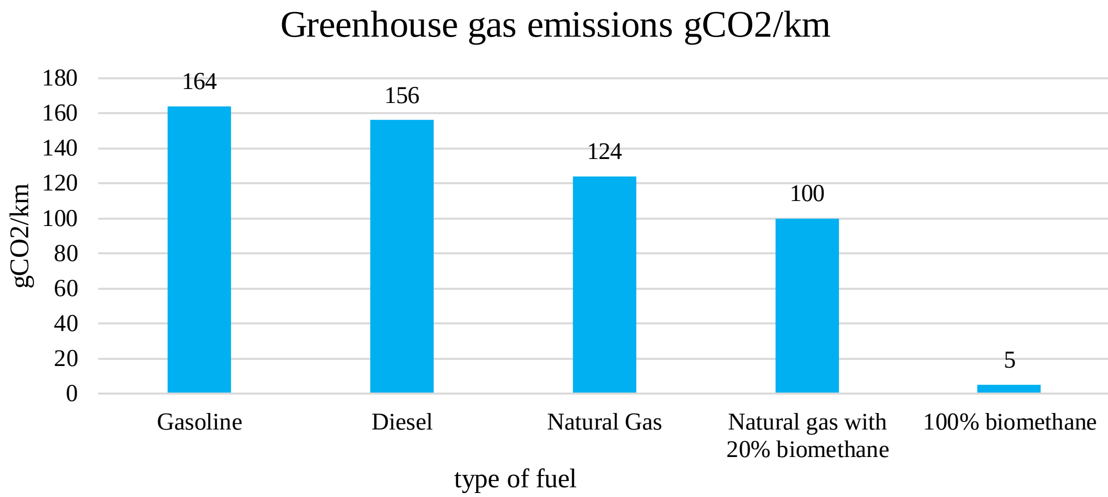
- 1lt of unleaded gasoline costed €1,55 on average, while in insular areas the price reached €1.78/lt, 1lt of diesel costs €1,25 on average,
- 1lt LPG costed €0,80 on average and 1kg CNG costed from €0.888 in Athens, with the lowest price to be €0.869/kg.
- Considering the energy equivalence of these fuels: 1 Kg of CNG is energetically equivalent to 1,77 liters of gasoline and 2,004 liters of LPG.

2.2 Environmental Performance

Most often cited advantages of CNG refer to pollution reduction (Demirbas A., 2002) (Lopez J.Ma., 2009) (Aslam M.U., 2006). The numbers may vary upon the source and the type of vehicle tested, but vehicles running on natural gas emit substantially lesser amounts of pollutants than gasoline powered vehicles. Non-methane hydrocarbons could be limited approximately by 50%, NOx by 50-87%, CO_2 by 20-30%, CO by 70-95% and almost no particulate matter (Semin, 2008). However, the clearer Euro 6 models make the air pollution benefits from the use of methane, much smaller compared to gasoline or diesel engines of the near past.

In the following table, tailpipe greenhouse gas emissions estimated in gCO_2/km for conventional fuel, natural gas and natural gas produced by biomethane are presented. The data refer to average estimations of medium size vehicles.

Figure 3-Greenhouse gas emissions generated by vehicles



Source : https://www.wingas.com/en/raw-material-natural-gas/mobility-with-natural-gas.html

Natural gas engines offer significant reduction of noise disturbance levels as they are on average 10 decibels quieter than even the diesel engines of the same category (NWGA, 2016) (Nijboer, 2010), without the need for major land use alterations (e.g. constructing low-emission zones or restricting vehicular movement in the city centre by blocking some entries from the ring road). Many developed countries have already established regulations imposing limits on noise pollution regarding, for example, urban night deliveries in city centres. Especially in crowded metropolitan areas, noise from traffic is a real problem, highly related with the wellbeing of the society that needs to be addressed. A lot of studies illustrated the impact on neurological and hormonal system, however governments, medical community or even the public did not perceive noise pollution as an urgent threat. Noise pollution is related to insomnia, fatigue, hormonal imbalances, vascular changes and high blood pressure even in pre-school children (Goines & Hagler, 2007) (Belojevic, Jakovljevic, Stojanov, Paunovic, & Ilic, 2008) (Sørensen, et al., 2014).

2.3 Current situation: number of cars, infrastructure and policy

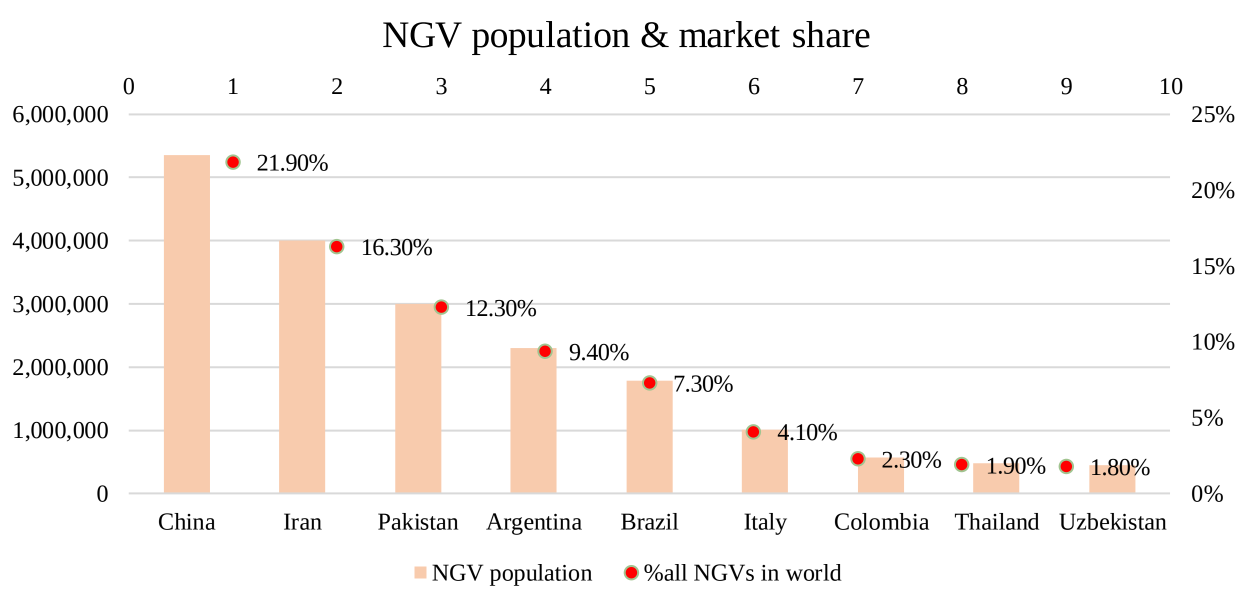
2.3.1 Worldwide

Although natural gas technology is not new, it is only the last decade that presented a significant growth as a fuel. While in 1996 there were less than a million NGVs worldwide, in 2019 the number stands for approximately 27 million vehicles. In Latin America and Asia, the increase of natural vehicles has been particularly strong when oil prices escalated. China has the largest population of NGVs in any nation and it is followed by Iran, Pakistan, Argentina, Brazil, and Italy. In China, the most significant reasons for fast adoption of alternative fuel technologies were environmental concerns and oil dependency. China was the world's second largest oil consumer; to minimise oil dependency, the government provided several incentives to promote the use of natural gas and expand the market, especially in public transport, as well as investments in R&D programs. (Yeh, 2007).

Globally, countries with saturated NGV markets such as Argentina, Brazil, and Italy, succeed this uptake mostly by developing the conversion market. However, the estimation of NGVs penetration rate, based on the number of converted vehicles, rather than dedicated NGVs, cannot substantially reflect the potentials of the new market. On top of that, converted vehicles do not have the environmental performance of dedicated NGVs and therefore lose their advantage over gasoline vehicles. (Janssen, Lienin, Gassmann, & Wokaun, 2006)

The following figure shows the ten countries with the largest population of NGVs (both converted and dedicated) and the respective market share. China, Iran, and Pakistan share the 50% of the total NGV population worldwide, with more than 12 million vehicles circulating in the country. The total share of rest of the countries reaches up to 27% of the NGV population.

Figure 4-Countries with the largest NGV population and the respective market share of NGV



Source: modified data from http://www.ngvglobal.org/

2.3.2 Europe

While the adoption of alternative fuel technologies worldwide is taken at a national level, in EU the challenge is different as 27 Member States must share a common voice on energy efficiency targets and strategies. In 2014, the EC published the Directive on the Deployment of Alternative Fuels Infrastructure which requires Member States to develop national policy plans for the development of alternative fuel markets (electricity, CNG, LNG, hydrogen) and their respective infrastructure.

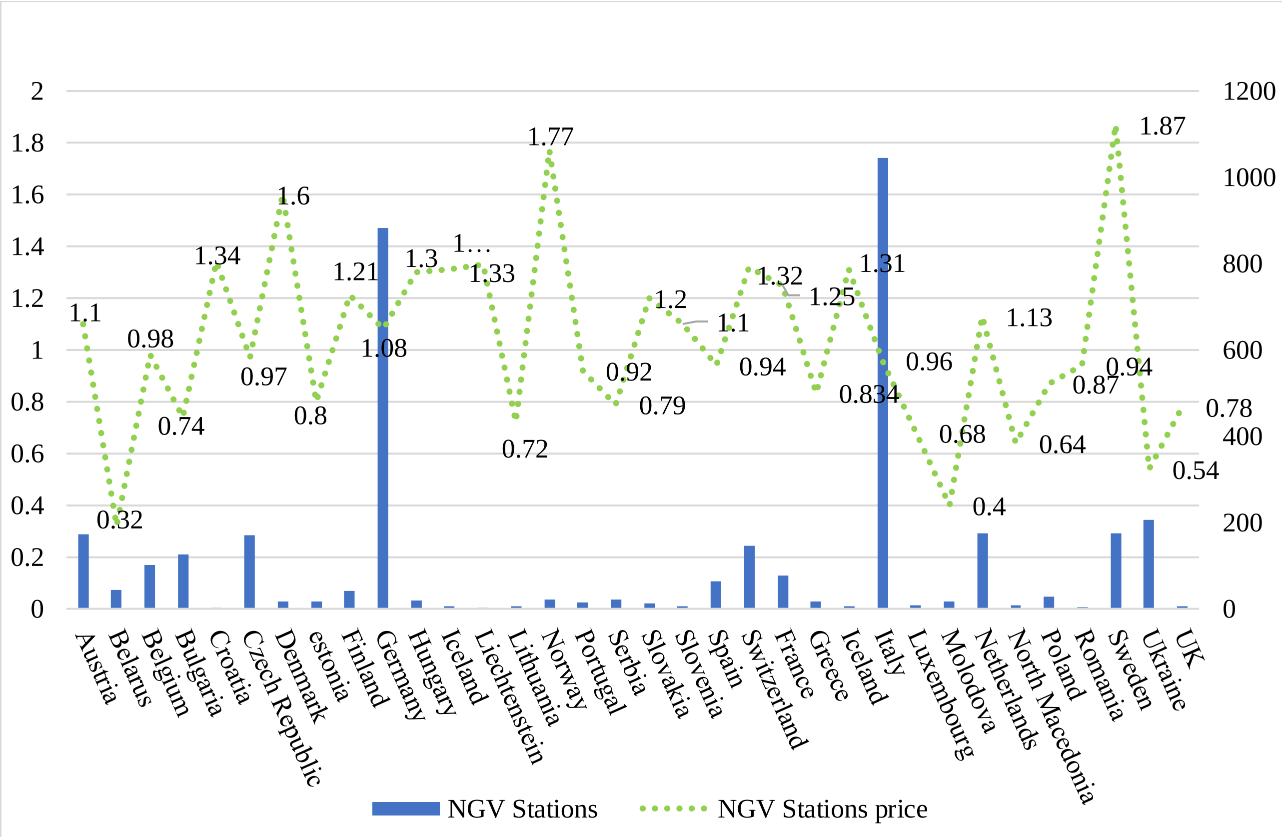
To overcome the issue of interoperability, the Directive also foresees the use of technical specifications for recharging and refuelling stations and introduces the set-up of appropriate consumer information and price comparison of alternative fuels. Regarding natural gas infrastructure the Directive requires the Member States to ensure enough stations in urban and suburban agglomerations and on the TEN-T network by the end of 2025, having as a tentative benchmark the construction of one station every 150km.

With the entering into force of the Paris Agreement, EC has committed to move forward into a low-carbon economy by reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990, under its wider 2030 climate and energy framework. To support this decision, the EC has adopted the Clean Mobility Package on 8 November 2017, to help accelerate the transition to low and zero emission vehicles. The EC has also published an action plan on alternative fuel infrastructure to reinforce the main objectives of the Member States regarding the development of alternative fuel infrastructure by 2030, as described in the Directive 2014/82/EU (EC, 2017). The action plan also includes an assessment of the objectives of the National Policy Plans that have been submitted to the Commission.

According to the Commission's Staff Working Document (EC, 2019), there are substantial differences on the estimation of the total investment needs by the Member States and the EC, for the deployment of alternative fuel infrastructure. Specifically, the estimated amount for alternative fuel infrastructure (CNG, LNG, Hydrogen stations and recharging points for EVs) are estimated up to 3€ billion from Member States, and up to 16-22€ billion from the EC. The incoherency in policy decisions between EC and the individual Member States further complicate the efforts for harmonised policy plan that meets the objectives of Paris agreement.

The following figure shows the number of stations and the CNG price in Europe. It can be easily noted that NGV population is growing in selected countries, especially Italy, which is not surprising considering the measures that have been implemented to encourage NGV uptake and the necessary fueling infrastructure available. The difference in every country's uptake is highly related to each country's long-standing legacy of gas vehicle usage. The increase of the global fleet is not equally distributed and there are significant differences among regions not only regarding the years of steep growth but also the composition of NGVs preferred.

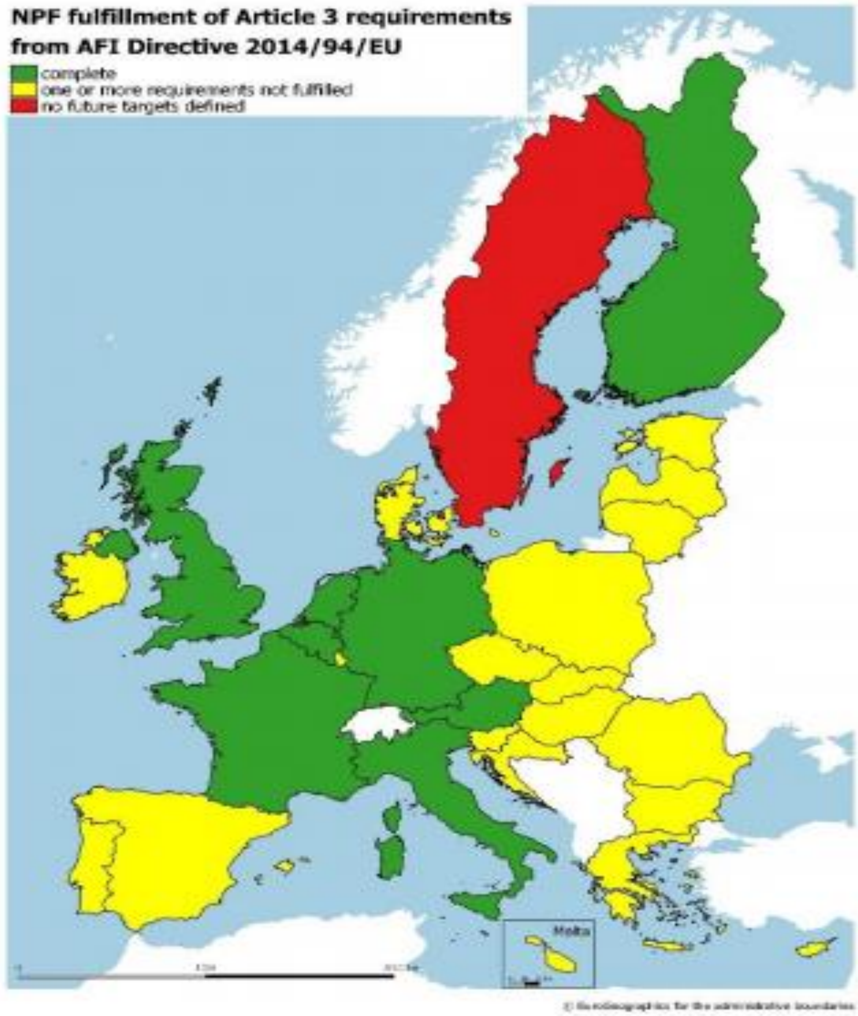
Figure 5-NGV stations and prices, Europe, 2019



Source: European Alternative Fuel Observatory, www.eafo.eu

The Commission Staff Working document for the assessment of National Policy plans (EC, 2019) provides an overview of the targets and objectives and the measure scores for comprehensiveness and the current level of attainment per Member state. There are 20 Member States that have not defined the alternative fuel infrastructure targets for all modes and fuels, or they do not meet the respective requirements of the Directive. Based on the findings of the assessment, the National Policy Plans are not coherent at Union level, presenting different kind of priorities and ambitions for the different fuels which can lead to a market fragmentation at EU level and even within certain Member States. The following figure shows a high-level overview on the compliance of the National Policy Plans with the requirements of the Directive.

Figure 6-Fulfilment of requirements from AFI Directive



Source: Commission Staff Working Document, 2019

The assessment of the National Policy frameworks reveals big differences between neighbouring countries, however a level of cross border continuity can be identified between Member States because of their proximity or because of the major ferry connections like: Belgium-France, Belgium-Luxembourg, Belgium-the UK, Bulgaria-Greece, Bulgaria-Romania, the Czech Republic-Poland, Germany-Denmark, Germany-France, Germany-Luxembourg, Germany-Poland, Denmark-Sweden, France-Italy, Ireland-the UK, Italy-Malta and the Netherlands-the UK.

The following table presents the overall score[4] of comprehensiveness in charging infrastructure and CNG stations for all Member States. It is more than evident that the score of

[4] The scoring methodology is published in the Commission's Staff Working Document. https://ec.europa.eu/transport/sites/transport/files/legislation/swd20190029.pdf

comprehensiveness for charging stations in almost all Member States is better than the score of CNG infrastructure. This score further validates the heterogeneity of the alternative fuel infrastructure in Europe and the different level of prioritisation which divides Europe into "leaders and followers". The rapid expansion of recharging infrastructure can be easily justified if we consider the relatively low cost of charging stations compared to the establishment of natural gas one. Based on the type of installation, the cost of a CNG station can range up to 200,000€ and 300,000€M, while smaller installations units can cost up to 10.000 (Wainwright & Peters, 2017). On the other hand the average total cost[5] of a public charging station (11-22kWh) is 4,500€, and for the fact charging and ultra-fast charging station the cost is 31,000€ and 75,000€ respectively (Transport&Environment, 2020).

Table 1-Overall score of comprehensiveness, 2019

AF infrastructure for fuel/mode	Electricity for vehicles	CNG for vehicles
Austria	c	n
Belgium	c	n
Bulgaria	c	n
Cyprus	c	x
Czech Republic	c	n
Germany	c	n
Denmark	c	n
Estonia	x	c
Greece	c	c
Spain	c	c
Finland	c	c
France	c	c
Croatia	c	n
Hungary	c	n
Ireland	c	c
Italy	c	c
Lithuania	n	n
Luxembourg	c	n
Estonia	c	n
Malta	c	x
Netherlands	c	x
Poland	c	c
Portugal	c	n
Romania	c	c
Sweden	c	n
Slovenia	c	n
Slovakia	c	n

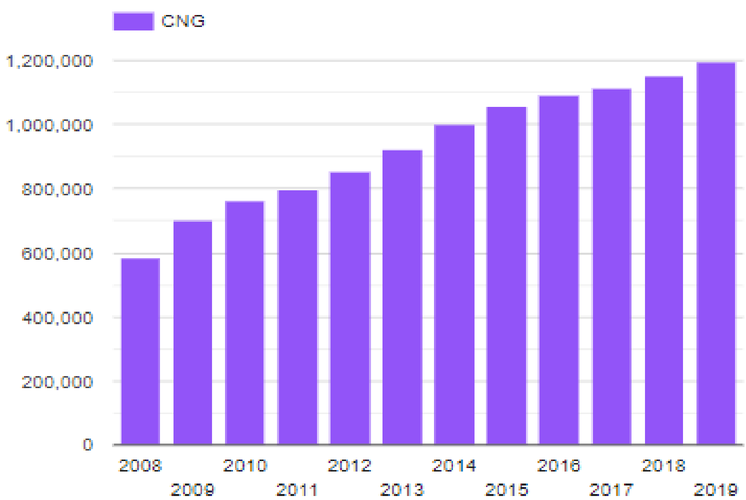
[5] Including installation cost, equipment cost and grid connection

United Kingdom	c	x
x = nothing assessable defined N = not comprehensive C = comprehensive		

Source: Commission Staff Working Document, 2019

The following figures provide insightful information regarding the number of circulating AFVs in Europe and the respective infrastructure, and the evolution throughout the years.

Figure 7-Total number of CNG passenger cars, Europe, 2019

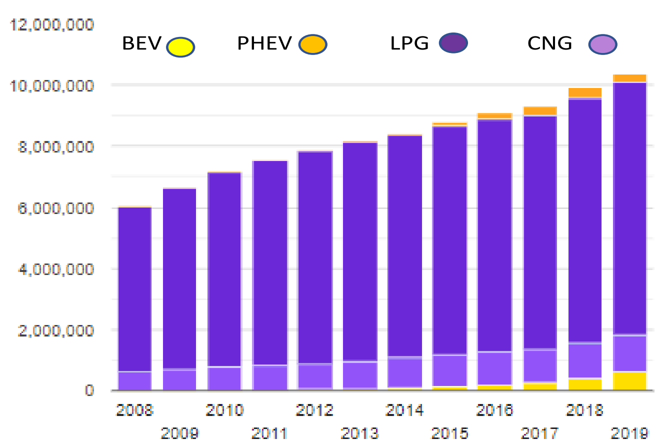


Source: European Alternative Fuel Observatory, www.eafo.eu

Generally, the demand for alternative fuel technologies in Europe continued to grow in 2019. Regarding EU, the respective percentage for alternative fuel vehicles were 35.1% higher than in the same period in 2016.

Currently, there are around 1.2 million vehicles running on CNG representing 0.7% of the EU28 vehicle fleet, including Switzerland, and 75% of the market is Italy. More than 3,000 refuelling points are available, 2/3 of them are in Germany and in Italy.

Figure 8-Total number Alternative Fuels passenger cars, all categories, 2019

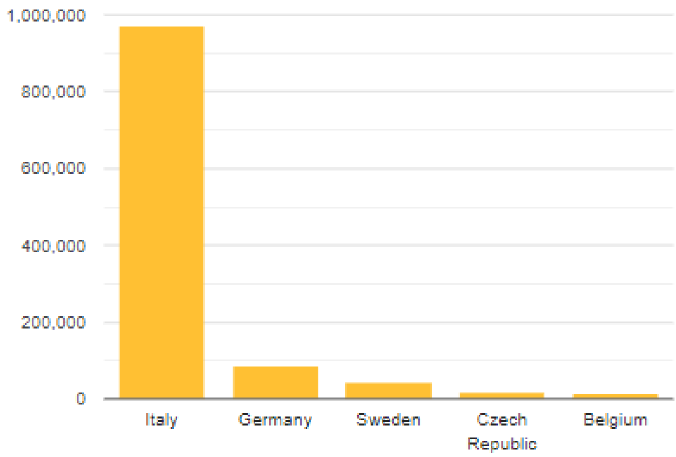


Source: European Alternative Fuel Observatory, www.eafo.eu

This figure illustrates the **total number of alternative fuel passenger cars** throughout the years. LPG has the largest share in all years whereas CNG shows a stable trend.

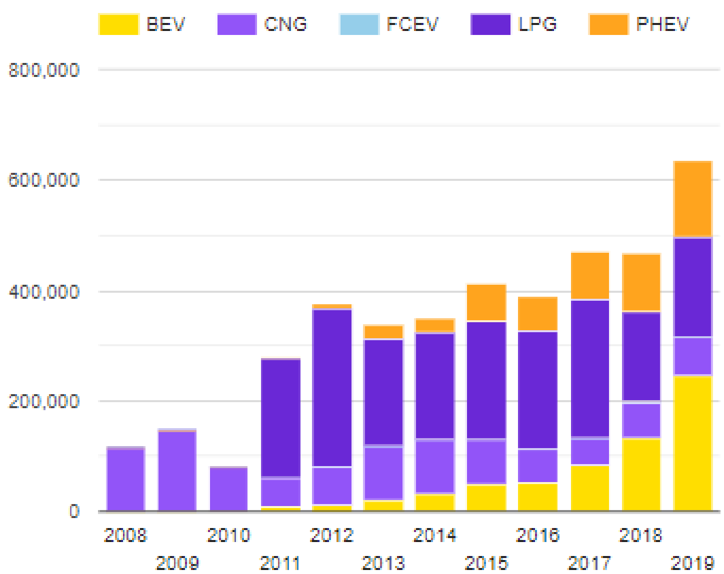
Plug-in Hybrid electric vehicles and Battery electric vehicles almost doubled from 2018.

Figure 9-Top 5 countries of CNG fleet



This figure presents the **Top 5 countries in CNG market** for 2019. The countries with the highest share of fleets have also a well-established refuelling infrastructure.

Figure 10-Alternative Fuel passenger cars new registrations,2019



In this figure the **new registrations** of alternative fuel passenger cars are presented. Battery electric vehicles have gained a substantial share since 2018 with an overall increase of +86% in 2019.

New registrations of CNG cars present a slight decrease throughout the years especially as of the introduction of new technologies in the market.

Source: European Alternative Fuel Observatory, www.eafo.eu

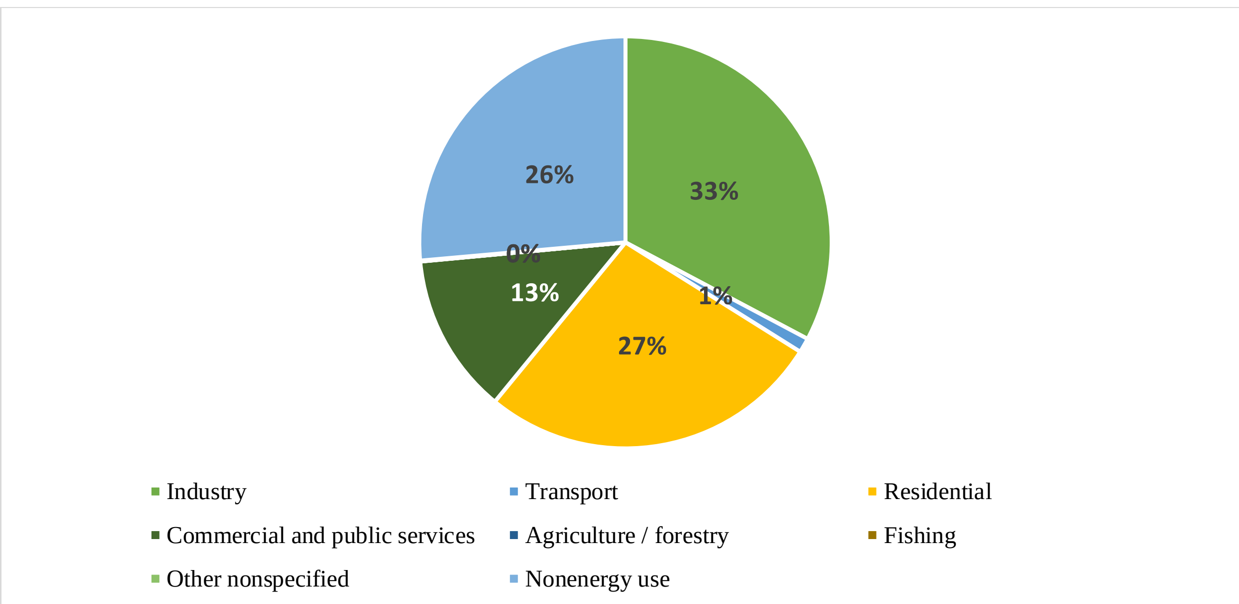
2.3.3 Greece

The general picture

The consumption of natural gas in Greece, has begun in the late 90's used mainly for power generation and industrial use and a small share in the residential sector. Greece's natural gas production is relatively small (0.009 billion cubic meters in 2016) compared to the total consumption of 4.1 bcm. Greece imports natural gas from Russian Federation (almost 65% in 2016), from Algeria (17% of LNG supply) and Turkey. Greece belongs to the Orient/East-Med Corridor (Corridor D), which connects major German seaports of the North Sea and the Baltic Sea with the Eastern Mediterranean region and the Black Sea. Corridor D passes through nine EU Member States: Germany, Czech Republic, Austria, Slovakia, Hungary, Romania, Bulgaria, Greece and Cyprus. It connects the cities capital of the crossed Member States except for Romania.

The following figure represents the share of natural gas by sector:

Figure 11-Share of natural gas consumption by sector- Greece (2018)



Source: Institute of Energy for SE Europe, IENE, 2019

Road transport

The total number of passenger cars are approximately 5 million. In 2019 the number of NGV is 3,472 representing 0.03% of the total vehicle population of the country. The refuelling network of Greece in 2020 comprises of 17 refuelling spots, while most of them are located in the two most densely populated areas: Athens and Thessaloniki. The main alternative fuel is Liquified Petroleum Gas (LPG) which is a by-product of oil and gas production and the main components are propane and butane. LPG vehicles have a share of 3.04% from all the vehicles in circulation. It is important to note that in NPF of Greece, LPG is expected to grow to shares higher than 4.5% in 2020, than 5.5% in 2025, and more than 7.5% in 2030.

Table 2-Number of alternative fuel vehicles in Greece 2009-2014

	2009	**2014**	**2019**
LPG	20,000	220,000	275,000
CNG	-	280	3,472
BEV	-	45	426
PHEV	-	17	570

Source: European Alternative Fuel Observatory, www.eafo.eu

During the last years, the growth rate of LPG in Greece was steep: the feasible conversion of the vehicles and the significant fuel economy, led to a widespread interest in this fuel. However, the number of bi-fuel vehicles (LPG-gasoline) is still unclear, as many of the drivers have not updated their license in the Technical Vehicle Control Centre, while others have installed sets without the required certification. However, according to the estimations, the cheap and easy-to-install LPG conversion is an attractive option for the drivers.

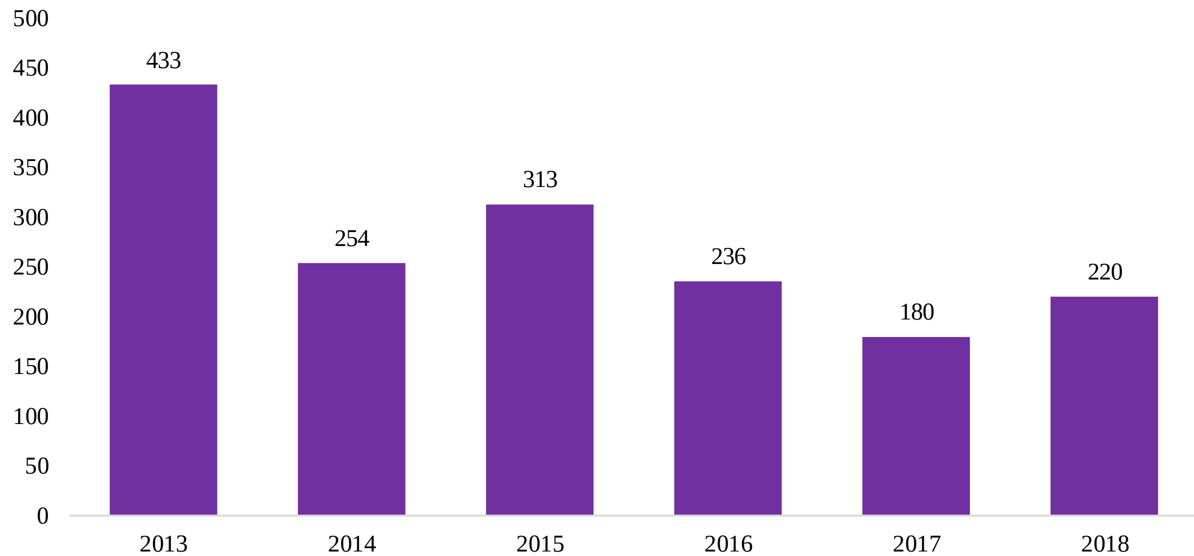
The well-established reputation of LPG hampered the introduction of the “cleaner fuel” CNG in the Greek market. Furthermore, the lack of CNG refuelling network and the misinformed public regarding alternative fuel characteristics was a discredit for CNG and its advantages and the respective share of NGVs is still marginal.

In 2015, for the promotion of natural gas, National Provider of Natural Gas (DEPA S.A.) has collaborated with TUV Austria in order to overcome the boundaries of technical support and repair shops for natural gas vehicles. TUV Austria Hellas undertook the training and certification program of the first independent repair shops for converted bi-fuel vehicles and dedicated NGVs in several cities of Greece in which there are already established natural gas filling stations. The training program was in accordance with the requirements of the Certifications and Audits Private Protocol which created in the context of the support of DEPA S.A. During the training program the participants were trained regarding the installation, the conservation and repair of CNG systems in vehicles, the building and electromechanical infrastructure, and the quality management system.

In 2016, DEPA S.A. has launched a subsidy program in collaboration with Volkswagen, Skoda and Mercedes. The amount of subsidy starts from 1,500€ up to 10,000€ for every new vehicle. A conversion subsidy program offered the opportunity to drivers to convert their gasoline and diesel vehicles into bi-fuel. The subsidy covered the total expenses of the conversion; for gasoline vehicles is up to 800€ and for diesel vehicles is 12,000€. Greece follows the policy of gradually excluding the circulation of diesel vehicles in Athens Metropolitan centre by the end of 2020.

The following table provides information regarding the number of new registered NGVs in Greece. However, the number cannot justify if these vehicles have been converted into bi-fuel. Plus, the majority of the NGVs in Greece are mostly garbage trucks, public buses, and taxis, operating in Athens. The number of passenger vehicles running on CNG is still marginal.

Figure 12-NGV new registrations, Greece (2018)



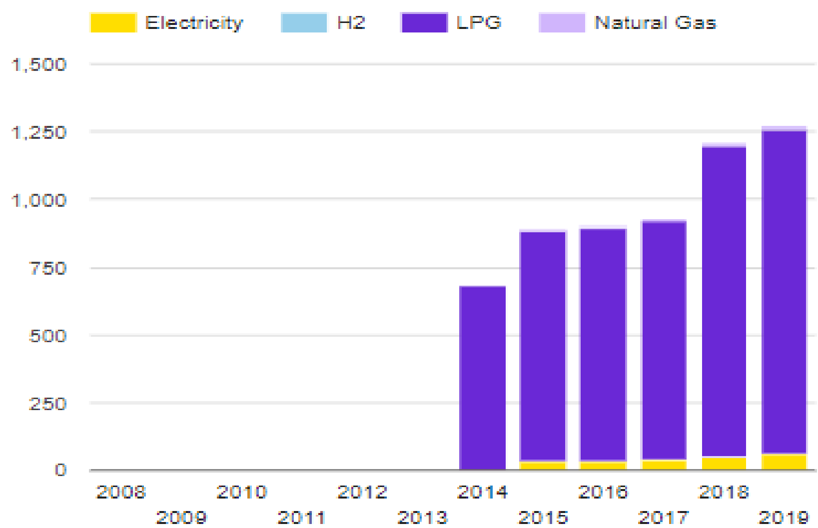
Source: European Alternative Fuel Observatory, www.eafo.eu

Greek Refuelling Network

The National Provider of Natural Gas has constructed the refuelling network which includes 6 refuelling stations in Athens, 3 refuelling stations in Thessaloniki, 1 in Volos, 2 in Larissa, 1 in Lamia and there are 7 under construction. Currently there are 34 authorized repair shops for natural gas vehicles of which: 18 repair shops in Athens region, 6 in Thessaloniki, 3 in Volos, 3 in Larissa, and 1 in Fthiotida, Chalkidiki, Kozani and Evia. The following map represents the current and planned refuelling stations in Greece.

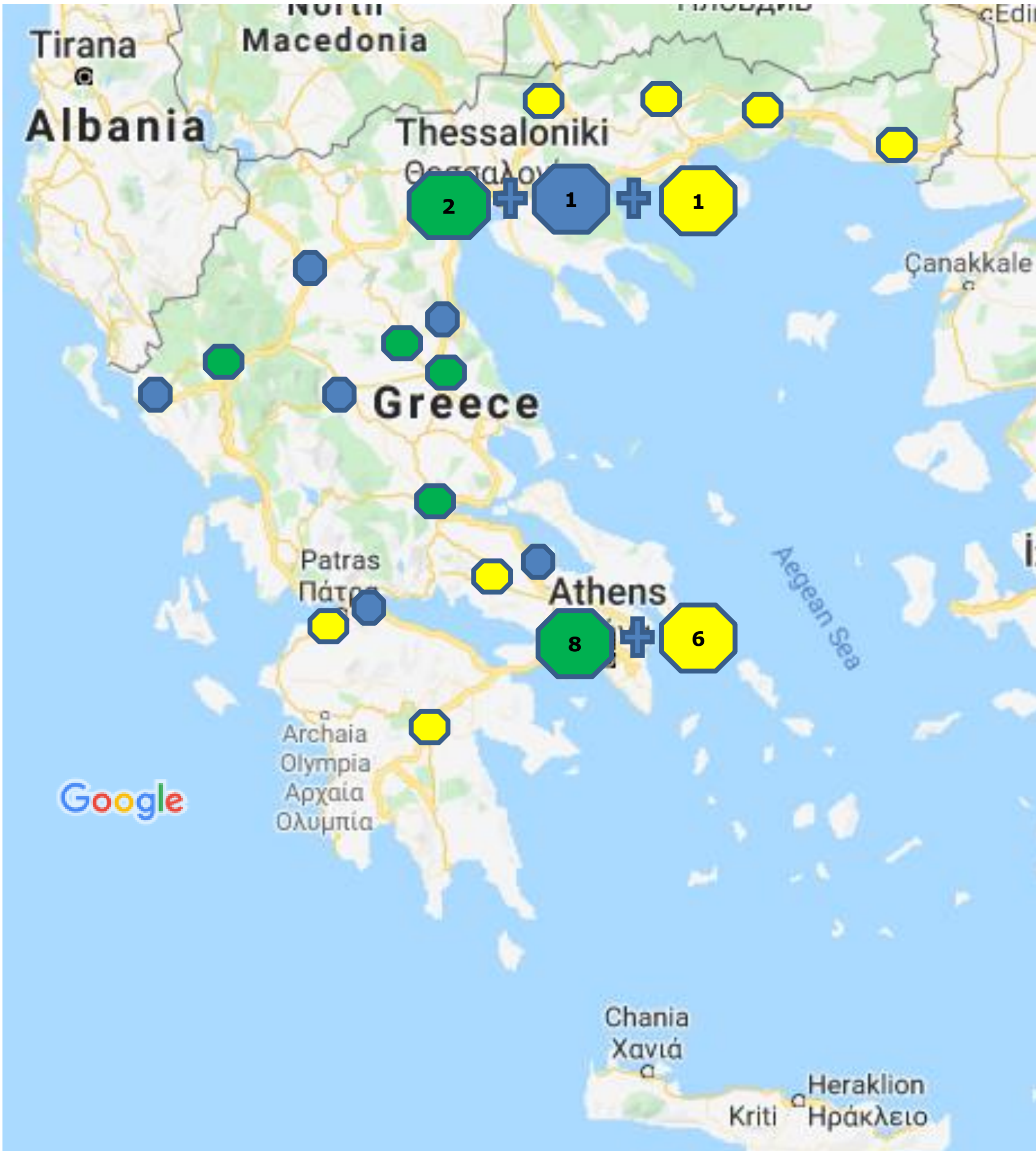
The following figure presents the number of alternative fuel stations in Greece from 2008 until 2019. The number of LPG stations is 1,196 in 2019, the number of CNG stations is 17 and the number charging points reached 58.

Figure 13-Alternative fuel stations Greece, 2008 -2019



Source: European Alternative Fuel Observatory, www.eafo.eu

Picture1-Natural Gas Refuelling stations in Greece



Source: *<u>https://www.fisikon.gr/</u>, map elaborated by the researcher*

(green)	Refuelling Stations currently operating
(blue)	Refuelling Stations planned to operate within 2020
(yellow)	Refuelling Stations in the design phase

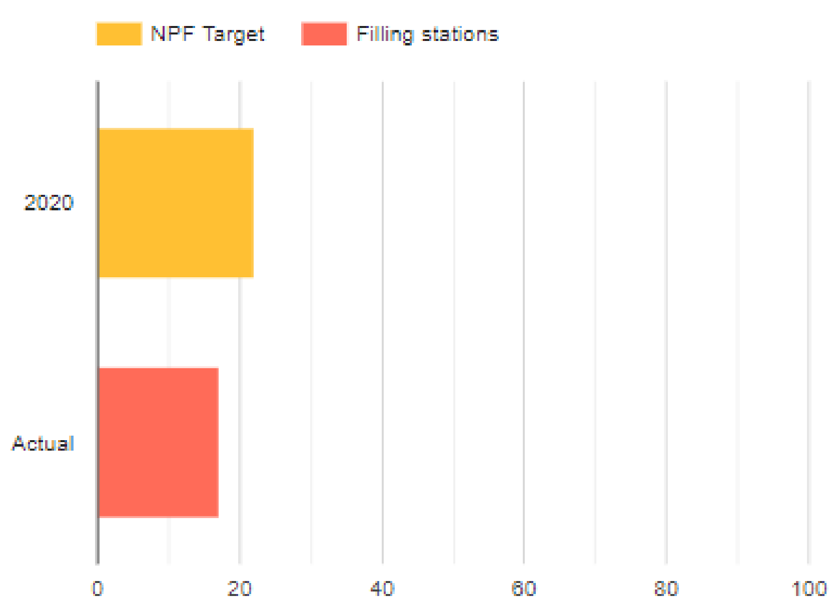
National Policy Framework Plan

According to the National Policy Framework, Greece has established appropriate refuelling infrastructure targets that reflect the vehicle projections. The wide portfolio of measures includes among others administrative, legislative and regulatory type of targets to facilitate the installation and operation of the alternative fuel infrastructure.

CNG

For natural gas, the focus is on the expansion of the refuelling network. Greece is also interested in cooperating with neighbour countries to ensure EU wide circulation of AFVs on the TEN-T network. By 2025, the CNG vehicle penetration rate, compared to all vehicles in circulation in Greece, is expected to be 0.5%. In Greece, a small number of vehicles use only CNG as a fuel, out of which 463 are passenger vehicles, 127 are trucks and 310 are buses. Demand for natural gas is gradually rising but at very low rates, and, in that context, a gradual increase in new CNG supply infrastructure is expected in the years to come, reaching 25 supply points in 2020 (public and private).

Figure 14-CNG infrastructure for road vehicles (2019) (NPF target compared to the current attained number of filling stations)



Source: European Alternative Fuel Observatory, www.eafo.eu

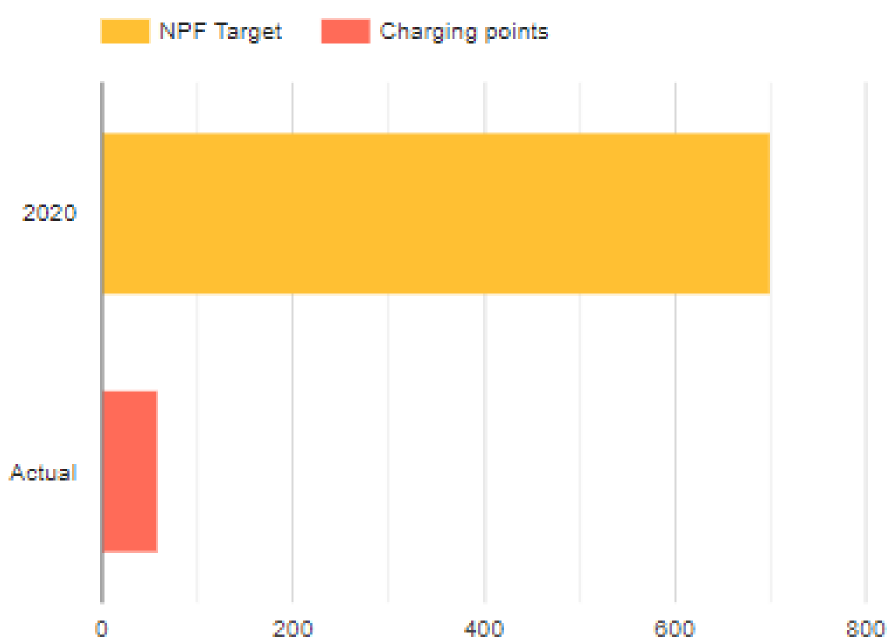
Electromobility

Electromobility is mostly promoted with financial measures (e.g tax exemptions, ownership tax benefits and luxury living tax) and purchase subsidies up to 30% of the price have been announced. The use of electric vehicles is at seed stage, mostly in street cleaning vehicles or municipal police vehicle. The first electric vehicle chargers were installed in Greece in 2011, whereas the sales of electric vehicles started in 2013.

According to the National Policy Plan of Greece, the optimistic scenario describes that: in 2020 there will be 3,500 electric vehicles of all types in circulation, in 2025, that figure will be 8,000 vehicles and in 2030, there will be 15,000 electric vehicles in circulation. The fact that the initial cost of acquiring electric vehicles is still high in Greece, it is estimated that the number of recharging points (both public and private) by 2020 will not exceed 2,000.

Figure 15-Electricity infrastructure for road vehicles, 2019

NPF target vs. current attained number of charging points



Source: European Alternative Fuel Observatory, www.eafo.eu

Investments in gas distribution infrastructure

Greece could secure the long-term natural gas supply and gain a fundamental know-how, pertinent to natural gas technologies in order to create sustain economic synergies with other countries in the region. Greece is in a transitive period, when accessibility to international gas supply networks is considerably increasing, creating important challenges. For that reason, Greece is involved in several international pipeline projects:

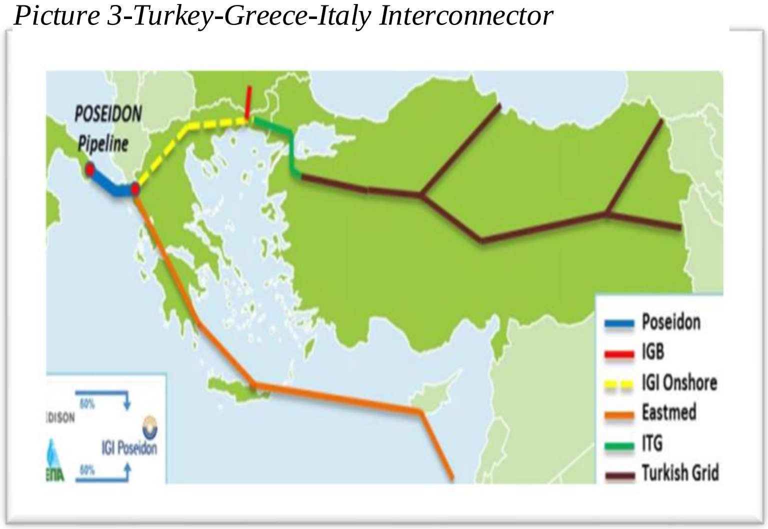
The Transadriatic Pipeline: The Trans Adriatic Pipeline (TAP) will start near Kipoi on the border of Turkey and Greece, where it will connect with the Trans Anatolian Pipeline (TANAP). A project that transfer gas from the Caspian region to Europe through Turkey, Greece and Albania to end up in Italy. The construction is ongoing while the commercial operation will begin in 2020. The total Greek share of the pipeline is approximately 550km, connecting to Turkey at Kiproi and Albania at Ieropigi.

Interconnector Turkey-Greece-Italy: This pipeline will transfer natural gas From Caspian Region, and it is comprised by three parts: the 296km Interconnector Turkey - Greece which is in operation from 2007, the 570km onshore pipeline from Komotini to Igouemenitsa and a 216km offshore Poseidon pipeline from Thesprotia to Italy. As it was already mentioned, the IGI Poseidon I a joint venture of Italy’s Edison (50%) and DEPA (50%).

Picture 2-Trans Adriatic Pipeline

Source : https://www.tap-ag.com/the-pipeline/route-map

Picture 3-Turkey-Greece-Italy Interconnector



Source: http://www.depa.gr

Interconnector Greece-Bulgaria Pipeline: The critical project of Greece-Bulgaria pipeline will enhance the security of supply in South Eastern Europe. It is designed to allow physical and commercial reverse flow, and it will connect with DESFA and Trans-Adriatic Pipeline near Komotini. The construction begun in 2018. The project is a joint venture of IGI Poseidon and state-owned Bulgarian Energy Holding.

Picture 4- East Med Pipeline

EastMed Pipeline: A project of an offshore/onshore pipeline by IGI Poseidon, with a total length of 1900 km that will directly connect Eastern Mediterranean gas reserves to Greece. The pipeline would transport 10bcm per year.

Source: https://www.edison.it

The interest in international pipeline projects show that Greece seizes the opportunity to become an energy gateway for natural gas into Europe. These fundamental projects will reassure the increase of the capacity and will allow the parallel expansion of the domestic gas network. By now, natural gas has been used largely on residential industrial use, but the development plan of the Public Natural Gas Distribution Networks Cooperation which includes the expansion of the network to 40 cities across the country and to the main islands will ensure the supply of natural gas to unserved areas.

Conclusions

This chapter presented the technical characteristics of natural gas vehicles, their energy performance, and it provides an overview of the evolution of natural gas vehicles and infrastructure around the world. The assessment of National Policy Plans for alternative fuel infrastructure further validates the fact that EU is divided in two groups based on their compliance score: the leaders and the game followers. The chapter also includes the current market status in Greece and where it stands it terms of National Policy Plan works and the future investments in natural gas supply.

Chapter 3

Market potential and diffusion barriers of alternative fuels: literature review results

3.1 Diffusion Barriers

As background of this thesis, in this chapter it is reviewed what is known from previous studies about the main factors that affect the market uptake of alternative fuel technologies, and the role of policy and financial incentives on the promotion of alternative fuels. Since, there is no significant literature on the estimation of the demand of NGVs in specific, in order to further understand some factors that affect the decision-making process, a literature review regarding the potential demand of AFVs running on different fuels not only natural gas (electric, hybrid, biomethane etc.) is reviewed. Finally, this chapter includes a brief reference of the major theories of Behaviour change.

The primary reason for the increasing policy interest on alternative fuel technologies adoption, is that they offer a pathway to reduce greenhouse emissions generated by transport sector without the need for road pricing measures or restrictive land use planning. However, there are numerous of barriers that prevent natural gas adoption. Literature review findings, shed light to the main barriers of the adoption of a new technology, which are categorised as follows:

1. Chicken and egg conundrum: Small number of circulating NGVs due to small number of refuelling stations and vice versa.
2. Vehicle technology;
3. Lack of coordinated national strategies with the stakeholders;
4. Imperfect information of the consumers regarding the benefits of natural gas;
5. The role of Electric vehicles in the alternative fuel market.

The above-mentioned barriers are the result of an in-depth literature review that will be thoroughly presented in the following sections.

3.1.1 Natural Gas Vehicles and Refuelling stations

The successful introduction of natural gas vehicles is highly dependent on the development of the respective infrastructure, with the establishment of new natural gas stations, either with the conversion of the existing ones. Therefore, the market uptake of an alternative fuel system depends also on the degree to which the new technology is compatible to the old system. (Flynn, 2002) (Yeh, 2007); (Mabit & Fosgerau, 2011); (Browne, O'Mahony, & Caulfield, 2012); (Wang-Helmreich & Lochner, 2012). Contemporary drivers are used to a well-developed high performing refuelling network and they also require available and qualified technicians to support their trips. Such demands hinder the viability of an alternative fuel, especially when the refuelling network is still under-developed and cannot support long-distance trips (Struben J. , 2006). The lack of coherency of the network is also a factor that burdens the adoption of natural gas because potential customers, such as tourists or everyday commuters with different work locations, cannot use their CNG vehicles for a cross-border travel. (Engerer & Horn, 2010).

To estimate the level of market penetration of natural gas, many researchers use the vehicle-to-refuelling station index (VRI = NGVs in thousands/ number of refuelling stations) source and compare the VRIs of benchmark countries that have successfully introduced natural gas in the market to others. As the indicator gravitates toward 1, countries have managed to deal with the "chicken and egg" problem. Well-established natural gas markets like in Argentina, Brazil and Italy, present a VRI close to 1 (Yeh, 2007) (Engerer & Horn, 2010). The satisfying VRI indicator in these countries, also reflects the successful market of vehicle conversion. The know-how and the affordability of a vehicle conversion, from gasoline to bi-fuel gasoline-CNG, provides significant motivation not only to potential users, but also to refuelling network investors.

In the following table the Vehicle Ratio Index of top ten countries worldwide is presented.

Table 3-Vehicle Ratio Index of top ten countries worldwide,2019

Country	***NGV population***	***%all NGVs in world***	***Refuelling stations 2018***	***VRI index***
China	5,350,000	21.9%	8,300	0.64
Iran	4,000,000	16.3%	2,400	1.66
Pakistan	3,000,000	12.3%	3,416	0.87
Argentina	2,295,000	9.4%	2,014	1.13
Brazil	1,781,102	7.3%	1,805	0.98
Italy	1,001,614	4.1%	1,012	0.98
Colombia	565,045	2.3%	801	0.70
Thailand	474,486	1.9%	502	0.94
Uzbekistan	450,000	1.8%	213	2.11

Source: modified data from http://www.ngvglobal.org/

Yeh (2007) highlighted the importance of VRI index, by examining the successful natural gas market of 8 countries with different market structure and adoption patterns (India, Pakistan, China, Argentina, Brazil, Italy, US, New Zealand). The importance of the establishment of a sufficient refuelling network, taking into consideration VRI index, could be used as an indicator for the level of spatial density and it could be also used to estimate the profitability of each station. For example, a profitable refuelling station requires a minimum indicator of 0.2~0.4, considering as well external factors and costs related to the filling station (commission fees, gas prices, costs associated with the connection to the gas grid) (Wang-Helmreich & Lochner, 2012).

VRI index and market penetration are indicators that reflect the imbalances of the refuelling network and are commonly used by:

- Station owners and investors in transport infrastructure to estimate the profitability of a CNG station;
- Public authorities and investors to define the optimum locations for the CNG stations to meet the needs of the demand and to achieve a better utilisation of the stations when there is fewer vehicle per station.

Even supposing the easy implementation of the VRI to measure the diffusion of natural gas, the aggregation to a national level differs, because of the geomorphological characteristics, the spatial differences, and socioeconomic characteristics of each region. Refuelling accessibility is a function of the driving distance and waiting time for refuelling, also the driver's desired trip distribution which includes the willingness of the driver to spend more time driving out of the way to reach a refuelling network. The unfavourable geographical dispersion of filling stations in the U.S. for example, along with the convenience cost of the extra driving time, were the main reasons that brought the NGV market close to collapse (von Rosenstiel, Heuermann, & Husig, 2015). These factors affect unequally the consumers, based on their needs, and add additional uncertainty to the validity of the VRI (Yeh, 2007); (Struben & Sterman, 2008).

To add to the complexity, many studies confirm the paradox and show that the existing refuelling stations that could serve bi-fuel vehicles in urban areas are, in many cases, more than enough to support the refuelling system with the appropriate technological modifications (Yeh, 2007); (Melaina & Bramson, 2008).

CNG stations have capital costs relating to connection to the gas grid, storage and compression of the gas, and the pumping hardware to transfer the natural gas to the vehicles. According to the Report on Clean Power for Transport Infrastructure Deployment (Wainwright & Peters, 2017), the total cost of this facility would be between 200,000€ and 300,000€, depending on the compression capacity of the installation (normally 300-500 m^3/h). A market study in Germany showed that the first steps of building up a sufficient infrastructure for NGVs should include subsidies up to 50% of the investment costs for the first refuelling stations (Janssen, Lienin, Gassmann, & Wokaun, 2006). However, the subsidies should be long-lasting and the successful transition of natural gas from an initial "niche" market to a mature and sustainable market, requires that alternative fuel stations to represent a minimum of 10%-20% of conventional stations. (Greene D. , 1998); (Nicholas, Handy, & Sperling, 2004).

On the other hand, the fast development of new CNG filling facilities is often a double-edged sword for their economic viability, as the number of circulating NGVs is not sufficient to meet the profitability goals of fueling station operators. Therefore, the "chicken and egg" problem becomes more intense. Once the subsidies for stations and for NGV customers are over, the investment to CNG stations is considered risky and non-attractive. Canada is a representative example of an NGV market collapse because of very low investments on filling stations. (Janssen, Lienin, Gassmann, & Wokaun, 2006).

NGVs and the refuelling network are complementary goods and requires investments from both car manufacturers and fuel network providers at the same time. The absence of coordination between automotive industry, fuel companies and infrastructure companies present the NGV market as highly unattractive for future investors and drivers. (Yarime, 2009)

3.1.2 Vehicle characteristics and fuel economy

The diffusion of natural gas is also hindered by the properties of NGVs, and the consumers' perceptions with respect to their advantages. Environmental performance of NGVs is their greatest advantage in terms of toxic emissions compared to any other hydrocarbon fuel, however, in order for NGVs to compete conventional vehicles running on gasoline or diesel, significant technological modification is required to achieve the same cruising range. In that case, larger tanks must be installed that will reduce the loading space of each vehicle and will reduce its efficiency to the extra weight (Gligorijević, Jevtić,, Borak, & Petrović, 2009).

With regards to purchase price, NGVs are affordable as a NGVs costs on average 200€ more than diesel ones, and approximately 2,500€ more than gasoline (CREG, 2018). Electric and hybrid models cost 15,000€ more than the respective NGV of the same category (comparison made based on the only available model in all fuel types, VW Golf). However, the limited variety of NGVs offered by the manufacturers is also an obstacle that hinders the successful uptake of NGVs. The introduction of NGV vehicles by the automotive industry relative to the gasoline and diesel models is an indicator, that reflects the respective level of penetration of natural gas in the market (Yeh, 2007).

Theoretically, the gradual reduction of the purchase price of an NGV throughout the years due to technological maturity, and the implementation of tax incentives or other subsidies, should have generated by now, an important boost for the natural gas diffusion. Nevertheless, consumers are sceptical in front of a long-term investment in a fuel-efficient car, and that is illustrated by the very short payback period they require. Survey findings show that this period is often less than 3 years, which is significantly shorter, comparatively to the lifetime of most passenger vehicles (Green, Patterson, Singh M, & Li, 2005). It has been also identified that consumers tend to exclude the estimation of the present value of fuel saving, in the decision-making process for the purchase of a vehicle. The inability to calculate the fuel savings and therefore, the reduction in operating costs, leads to an underestimation of the potentials of a new fuel. (Green, Patterson, Singh M, & Li, 2005); (Turrentine & Kurani, 2007). However, the inability or the unwillingness of the public to estimate correctly the future fuel savings and compare current operating costs with true economic benefits of their investment, shows little about the factors that affect the car-buying decision (Greene, Patterson, Singh, & Li, 2005). In a perfectly rational decision making, the duration of a payback period depends on i) annual distance travelled, ii) the upfront investment cost of an NGV, iii) difference of fuel price between new and conventional technologies, iv) vehicle efficiency (Yeh, 2007).

3.1.3 Lack of coordinated national strategies

The NGVs diffusion is inherently associated with four types of stakeholders: consumers reluctant to purchase vehicles that it is not easy to be refuelled, automotive industry reluctant to produce vehicles that will not be purchased and private infrastructure investors reluctant to invest in refuelling stations with high profitability risk due to low demand (Yarime, 2009); (von Rosenstiel, Heuermann, & Husig, 2015). The last critical stakeholder is the government of each Member State that can influence the adoption of AFVs with several policy instruments; mandates, subsidies, financial incentives. (Romm, 2006)

Even though, Member States are obliged to meet Directive's objectives, policy actions implemented so far are not efficient enough to commercialise natural gas technology. Governments play a major role in building infrastructure and instituting policies that could promote the adoption of natural gas. Furthermore, governments should form a national system of innovation in order to conclude strategic agreements between the car industry and auto dealers, for the construction of new fueling stations, to create a sufficiently large and self-sustainable market (Suurs, Hekkert, Kieboom, & Smits, 2010). However, issues regarding which stakeholders should undertake the costs of developing the infrastructure, and the investments regarding the modification of the existing infrastructure network, are still on the table. (Hall & Kerr, 2003)

Furthermore, the lack of cooperation between governments and policy makers can be justified by the fact that they refuse to commit the funds to support research and development in inaugural technology because of: a) limited sources and obliged austerity, b) "wait and see" approach instead of "first mover" approach, and c) international policy outlook that does not meet the needs of each nation separately (Browne, O'Mahony, & Caulfield, 2012).

Policies often include combination of several short-term measures such as emission taxes, standard taxes or mileage taxes, for the promotion of a new fuel technology. Germany has one of the largest automotive industry of Europe and the promotion of natural gas has been strongly promoted during the last decade. A tax reduction on CNG up to 80% lower than gasoline, could be considered as a promising policy action, especially when the tax benefits were significantly higher than the CO_2 emission reduction succeeded. Yet, tax exemption along with low CNG price in the market were not sufficient for the successful penetration of NGVs in the market. (von Rosenstiel, Heuermann, & Husig, 2015).

Hence, the combination of policy actions with the expansion of the refuelling network are not enough. The adoption of an innovative technology in the market also depends on the way that its benefits are communicated to the stakeholders especially when an innovation is considered radical. A radical innovation includes the destruction or the obsolescence of current behavioural or production system patterns and requires new fundamental organizational, administrative and infrastructure schemes, (Abernathy, 1985); (M. Rice, 1998) which incorporates high investment risk and the risk of a market failure. By identifying the needs of each key stakeholder in a new technological regime, it is easier to provide policy actions that will successfully introduce an innovation with environmental benefits for the society. Successful implementation of a new technology lies upon the perceived impact of a new technology leap which incorporates a perceived risk (Hall & Kerr, 2003).

Stakeholders, policy makers and transport academics agree that along with the proper policy implementation, there is a need for behaviour change in order to achieve the transmission to a low-carbon era. (Anable J. , 2005) (Banister, 2008). The key discussion point is how much change is required and what kind of mechanisms will be used to achieve this change: hard or soft?

Hard policy measures may require the development of a new infrastructure, tax increase for intensive car use or prohibition of car use in certain areas (Bamberg, Fujii, Friman, & Garling, 2011). However, these kinds of policies may be difficult to implement or have the opposite desired effect. On the other hand, soft policy measures and sophisticated choices have recently gained more attention, while classic economic instruments (e.g. pricing and taxing) have now been under dispute. Soft policy measures include, among others, techniques that are used to inform and persuade car users to change their current travel pattern and switch voluntarily to more sustainable travel modes (Cairns, et al., 2008); (Brog, Erl, Ker, Ryle, & Wall, 2009). According to Bamberg et al. (2011), hard policy measures may alter the objective environment while the way car users perceive this change will lead to reconsideration of their travel options (e.g. prohibition of car use in specific lanes, public transport alternative faster service). On the other hand, soft policy measures positively empower and motivate car users to switch their travel options by altering the perceptions of the objective environment. However, it is not only the nature of an implemented policy that could lead to a habitual shift, but also the timing. Verplanken et al. (2008) state that the efficiency of a habit-breaking intervention is increased when people face a life changing event: a new job, a new house, a new-born child. However, social view is subjective, and it is in a constant change. Consequently, it can work either as a driver or as hindering factor to the adoption of a new technology (Kemp, Schot, & Hoogma, 1998).

A successful development of a consensus between stakeholders happened in Tokyo. In, 1999 the Governor of Tokyo started a “Campaign for no Diesel Vehicles” in order to raise awareness regarding the severe air pollution in Tokyo and to further promote the use of natural gas in a higher level. However, the results were daunting and the main reason of the limited market penetration of NGVs was the lack of communication and effective coordination of car users, vehicle manufacturers and fuel providers. To overcome this obstacle, the Council signed the Tokyo Declaration for the Creation of New Markets with the relevant actors. Three significant agreements were established which clarify that vehicle users will adopt more CNG vehicles, that fuel service providers will invest in expanding the refuelling network and that vehicle manufacturers will provide a variety of affordable NGVs in the market (Yarime, 2009). The potential vehicle user that joined the initiative proving the credibility of the use of natural gas, was the Tokyo Municipal Bus. According to NGVA, in 2018 Japan placed 24^{th} in the global ranking in terms of natural gas vehicle fleets.

3.1.4 Lack of marketing and information campaigns

As it was mentioned before, the promotion of any kind of fuel innovation that has not been yet tested for its efficiency, its performance, and its safety, cannot be supported only with financial motives or environmental awards. An eco-wise behaviour which drives this kind of decisions, could successfully shape the intention of an individual, however it is not enough to convert it into action. Theoretically, the demand for NGVs should increase with tax reductions, low purchase price and other policy measures. However, in order for policy makers, fuel companies and vehicle manufacturers to approach potential customers, long lasting public campaigns should also take place to inform the consumers not only about the characteristics and the availability of natural gas as a fuel, but also about the technology of natural gas vehicles.

The misinformation of the public starts with the price display of natural gas in refuelling stations in per kilograms compared to per litre for gasoline, diesel, and LPG. 1 Kg of CNG is energetically equivalent to 1,77 litres of gasoline and 2,004 litres of LPG. Therefore, the consumers cannot immediately compare the advantages of CNG or the real price of CNG per litre. That is why European Commission include in Article 7 (3) of the Directive on the Deployment of Alternative Fuels Infrastructure (DAFI) (2014/94/EU), the following: “*Where appropriate, and in particular for natural gas and hydrogen, when fuel process is displayed at a fuel station, a comparison between the relevant unit prices shall be displayed for information purposes*”.

The reluctance of the consumers regarding NGVs, is also created by the misinformation about the technical characteristics and their practicality, and safety issues that have been raised regarding natural gas as a fuel. Regular changes in European policies and the policies of each country eroded trust not only of the consumers but also of the suppliers, and consequently enhancing the hesitation towards this fuel.

On top of that, car retailers must put more effort to inform potential customers about the technical characteristics of NGVs, fuel consumption advantages and/or the ongoing subsidy program, tax reductions and other benefits by the purchase of an NGV (von Rosenstiel, Heuermann, & Husig, 2015). However, since the hesitation of the consumers is strongly interrelated by the existing refuelling infrastructure, the car retailers cannot further influence their final decision. It is crucial that policy campaigns and favourable actions should maintain in a long-term basis to overcome the scepticism of the consumers.

3.1.5 The rapid growth of electromobility

Electricity is an energy carrier that can be converted from a wide variety of primary energy sources. The production of electricity by renewable energy sources, can offer a nearly zero well-to-wheel pathway, but is not always the case. Electricity offers an interesting alternative in vehicles, especially since using cheap energy sources, like coal or hydropower energy, the cost for electricity production is substantially reduced.

Many incentives have been established to promote the use of electric vehicles which is expected to gain a substantial share in the foreseeable future, especially for passenger mobility. According to the European Observatory for Alternative fuels, European countries have massively incentivised the use of electric cars with purchase subsidies, registration on tax benefits, company tax benefits etc. The weaknesses of electric cars are the limited driving range a battery can offer, and the low power density compared to conventional vehicles. Furthermore, the charging time of an electric battery could last some hours, however the new fast charging stations will eliminate this issue.

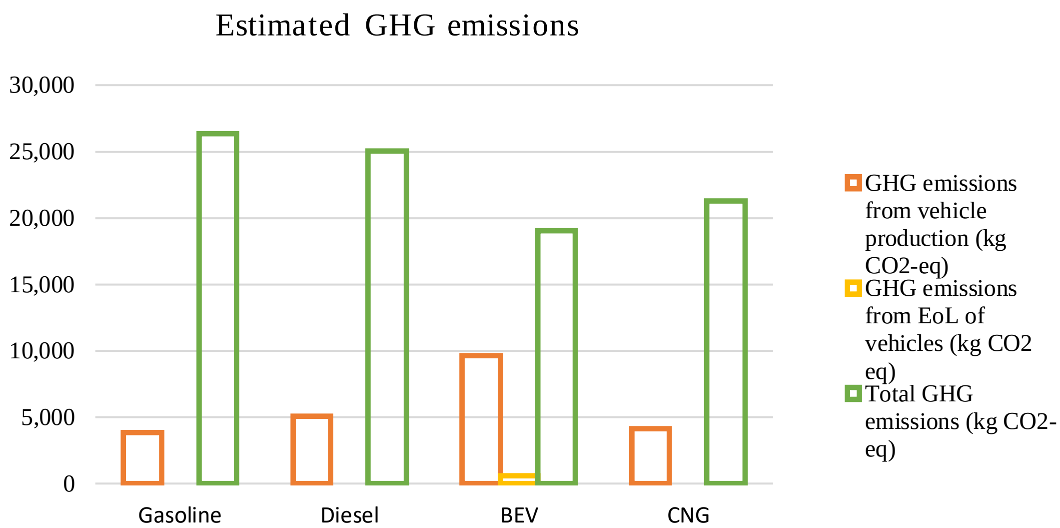
Many studies focus on the fact that EVs have no tailpipe emissions and therefore is the optimal route towards sustainability, however there is a significant environmental impact by the emissions generated during the production of vehicle batteries, the type of charging (normal-fast and ultra-fast), as well as the time of charging during the day (peak and off-peak) (Transport&Environment, 2018). There are still narrow views regarding what is a clean fuel and there are still issues that need to be unveiled. Pascoli et al. raised the issue of "reductionism" that enhances the prevailed approach of what is considered a clean fuel, since there is a tendency of focusing only on the tailpipe emissions and not considering the overall complexity of ecological and socio-economic systems. (Pascoli, Femia, & Luzzati, 2001)

In order to evaluate the greenhouse emissions of for transport fuels it should be taken under consideration the well-to-wheel, well-to-tank and tank-to-wheel emissions.

- Well-to-Tank analysis pursues to measure the GHG emissions produced by the resource recovery to the final step of the delivery of the fuel in the tank of the vehicle.
- Tank-to-Wheels analysis aims at measuring the GHG emissions produced from the use of the fuel in the vehicles.

Volkswagen have collected life cycle emissions data for many years providing important information on the results of many models running on different powertrains. The data presented on the following table is a summary of data from Volkswagen's assessment on life cycle emission data. The following table provides information about the End of Life emissions (EoL) of a Golf VII 1.2 TSI BMT running on diesel and gasoline, compared with an e-Golf with a range of 190 km and a Passat 1.4 TSI running on CNG. The GHG emissions generated by the production of a CNG powertrain were estimated to be about 280 kg CO_2-eq. The GHG emissions of the production of a BEV were considered and as it is illustrated, they are higher than the emissions from the production of other vehicles. The table below provides insight on the life cycle GHG emissions generated by the vehicles mentioned before in a life cycle of 150,000 km.

Figure 16-Estimated GHG emissions from production, use and EoL for passenger vehicles with different powertrains.



Source: (NGVA, 2017)

As it is expected, gasoline and diesel vehicles generate the highest GHG emissions comparatively to the BEV and CNG vehicle. The GHG emissions production of a BEV is higher than the emissions from the production of internal combustion vehicles. Still, a lot of assumptions have been made during the assessment of the GHG emissions of a BEV; first, the expected life cycle mileage of a BEV was assumed to be equal to the IC vehicles even if the lifetime range of a battery is limited. Secondly, it was also assumed that the annual mileage for a BEV was also 15,000 km for a 10-years-period, namely equal to an IC engine. Furthermore, the fact that manufacturers install more powerful batteries to overcome the limited range of a BEV may cause additional and difficult to estimate GHG emissions. The estimation of lifecycle emissions is complicated also by the fact that if the demand of BEV grows, the peak electricity demand will also increase. That means that if carbon or lignite power plants increase their power output, the carbon footprint of the electricity production will also be increased. Overall, according to “Greenhouse Gas Intensity from Natural Gas” study (NGVA, 2017) natural gas can reduce GHG emissions by 23% in passenger cars, compared with gasoline and by 7% compared with diesel. The mixture of natural gas with 20% of renewable gas can also reduce GHG emissions by 36% compared with oil-derived fuels.

The Handbook on the external costs of transport (EC, 2019) provides an insightful assessment of the external cost for passenger vehicles and a comparison between the different fuels. Based on the data presented Petrol-Hybrid electric vehicles (PHEV) and CNG vehicles have minimum differences in terms of external cost. For example, the external cost of a CNG bi-fuel vehicle of Euro 6 class has the same cost (€-cent per pkm) as the PHEV vehicle.

Table 4- Marginal air pollution costs road transport for selected cases

Vehicle	Fuel type	Size	Motorway
Passenger cars	Petrol	Medium (Euro 6)	0.09
	Diesel	Medium (Euro 6)	0.72
	PHEV (Petrol-Hybrid)	Small	0.06
	LPG	Small	0.10
	CNG (bi-fuel)	Small	0.09
	BEV	N/A	0.06

Source: The Handbook on the external costs of transport, 2019

EVs infrastructure

The availability of charging infrastructure in EU is ahead of the EVs deployment as the number of charging points can already serve the existing vehicles. Now, there are 5 EVs per public charging point, and by 2020 there will be about 220,000 charging points and a ratio of 10:1, in line with the EC recommendation. Also, by 2020 the coverage of the fast charging points along the European motorway network will be enough to serve the demand. The deployment of 1,000 ultra-fast chargers (150-350kW) will allow drivers to replenish up to 400km in only 15-30 minutes.

However, the deployment of charging points is not equal in the Member States. EVs market is mostly developed in western and norther Europe, while in Southern Central and Western Europe the market is lagging behind the front runners by 5-10 years. For that reason, EC has a commitment of spending at least 60% of the EU’s cross-border infrastructure on fund schemes, including 30€ billion for transport in the Connecting Europe Facility.

EVs market attractiveness is highly supported by:

- funding opportunities by the EC for the deployment of charging points;
- the attractive total Capital Expenditure (CAPEX) needed for a single charging point (approximately estimated at 30,000€ for a normal charging point and around 75,000€ for a fast charging point), while for NGVs, the total CAPEX of a refuelling station is estimated at 285,000€;
- growing demand for EVs.

More than 11 private companies (IONITY, Insta-volt, NEXT-E, Tesla etc.) announced the development of more than 1,000 charging stations across Europe in the next years, while many of them are financed by the EU.

The following figures represent the distribution of EVs and the respective charging points in EU.

Figure 17-%of newly registered plug-in electric vehicles

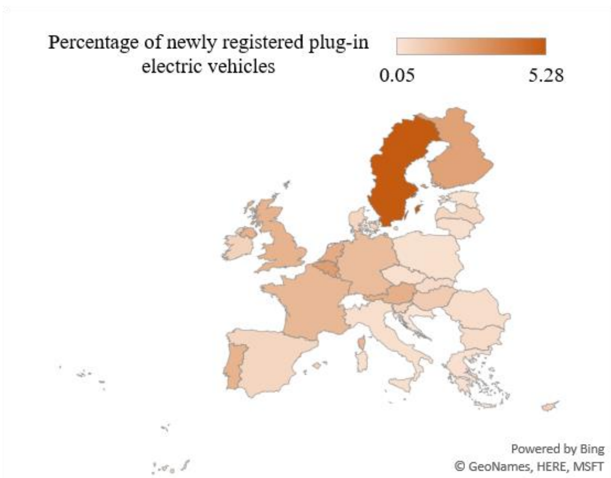
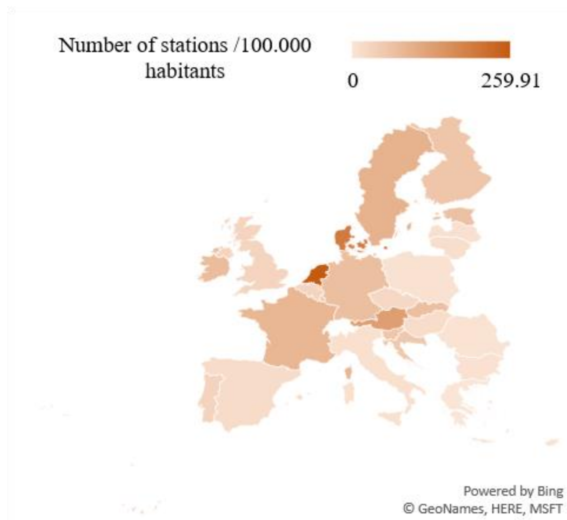


Figure 18-Number of stations per 100k inhabitants



Source: www.eafo.eu

3.1.6 Individual-specific factors

These section presents the factors that have been identified to affect potential car buyers through discrete choice surveys conducted all over the world. Because of the limited investigation on natural gas vehicles, factors that affect AFVs in general including electric vehicles, hybrid vehicles, bio-diesel vehicles etc, were further investigated.

The variables of age and gender are found important in determining AFV and are included as factors in most of the surveys. Many studies have shown that males are more interested in engine performance; acceleration and range, while females are more likely to choose an AFV even if the purchase price is relatively higher than a conventional one (Dagsvik, Wennemo, Wetterwald, &

R, 2002). Older respondents are less likely to choose AFVs s and they are most likely to choose the dominant conventional ones (Ewing & Sarigöllü, 1998). It is proved that young and well-educated people are environmental conscious and are more likely to adopt a natural gas technology to help reduce externalities (Ziegler, 2012); (Tanaka, Takanori, Murakami, & Friedman, 2014). Also, households with younger members, high car ownership and longer commute distance are more likely to choose AFVs over gasoline. On the other hand, households with older members and short commute distance reveal a reluctant behaviour over a new technology and they mostly prefer their current vehicle (Khan, Fatmi, & Habib, 2017). Other socioeconomic factors such as income and the number of household members have been shown to affect the final car/fuel choice (Beggs, Cardell, & Hausman, 1981).

Changes in annual fuel cost and purchase price has a strong negative effect on the representative utilities. Brownstone et al. (1996) conducted a study in California with a sample of 4,747 urban households. In their study, it was revealed that households having regular cars than luxury ones, make more rational choices and they are negatively affected by purchase price. Low income households are not interested in the engine performance in terms of acceleration time of the vehicle or horsepower, but they care about the range of the AFV and the existing refuelling network. However, households with a luxury car are more likely to purchase an expensive vehicle no matter the fuel, as a core element of a specific life status.

Ewing and Sarigollu (1998) examined the impact of various economic instruments on the potential demand for lower and zero emission vehicles in Montreal, conducting a stated preference survey. The results revealed a potential interest of Montreal car commuters on cleaner vehicles if their price, range and performance were equal to the conventional vehicles. Economic instruments that affect travel time and travel cost failed to raise the probability of an extra demand. A purchase subsidy for cleaner vehicles, though, was the optimal solution to achieve a substantial change in the demand. Hess et al. (2012) found that consumers are more likely to choose an NGV only with the implementation of extra subsidies and favourited policies.

A stated preference survey in Denmark (2011) investigated the potential demand of hydrogen, hybrid, bio-diesel, electric and conventional vehicles under certain tax regulations. The results showed that individuals are more likely to choose an AFV if the purchase price is significantly lower due to the absence of registration tax. Beggs et al (1981) used an order logit model to analyse the potential demand for electric cars. The results strongly indicate that limited range and refuelling time were the main barriers to the wider consumer acceptance of electric vehicles even though the operational costs of electric vehicles were relatively low compared to conventional ones.

A survey data conducted in Korea (Ahn, Jeong, & Kim, 2008) investigated how the introduction of alternative fuel passenger cars in South Korea will affect the purchase patterns. By the conjoint analysis, it was shown that gasoline-powered vehicles would still be dominant in the market. The simulation results revealed that if the purchase price of AFVs (hybrid and CNG) were equal to the conventional ones, the AFVs market will gain a significant portion of the market.

A recent comparative discrete choice analysis between the US and Japan, conducted by Tanaka et al. (2014) revealed the willingness to pay (WTP) for AFVs. The WTP in US for fuel cost reduction and alternative fuel network availability are one and a half times larger than those in Japan. The WTP values for driving range and emissions reduction are estimated almost the same for the US and Japan. It is important to note that households in the US that intent to purchase a new car in the next five years have large WTP values for a gasoline vehicle, but for an EV and PHEV this value decreases significantly. The same is also valid for Japan. A study by Hidrue et al. (2011) with a total sample of 3029 respondents in the US, estimated the WTP values between their preferred gasoline vehicle and two electric version of that. The respondents were willing to pay from $35 to $75 for a mile added in the driving range, and from $425 up to $3250 per hour reduction in charging time. As regards to the emissions level, households with children are willing to pay more for cleaner vehicles, no matter the fuel type, than the households without children.

The study of Potoglou et al. (2007) showed that households in the metropolitan area of Hamilton, Canada, would pay from $500 to $1200 to save from annual maintenance costs and regarding the purchase price, they are willing to pay an extra $2000 to $5000 to purchase a tax-free vehicle. Horne et al. in their study in Canada showed that the respondents are willing to pay an extra amount of €1350 to have access in express lane, while Hackbarth et al. (2013) claim that the WTP of German buyers for free parking and allowance to use base lanes, is from €1620-3280.

The study of Axsen et. al (2009) included different level of market penetration of AFVs in order to capture the “neighbour effect” in the model estimation. The significance of the infrastructure expansion is also proved by the study of Achtnicht et al. (2012). They estimated a model using data from a survey for potential car buyers in Germany. Conventional vehicles captured the largest market share, however, an expansion in alternative fuel network increases sharply the utility of CNG. The study of Hackbart et al. (2013) investigated in detail the preferences of German consumers by categorizing them in 6 groups with various tastes in vehicle characteristics and fuel types. The majority of the respondents rejected AFVs (except for PHEVs), however, participants with higher environmental consciousness revealed a positive attitude towards AFVs. The classification into 6 groups with different characteristics revealed also that monetary or non-monetary incentives affected differently each class.

A stated preference survey in the Netherlands investigated the consumers preferences among conventional technology and hybrid, plug-in hybrid, fuel cell, electric and flexifuel car. The results from the mixed logit model, reveals that preferences for AFVs are still lower than the conventional vehicles. Limited refuelling network and driving range are as usual the main barriers. They suggested that policy makers should provide tax advantages and purchase price incentives with low annual mileage. Even though that looks quite contradictory, the researchers highlighted that people with high annual mileage weigh more negatively driving range issues than the initial purchase cost (Hoen & Koetse, 2014).

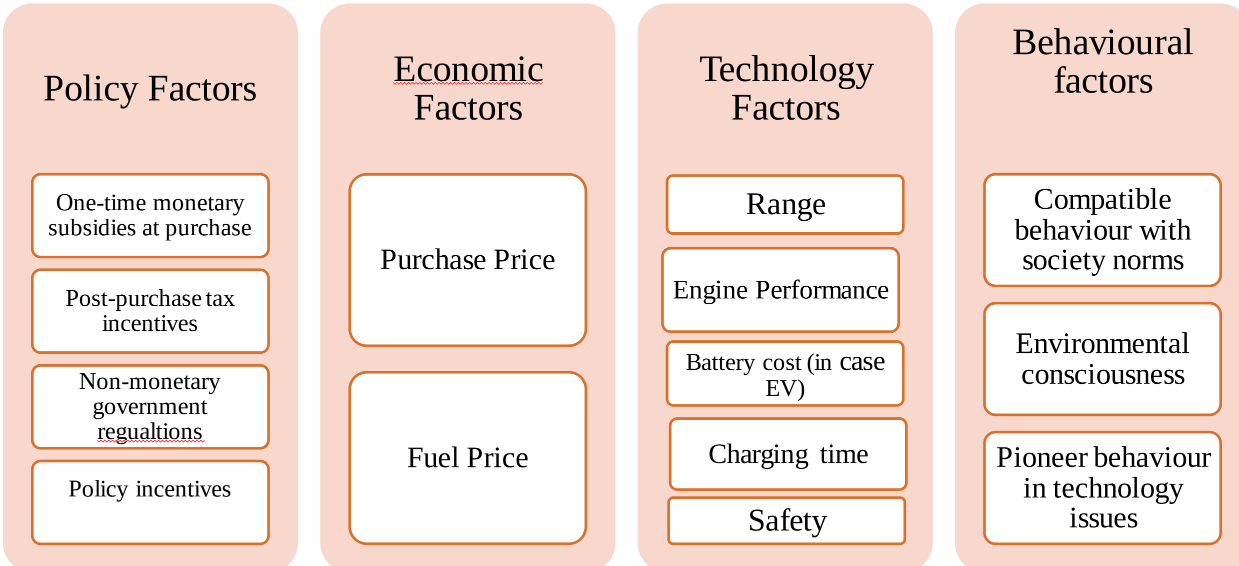
Table 5-Summary Discrete choice literature review

Discrete choice literature review		
Reference	**Methodology**	**Attributes examined**
Beggs et al. (1981)	Ranked Logit	Purchase price; Fuel cost; Range; Top speed; Acceleration; Number of seats; air conditioning; Warranty
Calfee (1985)	Disaggregate multinomial logit	Purchase price; Operating cost; Range; Top speed; Number of seats
Bunch et.al (1995)	Multinomial logit and nested logit	Purchase price; Fuel cost; Range; Emissions level; Fuel availability; Fuel type; Acceleration
Brownstone and Train (1999); Brownstone et al. (2000)	Multinomial logit and mixed logit; Joint SP/RP Mixed logit	Price; Home refuelling cost; Service station; Refuelling cost; Range; Emission reduction; Fuel availability; Home refuelling time; Top speed; Acceleration; Vehicle size; Body type
Ewing and Sarigollu (2000)	Multinomial logit	Price; Fuel cost, repair and maintenance cost Range Charging time Acceleration Commuting time
Dagsvik et al. (2002)	Ranked logit	Price; Fuel cost; Range; Top speed
Potoglou and Kanaroglou (2007)	Nested Logit	Price; Fuel cost; Maintenance cost; Emission reduction; Fuel availability; Acceleration; Incentives
Horne et al. (2005)	Multinomial logit	Purchase Price; Fuel cost; Emissions compared to current vehicle; Stations with alternative fuel; Power compared to current vehicle; Access to express lane
Ahn et al. (2008)	Multiple discrete-continuous extreme value	Fuel price; Maintenance cost; Fuel efficiency; Engine displacement; Fuel type; Body type
Mau et al. (2008)	Multinomial logit	Price; Fuel cost; Range Fuel availability; Subsidy; Warranty
Axsen et al. (2009)	Multiple discrete-continuous extreme value	Price; Fuel price; Fuel efficiency; Horsepower; Subsidy
Hidrue et al. (2011)	Latent class	Price; Fuel cost; Range; Emission reduction; Charging time; Acceleration
Qian and Soopramanien (2012)	Multinomial logit and nested logit	Price; Fuel cost; Range; Fuel availability; Fuel type; Policy incentives
Ziegler (2012)	Multinomial probit	Price; Fuel cost; Emissions; Fuel availability; Horsepower
Achtnicht et al (2012)	Logit	Price; Fuel cost; Emissions; Fuel availability; Fuel type; Horsepower

Hess et al. (2012)	Mixed multinomial logit, nested, cross-nested logit	Purchase price; Fuel cost per year; Maintenance cost per year; Driving range miles per gallon equivalent; Fuel availability; Refuelling time; Fuel type; Acceleration; Vehicle type; Age of vehicle; Incentives
Ito et al. (2013)	Multinomial logit and nested logit	Price; Fuel cost; Range; Emission reduction; Fuel availability; Refuelling time; Fuel type; Acceleration; Body type; Manufacturer
Hackbarth and Madlener (2013)	Mixed logit	Price; Fuel cost; Range; Emission reduction; Fuel availability; Refuelling time; Charging time; Policy incentives
Tanaka et. al (2014)	Mixed logit	Purchase Price; Fuel Cost; Driving range; Emission reduction; Fuel availability; Home plug-in construction
Hoen et al. (2014)	Mixed Logit	Purchase Price; Monthly costs (fuel cost, maintenance cost, road taxes cost); Driving range; Recharge/refuelling time; Fuel type; Number Of available brands; Incentives
Valeri and Cherchi (2016)	Hybrid Choice Model	Purchase price, expressed in Euros (€); annual operating cost (gasoline, insurance, tax, maintenance), acceleration, range and refuelling distance
de Wit, Dennis (2019)	Multinomial Logit	Purchase price; Driving range; Charging time; Charging distance; Fuel cost
This thesis	Multinomial logit	Purchase Price; Type of vehicle; Type of fuel; Fuel Price; Fuel availability; Fuel Consumption; Financial incentives; Policy incentives;

The following table presents the major motivational constructs concentrated by literature review that could lead to a successful new fuel technology adoption. Numerous studies provide indicators and coefficients that show the importance of one factor over another. However, it is significant to note that hypothetical scenarios used as a methodological tool to predict the potential demand of an innovative technology, captures a screenshot of an individual intention in specific time and under specific conditions. Adoption dynamics for AFVs are far more complicated and include not only the performance of the vehicle, fuel consumption and financial incentives, but also the exposure of the consumer on positive feedbacks, word of mouth and marketing promotion campaigns. The following table shows the most significant factors that contribute to the attractiveness on a new fuel technology.

Figure 19-Overview of Important Drivers based on previous studies



Source: synopsis of literature review elaborated by the researcher

Behavioural change theories

The analysis of an innovation process requires a multilevel perspective that lies upon the fact that the introduction of an innovative technology requires fundamental alterations in several economic and societal sectors. In order to explain attitudes and perceptions towards innovative or green products, many studies are based on Ajzen and Fisbein's cognitive and normative theories (1991). Theory of Reasoned Action (TRA) assumes that a consumer's beliefs about the consequences of an action, further formulate her attitude towards a behaviour and finally the adoption of a new product. Additionally, a consumer's behaviour is affected by the impact on several organisations or other reference groups (family, society etc). The consequences of an action and the impact on several reference groups, establishes the behavioural intentions. In conclusion, an individual is often motivated to "do the right thing" in order to avoid punishment or social exclusion and/or to be rewarded for this behaviour (Ajzen I. , 1991). In TRA, the core question refers to the role of intentions in the shaping of behaviours. An individual's attitude, that leads to a certain behaviour, is the result of the comparison between the negative and positive evaluations of a choice set. The main difference with discrete choice models is that the intentions are influenced by other factors, apart from the main intentions (Ben-Akiva, et al., 1999).

An extended version of TRA, the Theory of Planned Behaviour (TPB) (Ajzen I. , 1985), known as a self-regulation theory of travel change, states that a behavioural change occurs gradually passing through time-ordered stages, where in each stage specific cognitive and motivational reflections finally form the final action (Prochaska, Redding, & Evers, 2002). Based on this theory, Bamberg et al. (2011) developed four stages towards behavioural change of the public:

precontemplation, contemplation, preparation and maintenance. Based on the needs of each stage, policy makers should develop policy actions adjusted on each stage for the maintenance of the behavioural change (Davies, 2012). The Theory of Planned behaviour can be used to analyse the personality traits of the potential users of a new product, in this case alternative fuels, and to provide a method to implement several policies adjusted to an aggregate behavioural context. Although the intentions are considered to be the strongest indicators that could project an action, Theory of Planned Behaviour includes control beliefs in the equation. Control beliefs are based on experience regarding a certain behaviour, on a friend's experience (neighbourhood effect) (Mau, Eyzaguirre, Jaccard, Collins-Dodd, & Tiedemann, 2008), and on other factors that present how easy or difficult is to perform a behaviour in a specific period, with specific resources and opportunities. Ozaki and Sevastyanova (2011) reported that major constructs that could affect the final decision of a consumer to adopt or not an alternative fuel technology, include from government incentives such as parking, down-town accessibility, tax paybacks to a social responsibility framework including pollution reduction and oil independency, as well as the need for a leading edge behaviour in a new technological environment.

Literature on consumer behaviour and marketing, to further understand the decision-making mechanisms, focuses on the differences between the objective knowledge and the subjective knowledge of the consumers regarding a product. In other words, consumers use what they know (objective knowledge) and what they feel they know (subjective knowledge) about a product they end up buying (Alba & Hutchinson, 2000); (Carlson, Vincent, Hardesty, & Bearden, 2009). A study by Qian et al. (2017), has paid more attention on the decision-making mechanism between the repurchasing consumers and the first-time buyers. The identification of the differences and the similarities between these two groups and the attributes that affect the final purchase goal is particularly important, but could lead to a false interpretation (Alba & Hutchinson, 1987). A car owner has increased objective and subjective knowledge due to experience, but since AFVs is still a niche market, car owners should be treated as first time buyers. The study of Qian et al. (2017) proposes that marketing policies and promotion efforts should target at the experienced owners that are going to repurchase and the potential first-time buyers according to their level of subjective and objective knowledge about a certain product.

Several studies were based on the principals of the Norm Activation Model to predict pro environmental behaviour which is a combination of self-interest and the feeling of moral obligation to protect the next generations, the eco systems and the species (Hopper & Nielsen, 1991); (Onwezen, Antonides, & Bartels, 2013). This model was developed by Schwartz (1977) to describe the concept of an altruistic behaviour. According to the principals of Norm Activation Model (NAM), an environmental behaviour is formulated by a) a personal norm and the feeling of social obligation and the alignment with accepted behaviours b) awareness of the environmental problem c) evaluation of efficient solutions that could mitigate the problem c) realisation of the own ability to contribute to the problem solving (Peters, Gutscher, & Scholz, 2011). However, a pro-environmental behaviour can be triggered by emotions of guilt, instead of emotions of altruism or the sense of responsibility (Weiner, 1995). Furthermore, studies have illustrated that consumers often do not relate the environmental problem and the climate change with the fuel consumption of vehicles, therefore their responsibility over the car fuel type choice is out of the spectrum of possible solutions (Anable, Lane, & Kelay, 2006) The broad spectrum of perceptions regarding environmental consciousness often leads to misused results.

Environmental consciousness as a general indicator that refers to e.g. recycling, low energy household consumption, environmentally friendly products, differs significantly when it comes to a long-term investment (Hopper & Nielsen, 1991). Additionally, environmental concern is strongly affected by the cost of a greener choice; intentions are more likely to transform to environmentally conscious behaviours if that action does not require lot of time, money, or effort.

The reluctance to a new transport fuel which has not yet been tested in the market, the fear of an individual for the unknown risks (maintenance costs, specialised technicians for the specific technology, safety etc) usually overcomes the need of a consumer to act ecologically. Being ecologically friendly is not equivalent with being technologically aware. The engine performance, the technical characteristics of an AFV, the performance of a new fuel, the level of emissions, the fuel consumption per km etc., are issues that require specific knowledge, research and personal effort unless these issues are addressed to a specific public. Turrentine and Kurani (2004) in their study, underlined that most of the consumers have the perception that a fuel economy car is a cheap and small car and they are unaware of the difference between fuel efficiency and fuel economy. In addition, the prevailed perception was that to have a fuel-efficient vehicle it is necessary to sacrifice size, performance, safety, and price.

Conclusions

In this chapter, the existing work on factors that affect decision-making process, the role of policy implementation in the enhancement of alternative fuel technologies has been reviewed. It has been also highlighted the need for further exploration of the behavioural mechanisms that could enhance a wider market adoption. Furthermore, a gap in literature regarding the potential dynamics of a conversion market has been identified. Most surveys provided information regarding the factors that lead to the purchase of a new AFV rather the option of converting the existing one into a bi-fuel. Therefore, additional data collection focused on the potentials of a conversion market was included in the current survey.

The existing work on diffusion barriers of AFVs has been investigated. Over the last thirty years, several surveys have produced significant insights regarding the major diffusion barriers that affect the final vehicle choice. The results from the literature review indicate that the socioeconomic and demographic factors such as age, gender, household car ownership, income, educational level, and family status affect this choice in various ways, depending on the country of the survey. Economic and policy incentives such as tax reliefs and purchase subsidies also affect the fuel/vehicle choice. One of the major factors that hampers the NGV diffusion remains the non-coherent refuelling network, therefore, a variable that measures the level of network density was included in the final scenarios of the current study.

Also, it is known from behavioural sciences the role of social environment of an individual towards a specific behaviour. Literature review shows the importance of social acceptance over a “greener” vehicle choice. The “need of belonging” and the essence of “doing the right thing” are important factors that cannot be easily obtained during a survey. However, when it comes to real life options, an individual will feel reluctant about a new technology, creating a gap between estimated results and real potential demand. The reluctancy that is created by the fear of unknown and the low level of awareness regarding the new technology should be confronted with long-lasting information campaigns by the major stakeholders: the official natural gas authority of each country, the government and the automotive industry.

According to literature, a vehicle purchase is driven not only by cost factors, fuel economy and energy performance but also by the timing and the duration of each beneficial policy action. The level of awareness of the public regarding the adoption of an innovation is the key factor that is crucial for the market adoption. The questionnaire of this survey included questions that reveal the attitudes of potential customers towards policy actions and a set of true or false questions that indirectly raise awareness for the benefits of natural gas as a transport fuel.

Chapter 4

Implementation of surveys and model development

4.1 Research Methodology

This chapter presents the method used to develop the discrete choice model and to define the specific weight of the fuel/vehicle attributes and incentives in the final choice. The following sections describe the data collection and data analysis method, the survey design and the choice set experiments based on the relevant factors that influence the choice.

Demand forecasting is the core element in the analysis of the transportation systems. Researchers use econometric models focusing on the prediction of users' behaviour (travellers, shippers and international transport markets) and their response towards new products and services, investments in infrastructure and changes in pricing policies. The greatest milestone in the analysis of transportation demand was the development of disaggregate travel demand models by using discrete choice methods. So far, the most common analytic approach in travel demand forecasting, was the subdivision of the geographical area into zones. Traditionally, forecasts of aggregate travel demand use aggregate flows within a zone and are calibrated with zonal average trip attributes and socioeconomic characteristics. However, the level of data aggregation to a zonal level showed significant loss in terms of statistical precision. The collection of microlevel data and the estimation of models directly from disaggregate data, offered the advantage of significant precision, more reliable estimates, and the use of broader range of explanatory variables. In this kind of disaggregate model, the behaviour of an individual is described with discrete variables (Ben-Akiva & Lerman, 1985). The main principle of discrete choice analysis is that an individual, the decision maker, selects the alternative with the highest utility among those available.

The methodology includes two types of choice data collection paradigms: Revealed Preference *(e.g. 'what is your monthly fuel cost'?)* and Stated *Preference (e.g. 'which car/fuel combination would you choose?')*

The stated choice methods were originating in the field of psychology in the early 30's and used widely for data collection to model consumer preferences. Nevertheless, from the very inception of this method, many economists challenge the use of stated choice experiments, claiming that the hypothetical nature of this experiment may result in respondents manipulating their answers in such way to create plausible but inauthentic results (Wallis & Friedman, 1942). Respondents driven by the compatibility of the current incentives may choose a strategic decision rather than reveal their true preferences (Carson & Groves, 2007).

Discrete choice experiments are applied to several issues in research fields as transportation economics, environmental economics, health economics, marketing etc. The development of a stated preference choice experiment comprises of the following steps:

- identify the decision process, in this case vehicle/fuel combination choice
- identify and describe the attributes
- develop experimental design
- develop the questionnaire including revealed preference data
- collect data
- estimate model
- interpret model results for the formulation of policy analysis (Ben Akiva, 1985)

The main difference between Stated Preference and Revealed Preference is that Revealed Preference collects data regarding a choice that is actually made, whereas Stated Preference is a choice among hypothetical scenarios. Using only Revealed Preference does not allow the forecast of choices for new alternatives with different attributes or attribute levels. As CNG vehicles are currently very low in the Greek market, the collection of only revealed choices is not possible. Therefore, a stated choice experiment is developed to withdraw information on consumers preference for natural gas technology.

4.2 Data analysis method

This section briefly presents the random utility theory and introduces the mathematical form of the applied models and the motivation for their adoption in this research.

Random Utility theory

In the choice experiment process an individual determines and evaluates the list of attributes of each alternative and then makes the final decision. The core of each decision satisfies the following fundamental concepts:

- The individuals assign different weighted utilities for each alternative from the choice set and decide based on the trade-offs between the attributes
- The individuals choose the alternative that maximises their utility.

The utility function of an alternative can be expressed as a of observable (systematic) and unobservable components of the total utilities:

$$U_{nj} = V_{nj}\ (X_j, Z_n) + \varepsilon_{nj}$$

Where U_{nj} is the utility of alternative i Where V_{nj} is a deterministic utility component, depending on attributes Xj of alternative j and demographic variables Zn of person, and ε is the error term of the utility function implying the unobserved variables.

Multinomial Logit Model (MNL)

A multinomial logit (MNL) model characterises a choice from discrete alternatives by an individual (decision maker) as a function of attributes associated with each alternative as well as the characteristics of the individual. A multinomial logit model offers analytical and computational tractability and it has been extensively applied to discrete choice processes in such fields like econometrics (McFadden, 1981), transportation (Ben-Akiva & Lerman, 1985) and marketing (Guadagni & Little, 1983). MNL models can incorporate individuals-specific specific covariates, latent class modelling or individual-specific parameter models.

The model applied in this study is the Multinomial Logit Model. The MNL model satisfies the following assumptions:

Assuming that Unj = Vnj (Xj, Zn) + εnj for all i ∈Cn,

All the disturbances εnj are independently and identically distributed (IID) across alternatives, and Gumbel distributed with a location parameter n and a scale parameter μ>0.

$U\ (alternative\ i) = \beta 1 * X1 + \beta 2 * X2 + \cdots + \beta n * Xn + ASC\ (alternative\ i) + \varepsilon$

Where Xn represents the attribute value of the fuel/vehicle feature, βn is the coefficient of the taste parameter, and ASC is the alternative specific constant capturing part of the unobserved factors of the utility function.

The MNL model also gives the choice probabilities of each alternative as a function of the observable portion of the utility derived by the utility of all the alternatives. This feature of the MNL model will be useful to estimate market shares.

$$Pni = \frac{\exp\ (Vni)}{\sum_{i=1}^{j} \exp\ (Vnj)}$$

Thus, in this research a logit model in the form of an MNL model is used to estimate the attribute coefficients to identify the attribute importance in the consumer trade-off and to forecast market shares.

4.3 Survey Design

Greek Drivers' perceptions on natural gas technologies

The following section presents the design process of the choice experiment. First, the rationale of the selection of vehicle technology alternatives, attributes, and attribute levels are explained. Second, some general consideration of design is described and last, the choice sets of the experiment are generated.

The data used in this thesis come from a survey that took place in Greece. The online survey was conducted in Greece during June-August 2016 to estimate the potential demand of alternative fuel technologies in private cars and to define future market shares. A total number of 433 individuals from all over Greece participated in the survey. The sample of 433 individuals provided us with 2598 choice set responses.

In each choice set, 4 vehicle-fuel types of 3 different vehicle sizes (Small, Medium, SUV) were presented to the participants. The fuel choices are: Gasoline, Diesel, Compressed Natural Gas and Liquified Petroleum Gas. These 4 types of vehicle-fuels are already in the Greek market with, -except for CNG-, a well-established refuelling network around the country. The refuelling network for NGVs is already in process of expansion. As it was mentioned in the previous chapter, large infrastructure investments have already been programmed for the next decade.

Electric vehicles, as an option, was deliberately excluded by the choice set of this study. Stated preference data has suffered criticism because it is quite common that consumers often react differently to hypothetical experiments, especially when a product does not exist in the market. In this case, electric vehicles were excluded not because of their technological immaturity or the small share in the urban mobility, but for the time horizon set from the beginning of this study. The respective share in the market will be significantly low in Greece, in the next decade. To keep the objectives of the study realistic and to provide results that could reflect the real intentions of the consumers, the focus on this survey is to compare the dominant conventional fuels with the next important player in the Greek market for the next ten years: compressed natural gas. Including the option of an electric vehicle in the choice set would dilute the final choice of the respondents due to inhomogeneity of characteristics between the vehicle options.

4.3.1 Revealed preference data collection

In the revealed preference survey, several attributes were tested including socioeconomics characteristics of the respondents, major criteria of purchasing a new vehicle, as well as the level of awareness regarding the economic and environmental efficiency compressed natural gas (CNG).

a. **Socioeconomic variables**: age, income, occupation, teleworking, household members, number of vehicles in household, education, home address.
b. **Commuting variables**: car use in everyday activities, number of itineraries per week for different travel purposes, number of travelled kilometres per month, monthly fuel cost
c. **Current vehicle characteristics**: type of vehicle, type of fuel, year of manufacture, fuel consumption.
d. **Purchase criteria**: purchase price, circulation fees, level of emissions, engine performance, fuel consumption, purchase subsidy, label, design.
e. **Policies for the promotion of natural gas**: zero circulation fees for NGVs, toll exemption, subside for CNG stations, reduction of car ownership presumption, purchase subsidy, information campaigns, training programs for car engineers, free parking.
f. **Level of awareness**: fuel technology advantages, level of emissions, fuel efficiency, fuel price, purchase and conversion market price.

4.3.2 Stated Preference Choice Set Design

In the stated preference data set each attribute examined was explicitly defined for the respondent, in order to synthesise the information in an effective way.

In the case of vehicle choice, 4 vehicle fuel-types were identified: CNG, LPG, Gasoline, Diesel. Three separated Stated Preference choice sets were designed including, except for the fuel type, the vehicle size in order to capture different market segments: the respondents had to state their preference for a small city vehicle (up to 1400cc), a medium size vehicle (up to 1600cc) and a SUV which operates with 4 different fuels. Each respondent was presented to 6 hypothetical scenarios: 2 for a small city vehicle with 4 car-fuel type choice sets, 2 for a medium vehicle with 4 car-fuel type choice sets and 2 for an SUV with 4 car-fuel type choice sets. The questionnaire was developed in Sawtooth software which supports discrete choice surveys and provides the opportunity to exclude or prohibit some pairs of values and attributes to present realistic choice sets. The Choice-Based Conjoint version was used to allow web-based interviewing and accommodate up to 10 attributes and up to 15 levels per attribute.

By using this stated preference approach, it was able to consider every car-fuel type that is currently available in the Greek market and estimate later on the respective market share of each.

The development of the stated preference choice set was a very demanding process as it included 4 (car-fuel vehicles) * 7 (attributes) * 6 (hypothetical scenarios) with numerous combinations of upper and lower levels of each attribute.

Besides, purchase price, fuel price and fuel consumption, the following incentives were included: toll exemption in the Athens-Thessaloniki axis, free parking in public stations and access to parking meters. The last attribute refers to the refuelling infrastructure availability for each fuel. Since LPG, gasoline and diesel vehicles are supported by a sufficient network around Greece, this attribute refers only to CNG. Based on the work of others (Struben J. , 2006); (Nijboer, 2010); (Helmreich & Lochner, 2012) (von Rosenstiel, Heuermann, & Husig, 2015) and on the previous pilot survey, the attributes of this study do not include special performance or technical characteristics such as: acceleration time and range but the study aims to discover which policy instrument will dominate the choice process. Moreover, there are slight differences between the performance of the same size vehicle running in each of 4 fuels. In addition, it is highly unlikely for the respondents to synthesise the technical information presented and the policy or economic incentives to finalise their choice.

The range of each attribute had to be logical, to avoid only one or two attributes to be estimated as influencing factors. Furthermore, it was critical to ensure that the economic incentives did not favoured "clean fuels" or force the respondents to choose them because of unreasonable range of other attributes. For each type of fuel-vehicle experiment, the level of attributes portrayed the differences in market conditions, such as network density, financial subsidy, and purchase price. The implementation of stated preference surveys has the advantage of instantly informing the participants regarding the market conditions of each fuel-vehicle, through conceptual descriptions. In this survey, the participants were also informed about the advantages of natural gas as a fuel concerning the environmental performance and the existence of financial subsidies in the first part of the questionnaire. In this way, participants were informed in a short period about the characteristics of natural gas, how this technology works and its effects on society, enabling them to gain a good understanding before choosing their preferable fuel-vehicle type.

Purchase Price: The purchase prices presented are real and refer to vehicle models that are already in the European market. The range of purchase prices are different for small city vehicles, medium vehicles and SUVs. It was critical to ensure that no attributes range, especially price range, is so wide to bias the final choice. A very wide price range would make price to dominate the choice process. For that reason, indicative purchase prices as well as technical characteristics were chosen from the best-seller's vehicles from the main categories.

Fuel price: The range of this attribute contains values from minimum 0.50€ to maximum 2.00€ and remains the same for all car fuel-type vehicles. The fuel price range was structured based on the fuel prices on the last decade with several levels that are considered realistic.

Fuel consumption: The range of fuel consumption includes current fuel consumption data from vehicle manufacturers. Fuel consumption and purchase price are two attributes that describe current vehicles operating in different fuel technology, without revealing the brand.

Purchase subsidy: Purchase subsidy was included to reveal the group of participants willing to purchase an NGV and to estimate the threshold amount of subsidy that triggers them for purchasing an NVG. The purchase subsidy will be provided by the automotive industry and/or by the National Provider of Natural Gas in collaboration with the automotive industry.

Toll exemption in Athens-Thessaloniki axis: This attribute belongs to economic instruments category and could reveal the potential long-distance car owners interested in converting their vehicle to bi-fuel or to purchase an NGV if they were privileged by a toll exemption. The refuelling network for NGVs has already been expanded with 4 refuelling stations located in Athens, 2 in Thessaloniki and 3 more can be found on the Athens-Thessaloniki road axis. The overall cost for tolls from Athens to Thessaloniki is approximately 30€.

Free parking in public stations or park meters: Most of the participants live in Athens and in Thessaloniki. The residents of these cities face significant traffic congestion and lack of parking spaces. The gravity of this attribute during the choice process will be estimated and the results will further formulate the policy actions and whether to include free parking as an incentive for CNG promotion. Besides, the efficiency of the policy actions depends on the adjustment in the needs of each region.

Refuelling network availability: According to the literature review, the density of the refuelling network is one of the most dominant factors in alternative fuels adoption. Including the option of the refuelling availability as an attribute is another innovative aspect of the questionnaire. By redesigning the refuelling locations, it is more likely to reduce refuelling time and promote the wider diffusion of natural gas along with a strategic plan of an optimum supply network.

The attributes "purchase price" and "fuel consumption" were customised to avoid unrealistic values. The levels of the attributes were formulated based on energy performance and purchase prices of existing car models in the European market. In the choice experiment, the attribute levels were rotated independently between alternatives and choice sets.

The study primarily investigates sociodemographic data and behavioural and normative factors that affect attitudes and perceptions related to alternative fuels and more particularly natural gas. Further purchase criteria, environmental concern and technology awareness are also included. Athens, Thessaloniki, Lamia and Volos are the only cities with CNG refuelling infrastructure and consequently NGVs have a low penetration rate. Thus, it was important to focus on predictors of intention, measured by respondents' consideration to convert their own vehicle into bi-fuel or to purchase an NGV. In an early stage market, the factors influencing this initial interest and openness to a new technology must be considered.

The following table presents the attributes included in the RP and SP data collection.

Table 6-SP and RP survey

Surveys	Information to collect	Description
RP Survey	Socioeconomic information (personal attributes)	Gender; age; occupation; income; number of members in the household
RP survey	Drivers profile	Number of itineraries; Car ownership; Fuel cost; Current vehicle characteristics; Purchase criteria; Policies for the promotion of natural gas; Level of awareness of new technologies
SP survey	Preferred fuel/vehicle choice under 8 scenarios	Size of vehicle; fuel type of vehicle; purchase price; emissions; refuelling network availability; fuel price; vehicle fuel consumption; purchase subsidy*; toll exemption*; free parking*

**available only in CNG alternative*

The following table presents in detail the attributes and their respective levels for each alternative.

Table 7-Attributes and attribute levels in the choice experiment

Attribute	Number of levels	Levels
Fuel type	4	Gasoline, Diesel, LPG, CNG
Vehicle class	3	Small up to 1400 cc, Medium up to 1600 cc, SUV
Purchase price	3 (small) 6 (medium) 7 (SUV)	10,000€ 12,000€ 15,000€ 15,000€ 17,000€ 20,0000€ 22,000€ 25,000€ 27,000€ 15,000€ 16,000€ 17,500€ 20,000€ 23,500€ 25,000€ 28,500€

Fuel Price	8	0.50€ 0.70€ 0.90€ 1€ 1.20€ 1.30€ 1.50€ 2€
Fuel Consumption (lt/100km) For CNG was defined kg/100km	5 (small) 3 (LPG, Gasoline medium) 4 (CNG medium) 5 (Diesel medium) 3 (LPG, Gasoline SUV) 4 (Diesel, CNG SUV)	All fuels: 3 3.5 4 4.5 6.5 LPG, Gasoline: 5, 6.5, 7.5 CNG:3.5, 4, 4.5, 5 Diesel: 3.5, 4, 4.5, 5, 6.5 LPG, Gasoline: 4, 4.5, 5, 6.5 Diesel, CNG: 4, 4.5, 5, 6.5
NGV purchase subsidy	2	Yes/ No
Toll exemption in Athens-Thessaloniki axis	2	Yes/ No
Free parking in public stations or park meters	2	Yes/ No
Refuelling network density for NGVs	10	1/10, 2/10…sufficient

Example of a choice set experiment

Assume that the vehicle that you are going to purchase (e.g. small city up to 1400cc) is available in the Greek market with the following fuel technologies. Given the choices below, check the vehicle you would choose.

Table 8-Stated Preference Choice example

Vehicle/Fuel type	**CNG (available in kilos)**	**LPG**	**Gasoline**	**Diesel**
Attributes				
Purchase Price	10.000 €	10.000 €	15.000 €	12.000 €
Fuel Price	0.70 €	1.20 €	1 €	0.50 €
Fuel Consumption	4.5kg/100km	4.5lt/100km	5lt/100km	5lt/100km
Purchase Subsidy	1000€	-	-	-
Toll exemption	Yes	No	No	No

Free parking	Yes	No	No	No
Refuelling network availability	3 out of 10 stations	Sufficient	Sufficient	Sufficient

4.4 Sample characteristics

In the following table, the socioeconomic characteristics of the sample are illustrated. The resulting sample of N=433 respondents contains 61.4% men and 38.6% women while the respective percentage of the total population corresponds to 49% of men and 51% of women. The mean age is 33.5 years (min= 18 max= 6, SD=10.726), the majority of the sample (25.6%) belongs to the 4th annual income class of 10001€- 20000€. The average number of vehicles owned by a household is 1.65 (SD= 0.967) and 61.7% of the sample use their car for everyday activities.

Comparisons of the whole survey with the general population reveal that individuals with higher education are overrepresented.

Table 9-General characteristics

	Greece
Population	10.815.197
Population Density	82 people per square kilometre
GDP per capita	18,613.42 USD
Unemployment Rate	18%
Car ownership (cars/100habitants)	Athens:510 Thessaloniki:370

The characteristics of the participants are presented in Table 18.

Table 10-Socioeconomic characteristics of the Sample

Survey Question	Sample (N=433)	Population 10,816,286
Gender		
Male	61.4%	49%
Female	38.6%	51%
Age		
18-25	21%	6.55%
26-35	49%	14.28%
36-45	14.8%	15.19%

46 plus	16.2%	45.04%
Education		
High School	10.6%	
Private Technical College	4.9%	
University	32.3%	
Technical Educational Institute	11.1%	
MSc/PhD	40.2%	
None	0.9%	
Private Annual Income		
Zero Income	13.9%	
Income 1€-5000€	23.2%	
Income 5001€-10000€	22.6%	
Income 10001€-20000€	27.6%	
Income 20001€-40000€	12%	
Income 40001€-60000€	0.7%	
Type of Current Vehicle		
Up to 1400cc	64.4%	
Up to 1600cc	21.7%	
Up to 2000cc	6.7%	
Full Size (E)	0.7%	
SUV	3.4%	
Sport	1.5%	
Pick-up	1.2%	
Jeep-MPV	0.4%	
Type of Fuel		
Gasoline	78.7%	
Diesel	10.1%	
LPG	6.3%	
CNG	4.5%	
Electric	0.4%	
Monthly Fuel Cost		
1€-50€	12%	
51€-100€	26.8%	
101€-200€	17.6%	
201€-300€	3.5%	
301€-500€	0.5%	

Do not drive their own car/ they do not use a car in everyday activities	40.1%	

In order to explore which criteria and vehicle characteristics, the respondents combine to finalise their decision for a new vehicle, participants were asked to assess the importance of several criteria during the decision-making process (1=not important, 7= very important). Some of the criteria were also included in the stated preference choice scenario. The most important criteria as it shown in the following table, are the purchase price of the new vehicle and the fuel consumption. On the other hand, purchase subsidy and level of emissions are not considered that important during the decision-making process. Regarding the purchase subsidy, it can be assumed that new buyers are reluctant because this kind of financial policies have not taken place in the automotive market and the participants reveal their reluctance towards this criterion by rating it low. Furthermore, it is important to mention that the environmental performance of a vehicle is not one of the most significant criteria, showing once more that the participants are mostly cost-driven.

The participants were also asked to evaluate possible policies that could enhance the use of natural gas in Greece. The proposed policies refer not only to the end-users (new NGV buyers), but also to owners of fuel stations and repair shops and car engineers. The policy measure with the strongest impact on respondents' view is the exclusion of NGV from circulation fees.

Table 11-Evaluation of possible policies

Questions	Mean	Std. Deviation
Zero circulation fees for CNG vehicles	6.27	1.311
Toll exemption for CNG vehicles	5.55	1.817
Subsidy for fuel stations	5.44	1.608
50% reduction car ownership presumption	5.86	1.402
Purchase subsidy CNG vehicle 3000 euros	6.22	1.198
50% reduction in vehicle conversion	5.96	1.255
Free parking in public stations for CNG vehicles	5.06	1.861
Training programs for car engineers	5.28	1.7
Information campaigns for CNG benefits	5.61	1.596

Out of 433 individuals, 267 of them use their own car for ever-day activities. The rest of the participants either use it sporadically or they borrow the car from a family member. Only 15% of the sample has a registered vehicle from 2010 until 2016. In the following table, the sample was divided according to the cubic centimetres of their vehicles and the respective circulation fees for year 2016 for vehicles that were registered until 2000 and up to 2010. For registered vehicles, the circulation fees are calculated based on CO2/gr emissions.

The size of the vehicles of the sample belong to 3 main cc classes: 1072_1357cc, 1358_1548cc, 1549_1738cc.

Table 12-CC classes and circulation fees for 2017 for vehicles that were classified until 2000 and up to 2010.

CC classes	%	circulation fees
301_785	0.2	55 €
786_1071	6	120 €
1072_1357	17.1	135 €
1358_1548	20.3	250 €
1549_1738	11.5	265 €
1739_1928	3.2	300 €
1929_2357	2.1	850 €
2358_3000	1.2	1,250 €

The participants were also asked to evaluate the advantages of use of CNG as a transport fuel (1=strongly disagree, 7=strongly agree). As it can be seen from the following table of the descriptive statistics, the participants are aware of the fuel economy of the natural gas and the high environmental performance as an alternative fuel. It can be also assumed that the significant advantage of NGVs regarding the noise level is still unknown to the public because of the neutrality of the answers. The safety of NGVs is still a matter of doubt for most of the sample.

4.5 Cluster Analysis

The study aims to estimate drivers' behaviour by dividing individual drivers into several groups based on their personal characteristics and their perception towards natural gas as a fuel. The data were handled using SPSS data package, following the method of Two-steps Cluster analysis as it is appropriate for both categorical and continuous variables and it is recommended for large datasets. The primary objective of the cluster analysis is to categorise the sample into several classes based on same characteristics of these individuals. In this study 2598 observations were determined with three attributes: gender, CNG perception and car use in every-day activities.

Cluster analysis is determined by the interpretation of the researcher. In the presented example, the best solution is the one with the two classes because the AIC value minimises sharply in the second class. However, the ratio of distance measures is lower with four classes and the differences between classes are better described. The researcher has the option to override this default and specify more than two clusters. The results indicate that there are similarities in the ways that the participants respond to policy, cost incentives and environmental consciousness that are related to the intensity of car use in everyday activities.

Table 13-Automatic clustering

Number of clusters	**Akaike's Information Criterion (AIC)**	**AIC Change [a]**	**Ratio of AIC changes [b]**	**Ratio of Distance measures [c]**
1	62946.006			
2	58666.226	-42729.780	1.000	1.730
3	56243.323	-2422.902	.566	1.342
4	54468.848	-1774.475	.415	1.453
5	53285.520	-1183.327	.276	1.153
6	52275.063	-1010.457	.236	1.185
7	51441.128	-833.936	.195	1.064

a. The changes are from the previous number of clusters in the table
b. The rations of changes are relative to the change for the two-cluster solution
c. The ratios of distance measures are based on the current number of clusters against the previous number of clusters.

4.5.1 Cluster Distribution

The following table presents the distribution of the observations in each cluster. This is the first indicator regarding the size of the cluster. No observations were excluded since there are no missing values.

In the following table, the profile of the participants that respond to each cluster are identified. In order to perform the cluster analysis, an explanatory variable was developed based on the responses of the participants regarding the advantages of the CNG as a fuel. The predictor importance of this variable was the highest compared to other characteristics like gender, the car use and the age of the participants.

CNG perception is a transformed variable based on the participants' responses on their perception regarding the advantages of CNG. The participants were asked to rank from 1 to 7 the advantages of the use of CNG in transport. The list of questions is presented below.

Perception towards CNG

Table 14-Descriptive Statistics: mean scores for CNG advantages

Questions	Cluster 1	Cluster 2	Cluster 3	Cluster 4
I believe that CNG can contribute to oil independence	5.97	4.83	4.59	5.13
I believe that CNG cars provides significant fuel economy	6.27	5.50	5.33	5.46
I believe that CNG contributes significantly to CO2 reduction	6.41	5.40	5.33	5.45
I believe that CNG contributes significantly to level of nuisance in the cities	6.09	4.12	4.49	4.62
I believe that CNG cars are Safe vehicles	5.77	4.13	4.11	4.11

The interpretation of the clusters profiles shows that the first cluster includes 744 participants, mostly male and more than half of this subsample are intensive car users and reveal a CNG pro attitude. The second cluster is the biggest cluster, representing 29.3% of the sample, only men and intensive car users, showing a neutral perception towards use of CNG. The smallest cluster is the third one, representing 16.2% of the sample, sporadic car users and only men. The last cluster includes only female, half of them are intensive car users and they have a neutral attitude towards CNG.

Table 15- Cluster profiles

Label	Cluster 1 (group2)	Cluster 2 (group4)	Cluster 3 (group 3)	Cluster 4 (group1)
Inputs				
Size of cluster	28.60% (744)	29.30% (762)	16.20% (420)	25.90% (672)
CNG perception	supporter	neutral	neutral	neutral
Gender	male (55.6%)	male (100%)	male (100%)	female (100%)
Use of car in everyday activities	yes (66.9%)	yes (100%)	no (100%)	yes (50.9%)
Evaluation fields (Mean index)				
Age	34.90	34.22	31.56	32.52
Level of education	MSc/PhD	MSc/PhD	MSc/PhD	MSc/PhD
Private annual income (€)	15,017	12,653	8,434	11,000
Household members	2.82	2.99	2.67	2.87

In order to also explore the potentials of the conversion market, the respondents were asked to state their willingness to convert their vehicle under specific market conditions, vehicle characteristics or financial incentives (1=totally disagree, 7=totally agree). The results are illustrated in the following table.

It can be safely drawn as a general conclusion, that the respondents are positive towards the conversion. Important issues of safety, repair shops and space reduction that according to literature are discouraging factors toward the conversion, are also confirmed in this study.

The mean scores show the intention of the participants towards a possible conversion of their vehicle into a bi-fuel. The respondents of the first cluster show a greater willingness when it comes to financial incentives and social acceptance of converted vehicles. The second cluster are positive not only to financial incentives, but they also focus on their social circle positive feedback and they are more open to convert their car according to the first question. On the contrary, the representatives of the third cluster are more suspicious towards the new technology. It is high unlikely to convert their car; they are not motivated by toll exemption or free parking incentives and they are almost neutral towards subsidies and price reductions.

Perceptions towards conversion

Table 16-Mean scores for items within selected factors related to conversion or purchase of an NGV.

Label	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
How possible is to convert your car?	4.48	3.31	3.86	3.77
I would convert if subsidy conversion 1000€	6.18	5.66	5.74	5.71
I would purchase an NGV if subsidy 2000€	5.72	5.18	5.36	5.1
I would convert/purchase if my social circle had a positive experience	5.27	4.56	4.93	4.87
I would convert/purchase if free parking	5.26	4.77	4.94	4.89
I would purchase an NGV if its price equals to a conventional one	5.7	4.93	5.51	5.29
I consider gasoline to CNG conversion safe	5.31	4.5	4.84	4.79

Purchase criteria

In the following table, the classification of the purchase criteria of a new vehicle for each cluster are presented. Representatives of all clusters are cost sensitive paying attention to vehicle performance and the purchase price, whereas representatives of cluster 1 and 4 show an environment concern, rating higher the criterion of level of emissions.

Table 17-Mean scores for items within selected factors related to Purchase criteria

Label	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
Fuel Consumption	6.23	5.89	5.96	6.33
Purchase Price	6.09	6.11	6.37	6.45

Level of emissions	5.02	3.87	4.33	5.10
Engine performance	4.89	5.24	4.77	5.01
Label	4.75	4.97	4.90	4.67
Design	5.02	4.91	5.06	4.62

Technical awareness

The following table presents the overall score of the 4 clusters in the True False questions regarding the use of CNG. Representatives of cluster 1 appear to be the most well-informed regarding prices and technical characteristics of CNG. This outcome can be also confirmed by the results of Cluster profile table as representatives of cluster 1 considered to be CNG supporters.

The answers from this set of questions were used as an explanatory variable to further divide the sample into technical-aware participants and non-technical aware. The variable created was a dummy variable and it is further analysed in the model specification section below.

Table 18-True or False Questions

Question	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
1 kg CNG is equivalent with 2lt of LPG				
True	68%	52%	43%	47%
False	32%	48%	57%	53%
CNG is 60% cheaper than gasoline				
True	93%	91%	79%	82%
False	7%	9%	21%	18%
In case of leakage, there is no risk because CNG is lighter than air and disperses in the atmosphere.				
True	73%	65%	47%	51%
False	27%	35%	53%	49%
Automatic ignition is safe in NGVs				
True	91%	82%	84%	81%
False	9%	18%	16%	19%

NGVs emits 25% less CO2 than gasoline and 35% than diesel				
True	90%	87%	93%	88%
False	10%	13%	7%	12%
The conversion to a bi-fuel CNG-gasoline is a technologically easy process				
True	97%	91%	93%	93%
False	3%	9%	7%	7%
There are already authorised repair shops for vehicles conversion into bi-fuel in Greece				
True	92%	89%	90%	82%
False	8%	11%	10%	18%
The cost of conversion is usually depreciated in 12-18 months				
True	87%	73%	74%	88%
False	13%	27%	26%	13%
Bi-fuel engines change fuel with the push of a button, doubling				
True	85%	89%	79%	72%
False	15%	11%	21%	28%
A vehicle conversion in Greece, costs less than 1000€.				
True	70%	51%	53%	45%
False	30%	49%	47%	55%
Total				
Correct answers	74%	56%	47%	46%

In Table 18, several perceptions towards the policy implementation for the promotion of natural gas for the different clusters are presented. It is clearly shown that the representatives from the third cluster, which are intensive car users and mostly male, are very reluctant towards the new technology, they do not consider the promotion of NGVs in Greece an important issue and comparatively to the other two clusters, they believe that the refuelling network will not expand. On the contrary, the participants of the other two clusters identify the importance of the NGVs in Greece based on their answers. Cluster 2, which is represented mostly by occasional drivers and women, appear to identify the benefits of the use of CNG.

Table 19-General perceptions

Descriptive Statistics – Mean				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4
I believe that gasoline price will be equal to CNG	4.03	4.23	4.34	4.61
I consider CNG technology a trend that will fade	3.32	3.70	3.60	3.63
I believe that CNG refuelling station will expand in the next 5 years	5.14	4.43	4.59	4.74
I consider CNG benefits not known in public	5.69	5.14	4.83	5.25
I consider circulation fees classification regarding level of CO2 a just measure for environment	5.51	4.88	4.96	5.42

4.5.2 Intermediate Conclusions

Distribution of the observations of the cluster can be evaluated satisfactory, since the number of observations is well distributed among the clusters.

1st cluster = CNG supporters, 55.6% male, use of car 66.9%, ranked 1st in technical awareness overall score.

The individuals of this cluster rated fuel consumption and purchase price of the vehicle as the most important criteria to buy a new car. They are also concerned regarding the level of emissions of the car and they agree that circulation fees based on the emissions is a fair measure. They believe that CNG is not a trend that will fade, but a technology that will gain substantial share in the next 5 years. They consider the conversion of a vehicle to bi-fuel safe, and they are willing to convert or purchase if there was a subsidy in place. Individuals of this cluster stated that they would consider the adoption of natural gas technologies if neighbours (social circle) also have adopted.

2nd cluster = CNG neutral, 100% male, intensive use of car in every-day activities, ranked 2nd in technical awareness overall score.

The representatives of the 2nd cluster also rated fuel consumption and purchase price of the vehicle as the most important criteria, whereas the level of emissions has the lowest mean of all groups. They are not interested in converting their vehicle, but they do consider it as an interesting option if there is a conversion subsidy. Compared to the other clusters they rated lower the circulation fees based on emissions for the new vehicles and their perception regarding CNG as a trend that will fade is the highest between the clusters.

3rd cluster = CNG neutral, 100% male, sporadic use of car, ranked 3rd in technical awareness overall score.

The representatives of this cluster have the lowest income of all clusters and they also consider fuel consumption and purchase price as the most important criteria. The appear reluctant in purchasing or converting their car, but they would consider it if the purchase price is equal to the conventional ones. Circulation fees based on CO_2 emissions is not appealing to them and their overall attitude could be considered reluctant.

4th cluster = CNG neutral, 100% female, use of car in every-day activities 50.9%, ranked 4th in technical awareness overall score.

The representatives of this cluster are also cost-sensitive as they rated the purchase price and the fuel consumption as the most important criteria when buying a new car. Level of emission was the third most important criterion and the circulation fees based on CO_2 emissions was considered overall fair. They would consider a conversion if there was a conversion subsidy and they believe that CNG price will be equal to gasoline's in the next years.

4.6 The model development: Utility functions

Based on the data collection from the RP/SP surveys, the estimation coefficients of each attributes were obtained through the MNL using Biogeme. Four different models were created for each cluster. In addition, the estimation results of each sub model using individual grouping was compared with the one without grouping to determine if individual grouping improves the estimation accuracy.

Utility Functions Cluster 1

- $U_{CNG} = \beta_{CNG} + \beta_{\_PP1}$ * PurchasePriceCNG_SCALED + $\beta_{\_KMCOST1}$ * KmCostCNG + $\beta_{\_PS}$ * PurchaseSubsidyCNG_SCALED + $\beta_{\_Social}$ * SocialCircle + $\beta_{\_Network}$* NetworkDensity + $\beta_{\_Awareness}$* Awareness
- $U_{DIESEL} = \beta_{DIESEL} + \beta_{\_PP4}$ * PurchasePriceDiesel_SCALED + $\beta_{\_KMCOST4}$ * KmCostDiesel

- **$U_{GASOLINE}$** = $\beta_{GASOLINE}$ + $\beta_{\_PP3}$ * PurchasePriceGasoline_SCALED + $\beta_{\_GROUP}$ * Small
- **U_{LPG}** = β_{LPG} + $\beta_{\_PP2}$ * PurchasePriceLPG_SCALED

<u>Utility Functions Cluster 2</u>

- **U_{CNG}** = β_{CNG} + $\beta_{\_PP1}$ * PurchasePriceCNG_SCALED + $\beta_{\_KMCOST1}$ * KmCostCNG + $\beta_{\_PS}$ * PurchaseSubsidyCNG_SCALED + $\beta_{\_Social}$ * SocialCircle + $\beta_{\_TOLLS}$ * TollExemptionCNG
- **U_{DIESEL}** = β_{DIESEL} + $\beta_{\_PP4}$ * PurchasePriceDiesel_SCALED + $\beta_{\_KMCOST4}$ * KmCostDiesel
- **$U_{GASOLINE}$** = $\beta_{GASOLINE}$ + $\beta_{\_KMCOST3}$ * KmCostGasoline + $\beta_{\_PP3}$ * PurchasePriceGasoline_SCALED
- **U_{LPG}** = β_{LPG} + $\beta_{\_PP2}$ * PurchasePriceLPG_SCALED + $\beta_{\_KMCOST2}$ * KmCostLPG

<u>Utility Functions Cluster 3</u>

- **U_{CNG}** = β_{CNG} + $\beta_{\_PP1}$ * PurchasePriceCNG_SCALED + $\beta_{\_KMCOST1}$ * KmCostCNG + $\beta_{\_PS}$ * PurchaseSubsidyCNG_SCALED + $\beta_{\_Social}$ * SocialCircle + $\beta_{\_Network}$* NetworkDensity
- **U_{DIESEL}=** β_{DIESEL} + $\beta_{\_PP4}$ * PurchasePriceDiesel_SCALED + $\beta_{\_KMCOST4}$ * KMCOSTDIESEL + $\beta_{\_GROUP}$ * Small
- **$U_{GASOLINE}$** = $\beta_{GASOLINE}$ + $\beta_{\_KMCOST3}$ * KmCostGasoline + $\beta_{\_PP3}$ * PurchasePriceGasoline_SCALED
- **U_{LPG}** = β_{LPG} + $\beta_{\_PP2}$ * PurchasePriceLPG_SCALED + $\beta_{\_KMCOST2}$ * KmCostLPG

<u>Utility Functions Cluster 4</u>

- **U_{CNG}** = β_{CNG} + $\beta_{\_PP1}$ * PurchasePriceCNG_SCALED + $\beta_{\_Parking}$ * FreeParkingCNG + $\beta_{\_Network}$* NetworkDensity + $\beta_{\_Awareness}$* Awareness + $\beta_{\_KMCOST1}$ * KmCostCNG + $\beta_{\_Social}$ * SocialCircle
- **U_{DIESEL}** = β_{DIESEL} + $\beta_{\_PP4}$ * PurchasePriceDiesel_SCALED + $\beta_{\_KMCOST4}$ * KmCostDiesel
- **$U_{GASOLINE}$** = $\beta_{GASOLINE}$ + $\beta_{\_PP3}$ * PurchasePriceGasoline_SCALED
- **U_{LPG}** = β_{LPG} + $\beta_{\_PP2}$ * PurchasePriceLPG_SCALED + $\beta_{\_KMCOST2}$ * KmCostLPG

<u>Utility Functions without grouping</u>

- **U_{CNG}** = β_{CNG} + $\beta_{\_PP1}$ * PurchasePriceCNG_SCALED + $\beta_{\_Network}$* NetworkDensity + $\beta_{\_PS}$ * PurchaseSubsidyCNG_SCALED + $\beta_{\_TOLLS}$ * TollExemtpionCNG + $\beta_{\_KMCOST1}$ * KmCostCNG + β_{GROUP} * Small + $\beta_{\_Awareness}$* Awareness + $\beta_{\_Social}$ * SocialCircle + $\beta_{\_CARUSE}$ * Caruse
- **U_{DIESEL}** = β_{DIESEL} + $\beta_{\_PP4}$ * PurchasePriceDiesel_SCALED + $\beta_{\_KMCOST4}$ * KmCostDiesel + β_{DRIVER} * dieseltype + β_{GENDER} * Gender
- **$U_{GASOLINE}$** = $\beta_{GASOLINE}$ + $\beta_{\_PP3}$ * PurchasePriceGasoline_SCALED + $\beta_{\_KMCOST3}$ * KmCostGasoline + $\beta_{DRIVER2}$ * Gasolinetype
- **U_{LPG}** = β_{LPG} + $\beta_{\_PP2}$ * PurchasePriceLPG_SCALED + $\beta_{\_KMCOST2}$ * KmCostLPG

Where,

- PurchasePriceCNG_SCALED = purchase price of a new natural gas vehicle / 1000 (in Euro);
- PurchasePriceDiesel_SCALED = purchase price of a new diesel vehicle / 1000 (in Euro);
- PurchasePriceGasoline_SCALED = purchase price of a new gasoline vehicle / 1000 (in Euro);
- PurchasePriceLPG_SCALED = purchase price of a new liquified petroleum gas vehicle / 1000 (in Euro);
- NetworkDensity = existence of CNG refuelling stations as a ratio of the total conventional refuelling stations (1 out of 10, 2 out of 10…9 out of 10 and sufficient);
- KmCostCNG = FuelConsumptionCNG * FuelPriceCNG, indicates the fuel cost per 100km;
- KmCostLPG = FuelConsumptionLPG * FuelPriceLPG, indicates the fuel cost per 100km;
- KmCostGasoline = FuelConsumptionGasoline * FuelPriceGasoline, indicates the fuel cost per 100km;
- KmCostDiesel = FuelConsumptionDiesel * FuelPriceDiesel, indicates the fuel cost per 100km;
    - FuelConsumptionCNG = Fuel consumption of an NGV (in kg/100km);
    - FuelConsumptionLPG = Fuel consumption of an LPG vehicle (in lt/100km);
    - FuelConsumptionDiesel = Fuel consumption of a diesel vehicle (in lt/100km);
    - FuelConsumptionGasoline = Fuel consumption of a gasoline vehicle (in lt/100km);
    - FuelPriceCNG = Fuel price of CNG (in €/kg);
    - FuelPriceDiesel = Fuel price of Diesel (in €/lt);
    - FuelPriceLPG = Fuel price of LPG (€/lt);
    - FuelPriceGasoline = Fuel price of gasoline (€/lt);
- PurchaseSubsidyCNG_SCALED = Purchase subsidy for a new NGV / 1000 (in Euro);
- TollExmptionCNG = Toll exemption in Athens – Thessaloniki axis for natural gas vehicles, dummy variable, takes the value 1 if there is toll exemption, 0 otherwise;
- Awareness = dummy variable, it takes the value 1 if the respondent has responded correctly in more than 8 out of 10 of the True False questions regarding the characteristics of CNG, 0 otherwise;
- SocialCircle = dummy variable, it takes the value 1 if the respondent has indicated that is strongly willing to purchase a natural gas vehicle, if her/his social circle has already a positive experience with the use of CNG as a fuel;
- Gender = dummy variable, it takes the value 1 if the respondent is female, 0 otherwise;
- Caruse = dummy variable, it takes the value 1 if the respondent uses her/his car in everyday activities, 0 otherwise;
- Small = indicates the size of vehicle (small, medium, SUV), it takes the value 1 if it belongs to the "small" category, 0 otherwise;

- Gasoline_type = indicates the fuel type of the respondent's vehicle, dummy variable, it takes the value 1 if it runs on gasoline, 0 otherwise;
- Diesel_type = indicates the fuel type of the respondent's vehicle, dummy variable, it takes the value 1 if it runs on diesel, 0 otherwise.

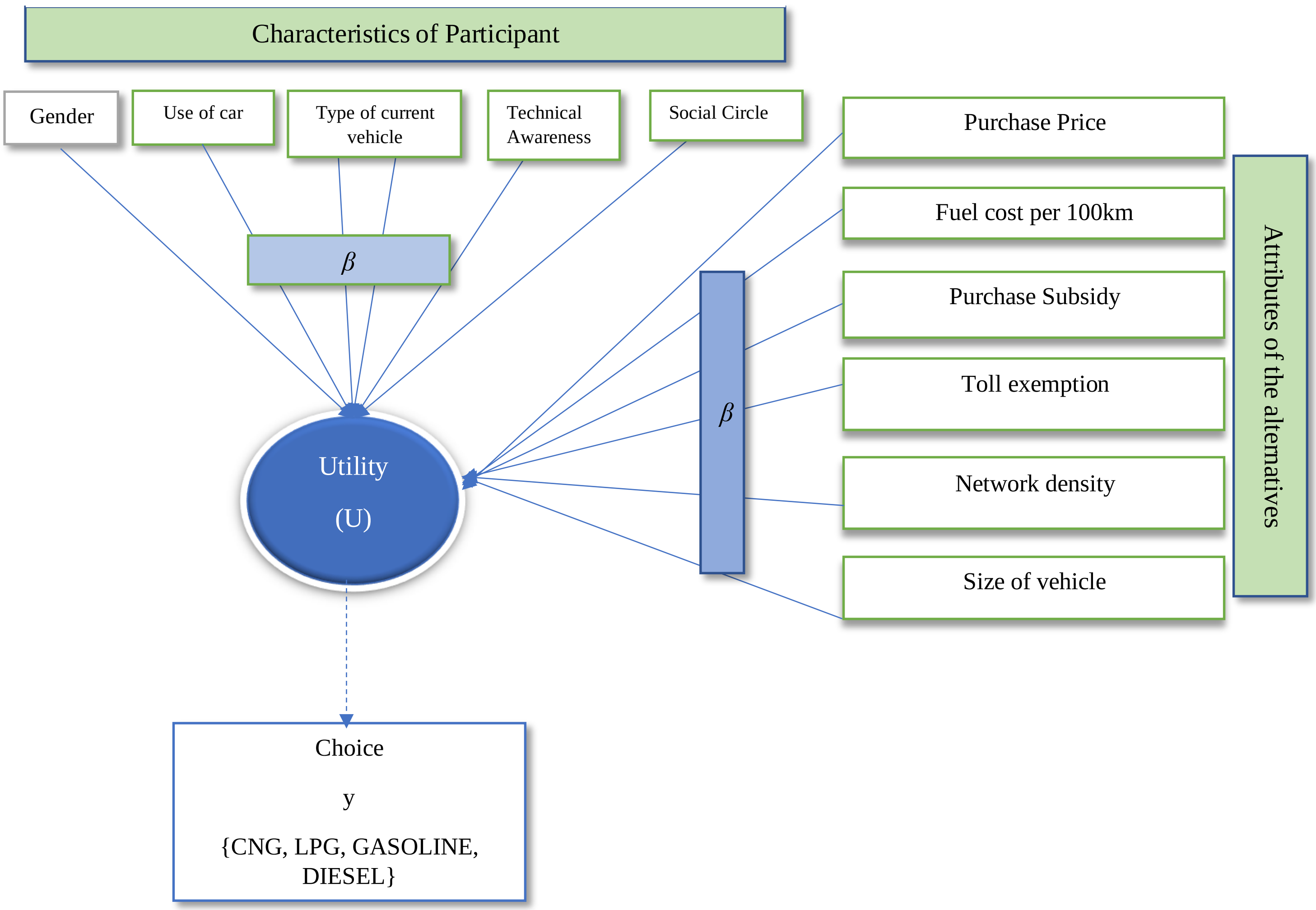
The following figure presents the modelling framework applied to the fuel/vehicle choice experiments. The utility of each fuel/vehicle combination is a function of the hypothetical scenarios' attributes as well as the characteristics of the participant.

In addition to the aforementioned variables, several other variables including household size, the residence in urban centres or rural areas were examined during the model estimation process. However, since these variables showed lower statistical significance were excluded by the final model. These variables offer precious insight regarding the policy implications; therefore, it is assumed that in larger datasets they would perform with higher statistical significance.

Two new variables were also identified that influence the final car/fuel choice: technical awareness and the neighbour effect. These variables were initially measured on a 7-point Likert scale that investigates their level of familiarization with the new technology (awareness) and the influence from interpersonal relationships regarding the new technology. The dummy variables assumed the value 1 if their overall score in the True False questions was 8,9, and 10/10, and the value 0 if otherwise. Same for the second dummy variable which assumed the value 1 if they stated that they would consider purchasing an NGV if their social circle had a positive experience with this technology.

The following figure presents the modelling framework.

Figure 20-Modelling Framework without Grouping



The following table presents the variables and coefficients obtained of the estimation model for the four groups and the whole sample without grouping by Biogeme.

Table 20-The model estimation results for groups

Coefficients						**Std Error (t-test)**				
Variables	cluster 1	cluster 2	cluster 3	cluster 4	**All**	cluster 1	cluster 2	cluster 3	cluster 4	**All**
βcng	0	0	0	0	0	Fixed	Fixed	Fixed	Fixed	Fixed
βdiesel	1.04	0.179	-0.853	0.209	0.155	0.58 (1.79)	0.53 (0.34)	1 (-0.85)	0.515 (0.41)	0.434 (0.36)
βgasoline	0.985	-0.355	0.931	-1.92	-1.53	1.06 (0.93)	0.598 (-0.59)	1.07 (0.87)	0.615 (-3.13)	0.486 (-3.16)
βlpg	-1.82	-1.16	0.921	-1.46	-1.63	0.691 (-2.64)	0.716 (-1.61)	0.984 (0.94)	0.702 (-2.08)	0.486 (-3.35)
CNG										
Purchase price CNG	-0.106	-0.0945	-0.158	-0.169	-0.138	0.0181 (-5.85)	0.0175 (-5.41)	0.0271 (-5.83)	0.0177 (-9.53)	0.012 (-11.56)
Fuel cost per 100km	-0.179	-0.201	-0.219	-0.167	-0.192	0.0413 (-4.33)	0.0418 (-4.79)	0.0615 (-3.56)	0.0438 (-3.82)	0.0231 (-8.30)
Network Density	0.0507	-	0.127	0.076	0.0654	0.0296 (1.96)	-	0.0394 (3.23)	0.03 (2.54)	0.0153 (4.29)
Free Parking	-	-	-	0.397	-	-	-	-	0.172 (2.31)	-
Technical awareness	0.399	-	-	0.379	0.286	0.184 (2.17)	-	-	0.174 (2.18)	0.0878 (3.25)
Social circle	0.762	0.57	1.18	0.445	0.721	0.199 (3.83)	0.159 (3.59)	0.256 (4.6)	0.187 (2.38)	0.0951 (7.58)
Purchase Subsidy	0.205	0.188	0.251	-	0.226	0.0725 (2.83)	0.0671 (2.8)	0.0951 (2.64)	-	0.0442 (5.11)
	-	0.0394	-	-	0.304	-	0.00858	-	-	0.0867

Toll Exemption							(4.59)			(3.51)
Small Vehicle	-	-0.677	-	-	-0.467	-	0.364 -1.96	-	-	0.197 (-2.37)
Car use	-	-	-	-	-0.245	-	-	-	-	0.0956 (-2.56)
Diesel										
Purchase Price Diesel	-0.129	-0.0868	-0.053	-0.146	-0.116	0.0209 (-2.83)	0.0178 (-4.88)	0.0311 (-1.70)	0.0208 (-7.01)	0.011 (-10.47)
Fuel cost per 100km	-0.252	-0.265	-0.292	-0.263	-0.271	0.055 (-4.58)	0.0491 (-5.40)	0.0672 (-4.34)	0.0566 (-4.65)	0.0282 (-9.62)
Small vehicle	-	-	1.7	-	-	-	-	0.436 (3.9)	-	-
Gender	-	-	-	-	-0.355	-	-	-	-	0.1 (-3.55)
Currently driving a diesel vehicle	-	-	-	-	0.596	-	-	-	-	0.186 (3.21)
Gasoline										
Purchase Price Gasoline	-0.251	-0.107	-0.237	-0.151	-0.135	0.0514 (-4.88)	0.0241 (-4.44)	0.0536 (-4.41)	0.0208 (-7.01)	0.0162 (-8.36)
Fuel cost per 100km	-	-0.177	-0.127	-	-0.105	-	0.0421 (-4.20)	0.0654 (-1.93)	-	0.024 (-4.37)
Small vehicle	-1.25	-	-	-	-	0.52 (-2.42)	-	-	-	-
	-	-	-	-	0.681	-	-	-	-	0.147

Currently driving a gasoline vehicle										(3.21)
LPG										
Purchase price LPG	-0.0976	-0.0822	-0.216	-0.137	-0.111	0.0299 (-3.26)	0.0304 (-2.70)	0.0457 (-4.74)	0.0339 (-4.05)	0.0165 (-6.75)
Fuel cost per 100km	-	-0.227	-0.141	-0.14	-0.133	-	0.0596 (-3.81)	0.0613 (-2.30)	0.0548 (-2.55)	0.0272 (-4.91)

	Statistics				
	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**All**
Number of Observations	744	758	420	672	2598
Initial Log Likelihood	-1031.403	-1050.811	-582.244	-931.590	-3601.593
Final Log Likelihood	-670.445	-791.013	-399.271	-638.639	-2519.553
Likelihood ratio test	721.917	512.843	365.945	585.901	2164.080
Rho square	0.349	0.244	0.314	0.314	0.300
Adjusted Rho square	0.336	0.231	0.288	0.299	0.295

4.6.1 Model Interpretation

As it was expected, the signs of the coefficients of purchase price and fuel cost per 100km are negative in all models. The variable **of fuel cost** is a constructed variable of fuel price multiplied by fuel consumption for each type of vehicle. From this, it can easily be implied that an increase in the values of the variables for a fuel/vehicle type, reduces the utility of that fuel/vehicle and the probability to be chosen.

Purchase price is highly statistically significant for all models, indicating that individuals are cost sensitive regarding the purchase of a new vehicle. A comparison of the coefficients of cost per 100 km variable to purchase price coefficients, show that the individuals are more sensitive to every day operational costs, rather than capital costs (purchase price) of a new vehicle. The results are in consistent with earlier findings (Brownstone, Bunch, & Train, 2000); (Musti & Kockelman, 2011); (Achtnicht, Bühler, & Hermeling, 2012). This is intuitive because of the mistrust of the public on price fluctuations, as well as the uncertainty political framework regarding the implementation of an increased VAT on conventional fuels as well as CNG. This can be also justified by the belief that CNG price will be equal to gasoline's in the next years. Although, the purchase price of a new vehicle is indeed a large investment at one point in time, it does not change significantly throughout the time. The consumers have the time to consider the family budget distribution and to evaluate the advantages of each type of vehicle without worrying for a price change.

The coefficient of **density** of the refuelling network variable has a positive sign and it is highly statistically significant, indicating that a well-established network for NGVs affect positively the utility of CNG. The results are in alignment with the outcomes of other studies (Bunch, Bradley, Golob, & Kitamura, 1993);(Brownstone D., 2000); (Achtnicht, Bühler, & Hermeling, 2012). Dagsvik et al. (2002) show that except for purchase price and fuel range, the suitable infrastructure for refuelling and maintenance is also important. This is not the case for Cluster 2 as the coefficient of density was not statistically significant and it was excluded from the model, whereas the policy of toll exemption appears to have a positive impact on their utility.

Regarding CNG, the variables of **Purchase Subsidy** for a new NGV and the implementation of the policy measure of **toll exemption** for the owners of NGVs have a positive impact on the utility of CNG.

Regarding the **size** of the new vehicle, the participants are more likely to purchase a CNG vehicle that falls to the category of Medium and SUV, because of the greater fuel efficiency as well as comfort (Brownstone, Bunch, & Train, 2000).

The coefficients of the variables of **technical awareness** and influence from **social circle** have a positive impact on the utilities of the clusters and overall sample. Specifically, the utilities of well-aware representatives of cluster 1 and cluster 4 are positively impacted. Cluster 4 comprises solely by female and the coefficient shows the highly stated preference of women towards eco-friendly technologies. The results are in alignment with previous studies showing that young women have demonstrated environmentally friendly attitudes and are more likely to prefer an AFV (Dagsvik, Wennemo, Wetterwald, & R, 2002); (Cumhur E., 2010); (Mabit & Fosgerau, 2011); (Ziegler, 2012).

The coefficient of **social circle** is statistically significant in Cluster 1,2,3 and in the overall model. The interpersonal influence coming from neighbours, or immediate family and friends is an important factor of innovation adoption in general and for NGVs specifically. The study of Janson et al. (2017) signifies the importance of social and normative influence on cleaner transportation adoption by the consumers and analyses the influence from neighbours to car/fuel choice. Stimulating social interaction and discussion concerning alternative fuel technologies by the policy makers could be more important and beneficial than the usual implications from manufacturers and markets of AFVs.

Two more variables affect the final choice of the respondents, **the use of car in everyday activities**. From the coefficients, it can be concluded that respondents who are not intensive car users are more likely to choose an NGV as a final choice. It can be safely concluded that the respondents who do not own a private vehicle, or they share a vehicle with other household members and use it occasionally, are more likely to be NGV purchasers. Findings from a survey for Chinese drivers, show that first time buyers are more likely to proceed to a thorough analysis of their options regarding the available fuel technologies in the market (Qian, Soopramanien, & Daryanto, 2017). Customers who haven't owned a product before try to obtain any kind of information available through the use of internet and the shared experiences on social media (Bei, Chen, & Widdows, 2004).

Similarly, in Diesel alternative, **fuel cost per 100 km** is the most statistically significant variable which negatively affects the utility of a Diesel vehicle. The results are also in alignment with worldwide literature; **males** are more likely to choose a diesel vehicle as it can be seen by the respective coefficient. What is important to state is that respondents who already own a diesel car are more likely to purchase a diesel car. The same is valid for **gasoline car owners**, who also reveal a reluctancy towards the new fuel. As it was mentioned in the literature review, habit is a driver of behaviour which is hard to mitigate or alter it only with the implementation of policy or financial drivers.

Fuel cost per 100km and **Purchase price** for LPG are the only two statistically significant variable for this alternative. Gasoline and LPG vehicles usually have higher fuel consumption in all three types of vehicles (Small, Medium, SUV). In many cases though, LPG vehicles had even poorer fuel efficiency than gasoline vehicles and that is depicted by the value of the coefficient. The lack of other variables on the formation of the utility, shows that LPG was chosen when the level of attributes favoured this choice.

4.9 Conclusions

The aim of this chapter is to provide insight on the drivers' perceptions on the use of natural gas technologies. The results from the data collection show relatively consistency in terms of the key issues that concern future buyer: purchase price, fuel cost, number of subsidies. A cluster analysis was also developed, providing four clusters based on: gender, pro CNG attitude, level of technical awareness, car use in every-day activities. An MNL model was developed for each of the group and an improved predictive accuracy of the models was expected. The advantage of this method (grouping compared with no grouping) is that we considered more characteristics to analyse consumers' behaviour. The proposed model can be also adopted by policy makers to analyse consumers' behaviour and adapt necessary strategies for the deployment of the alternative fuel infrastructure.

The results of the MNL indicate that Greek drivers perceive the various combinations of fuel/vehicle in different ways. The statistical significance, ease of interpretation and stability of the SP modelling results provided a useful database for estimating preferences for AFVs in Greece. Results indicate that purchase price, fuel cost and purchase subsidy are particularly important attribute when choosing a fuel/vehicle combination. It is worth to mention that even with the presence of incentives in terms of subsidies and sufficiency of refuelling infrastructure, natural gas is not maximising consumers' utilities so to define their final choice.

The differences in preferences capture by the person are readily interpretable and provide a strong foundation for future studies of the demand of AFVs. These estimates are used to evaluate scenarios for AFVs, and implications of policy packages based on the significance of each attribute and are presented in the following chapter. The scenarios reveal that a change in the market share could occur only if a mix of targeted policies in place rather and not the "one step at a time" approach.

Chapter 5

From model estimation to transport policy suggestions

In this chapter, the proposed policies for the promotion of the use of NGVs are presented. The following policies were formulated according to the most significant factors that affect the consumers, drawn by the results of the multinomial logit model.

The following table illustrates the targeted actions for each policy package that includes several estimated attributes: purchase price, fuel cost/100km, network density, purchase subsidy and toll exemption in Athens-Thessaloniki road axis.

Table 21- Synopsis of proposed policies

	Purchase Price	**Cost/100km**	**Network Density**	**Purchase Subsidy for NGV**	**Toll exemption for NGV**
Policy Package 1	25.000€	Minimum: 2,4,4,2 Medium:4.5, 7.2, 7.4, 4.5 Maximum: 8, 15, 15, 9	Sufficient	Not available	Not available
Policy Package 2	25.000€	Medium values for all fuels	Sufficient	1000, 2000, 3000, 4000, 5000	Not available
Policy Package 3	25.000€	Medium values for all fuels	Sufficient	1000, 2000, 3000, 4000, 5000	Available
Policy Package 4	10.000€ 15.000€ 17.000€ 25.000€	Medium values for all fuels	50%	Not available	Not available
Policy Package 5	25.000€	Medium values for all fuels	20%, 40%, 60%, 80% Sufficient	Not available	Not available

The following table describes in detail the attributes considered for the development of each policy package. Each Policy Package focuses on the combinations of the values of several attributes and it provides information regarding the change in the respective probability of the final vehicle/fuel choice. In order to facilitate the evaluation of each policy package, the impact of each measure is classified by colour. The evaluation method is presented below.

- **Grey**: not the desired impact, not recommended
- **Blue**: desired impact, recommended
- **Yellow**: desired impact, not more than 1%, moderate recommended
- **Green**: highly recommended

Desired impact: the probability of choosing a natural gas vehicle raises compared to the base model and/or the probability falls for conventional vehicles.

5.1. Policy Package 1: The fuel cost effect

The first policy package focuses on the impact of the cost per 100km of each vehicle. Three levels of this attribute were examined: the minimum values, the medium values, and the maximum values. The purchase price variable remained the same for each probability calculation. In addition, it was assumed that there were no financial incentives and that the refuelling network for natural gas vehicles is sufficient. As it can be seen, the probability raises in the final option, were the cost/100km is maximum for all fuels. The probability of choosing natural gas raises more than 1%, from 54.20% to 57.17%, while the probability for diesel falls from 28.29% to 24.83%. The probabilities for LPG and Gasoline raise not more than 1%.

Table 22-Policy package 1 evaluation

Policy Package 1: **The fuel cost effect**	**CNG**	**LPG**	**GASOLINE**	**DIESEL**
BASE	54.20%	7.7%	9.7%	28.29%
COST/100KM: Minimum **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: Sufficient	40.91%	8.6%	8.64%	41.83%

COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: Sufficient	44.66%	9.4%	10.03%	35.83%
COST/100KM: Maximum **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: Sufficient	57.17%	7.79%	10.18%	24.83%

Grey: not the desired impact, not recommended ***Blue: desired impact, recommended*** ***Yellow: desired impact, not more than 1%, moderate recommended*** ***Green: highly recommended***

5.2 Policy Package 2: The subsidy effect

The core of the second policy package is the impact of the level of subsidy for the purchase of a new natural gas vehicle. Five levels of purchase price were examined from 1000 to 5000. The combination of a purchase subsidy of 3000€, 4000€ and 5000€ with a dense refuelling network raises the probability of the natural gas choice more than 1% in all three scenarios with a simultaneous decrease of the probability for the conventional vehicles. As it is expected, the highest subsidy of 5000€ has the strongest effect on the final choice. The probability of diesel remains higher than gasoline and LPG, however it decreases more than 5% from the base scenario.

Table 23-Policy Package 2: The subsidy effect

Policy Package 2: The subsidy effect	**CNG**	**LPG**	**GASOLINE**	**DIESEL**
BASE	54.20%	7.7%	9.7%	28.29%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 1000€ **NETWORK**: Sufficient	48.91%	8.73%	9.26%	33.07%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 2000€ **NETWORK**: Sufficient	53.19%	8.0%	8.48%	30.31%

COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 3000€ **NETWORK**: Sufficient	57.41%	7.28%	7.72%	27.57%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 4000€ **NETWORK**: Sufficient	61.53%	6.5%	6.97%	24.91%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 5000€ **NETWORK**: Sufficient	65.49%	5.9%	6.25%	22.34%

Grey: not the desired impact, not recommended Blue: desired impact, recommended Yellow: desired impact, not more than 1%, moderate recommended Green: highly recommended

5.3 Policy Package 3: The toll effect

In the third policy package, the effect of the toll exemption for the drivers of NGVs on Athens-Thessaloniki national road. The policy package that includes all five levels of subsidy, the implementation of the toll exemption and a sufficient refuelling network, provides the most positive effects on the probability for NGVs. The gradual increase of the purchase subsidy along with the toll exemption increases the final probability of natural gas and the decrease of the main competitor: the diesel vehicle. The probability of diesel has the biggest difference compared to the former policy packages so far. The same stands also for natural gas. Furthermore, the difference between the probability of natural gas and diesel vehicle is more than 50% in the final combination scenario.

Table 24-Policy Package 3 evaluation

Policy Package 3: The Toll effect	**CNG**	**LPG**	**GASOLINE**	**DIESEL**
BASE	54.20%	7.7%	9.7%	28.29%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 1000€ **NETWORK**: Sufficient **TOLL EXEMPTION**: Yes	56.31%	7.47%	7.92%	28.29%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 2000€ **NETWORK**: Sufficient **TOLL EXEMPTION**: Yes	60.46%	6.7%	7.1%	25.60%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 3000€ **NETWORK**: Sufficient **TOLL EXEMPTION**: Yes	64.66%	6.07%	6.44%	23%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 4000€ **NETWORK**: Sufficient **TOLL EXEMPTION**: Yes	68.28%	5.42%	5.75%	20.53%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **SUBSIDY**: 5000€ **NETWORK**: Sufficient **TOLL EXEMPTION**: Yes	71.86%	4.81%	5.1%	18.21%

Grey: not the desired impact, not recommended ***Blue: desired impact, recommended*** ***Yellow: desired impact, not more than 1%, moderate recommended*** ***Green: highly recommended***

5.4 Policy Package 4: The purchase price and the network density effect

The fourth policy package evaluates the impact of the initial purchase cost of a new vehicle and a moderate developed refuelling network, namely, only half of the refuelling points in the city are for AFVs. Neither purchase subsidies nor toll exemption are available in this kind of policy scenario. As it can be seen from the grey coloured table, the desired impact is not achieved. Even in the lowest price of vehicles, the probability of diesel remains higher than all other options, and as the purchase price increases for the vehicles so is the probability of diesel. A moderate developed refuelling network cannot counterbalance the low initial purchase cost of an AFV. In this policy package, the probability of conventional vehicle increases in all different policy scenarios and the probability of diesel reaches the highest share of 36.34%.

Table 25-Policy Package 4 evaluation

Policy Package 4: **The purchase price effect and the moderate network density**	**CNG**	**LPG**	**GASOLINE**	**DIESEL**
BASE	54.20%	7.7%	9.7%	28.29%
COST/100KM: Medium **PURCHASE PRICE**: 10,000€ **INCENTIVES**: No **NETWORK**: 5 out of 10	40.71%	9.04%	13.33%	36.9%
COST/100KM: Medium **PURCHASE PRICE**: 15,000€ **INCENTIVES**: No **NETWORK**: 5 out of 10	41.79%	9.23%	12.20%	36.76%
COST/100KM: Medium **PURCHASE PRICE**: 17,000€ **INCENTIVES**: No **NETWORK**: 5 out of 10	42.22%	9.31%	11.77%	36.69%

COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: 5 out of 10	43.87%	9.6%	10.17%	36.34%

Grey: not the desired impact, not recommended Blue: desired impact, recommended Yellow: desired impact, not more than 1%, moderate recommended Green: highly recommended

5.5 Policy Package 5: The network density effect

The fifth policy package explores the impact of the refuelling network density. No incentives are available and the purchase price for a new vehicle is 25,000€ for all alternatives. As it expected, the desired impact is not achieved. The share of conventional vehicles increases sharply compared to the base scenario. The probability of natural gas increases insignificantly as the density of the refuelling network reaches the sufficient level.

Table 26-Policy Package 5 evaluation

Policy Package 5: **The network density effect**	**CNG**	**LPG**	**GASOLINE**	**DIESEL**
BASE	54.20%	7.7%	9.7%	28.29%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: 2 out of 10	43.40%	9.68%	10.26%	36.64%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: 4 out of 10	43.72%	9.62%	10.20%	36.44%
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: 6 out of 10	44.03%	9.57%	10.14%	36.24%
COST/100KM: Medium	44.35%	9.51%	10.09%	36.03%

PURCHASE PRICE: 25,000€ **INCENTIVES**: No **NETWORK**: 8 out of 10				
COST/100KM: Medium **PURCHASE PRICE**: 25,000€ **INCENTIVES**: No **NETWORK**: Sufficient	44.66%	9.46%	10.03%	35.83%

Grey: not the desired impact, not recommended Blue: desired impact, recommended Yellow: desired impact, not more than 1%, moderate recommended Green: highly recommended

From the combinations of the policy packages above, it can be concluded that a policy plan that will include not only the development of a well-established refuelling network but also financial incentives such as purchase subsidies and/or toll exemption for natural gas vehicles, will affect positively the share of natural gas. The change in probabilities show that the participants are mostly cost sensitive. The aforementioned measures can only be considered as a compass, a map with general instructions for policy makers that aspire to enhance the share of alternative fuel technologies with a combination of actions.

The table below summarises and prioritises the set of policies that achieve the largest market share of CNG with a parallel decrease of the market share of conventional vehicles.

Table 27-Summary of policy packages

Policy package	**Market share of CNG**
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 5000€** NETWORK**: Sufficient** TOLL EXEMPTION**: Yes**	**71.86%**
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 4000€** NETWORK**: Sufficient**	68.28%

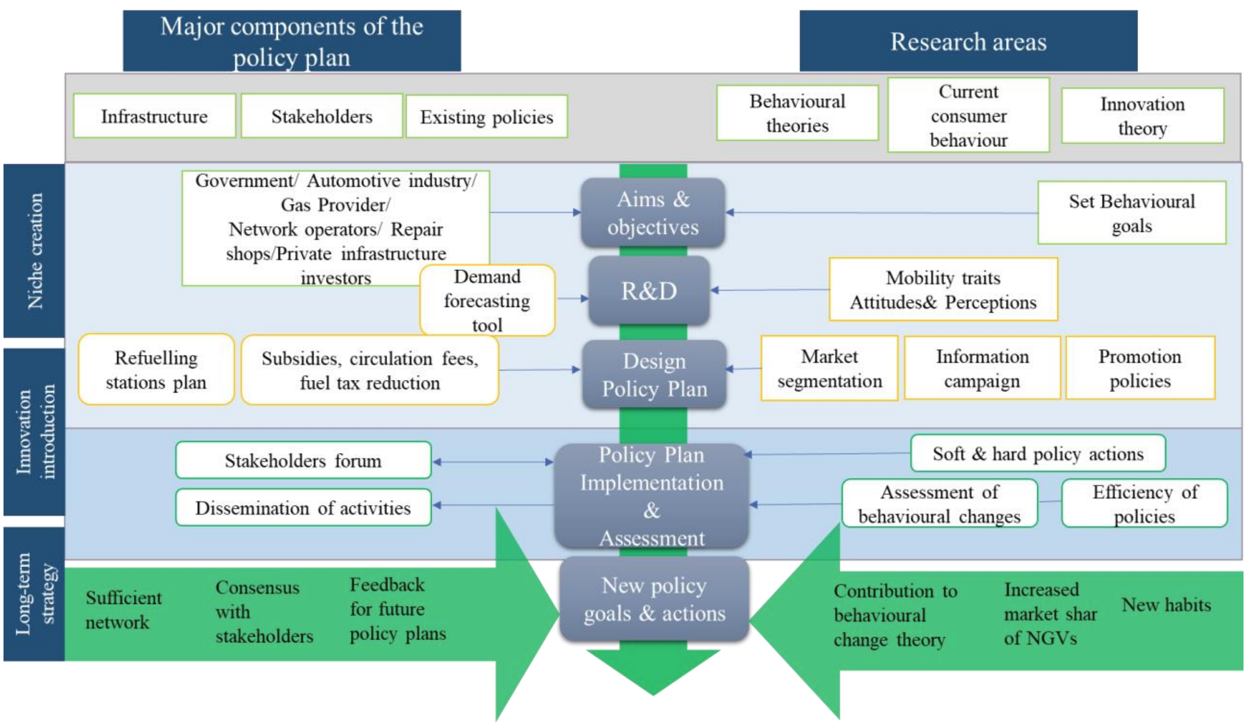
TOLL EXEMPTION**: Yes**	
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 5000€** NETWORK**: Sufficient**	65.49%
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 3000€** NETWORK**: Sufficient** TOLL EXEMPTION**: Yes**	64.66%
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 4000€** NETWORK**: Sufficient**	61.53%
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 2000€** NETWORK**: Sufficient** TOLL EXEMPTION**: Yes**	60.46%
COST/100KM**: Medium** PURCHASE PRICE**: 25,000€** SUBSIDY**: 3000€** NETWORK**: Sufficient**	57.41%

5.6 Conclusions and proposed measures

Integrated Policy Plan- Greece

In this section, an integrated policy plan based on the evaluation of the policy packages are presented. Every policy package included both hard and soft policy measures to increase the probability of choosing natural gas over the other fuels. Apart from the proposed policy measures, the stages and the respective market targets and stake holders of the policy implementation will be presented. The behavioural change of the consumer is the key element to achieve market goals, but the strong collaboration of the stakeholders is also essential. The logit model is used as a tool to construct clearer objectives based on the attitudes and perceptions of the logistics companies and the Greek drivers and to develop customised solutions for specific audiences. The proposed policy plan process should provide to policy makers a holistic understanding of the consumers' behaviour and the ability construct customised policy actions for targeted audiences.

Figure 21-Integrated Policy Plan Greece



Niche Creation phase

Specific and measurable aims based on behavioural goals are important in the first stages of the policy plan. The main objective is to establish a new culture to facilitate change towards the image of natural gas vehicles. In this context, the behavioural goal is to develop a collective feeling of responsibility towards the environment, but to achieve that the change of the perception of CNG is important. According to the results of this survey, there is a significant knowledge gap on safety issues because of the misconception with LPG and a mistrust on the consistency of the announced policy measures regarding the reduced fuel price and the expansion of refuelling network. Furthermore, the outcome of the survey reveals that a behavioural change is more possible to occur when it is followed by subsidies and tax reduction.

Innovation introduction

The dissemination of the results of previous policy actions is essential in the first stages of the current policy plan. The combination of several communication approaches has a positive impact on the behavioural change. The results of the questionnaire illustrate that the majority of the respondents do not have a clear picture of the benefits of natural gas. It is crucial for the public to be informed about the policies of the European Union -and the respective time horizon- about the adoption of alternative fuels and the contribution of Greece in the decarbonisation of the transport sector. To achieve this, the establishment of a network among stakeholders that share information and intelligence, would further enhance this initiative.

Policy makers could communicate to the public the international agreements on pipeline infrastructure and the national refuelling network plan that facilitates the energy capacity. As it was presented in the results of the estimated model, the expansion of the refuelling infrastructure plays a significant role on the decision-making process. A part of the communication campaign should also include the results of the education program for car engineers; the existence of authorised repair shops enhances the credibility of the policy actions and validates the long-term nature of the policy plan regarding the use of natural gas. It is proved by many case studies regarding information campaigns and travel behaviour change, that the exposure of potential buyers to clean fuels (Jansson, Pettersson, Mannberg, Brännlund, & Lindgren, 2017) raises awareness and have an impact on peoples' preferences (Davies, 2012).

Policy makers should disseminate the results of the conversion subsidy program for fleet owners (described in Chapter 6) by including as key elements: the number of companies involved, the size of their fleets, the achieved fuel cost reduction and the engine performance after a year. By developing a climate of trust, more companies will follow the actions of a leading company and proceed to a business strategy change.

A reliable outcome of this survey that further confirms the importance of habit in the behavioural change, is that gasoline and diesel drivers are more likely to repurchase gasoline and diesel vehicles respectively. Additionally, the constructed variable of "social circle" further intensifies the importance of exposure of the consumers to informational material and positive word of mouth. For that reason, it is crucial that at the first stages, the policy plan will include information campaign on: the benefits of natural gas, the available options of AFVs in the market, the specific goals of European Union regarding the level of CO_2 emissions and the exclusion of diesel vehicles in metropolitan centres in the near future. However, the exclusion of diesel vehicles should not be balanced with the purchase of new vehicles. This trend could lead to the opposite result, since the increased number of vehicles would create further congestions and CO_2 emissions. In that case, diesel vehicles could possibly formulate an initial target market since the conversion of diesel vehicles to bi-fuel (diesel-CNG) is technologically feasible and in alignment with latest safety regulations.

The ongoing purchase subsidy program in collaboration with the automotive industry should now emphasise on specific audiences offering a wider range of vehicles. From the results of this survey young people, especially female, first time potential buyers and non-intensive car users are more likely to adopt an alternative fuel technology. Regarding the size of the vehicle, NGVs are more attractive in the medium category of up to 1600cc. Moreover, according to data analysis, the implementation of toll exemption for NGVs on Athens-Thessaloniki national road has a strong positive impact on the probability of natural gas choice. This measure could be also valid for converted vehicles with a total or partial toll exemption. Policy makers should also make known to the public that the price of natural gas will not suffer steep fluctuations and tax additions.

To reduce investment cost in new sites, whenever possible, natural gas stations should be located at existing conventional fuel stations along the main roads. This criterion should be considered by the policy makers, for additional space requirements for alternative fuel stations.

Long-term strategy

The development of a mix soft and hard policy measures is expected to have the most efficient outcome. The traditional paradigm of establishing hard policy measures to force the desirable outcome may lead to the desired change, however, the blend of soft policy actions can lead to the desired change faster and more stable. The overall outcome of the interviews with logistics companies, professional drivers as well as with the general public, is that there is a lack of understanding not only regarding the fuel properties, or the technical characteristics -something that is actually expected- but also regarding energy policy actions that affect them in the near future. Traditional policy plans would also first favourite the audience with "the highest intention". Since the AFV market in Greece is still in seed stage, and the main focus is on professional fleets, the general public remains misinformed and the market uptake is further delayed. Soft policy measures that alter the perceived objective regarding the use of alternative fuel technology, raise awareness and release feelings of concern regarding safety issues. Additional measures could include the exemption of circulation fees for CNG vehicles, insurance premiums, lower presumptive value, provision of fuel card for the first year, leasing options for companies with fleets and grace periods for potential customers to familiarise with the natural gas technology.

An effective exploitation of a new technology begins by the innovators, is supported by the governance and the industry, and is provided to the end users, in this case car owners. Meeting the needs of all key stakeholders is a complicated process and there is not an "one size fits all" approach.

There are number of general actions to be taken from policy makers to address each identified barrier.

Actions to be taken from policy makers to support the expansion of the refuelling network and support the adoption of natural gas as a fuel:

1. **Informational – organizational:** Ensure that best practices are shared and that potential partners (public sector, local authorities etc.) are informed on the current priorities in terms of fuel adoption in order to focus on the right types and projects. The coordination of key stakeholders across geographies and Member States should be ensured.
2. **Political/ Legal:** Coordination between Member States to ensure cross-border expansion of the network and provision of a framework for financing arrangements to ensure different size of projects on the network.
3. **Market:** To ensure the successful deployment, there is a need for coordinated actions between Member States and local authorities to create packages of policy incentives, requirements and standardization in order to stimulate demand. Furthermore, regional and local partners should identify the appropriate locations for potential stations. In that case, local authorities could play a role in sponsorship each project.
4. **Financial:** The biggest obstacle on the expansion of the refuelling network is the slow and uncertain growth of the market, and therefore the limited revenues. Policy makers should develop appropriate funding and financing schemes to support the network development for CNG regarding:
    a. Demand guarantee mechanisms
    b. Technology upgrade facilities
    c. Additional funding to cover initial operating losses and periods when the utilization of the stations is not yet possible to reach profitability threshold.
    d. Agreement on price controls and guarantee that tax levels will not be quickly eroded as the competition increases.

Chapter 6

Alternative fuels in city logistics: actors' perceptions

This chapter analyses the perceptions of another significant market segment of transport, the city logistics operators. It provides an overview of the main findings of past studies focusing on the decarbonisation of this segment and sheds light on specific aspects of the organizational behaviour that influence the use of alternative fuels. It presents the main findings from the interviews conducted to logistics companies in Athens, and it proposes measures and actions that could enhance the gradual decarbonization of the sector.

6.1 Urban logistics

The ease of the collection and distribution of goods in urban areas influences the quality of life, the economic growth, and the attractiveness of the city itself. The limited space in urban areas, which are occupied by freight and passenger transport, hinders the efficiency of the system in terms of travel times, emissions, and car accidents. Ensuring the fluidity of urban logistics, which operate at the end of a door-to-door supply chain along with the passenger transport, which is dedicated to individual needs, is a major challenge for the policy makers.

During the past decades the term of green city logistics has been widely used in an effort to include supply chain management practices to reduce energy footprint, activities related to eco-efficient management and waste reduction (Lee & Ho, 2011). Within the context of sustainable development, green city logistics can be defined as, "*the process for totally optimising the logistics and transport activities by private companies with support of advanced information systems in urban areas considering the traffic environment, the traffic congestion, the traffic safety and the energy savings within the framework of a market economy*" (Taniguchi, Thompson, Yamada, & Duin, 2001).

However, fleet management is a multidisciplinary task as it includes a wide range of functions such as: vehicle procurement and maintenance, telematics, driver management, fuel management and safety management. A sustainable fleet management refers to an efficient way of managing a company fleet by reducing operational costs, energy consumption and emissions and by improving company's performance and image, by creating added value for the customers, by increasing the security of the drivers and the goods transported, etc.

EU objective of transforming city logistics CO_2-free by 2030 is a growing concern for many enterprises and stakeholders. The challenge to decarbonise logistics sector lies upon four main points: firstly, according to forecasts, transport activity is going to increase significantly in the coming decades: passenger transport by 42% by 2050 and freight transport by 60% (EC, 2019). Furthermore, the growing amount of e-commerce and the availability of tracking and tracing services have forced for shorter deliver times, even same-day deliveries. The current just-in-time distribution system requires reliable delivery schedules, shorter lead times and tight time window in highly congested areas. Secondly, this sector relies heavily in fossil fuel consumption and is highly fragmented as it is composed by many small companies with different organization schemes (EC, 2011). Finally, the number of stakeholders involved and the often-contradictive objectives, are resulting in a variety of barriers that challenges more the implementation of an integrated decarbonisation strategy (Gonzalez-Feliu, 2010).

The urban goods transport flows differ significantly based on the nature of delivery and the type of commodity, including for example: building materials, waste collection, retail deliveries and courier services. These tasks may occur in different time slots during the day, conducted using different kind of vehicles and may follow different kind of spatial coverage and frequency of itineraries (Taylor, 2005). The urban flows could be further split in three categories (Segalou, 2004):

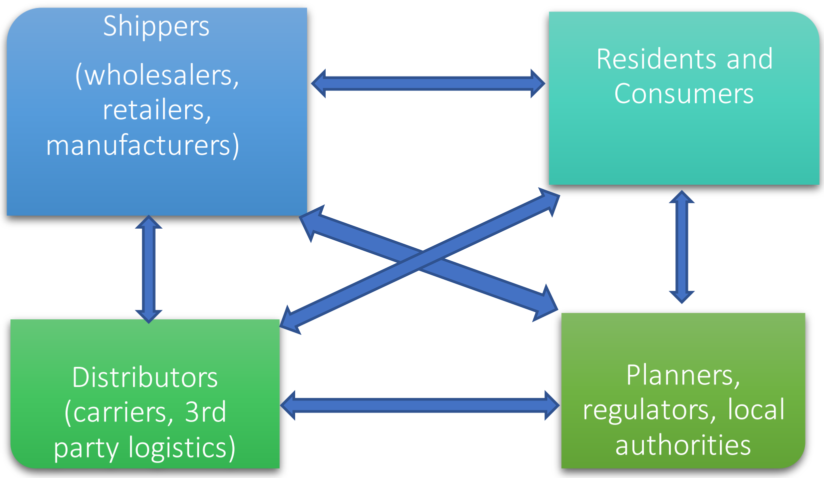
-*Inter-establishment movements (IEM)*, include freight distribution deliveries and pick-up trips, with regards to all economic activities of the urban area. This type of flow represents 40% of the total road occupancy issues of urban goods transport.

-*End-consumer movements (ECM)* include mostly purchasing trips by car like home deliveries, e-groceries and direct B2C services. This type represents 50% of the road occupancy rate and it is expected to increase and substitute IEM flows in the terminal part of supply chains.

-*Urban management movements (UMM)* are activities related to the development and maintenance of the city, including build and road network activities, waste collection, recycling management. This type of flows, along with other flows concerning household and enterprise itineraries represent about 10% of the total urban goods transport movement. According to Segalou (2004), urban transport including consumer movements produces 25% of the total CO2 emissions, 35% of the NOx emissions and 40-50% of the solid particles.

Policy makers, local authorities, municipalities, and private enterprises are seeking optimal solutions to enforce urban sustainability. Each stakeholder has different objectives and behave in a different manner in formulating urban freight distribution and that is the main challenge for transport planners. The interlinked relationships between stakeholders can be seen in the following figure:

Figure 22-Main stakeholders in urban freight distribution



The generation of freight demand is from the shippers to consumers, whereas freight carriers and transport planners establish the overall framework that carriers can operate within. A minor change in one part can affect the equilibrium and lead to responses that can cause other transport or land use problems. Within the complex structure of urban freight distribution, stakeholders are implementing the following policy instruments to promote sustainability:

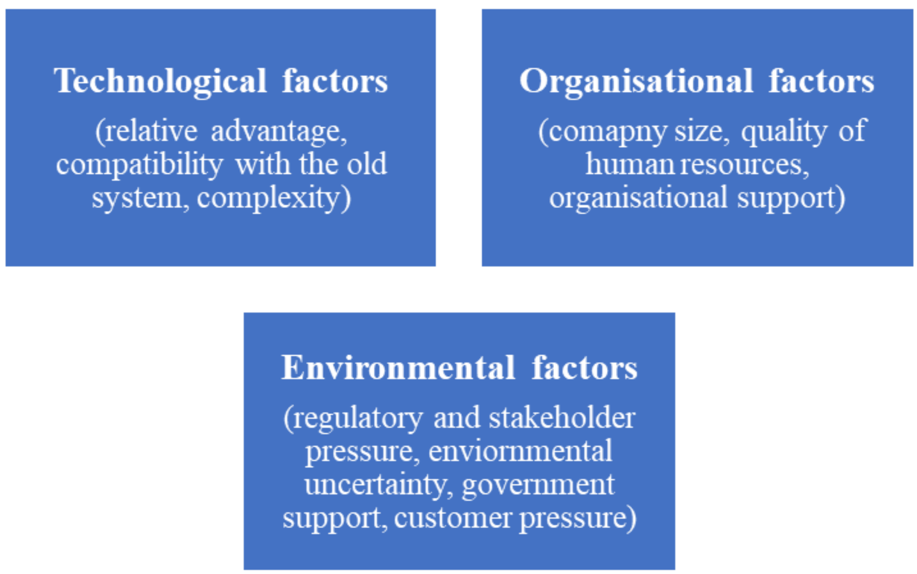
- The development of Urban Consolidation Centers to optimise freight flows, to reduce itineraries number of vehicles congestion and therefore emissions.
- The use of Access Restriction Schemes in general, and Low Emission Zones
- The implementation of Intelligent Transport Systems
- The use of alternative fuel technologies

These four pillars can be cost-effective for the logistics companies and have a positive impact both from an economic and environmental point of view. This study focuses on the fourth pillar, the inclusion of AFVs in urban freight distribution.

6.2 Factors determining green logistics

Many studies have proposed various explanations as to which factors can influence the adoption of practices that promote environmentally friendly solutions. The distinguishment between internal and external factors of these practices is a step forward on understanding a firm's decision pattern. The implementation of environmental regulations, the size of the company, the geographical location, the industry sector they represent, or the stakeholder pressure are some of the factors that can positively affect the adoption of sustainable solutions (González-Benito & González-Benito, 2006). On the other hand, factors like the lack of know-how, the lack of professional advice, the uncertainty related to a new organizational scheme, the lack of resources and the additional initial and maintenance cost, are negatively related to environmental behaviour (Chan, 2008). The following figure summarises the determinant characteristics of the adoption of sustainable practices in logistics companies from a study conducted in 353 Chinese companies (Lin & Ho, 2010):

Figure 23-Synopsis of determining factors of green practices elaborated by the researcher



Limited research has been conducted to analyse the complexity of the decision patterns of logistics firms with regards to the vehicle technology of their fleet. A vehicle fleet is owned by private companies, public companies, local businesses, or large corporations. Sometimes, the fleet plays a minor role in the organization, while sometimes is the core of the whole business (transport companies, taxis etc.). The diversity of vehicle fleets in terms of size, type of services, type of vehicles, purpose and composition, as well as the city characteristics within they operate, complicates more the way a decision is made (Berg, 1985); (Golob, Torous, Bradley, Brownstone, & Soltani Crane, 1997). The criteria of an alternative fuel fleet composition include not only operational costs, driving range, fuel costs and purchase price but also the sufficient number of alternative fuel station as well as the support from the government with subsidies. (Davis & Figliozzi, 2013); (Feng & Figliozzi, 2013); (Koetse & Hoen, 2014).

Public and private vehicle fleets which have already been targeted as an ideal initial market for AFVs from policy makers, are characterised by business inertia; they hesitate to adopt new technologies which often require high upfront investment and have not yet been proven widely in terms of cost efficiency, engine performance and safety (Yeh, 2007); (Helmreich & Lochner, 2012); (Ito, Takeuchi, & Managi, 2013). The intense use of vehicles in urban logistics sector requires high engine performance, low fuel costs and authorised service stations for the fleet maintenance. Therefore, logistics operators are high unlikely to accept lesser performance in return of a lesser environmental impact. The reluctance can be limited if satisfying engine performance is combined with lower fuel costs and affordable investments.

Vehicle fleets is a favourite target market for an alternative fuel regulatory policy because of the multiplying effects that could be achieved. The total environmental impact of the car fleet is more likely to decrease if conventional vehicles are replaced by AFVs by large consumer groups. The application of an alternative fuel in vehicle fleets could generate the initial critical mass of vehicles needed for the development of a refuelling network (Nesbitt & Sperling, 1998). The advantages of targeting fleet vehicles are summarised below:

- The accumulated fleet mileage of a commercial vehicle is twice as large than an average private vehicle. Therefore, the benefits of converting a fleet to alternative fuel are greater in terms of emissions and energy consumption.
- Transport volumes have been increased, reflecting the growth in last mile distributions due to the increased use of e-commerce which has risen the movements of smaller goods within the city centers. Light commercial fleets consume more fuel per ton-km compared to heavy duty vehicles (ICCT, 2017). Plus, high vehicle turnover enhances a fast penetration of alternative fuels in the market.
- The mandate regulatory framework of public utility fleets and government fleets is a helpful predisposition for the implementation of new business strategies. Within this context, it is more likely for the governments to adopt long term strategic actions taking into consideration the social and environmental impact (Golob, Torous, Bradley, Brownstone, & Soltani Crane, 1997). A public organization is expected to change the status quo and play a leadership innovation towards social well-being.
- Commercial fleet is an attractive market because a single decision maker is responsible for a significant number of vehicles. Targeting fleet owners to adopt alternative technologies, conduces to multiple benefits by reducing emissions, energy consumption, noise as well as operational costs for each firm. Especially, firms with a specific decision-making structure (e.g. high-low decentralization) share different needs and business strategies. Policy makers can achieve a successful agreement if special requirements are met based upon the company structure. (Nesbitt & Sperling, 2001)
- Finally, most commercial fleets are refueled at one location in order to serve fixed daily routes. The establishment of a private refuelling spot within the premises of an

organization facilitates the refuelling of the fleet in the first phases of the market, where the refuelling network is still under-developed.

6.3 Survey design and results

Part A

The idea of the present research is based on the primary results of a pilot survey taken place in Athens metropolitan area during the summer of 2012, on behalf of DEPA S.A., the National Provider of Natural Gas in Greece. The objective of the pilot survey was to understand the attitudes of urban logistics actors regarding the perspectives of CNG use in bi-fuel or dedicated engines, as well as to identify the actor groups with the higher potential. Furthermore, it was an opportunity to determine whether the marketing policy of the fuel company provider was efficient as well as to propose new policy actions and economic incentives to fulfil the needs of logistics operators.

The survey was based on a questionnaire including two types of data: operational data and behavioural data. The former set of questions was concentrated in fleet operating characteristics, namely, number of trucks, size, distances, frequencies, number of stops etc, organizational and operational data of the company, costs and previous operational experience, whether the participants had already converted a part of the fleet into bi-fuel engines. The latter set of questions draw information about the perceptions and attitudes of the potential users towards the perspectives of CNG use as a fuel and its performance advantages. Finally, the questionnaire ends up with the major motivations and constraints that influence the companies to proceed to the conversion or the purchase of natural gas vehicles.

The survey sample targeted comprises the majority of the actor types involved in the logistics sector in the Athens metropolitan area: freight forwarders and urban transport operators, shippers performing urban delivery operations by their own means, courier and companies with fleet of more than 10 light duty vehicles. The sample size corresponds to 169 companies.

Regarding the fleet sizes, the research identified two company sub-groups:

- Companies using between 15 and 40 light trucks
- Companies using between 120 and 360 light trucks

Furthermore, the research revealed a large variety of operational patterns, difficult to categorise into sub-groups. The companies of the sample operate urban freight operations:

- at distances between 25 and 120 km per day per vehicle
- with vehicles operating between 2 and 5 round trips per day
- including between 4 and 25 stops per vehicle per itinerary

The overall picture revealed form the survey shows a considerable traffic amount and, consequently, a significant potential to be explored for the future penetration of natural gas technologies in the urban freight sector, considering the respective operational benefits for the users on the one hand and the performance in terms of emissions on the other.

The aforementioned operational benefits were also communicated to the respondents during the survey. They were informed about the energy performance comparisons between CNG, LPG and gasoline. Similarly, they were informed about actual fuel prices in the Greek market: indicatively, CNG costs 1,115 € / kg (including VAT) while LPG costs 0,93 €/litre and gasoline costs 1,7 €/litre (average prices in Athens metropolitan area).

These figures were considered by the respondents in order to express their attitudes towards the potential use of natural gas. As regards to a preliminary estimation of the natural gas market potential, the survey results allowed to provide the following segmentation (with a response rate 45%):

- Companies that had already converted their vehicles into bi-fuel: 3%
- Potential users in the short term: 11% of the companies
- Potential users in the medium-term: 20% of the companies
- Companies not interested in short and medium term: 66%

Through personal interviews with several urban logistics operators, main motivations, incentives, and constraints were identified regarding the conversion to a bi-fuel vehicle or the purchase of a new AFV.

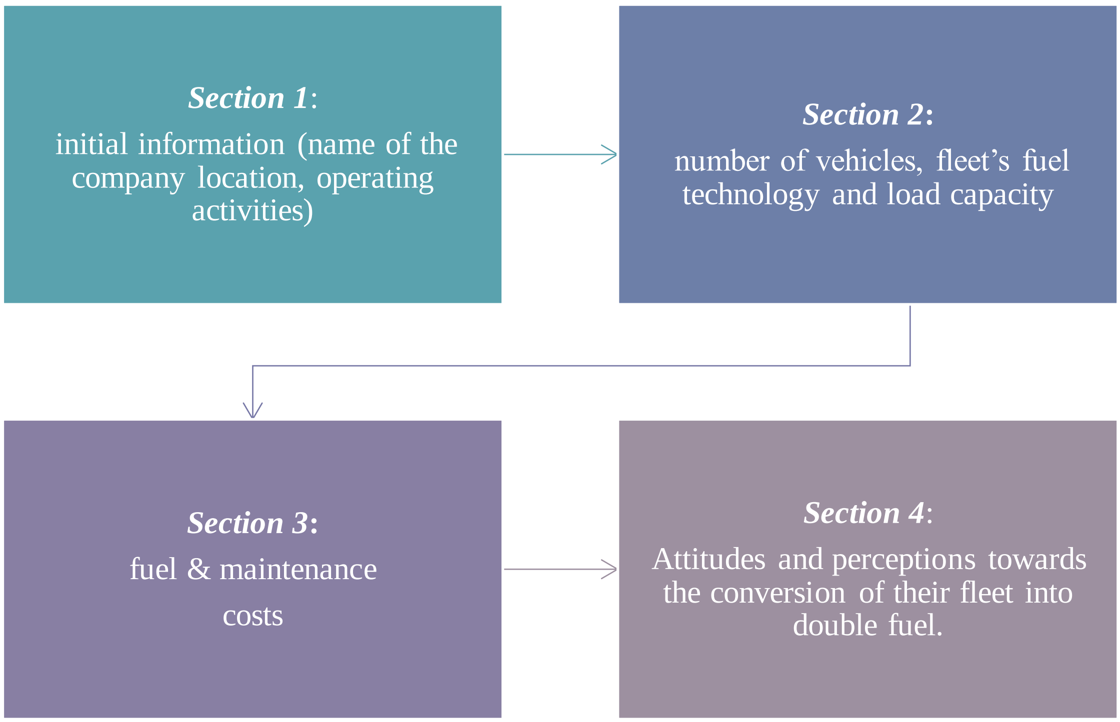
In 2012, CNG was still an unknown fuel with doubted economic efficiency. There were only 2 refuelling stations in Athens metropolitan area and no subsidies for purchase of an NGV or conversion to bi-fuel. During the interviews with the participants it was revealed that they would be willing to adopt natural gas technology because of fuel consumption savings and favourable traffic regulations. Regarding financial incentives, they were more likely to choose a subsidy for conversion of their fleet rather than take advantage of a purchase subsidy for a fleet renewal. The classification of the adoption criteria reflects a prudent decision-making process focusing on minimizing the risk of a potential investment.

Part B

This first pilot survey (Part A) formed the groundwork for a second stage (Part B) of an integrated survey. During 2015, the Public Gas Corporation of Greece introduced a subsidy conversion program for light commercial vehicles by authorised technicians, yet the target-market did not embrace this policy action and the participation rate was relatively small.

The questionnaire which aimed at capturing the perceptions of logistics companies operating in Athens, consists of the following sections:

Figure 24-City logistics questionnaire sections



The objective of the subsidy program and the prerequisites are described below:

- In 2015, for the promotion of natural gas, DEPA has collaborated with TUV Austria in order to overcome the boundaries of technical support and authorised repair shops for natural gas vehicles. TUV Austria Hellas undertook the training and certification program of the first independent repair shops for converted bi-fuel vehicles and dedicated NGVs in several cities of Greece in which there are already established natural gas filling stations. The training program was in accordance with the requirements of the Certifications and Audits Private Protocol which created in the context of the support of DEPA S.A. During the training program the participants were trained regarding the installation, the conservation and repair of CNG systems in vehicles, the building and electromechanical infrastructure, and the quality management system.
- After their certification, the authorised technicians practiced, under the supervision of TUV Austria stuff, on companies' fleets that agreed to participate in the Subsidy Conversion Program. In this way, companies were benefited by a free conversion by authorised

technicians and the technicians further developed their skills and had the opportunity of building their first client base of AFVs.

The results of the current survey reveal the importance of the organizational structure of the company during the decision-making process.

A pilot study was conducted during the subsidy program to capture logistics operators needs and perceptions and to enhance our understanding of fleet behaviour. Secondly, several effective policies regarding the conversion and purchase of natural gas vehicles were proposed to DEPA S.A. This study leads to a better understanding of the decision-making process of the fleet owners and classifies the main assumptions and intentions which are useful for developing successful policies. According to the results of the pilot survey and the personal interviews with fleet owners of the urban logistics sector, the inadequate refuelling infrastructure, the confusion of LPG and CNG characteristics and the ignorance of CNG benefits remain the most important obstacles for the successful adoption of natural gas. However, these obstacles reveal only one aspect of the story.

The sample of the survey consisted of 13 companies with a total number of 672 vehicles. More than 400 companies were approached with an email and through telephone meetings, a personal interview was finally arranged. Semi-structured interviews with the fleet owner (decision-maker) were conducted and several issues were brought up, giving insight on the perceptions of the participants regarding alternative fuels. In case of more than one decision makers, efforts were taken to include all those responsible on influencing the final decision. Some limitations of the study were: (1) the lack of an official company register, that excluded some types of fleets. (2) the limited ability to arrange a personal interview with the fleet owner as the person responsible for public relations did not convey the details of the subsidy program to upper level executives.

During the semi-structured interviews, the participants discussed upon the need for creation of business models towards a coherent low-carbon value chain and they expressed their major concerns about the energy transition period and the role of the dominant alternative fuels. The major points are described below:

1. The participants were informed on the Subsidy Program by a representative of National Gas Provider to create a climate of trust with the participants. According to the clauses of the contract for the participation on the Subsidy program, each participant agreed to provide a part or the whole of their fleet to specialised technicians, for three to four days for each vehicle, to proceed with the conversion. They were fully subsidised for the conversion of the vehicles agreed, with no extra or hidden costs. Although the opportunity was tempting, they hesitated and most of them agreed to provide only a part of their fleet to the conversion program.
2. Fleet operators also expressed concerns associated with the vehicle “downtime”, namely, when the vehicle is out of service due to scheduled or unscheduled repairs after the conversion. The interviews revealed much reluctancy regarding official repair shops for

bi-fuel vehicles and they requested for credentials that they would be fully compensated in case a converted vehicle indicates engine problem.

3. Most of the fleet owners were not aware that LPG and CNG are different fuels with different technical characteristics. They were influenced by the fact that many of their friends or colleagues had converted their private vehicles or their commercial fleet to a bi-fuel LGP-gasoline and they were not satisfied because of engine problems, low quality spare parts and frequent maintenance services. To overcome misconception, they were informed during the interview regarding the energy equivalence of CNG with the other fuels and the differences on engine systems.
4. They appeared skeptical regarding the timeline of the expansion of the refuelling network, but most importantly they doubted regarding the taxation on CNG. Many of the interviews' outcomes reflected the decision makers' personal taste and past experiences. The participants were strongly influenced by recommendations from colleagues and they tempted their own intuition or systematic analysis of the options available. Logistics operators tend to judge the new technology based on the characteristics of the dominant technology, diesel.
5. The structure of each company strongly affected the decision. Fleet managers were least interested in participating in the program or conveying the potentials of such a decision to a focus group. On the other hand, fleet owners were more interested in considering the participation to a subsidy program, if no additional cost occurred with the conversion or other restricted conditions.

Table 28-Descriptive Statistics-City Logistics Survey

Descriptive Statistics		
	Mean	Std. Deviation
I am interested in converting my vehicle into bi-fuel but there are no specialised technicians	3.92	2.139
I am interested in a conversion or a purchase subsidy	5.85	1.144
Compressed Natural Gas provides greater fuel efficiency than Liquified Petroleum Gas	5.15	1.345
There is a wide range of natural gas vehicles available in the market	3.00	1.225
I am interested in preferential treatment in circulation measures for NGVs	5.69	1.109

Compressed Natural Gas is safer than Liquified Petroleum Gas as a transport fuel	4.77	1.092
I am interested in emissions reduction generated by vehicles	6.15	1.214
Maintenance cost for NGVs are higher than LPG vehicles	4.00	.000
Conversion cost for a bi-fuel gasoline-CNG is higher than gasoline-LPG	4.58	.996
The price of CNG will be equal to conventional fuels in the next 5 years	2.92	1.256
I heard from colleagues that CNG does not provide any fuel economy	2.69	1.548

The overall perception towards CNG as a fuel, is positive. It can be easily identified that acknowledge that natural gas provides fuel economy, and that will be cheaper in the future without being significantly affected by taxation, but they are not aware about the technical characteristics of the fuel. There is a confusion on safety comparing to LPG, on conversion cost and whether there are authorised repair shops for bi-fuel vehicles. The only answer revealing their clear intention is the one that indicates their environmental awareness.

An answer that enhances a company's environmental image is crucial during the interview. However, the primary goal for a fleet owner/manager is to keep the every-day vehicle activities at minimum cost. This is quite contradictory, and it reveals a "politically correct" attitude towards environmental issues. Since they state that they are sensitive on emissions reduction on transport sector, one would expect that they are better-informed, tech-aware, and more positive on participating in a subsidy program for bi-fuel vehicles.

The formalisation of each company, namely the established rules and procedures, revealed different decision-making patterns. Ten out of thirteen companies were highly centralised companies. The fleet owners were easily approachable and were motivated by the opportunity of the subsidy program. This kind of companies had small fleets and the business owner made the final decisions. Although, fleet owners had many responsibilities unrelatable to fleet issues, once they were informed about the opportunity of a subsidy they behaved proactively. It is exactly because the decision is not encumbered with certain procedures, detailed evaluation, and formalities, that the final agreement came easily. Fleet owners of small/medium companies were very cost-sensitive and risk averse. However, they did not keep a record of annual operating costs to compare the advantages of a conversion regarding fuel economy. They were highly affected by past experiences and fellow business owners that already proceed to an LPG conversion. They expressed their interest on reducing emissions, but their final choice was affected by the operating cost reduction and the exploitation of the subsidy program.

Three out of thirteen companies followed a hierarchic decision-making structure. These three companies had the largest fleet of the sample. They follow highly formalised decision-making process, and the final choice was made by the president of the company. The interviews were made with the fleet manager and the details of the subsidy program were finally conveyed up to the president. As a fleet strategy, two of the companies decided to lease their fleet and the third company had already chosen to convert part of their fleet to LPG vehicles.

Depending on the organization structure, fleet manager responsibilities were assigned to different departments within the company. Therefore, a fleet manager may or may not have the final word regarding the participation in the program and the final decision is made by upper level executives. The answers of fleet managers are important but not strongly indicative of the general intention of a company towards alternative fuel technologies. Consequently, as the decision slides down hierarchically, fleet managers indicated less interest on exploiting the benefits of the subsidy program.

The urgency of the subsidy program evoked fast decisions. It was an opportunity decision, on a solely voluntary basis which will efficiently change a business system that is already satisfactory. Fleet managers had to decide to take advantage of a temporary subsidy program offered by the official provider. As the urgency rises, the decision process shortens. Since, an opportunity decision is more like a “crisis” situation, the participants put less effort on finding the optimal solution without analysing on a detail the alternatives. Because of the urgent nature of the decision and the accurate information they were provided, 10 out of 13 companies agreed to the conversion program that year.

In the section of True/False/Not Aware section, the results are described in the following table:

Table 29-True/False/Not aware questions

Questions	True	False	Not aware
CNG and LPG are different fuels	12	1	0
CNG is provided in kilos	8	3	2
1 kg of CNG is energetically equivalent with approximately 2 lt of LPG	2	2	9
1 kg of CNG is energetically equivalent with approximately 1,3 lt Diesel	3	0	10
CNG is approximately 60% cheaper than gasoline	11	1	1
Depreciation of initial conversion cost in 12-18 months	11	0	2

There are plenty of NGV models in the Greek market but no LPG models	8	1	4
NGV emit 25%-30% less CO_2 than Diesel vehicles	9	0	4

According to the table above, it can be concluded that the technology of alternative fuels is still a "terra incognita" for most of them. Engine performance and energy equivalence are the two most important issues that should be noted. Even though the sample size is not representative, the results can be capitalised because they are in accordance with the literature review findings as well as with the results of the national main survey on private vehicles which follows in the next chapters.

6.5 Conclusions and proposed measures

DEPA S.A in order to attract a new target group in a yet unformed market, followed a series of small steps to glean information on the intentions of the public, before finalizing an integrated strategy.

1. The first step included a pilot survey to receive first perceptions on natural gas. Companies were approached through company registers for a telephone interview. The sample-target were - fleet operators, urban logistics companies in Greece.
2. The second step included the launch of a subsidy conversion program, available for companies with light commercial vehicles. Unlike the traditional command government programs, the Subsidy program takes a voluntary approach to the development of natural gas market. The details of a parallel program including a progressive infrastructure expansion of refuelling points, were also communicated to the participants.

The private interviews reveal precious conclusions on the impact of the business strategy to final decision. Organizations with low formalisation on standard procedures may not act as leader in the alternative fuel adoption but they are highly influenced by the example of larger fellow companies. Therefore, they should not be ignored from policy makers because of the small size fleet. Owners of small-medium enterprises must make a leap of faith to gain a competitive advantage to operate in such competitive markets. Policy makers should focus on information campaigns for the advantages of natural gas regarding operational costs and incentives that facilitates the conversion or the purchase of an NGV.

On the other hand, organizations with high formalisation on procedures, is more likely to make reasoned choices based on the established strategy and thorough cost evaluations. They are interested on near term opportunities with promising long-term results regarding operational costs. They have the ability to force decisions regarding alternative fuels since that was the first time a subsidy program took place for AFVs and there are no existing procedures that fit in the business structure. The size of the fleet facilitates the conversion of part of the fleet without jeopardising the current business system. Even though, large fleet organizations appear to be the optimal candidate for leading the AFV market, the lack of communication between the respective departments and the ignorance of technical issues delayed the final choice. Policy makers should act proactively and focus on establishing a regulatory framework that facilitates the standardisation of the process and the implementation of the program. High centralised companies can be very responsive to incentives concerning purchase subsidies and refuelling spot within the company's premises. Information campaigns and interviews with the respective departments and authorised stuff from DEPA S.A will enhance the knowledge for alternative fuel technologies and will diminish the misconceptions regarding natural gas technology.

Despite the decision-making structure of each company, the timeline and the regularity of each promotion program plays an essential role in the responsiveness of the participants. Short-term but regular programs limit the long delays and no actions. A subsidy program should be considered as an opportunity that needs to be taken immediately. In the beginning the companies will face an unprecedent situation with no former guidelines. Because of the uniqueness of the situation, the conversion, or the purchase of NGVs will transform into an important "strategic" decision. The opportunity-seekers will take advantage of this opportunity and will lead the way. Consequently, the establishment of a good reputation of natural gas technology along with the expansion of the refuelling network, will attract the "follower" companies with smaller fleets.

Based on the results of this survey, it is safe to say that face-to-face interaction and personal meetings with major fleet owners and logistics companies (e.g. taxis, police cars, buses, courier fleets) had a faster and more efficient outcome instead of a media coverage. During a personal interview, messages and proposed incentives are more readily accepted especially when authorised representatives offer a long-term credible agreement. This agreement will be helpful if it included a strong collaboration with authorised repair shops in case of maintenance services as a part of the conversion process.

6.6 Policy suggestions for the promotion of alternative fuels in city logistics

The findings of this survey underscore the importance of the structure of the companies in the adoption of an alternative fuel. An integrated policy plan should take under consideration not only the improvement of technical characteristics and the expansion of the refuelling network, but also the dissemination of knowledge among the major stakeholders.

The following table summarises crucial findings by the interviews and suggestions to the mentioned barriers.

Table 30-Policy suggestions

Economic Incentives	
Barriers	**Proposed Measures**
Lack of information regarding existing and future financing schemes for investments in sustainability and infrastructure Companies, especially SMEs lack financial resources and do not invest in energy efficient technologies Regulatory schemes keep changing and companies as well as private car owners struggle with keeping up to date Greek government devote little resources to open call form EC that are open for a limited amount of time	Permanent financing incentives for low emission vehicles Retrofitting/conversion activities to reduce emissions below thresholds
Tax incentives	
Barriers	**Proposed Measures**
The tax calculation does not include in high accuracy the environmental performance of the engine Natural gas vehicles would not receive the same tax reduction as the electric ones	European guidelines on taxation of vehicles. Low emission vehicles should be favoured and if possible, be exempted from any charges, within a long-term policy plan. The real environmental performance of the vehicle should be calculated by considering Life Cycle Emissions.
Tolls	
Barriers	Proposed Measures
Vehicles running on conventional fuels pay the same amount of toll as the natural gas vehicles	Adoption of user pays, and polluter pays charging scheme
Training and qualification of drivers	
Barriers	Proposed Measures
Professional drivers are not aware of training procedures and certifications available	Amendment of the current regulation in a way to assure the early information of drivers and car technicians about the

Many conversion procedures have been realised by non-experienced technicians Drivers and fleet owners lack expertise in sustainable fleet management practices	differences in engine performance and operation needs. Early implementation of certification systems for car technicians. Education and training programs on sustainable fleet management for fleet managers, fleet owners as well as professional drivers.
Information	
Barriers	Proposed Measures
Fleet owners/managers are not paying attention on energy efficient options. They are not aware on financial incentives for the adoption of natural gas vehicles and the respective traffic circulation benefits. On top of that, highly polluting vehicles are not adequately labelled. Car dealers and sellers do not display information for highly polluting vehicles Most companies are not aware on the benefits of AFVs, or they consider it insignificant	Implementation of mandatory labelling system for different fuel consumption (e.g. l/100km and kg/100km) as well as CO2 emissions. Government announcements for future policy and financial incentives enabling the adoption or conversion of current fleets to AFVs. Launching campaigns of the benefits of AFVs in terms of emissions, air quality and health. Establishment of "sustainable practices" public award to motivate logistic companies to adopt AFVs.
Procurement processes	
Since purchase price of AFVs is still higher than conventional ones, companies fear that the reduction on operation costs will not counterpart the initial investment Public companies with fleets face bureaucratic issues that can be time consuming. For that reason, they prefer long-term leasing contracts with third parties	CO2 emissions per tonne km (or in case of taxis, school buses CO2 per passenger km) should be included as criteria in public tenders. The contract with third party operators should be valid for limited periods and include clauses regarding the energy performance of the fleet and the quality of the maintenance.

Chapter 7

Conclusions

This thesis was motivated by a number of factors including: 1) the role of Natural gas as a bridging technology in passenger cars and commercial fleets 2) the inconsistency of Member States in meeting the targets for reduction of externalities and promoting the use of alternative fuels 2) the role of Greece in the deployment of alternative fuel infrastructure on the TEN-T network facilitating the use of natural gas 3) the close collaboration with the National Gas Provider that inspired the researcher on proposing policy packages easy to implement. The main objective of this thesis was to investigate and quantify the effect of various factors that affect Greek drivers and logistics operators, in that way reflecting two sides of the market: freight and passenger transport. The final model was designed to be used as a tool from the policy makers to compare and evaluate different policy plans in order to foster the deployment of alternative fuel market.

The results of the models for each of the clusters identified indicate that Greek drivers perceive the various combinations of fuel/vehicle in different ways. Results indicate that purchase price, fuel cost and purchase subsidy are particularly important factors when choosing a fuel/vehicle combination. The density of the refuelling network is also a highly significant attribute, but according to the evaluation of the model, the increased number of stations is not enough for the wider acceptance of natural gas. It is important to note the role of habit when making a car/fuel choice: the model results indicate that drivers who own a gasoline or diesel vehicle are more likely to continue purchasing conventional ones, even if significant incentives for an NGV were in place or even if they were technically aware on the engine performance and the environmental benefits of natural gas vehicles.

The table below provides a synopsis of the characteristics of the participants of each cluster and the statistically significant variables for each fuel/vehicle choice.

Table 31-Overview of clusters and respective attributes

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Overall sample**
CNG perception	CNG supporters	CNG neutral	CNG neutral	CNG neutral	
Gender	55.6% male	100% male	100% male	100% female	
Use of car	66.9% use of car every day	Use of car every day	Sporadic use of car	Use of car every day 50.9%	
Awareness score	1st technical awareness	2nd technical awareness	3rd technical awareness	4th technical awareness	
CNG					

Purchase Price	•	•	•	•	•
Fuel cost/100km	•	•	•	•	•
Network density	•		•	•	•
Free Parking				•	
Technical awareness	•			•	•
Social circle	•	•	•		•
Toll exemption		•			•
Small vehicle		•			•
Car use					•
Diesel					
Purchase Price	•	•	•	•	•
Fuel cost/100km	•	•	•	•	•
Small vehicle			•		
Gender					•
Currently driving a diesel vehicle					•
Gasoline					
Purchase Price	•	•	•	•	•
Fuel Cost/100km		•	•		•
Small vehicle	•				
Currently driving a gasoline vehicle					•
LPG					
Purchase Price	•	•	•	•	•
Fuel cost/100km		•	•	•	•

The results of the model were translated into different policy packages with a combination of measures including the purchase price of the vehicle, the subsidy, the density of the network, the toll exemption and the fuel cost. It was evident that natural gas vehicles become competitive if they were supported by a combination of financial and policy measures.

The table below provides an overview of the packages that could achieve the greatest CNG share.

Figure 25-Overview of the policy packages with the greatest CNG share

Attributes included

Cost/100km	Purchase price	Subsidy	Network	Toll exemption	CNG share
Medium	25,000	5,000	Sufficient	yes	**71.86%**
Medium	25,000	4,000	Sufficient	yes	**68.28%**
Medium	25,000	5,000	Sufficient	no	**65.49%**
Medium	25,000	3,000	Sufficient	yes	**64.66%**
Medium	25,000	4,000	Sufficient	no	**61.53%**
Medium	25,000	2,000	Sufficient	yes	**60.46%**
Medium	25,000	3,000	Sufficient	no	**57.41%**

The results from the semi-structured interviews with logistics operators' perceptions verified our general assumption that professional drivers are unaware of the available natural gas technologies and often react suspiciously in an optional policy incentive. The feedback from the interviews showed the impact of the business organisation structure to the vehicle choice. Companies with low formalisation on standard procedures may not act as leader in the alternative fuel adoption but they are highly influenced by the example of larger fellow companies. On the contrary, companies with high formalisation on procedures, is more likely to make reasoned choices based on the established strategy and thorough cost evaluations. They are more interested in near term opportunities with promising long-term results regarding operational costs. Even though, large fleet organisations appear to be the optimal candidate for leading the AFV market, the lack of communication between the respective departments and the ignorance of technical issues delayed the final choice. Despite the decision-making structure of each company, the timeline and the regularity of each promotion program plays an essential role in the responsiveness of the participants.

The table below provides the main points from the interviews for each of the organisation type identified from the sample.

Table 32- Insights from the interviews

Low formalisation decision-making structure	**Hierarchic decision-making structure**
• Decision maker = Fleet owner • Easily approachable motivated by the opportunity of the subsidy program. • Small fleets (<10 vehicles) • Proactive behaviour • Decision making process not encumbered with certain procedures, detailed evaluation, and formalities • Cost-sensitive and risk averse • Affected by the operating cost reduction and the exploitation of the subsidy program • Final agreement came easily	• Decision maker = CEO of the company • Large fleet (>30 vehicles) • Interviews were made with the fleet manager and the details of the subsidy program were finally conveyed up to the president. • As the decision slides down hierarchically, fleet managers indicated less interest on exploiting the benefits of the subsidy program. • 2 of the companies decided to lease their fleet and the third company had already chosen LPG

The results from the literature review and the surveys conducted for this thesis show that the purchase of a cleaner vehicle is heavily affected by the policy implications and long-term strategies at a national and European level. Even though the ambitious plan of EC of pushing further down the level of emissions appears to be feasible and achievable there are still issues that remain unclear.

Targeting zero emissions in the long run is a must in each Member State's agenda. To achieve this there needs to be a portfolio of alternative fuel technologies that can satisfy two conditions: a fuel technology that can rapidly support the decarbonisation process while matching the needs of the market which requires affordability and accessibility.

In the next decade, electromobility will be further favoured and will gain a substantial share in the alternative fuel market. However, the absence of a well-established and functioning after life market for the batteries and the particular pollutant production process of the electric vehicles could lead to a vicious circle: tailpipe emissions will be limited, whereas emissions from the massive production of electric vehicles will be further increased. Electric vehicles have been labelled as the fastest solution towards sustainable mobility but it is not widely known that it needs approximately 70% more primary energy to make BEVs than conventional vehicles, mainly for the batteries and the electric engine system (EC, 2015). Furthermore, the scarcity of the rare raw materials may restrict the electric vehicle manufacture in the future.

On the other hand, the turning point for the future demand of gas will be determined by the level of market penetration of the different fuels like biogas, biomethane, hydrogen and synthetic methane, in buildings, in industry and in transport sector. The diffusion of these fuels will mostly depend on the respective energy supply availability, internal market competition and cost advantages of the fuel technologies. Transport sector, especially in North-West Europe, including private cars and light duty vehicles, will be decarbonised with the introduction of electric and fuel cell vehicles. However, the different decarbonisation options available from natural gas to hydrogen or biomethane will be crucial in the upcoming years for some Member States like Greece, but insignificant or even irrelevant for some others.

Greece has put into force specific plans for energy sector transformation energy. The transformation of the energy sector will provide sustainable outcomes for the environment, the economy and social welfare. After a long-term recession period, Greece could use the kick-off of economic recovery as an opportunity to pursue initiatives that support sustainability by increasing the share of renewables and natural gas in the energy mix. The backbone of this strategy should be the detailed National Energy and Climate plan for 2030 and beyond.

Future steps and research

Although several topics were addressed in this thesis, there are still important issues for future research. Firstly, a number of extensions could be considered regarding data collection. A bigger sample of logistics companies could provide significant insight on the decision-making process of this market segment. It is also proposed that the data collection should include GPS devices in order to better track the kilometres travelled in urban and suburban areas, the number and the location of stops, in order to estimate the relative operational costs as well as the fuel consumption and CO_2 emissions. This data could help us to identify the load of traffic generated by the urban freight sector, to optimise the routes according to the location of CNG refuelling stations and/or propose additional locations for future stations, in order to reduce the operational cost and mitigate the externalities. This data could also help policy makers to propose policy packages adjusted to the needs of this sector, which is responsible for traffic congestion and air pollution in densely populated areas.

For passenger transport, a number of extensions will be also useful to support the modelling framework developed in this thesis. First, a future methodological framework that include further characteristics of the available natural gas technology such as: the use of renewable natural gas, electricity and hydrogen technologies is also required. Future research should also investigate a number of policy and financial incentives such as: exemption of circulation fees for CNG vehicles, insurance premiums, lower presumptive value, provision of fuel card for the first year, leasing options for companies with fleets and grace periods for potential customers to familiarise with the natural gas technology. Furthermore, latent model class models could shed light to more layers of the decision-making process by zooming in the behavioural dynamics of an ecological behaviour. The relatively unexplored impact of social influence and the importance of collective-action behaviour could be useful model extensions pointing up how government policies and personal behaviours could affect climate change.

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APPENDIX A

Questionnaire: CITY LOGISTICS SURVEY

1st Part:

1.

Name of the company	
Address	
Type of company	

2. Fleet Ownership (Fill an X)

Leasing	
Private	

3. Number of vehicles

4. How many of these vehicles operate on:

Gasoline	
Diesel	
Gasoline-LPG	
Gasoline-CNG	

APPENDIX B

QUESTIONNAIRE: Greek Drivers Survey

The University of the Aegean, in collaboration with the Public Gas Provider (DEPA), is conducting a survey to capture the perceptions of Greek drivers about the use of gas as a transport fuel, to shape policies that will help its wider adoption.

Natural gas is a gaseous hydrocarbon mixture extracted from underground wells and is a different fuel than petroleum gas.

The questionnaire you fill out will take about 7 minutes to complete. The data are confidential and will be used only for the purpose of this survey. Your answers are valuable and without them there can be no results.

Click to continue!

Socioeconomic Characteristics

Gender

Male	
Female	

Age

Household Members

Level of education

Elementary School	
High School	
Private Technical College	
University	

Technical Educational Institute	
MSc PhD	
None	

Professional Status

Private employee	
Public employee	
Military	
Student	
Retired	
Household	
Farmer	
Free lancer	
Unemployed	

Private Annual Income

Residency Postal Code

Workplace Postal Code (Leave Blank if teleworking)

Driver's Profile

Number of vehicles in household

Do you use your car for everyday activities?

Yes	
No	

Characteristics of your current vehicle

Type of vehicle	
Type of fuel	
Year	
CC	
Fuel consumption	
Travelled km/month	
Fuel cost/month	

Number and type of itineraries

Professional trip	
Trip to work	
Entertainment	
Social obligations	
Household activities	
Education	
Military	
Other personal reasons	

Are you planning to purchase a new vehicle in the next:

1-3 years	
3-5 years	
5-7 years	
Just purchased one	
I am not planning on buying one	

What type of vehicle are you planning to purchase? (Skip if you are not planning on buying a new one)

Up to 1400cc	
Up to 1600cc	
Up to 2000cc	
Full size	
Sports	
Jeep-MPV	

Rate from 1 to 7 the following factors that you take under consideration when buying a new vehicle:

Purchase Price	

Engine Performance	
Level of emissions	
Purchase Subsidy	
Fuel Consumption	
Circulation fees	
Label	
Design	

What do you know about Natural gas?

Question	True	False
1 kg CNG is equivalent with 2lt of LPG		
CNG is 60% cheaper than gasoline		
In case of leakage, there is no risk because CNG is lighter than air and disperses in the atmosphere		
No worries for automatic ignition on NGVs		
NGVs emits 25% less CO2 than gasoline and 35% than diesel		
The conversion to a bi-fuel CNG-gasoline is a technologically easy process		
There are already authorized repair shops for vehicles conversion into bi-fuel in Greece		

On a scale of 1 to7 how much you agree with the following statements?

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I would convert if I could achieve 50% fuel economy							
I would convert if authenticated repair shops exist							

I would convert if subsidy conversion 500€							
I would convert if subsidy conversion 1000€							
I consider gasoline to CNG conversion safe							
I would convert if conversion cost less than 1000€							
Bi-fuel (CNG-gasoline) vehicles demonstrate engine problems							
I would convert if I had positive feedback from my social circle							
I would be interested in purchasing an NGV if subsidy 2000€							
I would be interested in purchasing an NGV if subsidy 3000€							
I would be interested in purchasing an NGV if purchase subsidy 1000€							
I would be interested in purchasing an NGV if price equals conventional vehicles							
I would be interested in purchasing an NGV if greater variety of models							
I would be interested in purchasing/converting if free parking							
I would be interested in purchasing/converting if toll exemption Athens-Thessaloniki road axis							
I would be interested in purchasing/converting if							

sufficient refuelling network							
I consider space reduction from conversion not important							
I believe that gasoline price will equal CNG in the next 5 years							
I consider CNG technology a trend that will fade							
I believe that CNG refuelling station will expand in the next 5 years							
I consider CNG benefits are not known to the public							
I consider that the classification of circulation fees based on CO2 emissions is a fair measure for environment							

On a scale of 1 to 7 how possible is to convert your car into bi-fuel (natural gas-gasoline)

Impossible (1)	(2)	(3)	(4)	(5)	(6)	Very possible (7)

How important is the diffusion of NGVs in the Greek market?

Not important at all (1)	(2)	(3)	(4)	(5)	(6)	Very important (7)

I consider the diffusion of natural gas as a transport fuel important, because:

It contributes to oil						

dependency decrease						
It provides significant fuel economy						
It contributes to CO2 reduction						
It contributes to decrease the level of nuisance						
They are safe vehicles						

Rate from 1 to 7 the following policy actions that could contribute to the promotion of natural gas in the Greek market.

Zero circulation fees for NGV	
Toll exemption for NGVs	
Subsidy for owners of fuel stations	
50% reduction car ownership presumption	
Free parking in public stations for CNG vehicles	
Training programs for car engineers	
Information campaigns for CNG benefits	

1. *Assume that the vehicle you are going to purchase is* ***a small city vehicle up to 1400 cc.*** *This model is available in the Greek market in all fuel technologies (CNG, LPG, gasoline and diesel). According to your criteria, choose the best option.*

Fuel type Attributes and incentives	CNG (available in kilos)	LPG	Gasoline	Diesel
Purchase Price	X€	X€	X€	X€
Fuel Price	X€	X €	X€	X€
Fuel Consumption	Xkg/100km	Xlt/100km	Xlt/100km	Xlt/100km
Purchase Subsidy	X€	-	-	-
Toll exemption	Yes	No	No	No
Free parking	Yes	No	No	No
Refuelling network availability	X out of 10 stations	Sufficient	Sufficient	Sufficient

On a scale of 1 to 7 how possible is to purchase the chosen vehicle?

Impossible (1)	(2)	(3)	(4)	(5)	(6)	Very possible (7)

2. *Assume that the vehicle you are going to purchase is* ***a medium vehicle up to 1600 cc.*** *This model is available in the Greek market in all fuel technologies (CNG, LPG, gasoline and diesel). According to your criteria, choose the best option.*

Fuel type Attributes and incentives	CNG (available in kilos)	LPG	Gasoline	Diesel
Purchase Price	X€	X€	X€	X€
Fuel Price	X€	X €	X€	X€
Fuel Consumption	Xkg/100km	Xt/100km	Xlt/100km	Xlt/100km
Purchase Subsidy	X€	-	-	-

Toll exemption	Yes	No	No	No
Free parking	Yes	No	No	No
Refuelling network availability	X out of 10 stations	Sufficient	Sufficient	Sufficient

On a scale of 1 to 7 how possible is to purchase the chosen vehicle?

Impossible (1)	(2)	(3)	(4)	(5)	(6)	Very possible (7)

3. *Assume that the vehicle you are going to purchase is an* ***SUV.*** *This model is available in the Greek market in all fuel technologies (CNG, LPG, gasoline and diesel). According to your criteria, choose the best option.*

Fuel type	CNG (available in kilos)	LPG	Gasoline	Diesel
Attributes and incentives				
Purchase Price	X€	X€	X€	X€
Fuel Price	X€	X €	X€	X€
Fuel Consumption	Xkg/100km	Xt/100km	Xlt/100km	Xlt/100km
Purchase Subsidy	X€	-	-	-
Toll exemption	Yes	No	No	No
Free parking	Yes	No	No	No
Refuelling network availability	X out of 10 stations	Sufficient	Sufficient	Sufficient

On a scale of 1 to 7 how possible is to purchase the chosen vehicle?

Impossible (1)	(2)	(3)	(4)	(5)	(6)	Very possible (7)