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Cost-Benefit Analysis of an Investment Project: a Hydrogen Fuel Cell Bus Project for the City of Athens, Greece

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ABSTRACT

The present Master Thesis aims to provide a Cost-Benefit Analysis of a project involving the integration of a small fleet of Hydrogen Fuel Cell Buses in a daily public transport operation in the capital of Greece, along with the development of the associated infrastructure. The study illustrates the potential that FC technology has in tackling the challenge of decarbonisation, a major challenge strongly connected with concerns surrounding national security, the economy and the environment. The project's coherence with the strategic direction of both the European and national transport policy is also demonstrated. The results of the study, contingent upon the assumptions made, suggest that the economic benefits stemming from the project are not currently adequate enough to outweigh the high initial costs. Nevertheless, the prospect of mass commercialisation along with the subsequent cost reduction implies that such a project could become economically profitable if chosen to be implemented at a later stage.

Keywords: Cost-Benefit Analysis, Hydrogen FC Technology, Fuel Cell Buses, European Union, FCH JU, decarbonization, public transport

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Dedication

This thesis is dedicated to my parents, Emmanouil and Maria Mitsotakis, who have always been tremendously supportive of all my endeavors, endlessly encouraging and inspiring me in my constant pursuit of knowledge.

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List of Abbreviations

BAU	Business-As-Usual
B/C	Benefit/Cost
bar	unit of pressure
c€	Euro cent
CAFE	Clean Air for Europe Program (2005)
CBA	Cost-Benefit Analysis
CHIC	Clean Hydrogen In European Cities
CH_4	Methane
CF	Conversion Factor
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRES	Centre for Renewable Energy Sources and Saving
dB (A)	decibel (A-weighted), a unit of sound pressure level
EC	European Commission
ECB	European Central Bank
ELSTAT	Hellenic Statistical Authority
ENPV	Economic Net Present Value
ERR	Economic Rate of Return
EU	European Union
EUR	Euro
FCB	Fuel Cell Electric Bus
FCEV	Fuel Cell Electric Vehicle
FCH	Fuel Cell Hydrogen
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
FDR	Financial Discount Rate
FNPV	Financial Net Present Value
FP	Framework Programme
FRR	Financial Rate of Return
GHG	Greenhouse Gases
GDP	Gross Domestic Product
H_2	Hydrogen
HC	Hydrocarbons
HEATCO	Developing Harmonised European Approaches for Transport Costing and Project Assessment, EU FP6 project (2004-2006)
HICP	Harmonised Index of Consumer Prices
HRS	Hydrogen Refuelling Station
IMPACT	Internalisation Measures and Policies for All external Cost of Transport, study on behalf of European Commission, (2007-2008)
IPA	Impact Pathway Approach
kW	Kilowatt, a unit of power
kWh	Kilowatt-hour, a unit of energy equivalent to one kilowatt (1 kW) of power sustained for one hour

Mtoe	Million tonnes of oil equivalent on a net calorific value basis
NO_2	Nitrogen Oxide
NOx	Oxides of Nitrogen (NO_2, NO)
NMVOC	Non-Methane Volatile Organic Compounds
OASA	Transport for Athens
OSY	Athens Bus & Trolley Transport Company
OEM	Original Equipment Manufacturer
O&M	Operation and Maintenance
PES	Primary Energy Source
PM	Particulate Matter
PPP	Public-Private Partnership
R&D	Research and Development
RES	Renewable Energy Source
SCF	Standard Conversion Factor
SMR	Steam Methane Reforming
SOCC	Social Opportunity Cost of Capital
SO_X	Sulphur Oxides
SO_2	Sulphur Dioxide
STASY	Athens Metro & Tram Transport Company
TCO	Total Cost of Ownership
TTW	Tank-To-Wheel
VAT	Value-Added Tax
vkm	vehicle per kilometre
VOC	Volatile Organic Compounds
WWT	Well-To-Tank
WTW	Well-to-Wheel

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Introduction

Energy forms an integral part of our everyday lives, lying at the core of virtually every human activity, from the simplest to the more complex: we rely on it in order to provide us with electricity and heat as well as to power our industries and vehicles. The driving force behind socioeconomic development and economic growth, uninterrupted energy supply is considered a given in all modern societies.

At the same time, the constant growth in the world's population in combination with economic growth and development has been inevitably leading to a significant increase in demand for energy. According to IEA's 2014 Key World Statistics, the world's total primary energy supply (TPES) in 2012 amounted to 13,371 Mtoe (million tonnes of oil equivalent on a net calorific value basis) having increased by 52.3% compared to its 1990 level. Final consumption stood at 8,978 Mtoe while its 1990 level was 6,287 Mtoe. The same report estimates that worldwide energy demand will range between 10,442 – 12,001 Mtoe in 2035.

The current, heavily dependent on fossil fuels, global energy system can in no way support this trend since the use of fossil fuels is associated with a series of challenges that will inevitably have to be dealt with:

Security

Fossil fuels, especially oil and gas, are found only in certain places on Earth. As a result, most countries have to rely heavily on net imports –often from politically unstable regions- in order to meet their energy needs. Depending on the production capacity of other countries, while having no control over prices or supply raises instantly the issue of energy security. A possible interruption to the supply of imported fuel, either deliberately or due to unexpected shocks can lead to severe economic and social implications, as the history has many times proven.

Sustainability

Fossil fuels are non-renewable energy sources; sometime in the future their supply will start to decline and they will eventually be depleted. According to projections, reserves are estimated to last for 50 years more. Consequently, an energy system based on fossil fuels cannot be considered sustainable.

Environmental

Combustion of fossil fuels produces noxious gases, such as carbon dioxide, nitrous oxide and sulfur dioxide, which have detrimental effects both to the environment and to human health. In 2012, CO_2 emissions from fuel combustion on a global basis reached the amount of 31,734.35 Mt, representing a 1.2% year-on-year increase. The 2015 United Nations Climate Change Conference held in Paris, reiterated once again the need for the elimination of anthropogenic GHG emissions and set a revised goal of limiting global warming to less than 2 degrees Celsius (°C) compared to pre-industrial levels. Hopefully, the Paris Agreement will lead to a binding, universal agreement on climate between its 196 participating members.

Despite the growth of non-fossil energy, such as nuclear, and the progress in promoting renewable forms of energy (namely hydroelectricity, biomass, wind, solar, tidal and geothermal energy) as a means of tackling the aforementioned challenges, the latter still account for only a small fraction of the present energy mix. In 2012, oil, natural gas and coal constituted almost 82% of the world's total final consumption, a share which has remained relatively unchanged over the past 41 years.

In an effort to address more drastically these ever-growing concerns, government as well as intergovernmental bodies around the world have been actively engaged in recent years in extensive research programmes in search of key technologies that could effectively substitute the consumption of fossil fuels.

Among the alternatives identified, hydrogen based technology has emerged as the most promising one. Hydrogen is the simplest, lightest and most abundant chemical element in the universe and, at the same time, exhibits the highest energy content per unit weight of all fuels. Not occurring naturally in its pure form, it has to be extracted using some kind of energy source, therefore constituting an energy carrier rather than a primary energy source (PES).

Still, the fact that it can be produced from any regionally prevalent PES makes it quite a flexible energy carrier: hydrogen production pathways range from fossil fuels to renewable ones and to chemical substances, such as water, while the generated hydrogen can be converted into any form of energy and deliver power for various end-use applications. Its role as a versatile energy carrier is especially valuable in integrating renewable electricity in the energy system. Hydrogen has the ability to store and transport the excess supply of renewable electricity, thereby closing the loop between energy supply and demand. The surplus of wind and solar power, for instance, which cannot be absorbed by the electric grid, can be split, via a process known as water electrolysis, into oxygen (O_2) and hydrogen (H_2). The latter can then be stored and used as needed, after being transformed into electricity.

In this context, fuel cell technology, which can transform hydrogen into electricity, is of paramount importance: fuel cells are electrochemical devices that combine hydrogen and oxygen in order to generate power leaving water and heat as their only by-product. Very appealing for transportation applications, in particular, HFC technology has garnered a lot of attention since:

1) Fuel cells have double the efficiency of internal combustion engines
2) It constitutes one of the most promising lower carbon energy options for transport as it can contribute to a significant reduction in CO_2 emissions, depending on how clean the energy source hydrogen originates from is; it can be a completely emissions-free technology in the case hydrogen comes from RES.
3) It provides an efficient solution to fossil fuel dependency in the field of transportation, which forms the largest energy consuming sector.

Europe, having recognized the multiple benefits hydrogen affords as well as its prospect of being our system's main energy carrier in the medium to long-term, is at the forefront of enacting policies and implementing initiatives aiming to promote, deploy and make HFC technology commercially viable.

Among the initiatives that will help it gradually move to a "hydrogen economy", as this transformation of the energy system is many times referred to, are those primarily undertaken in the public transport sector. A sector particularly conducive to the introduction of hydrogen, thanks to the fact that fuel demand for fleet vehicles, such as urban buses, is predictable and localized, public transit is set to become the precursor of the wider introduction of Fuel Cell Electric Vehicles (FCEVs).

In this framework, the current study proposes a Hydrogen FC Bus project for the city of Athens as part of a new wave of demonstration projects within the EU. More specifically, we will try to evaluate, using the Cost-Benefit Analysis Method, the introduction and operation of 5 Hydrogen Fuel Cell Buses, on a main route in the centre of Athens, along with the respective infrastructure for a period of 10 years.

The paper will follow the 6-step structure proposed by the European Commission's "Guide to Cost Benefit Analysis of Investment Projects":

Chapter 1 provides an overview of the socio-economic and legislative context in which the project is to be set as well as a description of the objectives that it is expected to achieve.

Chapter 2 contains a detailed presentation of the project's characteristics. After a brief review of the investment under consideration, all of the projects' technical parameters, such as the bus type, refuelling infrastructure and route, are defined.

Chapter 3 examines the current and future trends in demand for public transport services and also conducts an option analysis in order to compare the project against feasible, alternative scenarios, namely the "BAU" scenario and the "do-something else" scenario.

In chapter 4, the project's financial analysis is carried out. Based on the technical specifications presented in chapter 2, the project's initial investment costs as well as its operation costs are estimated in order to calculate the cash outflows. Having formed the project's cash flow tables and after discounting at an appropriate discount rate, the project's financial performance indicators (FNPV,FRR) are derived enabling us to determine whether or not the investment is profitable and should be undertaken.

Chapter 5 performs an economic analysis aiming to assess the project's impact on net economic welfare. Market prices are converted into accounting/shadow prices which properly reflect their social opportunity cost. Any externalities arising from the implementation of the project are accordingly taken into account. Costs and benefits are then discounted at a real social discount rate.

Chapter 6 concludes with a sensitivity analysis in order to assess the project's risk level. The fact that the content of the study is based on a range of sources including official agencies, market research as well as own estimates (in the absence of data), adds to uncertainty about the accuracy of the project's parameters and thus needs to be addressed through a proper scenario analysis as well as through the identification of critical variables.

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Chapter 1: Project Objectives and Context Analysis

1.1 Definition of Project Objectives

The project under evaluation refers to the launch of a fleet of 5 hydrogen powered buses on a central route of Athens and the establishment of the associated infrastructure for a period of 10 years. This project can be seen as part of the wider European effort towards the gradual transition to a low-carbon energy system. As such, it serves multiple objectives laid out in the EU's various Roadmaps and Strategic Frameworks that will be presented further below.

In particular, the project is based on fuel cell technology, a novel technology which currently constitutes the most promising zero emissions alternative in the transport sector; fuel cell buses have the potential of achieving the objective of greening public transportation without compromising the operational flexibility demonstrated by conventional diesel buses. More specifically, the FC bus deployment will directly contribute to reducing the external costs associated with the use of fossil fuels technology, namely by:

- improving air quality and reducing GHG emissions, considering that no harmful tailpipe emissions will be produced, and
- reducing noise levels as a result of the quiet operation of the electric drivetrain.

Therefore, the project will offer the chance to the general public to witness first-hand the benefits of this ground-breaking technology: the work environment for bus drivers will be largely improved as will the travelling experience for passengers. In addition, aside from the benefits stemming from the direct use of the buses, the project is intended to contribute to supporting the -still not mature- FC bus sector in moving towards the stage of commercialization: the more the FC buses deployed the sooner economies of scale will be achieved.

Despite the considerable direct benefits of the project as to a cleaner and quieter transport service, the mainly demonstrative nature of the project suggests that its main objective lies elsewhere: given that society inevitably moves towards a low carbon future, engaging early in such projects that encourage technological progress means that Greece will have the opportunity to prepare in time for future developments and to comply with the EU targets set on low-carbon mobility.

The project therefore aims to increase awareness, promotion and broader adoption of hydrogen buses, to contribute to the standardization of the hydrogen refuelling infrastructure and ultimately to form the beginning of a long-term strategy focused on the reduction of fossil fuel dependency and of its associated environmental impacts.

1.2 Description of the Context

Having defined the project's objectives we can proceed with the description of the social and economic context in which the project will be implemented as well as the institutional set-up and existing conditions of the transport infrastructure. This presentation is of utmost importance since it can verify whether or not the project is appropriate to the context in which it is proposed to take place.

1.2.1 The Socio-Economic Context

Deeply impacted by the 2008 global financial crisis, which a year later unveiled a creeping sovereign debt crisis, Greece was taken into uncharted waters. Unable to borrow from the markets, the country turned initially to the EU and to the International Monetary Fund (IMF) seeking a way to cover its financial needs. Since then, it has entered into bailout loan agreements with the European Commission (EC), the European Central Bank (ECB) and the International Monetary Fund (IMF), known as the "Economic Adjustment Programmes", being able to receive loans only on the condition that it implements a series of austerity measures.

In spite of the success that these measures had in bringing down the country's primary deficit, they pushed the economy down further into recession. The Greek GDP declined significantly, unemployment figures soared and Greeks lost a great part of their purchasing power. Following these events that hugely reshaped its national political landscape, Greece managed to maintain the Community acquis and currently struggles to make the necessary economic reforms that will enable it to eventually return to a path of growth. Innovative technologies, such as the one proposed by the project, can inarguably contribute towards this way. As we will explain further below, Greece can harvest the benefits offered by the Fuel Cells technology on multiple levels, such as on the environmental, economic and job creation levels.

With regard to specific macroeconomic figures, the country's 2014 nominal GDP stood at about EUR 177.5 billion, translating into EUR 16,200/capita while having lost a quarter of its value compared to 2009, the year which signaled the beginning of the debt crisis. In particular, Athens, the capital of Greece and the region where the project is proposed to take place, represents along with the wider prefecture of Attiki, about half of Greece's GDP (48.27% to be exact), as shown by Eurostat's most recent figures for 2013. A densely populated metropolis and the 4th most populous capital in the EU, it is inhabited by almost 4 million people, approximately one third (35.4%) of the total population according to the most recent census (2011).

Athens is also a highly car-dependent city. According to the EPOMM Modal Split Tool, the modal share in 2006 was 53% cars and 37% public transport (out of which 21% buses). In spite of the fact that the urban public transport has been considerably enhanced since then, cars continue to be the most preferred means of urban mobility. Data on motorization provided by the Hellenic Statistical Authority (ELSTAT) show that in 2014 Attiki, the prefecture to which Athens belongs, had 2,766,696 passenger cars in circulation out of a nationwide total of 5,110,873 (54,13%).

With such a high urbanization rate and the country's major part of economic activity taking place in the capital, the energy consumed and therefore the carbon footprint induced, especially from transport activities, is rather significant. The graph below provides a picture of Greece's energy consumption profile. Evidently, as is the case for most countries, the transport sector accounts for the lion's share of the total energy consumption in Greece.

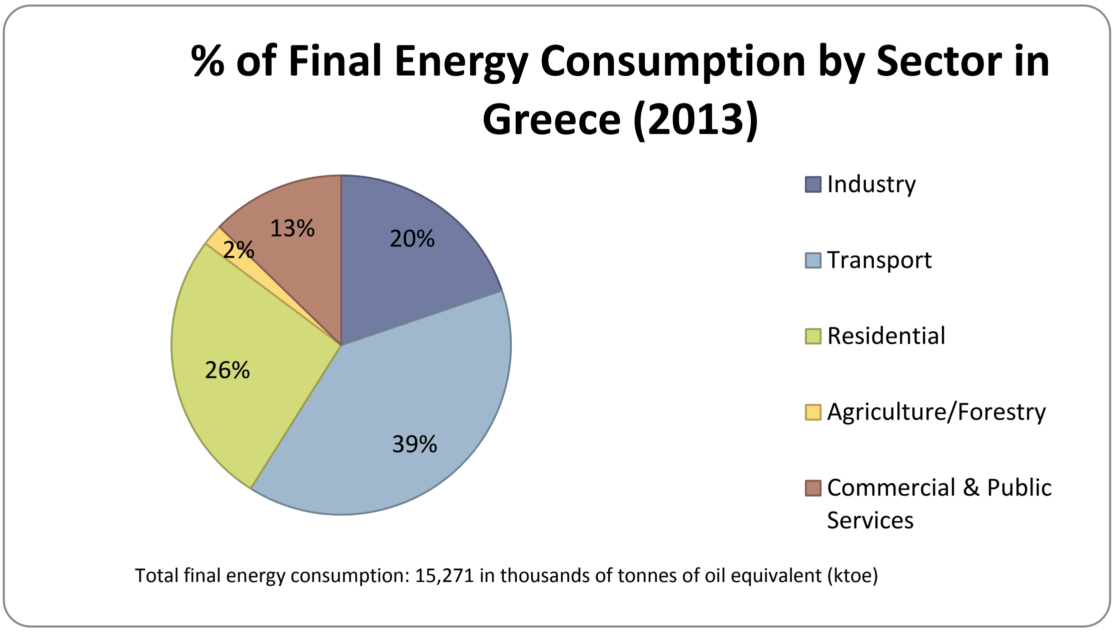

Figure 1 Final Energy Consumption by Sector for 2013, in ktoe on a net calorific value basis
Source: International Energy Agency (IEA)

Regarding the impact energy consumption has on the environment, the EU's 2014 Statistical Pocketbook reveals that Greece's CO_2 Emissions from transport in 2012 amounted to 25.6 million tonnes accounting for 25.6% of the total CO_2 emissions. The road transport sector in particular, was responsible for about half of the emissions (53%) attributed to the transport sector as a whole. Despite the fact that, following a steady increase between 2000-2010, GHG emissions induced from transport activities have started to decline, due partially to the economic crisis and partially to policies already in place, it has been made clear that further work needs to be done in order for the country to be able to meet the CO_2 reduction targets set by the EU.

1.2.2 The Institutional Set-Up of the Athens Public Transport System

Originally at the hands of the private sector, the mass provision of public transport services in Athens evolved through several stages during the last century, starting to take its current form in 1993, when the Athens Area Urban Transport Organisation (OASA S.A.) was founded as a Legal Entity of Private Law. The 2669/98 Public Transport Act set the legal framework for public transport operation by assigning to OASA S.A., which is totally owned by the Greek State, the responsibility for the planning, co-ordination, control and provision of the transport work of all public transport modes in the greater Athens area.

With a jurisdiction currently extending to 52 1st Degree Local Government units/municipalities, the Athens Transport Authority operates, under the supervision and control of the Ministry of Transport and Communications, an extensive bus and trolley network as well as metro and tram services through its two wholly owned subsidiaries, Odikes Sygkoinonies S.A. (OSY) and Statheres Sygkoinonies S.A. (STASY). The former, OSY S.A., which resulted from the merging of ETHEL S.A. (thermal buses) and ILPAP S.A. (trolley buses), aims at the operation and exploitation of the transport services provided by thermal and trolley buses in the metropolitan area of Athens. The latter, STASY SA, which resulted from the merging of AMEL S.A. (Metro lines 2 &3), ISAP S.A. (Metro line 1) and TRAM S.A., aims at the operation and exploitation of the transport services provided by the metro, electric railways and tram in the same area. The organisation's main sources of financing include ticket revenue, government subsidies and advertising.

With regard to specific operational figures, OASA's 2014 Annual Report, published in June 2015, shows that Transport for Athens operated:

- 2,052 buses in 255 Routes covering a network of 5,700 km
- 356 trolleys (electric buses) in 19 Routes covering 352 km
- 3 metro lines covering 82.8 km
- 3 tram lines covering 23.7 km

Total passenger journeys amounted to 651,095,190. Road transportation accounted for the majority of journeys with 46.8% of them having been made by thermal buses and roughly 10% by trolleys. The total annual mileage covered by all modes of public transport totalled 145,840,400 km, out of which 64% was attributed to thermal buses and trolleys.

OASA has a workforce of 7,949 people out of which 68.4% are employed in its bus services division. Since 2010, the staff has been significantly reduced by an overall of 2,912 people with OSY-employed personnel having undergone the largest part of cuts (2,066 employees).

With regard to financial results, OSY SA's and STASY SA's sales revenues amounted to EUR 117 million and EUR 129.7 million respectively. OSY's operating expenses reached EUR 237.5 million while those of STASY totalled EUR 135.6 million, thereby resulting to an operating loss for both companies. Nevertheless, having reduced its operational costs significantly during the last years, OASA's companies managed to increase their cost-recovery ratio from 42% in 2010, to 60% in 2012 and to 73% in 2014.

Finally, regarding future developments, OASA's Annual Report for 2014 explicitly proposes "the renewal of the bus and trolleybus fleets, as well as evaluation of new technologies, new types of vehicles and alternative fuels", among the priority actions that it will enable it to fulfill its vision of "making the Athens Public Transport the preferred means of travel in the wider area of Athens, by ensuring financial sustainability, by further improving the services provided to passengers and by reducing the transport sector's environmental footprint, thereby contributing to the economic, social and environmental development of the capital."

1.3 Consistency with EU and National Frameworks

1.3.1 The EU Framework

Prior to examining the legislative framework pertaining specifically to the project under consideration, we will make a reference to the overarching objective underlying EU policies in order to understand the drivers and challenges that shape EU transport policies and measures.

At the core of every EU policy lies the concept of sustainable development which is largely defined as "the development that meets the needs of present generations without compromising the ability of future generations to meet their own needs". This concept regards social, economic and environmental issues as inseparable and interdependent components of human progress and consequently views the environmental pillar of EU policies equal to the economic and social ones.

Sustainable development became a fundamental objective of the EU with its inclusion in the Treaty of Amsterdam in 1997. Later, in June 2001, the European Commission presented to the Gothenburg European Council the first EU Sustainable Development Strategy "A Sustainable

Europe for a Better World: A European Union Strategy for Sustainable Development''. The strategy set overall objectives and concrete actions for seven key priority challenges among which there were those of "climate change and clean energy" and "sustainable transport".

Sustainable development is, therefore, closely attached to the goal of decarbonisation of the energy and transport sectors which has been put forward by the EU in an effort to tackle the major issues of climate change and air pollution, dependence on foreign fossil fuels and competitiveness of the European economy. Driven by this philosophy, the Union has made significant steps towards adopting strategies and implementing policies that will help it attain its objectives.

The current framework steering the EU's climate and energy policies, which integrates the abovementioned objectives was agreed in the end of 2008 and sets the following three headline targets to be achieved by 2020:

- a 20% GHG emission reductions compared to 1990 emission levels;
- a 20% share for renewable energy sources in the energy consumed in the EU with specific targets for the Member States;
- 20% savings in primary energy consumption compared to projections made in 2007, through energy efficiency improvements.

In addition, specific 2020 sub-targets have been set for the transport sector, namely a 10% share of renewable sources in the final energy consumption in transport and a 6% decarbonisation of transport fuels.

At the same time, the European Commission, having acknowledged the need for a longer term perspective, issued in 2011 the following three Roadmaps, in line with the EU objective of reducing GHG emissions by 80% to 95% by 2050 compared to 1990 levels:

1) A Roadmap for moving to a competitive low carbon economy in 2050

This Roadmap, which was intended to provide the basis for the development of sector specific policy initiatives and Roadmaps, such as the 2050 Energy Roadmap and the White Paper on Transport described below, presented a detailed analysis of cost-effective ways which could enable the EU to deliver greenhouse gas reductions in line with the 80% to 95% target agreed in the context of necessary reductions according to the Intergovernmental Panel on Climate Change by developed countries as a group. More specifically, the Roadmap indicated that in order to reach this target, a cost effective and gradual transition would require a 40% domestic reduction of greenhouse gas emissions compared to 1990 as a milestone for 2030, and 80% for 2050.

2) The Energy Roadmap 2050

The Commission's Energy Roadmap 2050 recognized the imperative need for a transformation of the European energy system for environmental, security and competitiveness reasons and explored the different pathways under which this could be achieved. Concluding that decarbonisation was both technically and economically feasible, the Roadmap highlighted, among other things, the importance of a shift towards alternative fuels and the need for European level support in terms of "regulatory developments, standardisation, infrastructure policy and further research and demonstration efforts particularly on batteries, fuel cells and hydrogen." It also underlined the role of public and private investments in R&D and of technological innovation in accelerating the development of low-carbon solutions.

3) Transport White Paper "Roadmap to a Single European Transport Area – Towards a competitive and resource-efficient transport system"

With road transportation in Europe emitting 843.2 million tonnes of CO_2 equivalent per year (71.9 % of all GHG emissions from transport according to the 2012 Statistical pocketbook), the transport sector is undoubtedly set to play a key role in Europe's long-term decarbonisation efforts. To this end, the European Commission, building on the 2009 Action Plan on Urban Mobility (COM (2009) 490) and the 2050 Energy Roadmap, published the 2011 White Paper on Transport Policy which established an ambitious goal to reduce GHG emissions from the transport sector by at least 60% by 2050 compared to emissions in 1990 and by around 20% by 2030 with respect to 2008. Moreover, through the development and deployment of new and sustainable fuels and propulsion systems, it set goals to halve the use of 'conventionally-fuelled' cars in urban areas by 2030, while gradually phasing them out by 2050, and achieve essentially CO_2-free city logistics in major urban centres by 2030.

In the light of recent developments on EU and global energy markets and of the difficulty in mobilizing funds for long-term investments due to the on-going economic crisis, but with a view to the longer term climate change objectives set in the aforementioned Roadmaps, the EU moved on setting intermediate targets. In 2013, the European Commission issued a Green Paper on a new 2030 Framework for climate and energy that would include EU-wide targets and policy objectives for the period between 2020 and 2030.

The targets on which EU countries agreed comprise of:

- a 40% cut in greenhouse gas emissions compared to 1990 levels
- at least a 27% share of renewable energy consumption
- at least 27% energy savings compared with the business-as-usual scenario

The policies proposed to meet these targets include, inter alia, a reformed EU emissions trading scheme (ETS), diversification of supply, and interconnection capacity between EU countries, as well as plans aiming to ensure stronger investor certainty, greater transparency, enhanced policy coherence and improved coordination across the EU.

It should be noted here that while setting up coherent policies in order to fulfill its aspiring objectives, the EU promotes an equitable distribution of the efforts required to meet the overall targets, recognizing the diversity among its Member States in terms of economic wealth, social and industrial structure, energy mix and intensity.

The fundamental objectives laid out in the aforementioned strategy frameworks are accomplished through the implementation of several legislative instruments. Prominent legislative measures regarding the use in the transport sector of hydrogen technology in particular include:

1) Regulation (EC) No 79/2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC

This Regulation established the requirements for the type-approval of motor vehicles with regard to hydrogen propulsion, of hydrogen components and hydrogen systems as well as the requirements for the installation of such components and systems. The harmonization of technical requirements concerning motor vehicles using hydrogen was deemed necessary in order "to avoid the adoption of different requirements in different Member States and to ensure the proper functioning of the internal market while, at the same time, ensuring a high level of environmental protection and public safety".

2) Directive 2014/94/EU on the deployment of alternative fuels infrastructure

The European Parliament and the Council of Europe, having taken into consideration the Commission's 2011 White Paper on Transport, which called for a reduction in the dependence of transport on oil and mitigation of transport's environmental impact, as well as the 2013 "Clean Power for Transport: A European alternative fuels strategy" EC Communication, which identified electricity, hydrogen, biofuels, natural gas, and liquefied petroleum gas (LPG) as the principal alternative fuels with a potential for long-term oil substitution, established a common framework of measures for the deployment of alternative fuels infrastructure in the Union.

The Directive "sets out minimum requirements for the development of alternative fuels infrastructure, including recharging points for electric vehicles and refuelling points for natural gas (LNG and CNG) and hydrogen, as well as common technical specifications for such recharging and refuelling points, and user information requirements." Furthermore, "Each Member State shall adopt a national policy framework outlining its national targets and objectives, and supporting actions for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure."

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

Undoubtedly, the ambitious commitment to reduce greenhouse gas emissions in line with the 2050 Roadmaps requires a combination of instruments, both regulatory and financial. According to European Commission estimates**,** the development of low-carbon energy and transport systems will require on average public and private investments amounting to around EUR 270 billion annually over the coming 40 years. The EU has proved, beyond any doubt, that it has been, and still remains, actively engaged in providing this much needed financial support, particularly through Cohesion Policy and the various EU Research Programmes, with the aim of accelerating innovation, bridging the gap between research and the market and scaling up the technologies that are destined to be the backbone of our energy system by 2030 and 2050.

The most prominent example of such an initiative is the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The EU, realizing that hydrogen and FC technologies offer the untapped potential for the aforementioned transition to a carbon-clean energy system and at the same time acknowledging the fact that their market penetration would be a lengthy process that would require "research, development and deployment strategies in which all participants would have to be committed to common objectives", launched originally, under the 6th Framework Programme for Research (FP6), the "European Hydrogen and Fuel Cell Technology Platform".

This platform provided the context where representatives of industry, scientific community, public authorities, technology users and civil society could closely interact and jointly define research programmes in the field of this emerging technology.

The EU's commitment to support research of long duration on hydrogen and fuel cells was reconfirmed with the establishment by a Council Regulation of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) on May 30, 2008, under the European Strategic Energy Technology Plan (SET-Plan), the technology pillar of the EU's energy and climate policy. The FCH JU was set up as the first European public-private partnership with the scope of supporting the research, development and demonstration of various hydrogen FC projects towards their commercial introduction through annual and competitive calls for proposals aiming ultimately to accelerate the development and deployment of fuel cell and hydrogen technologies.

The FCH JU is comprised of three members:

1) the European Commission
2) the NEW Industry Grouping, which represents fuel cell and hydrogen industries and
3) the Research Grouping N.ERGHY, which represents the interests of European universities and research institutes

This coalition of industrial companies, research organizations and public authorities provided by the FCH JU offers some significant advantages:

- First and foremost, the scale and complexity of the research needed in order to develop and deploy FCH technologies make the undertaking prohibitive for single firms or public research institutions. A joint approach is a prerequisite at this early stage of development in order to overcome the various technical and non-technical barriers and create the conditions that will allow the emergence of a competitive market.

- Secondly, private funds are matched with public funds. Investment projects are partly financed by the EU and partly by the private sector with private investments being leveraged at least at the same amount as the EU funding. This mechanism, which functions through a reliable platform, provides the industry, which is more risk averse than governments, with the right incentives and confidence to commit more of its own resources while it benefits, at the same time, in terms of competitiveness and the creation of high-skilled jobs.

- Thirdly, concentrated effort, targeted at better matching the industry's needs and expectations, leads to cost reduction and acceleration of processes to the point of market introduction. Activities integrated under a common management facilitate budgeting and the setting of timelines.

In its first stage of operation, between 2008-2013, the partnership had engaged in 155 projects where 1,266 participants, 545 beneficiaries and 22 EU Member States were represented and where investments of close to EUR 1 billion were made (EUR 940 million to be exact). Since 2010, the FCH JU has supported Fuel Cell Bus Demonstration Projects with a funding of EUR 61 million out of a total budget amounting to EUR 172 million.

With regard to the extension of the FCH JU, the Council of the European Union formally agreed, on the 6th of May 2014, to continue this initiative under the EU Horizon 2020 Framework. The activities covered by the FCH 2 JU, which is set up to run through the end of 2024, will be allotted a total budget of EUR 1.3 billion for the period between 2014-2020, 40% higher than the first one. As in the previous phase, contributions of up to EUR 665 million each are expected to be made by both the EU and the private sector.

This second phase of the Initiative aims to bring Europe one step closer to the commercialization of hydrogen and FC applications by demonstrating through projects of a larger scale the readiness of the technology to enter the market. The FCH JU's vision for the bus sector in specific is depicted in the following figure:

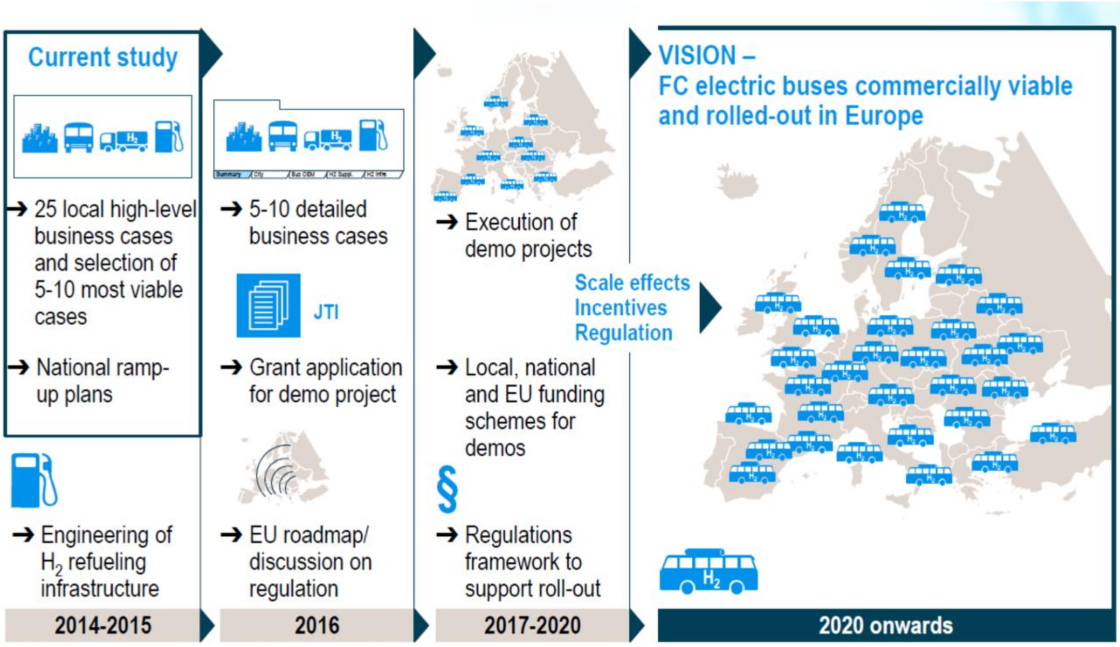

Figure 2 Commercialisation Path of Fuel Cell Buses
Source: Berger, R. (2015) "Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe", report funded by the FCH JU

Current FC JU projects are presented below:

Project	No of FC buses	Participating Cities
CHIC*	26	Aargau, Berlin, Bolzano, London, Milan, Oslo
HIGH V.LO-CITY**	14	Aberdeen, Antwerp, San Remo
HYTRANSIT**	6	Aberdeen
3EMOTION**	21	Cherbourg, Flanders, London, Rome, Rotterdam
*In operation **Planned for operation		

Table 1 Current EU-funded Fuel Cell Bus projects
Source: Nicolas Brahy "Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe", FCH JU, (Lyons, April 2015)

1.3.2 The National Framework

The 2007-2013 Greek National Strategic Reference Framework (NSFR) in its Operational Programme (OP) for the Improvement of Accessibility set five general objectives to face the challenge of air pollution and congestion due to the increased motorised traffic. One of them, compatible with the Priority axis 11: "Clean Urban Transport - Transport Means" was "the development of an urban infrastructure and an urban transport system in major urban centres, with emphasis on reduction of travel time and pollutants in order to support sustainable mobility".

In addition, the 2010 - 2014 Mobility Management Plan for the City of Athens defined its overall goal as “to support “green mobility” in Athens and to reduce pollutants and greenhouse gas emissions”.

The “Strategic Plan for Athens: Attica 2021”, issued in 2011 has also set the reinforcement of sustainable mobility as a basic Priority Axis for transport policy.

The above goals were reconfirmed in the 2014 -2020 NSFR which set the transition to a low-carbon economy as a key funding priority.

On a legislative level, it should be noted that Greece was one of the first countries to actively support the spread of hybrid technology through tax incentives adopted in as early as 1992.

More specifically, according to Law 2052/92 – FEK A 94 of 5 June 1992, Article 2,
Par 9a : “Electric or hybrid engine cars, whose emissions are in accordance with the applicable provisions for vehicles pollutant technology, are not subject to excise tax rate, added special duty and registration fees.”
Par 9b: “By joint decision of the Presidency of Ministers of the Government, Environment, Planning and Public Works and Transport and Communications may require the use of vehicles in the previous paragraph in the wider public sector or in organizations and enterprises controlled by the State.”

However, electric mobility did not meet the expected market uptake. Instead, more emphasis was given to the deployment of natural gas in the transport sector as an alternative option to diesel. Legislation surrounding natural gas matters progressed relatively fast while legislative procedures regarding the use of other alternative fuels fell somewhat behind. A first step was taken with Law 3423/2005 (Government Gazette 13/09/2005), which transposed the EU Directive 2003/30 on the “Introduction of Biofuels and Other Renewable Fuels on the Greek Market”. Still, no explicit provision for the use of hydrogen as a transport fuel was included in this Act.

Due to perplexed bureaucratic procedures, Greece lacked for a long time a legislative framework regarding the provision and use of alternative fuels such as hydrogen. Steps towards this direction were taken fairly recently. The basic regulations for alternative fuel stations in Greece were first set out with Law 4070/2012 and later with Law 4233/2014.

The latter, proposed by the Ministry of Transport and Networks and entitled "Hellenic Slot Coordination Authority and other provisions", was passed on January 15, 2014. According to the provisions of one of its articles (Article 15), which replaced Par. 7 of Article 114 of Law 4070/2012 (A 82), public-use electric car charging stations and hydrogen fuelling stations can be installed at conventional/existing refuelling stations, at indoor and outdoor parking lots, at car and motorcycle workshops as well as at MOT test stations.

The excerpt of the Act referring to this amendment is given below:
According to the provisions of the Greek Law 4233/2014 (article 15), replaces par 7 (article 114) of the Law 4070/2012 (A' 82) as follows:

“7. The term "Fuel and Energy Supply Stations" includes pure or mixed liquid fuel, liquid gas (LPG) and / or compressed natural gas (CNG) stations, in any combination thereof. These stations can provide passing vehicles, in addition to the aforementioned fuels, with (pure) biofuel (such as bioethanol and biodiesel), electricity and hydrogen, as well as with other types of alternative fuel. By decision of the Ministers of Infrastructure, Transport and Networks on the one hand and

Environment, Energy and Climate Change on the other, which is to be issued within six (6) months from the effective date of this, the terms, conditions and technical specifications are determined regarding:

a) the installation of charging devices for electric vehicles at existing or under licensing " Fuel and Energy Supply Stations ", at existing or under licensing indoor and outdoor parking lots under the provisions of the Presidential Decree 455/1976, as amended, at existing or under licensing maintenance and repair shops for cars, motorcycles and scooters, under the provisions of the PD 78/1988, as amended, at existing or under licensing public or private MOT test stations.
b) the establishment of facilities for the provision of alternative types of fuel, such as biofuels and hydrogen, at existing or under licensing " Fuel and Energy Supply Stations ".

The joint ministerial decision, providing the details on the alternative fuel infrastructure, has yet to be made but is expected upon the completion of the process of the results of the public consultation.

The abovementioned legislative initiatives have managed to address certain compelling issues on a national level such as the:

1) Encouragement towards the wider use of non-polluting, alternatively-fuelled vehicles.
2) Renovation and modernization of existing refuelling stations in order to cater for the drivers' needs for green energy as well as for fuels other than the conventional ones.
3) Liberalization of the profession of the fuel gas fitter.

The Greek Hydrogen & Fuel Cells Technology Platform

Despite the adverse economic conditions the country is struggling to cope with in recent years, considerable effort has been made by both Greek governments and various research institutions in order to keep up with international developments in the FCH sector.

In 2006, following two meetings with the then Ministry of Development on the subject of "Directions of National Strategic Research & Development of Hydrogen Technologies", the Greek Hydrogen Platform was created. The Secretariat of the Greek Hydrogen Platform was assigned to the Centre for Renewable Energy Sources (CRES) and the Greek Hydrogen Company (EL.ET.Y). The Platform's aim is to contribute to the promotion of the hydrogen economy as a means of sustainable development for the country.

The Greek Hydrogen Platform's scope of activities included:

- The creation of a strategic Roadmap for the development and use of HFC technologies in Greece with a horizon up to 2050 and 2100.
- A detailed definition of the R&D projects that should be implemented at national level in order to support the implementation of the Roadmap.
- Ensuring the State's support in R&D strategies as well as in market development.
- The adoption of a joint approach and the coordination of the efforts between the research community and the industry.

The Greek Roadmap for Hydrogen and Fuel Cells was drawn up in April 2007 by the Coordinating Committee, and was delivered to the Ministry of Development.

However, due to the redefinition of R & D issues at EU level at the time, practically no relevant projects were proclaimed, apart from a few prominent cases. As a result, and in conjunction with the upcoming debt crisis in Greece, the Greek Hydrogen Platform remained relatively dormant.

Still, it should be noted that Greece managed to have a continuous presence in the European Research area on matters of HFC technologies mainly through the participation of universities and research centres in similar programmes.

Under the 5th Framework Programme, Greece participated in 13 out of 66 projects, being represented by 17 bodies out of a total 352. Under the 6th Framework Programme, and up to 2005, Greece was involved in 12 out of 30 projects.

Additionally, Greece has an active presence in both the industrial and research sector within the FCH JU presented in the previous section. Four Greek research organizations participate in the N.ERGHY association, namely:

- National Centre for Research and Technology Hellas (CERTH) with CPERI
- NCSR Demokritos – INRASTES
- CRES – Centre for Renewable Energy Resources
- Foundation for Research and Technology, Hellas (FORTH)/ Institute of Chemical Engineering Sciences (ICE-HT)

while in the New Energy World Industry Grouping (NEW-IG), Greece is represented by Advent Technologies, a company working in the development of new materials and systems for energy applications, and more specifically in the commercialization of the technology of high temperature membrane-electrode-assemblies (HT MEAs).

Having examined the legislative framework on a national and EU level, we can conclude that the project is fairly consistent with the objectives of both the national strategies and the EU operational programmes.

Chapter 2: Identification of the Project

The investment programme consists of the integration of 5 hydrogen powered buses in a daily public transport operation in the capital of Greece, Athens. The buses will make use of a highly innovative technology: they will be equipped with fuel cells, batteries that essentially run on hydrogen and produce electricity emitting only water vapour as a by-product. The project also involves the development of the supporting fuel infrastructure, namely a specially designed maintenance facility where a hydrogen refuelling station will be housed.

As already stated, the project is intended to demonstrate the potential of FC bus technology in tackling the challenge of decarbonisation in the transport sector. Furthermore, its objectives are coherent with the strategic direction of both the European and national transport policy.

2.1 Physical Elements and Activities

2.1.1 Bus Type Specifications

Hybridized Fuel Cell Buses

Since the inception of the fuel cell bus projects in the 1990's, a number of different design configurations and various fuel cell technologies have been used. Out of the three main hydrogen bus technologies, namely hydrogen-fuelled Internal Combustion Engine Buses (H2-ICE), non-hybridised Fuel Cell Buses and Hybrid Fuel Cell buses, the latter has been proved to demonstrate far better fuel economy. The unquestionable advantages in terms of efficiency provided by hybrid FC buses over the other two alternatives have led the bus industry to opt for a hybridized FC system as the drivetrain of choice for commercializing hydrogen buses. Today, virtually every FC bus demonstration is based on hybridized architectures and so this is the one we will assume to be employed in the project under consideration.

The main structural components of a hybridized FC bus are presented below:

- **Bus Body**
  It can refer to 18, 12, 10, and 6 meter platforms. CNG bus bodies are often used thanks to similar structural requirements for roof-mounted fuel tanks.
- **Bus Chassis**
  It is similar to diesel / diesel Hybrid. Again, 18, 12, 10, and 6 meter platforms are used.
- **Fuel Cell System**
  Fuel cell systems are based on Proton Exchange Membranes (PEM) stacks. Power output ranges between 10kWe to 200KWe, depending on the bus platform and manufacturer. These cells present the advantages of being robust, easily turned on and off, and having high efficiency and low (or zero) polluting emissions. They are accompanied by warranties ranging from 15,000 to 20,000 hours.
- **Power Electronics**
  Various power electronics are offered as ad hoc packages by integrator firms or directly by fuel cell / bus manufacturers.
- **Electric Motor**
  DC, AC induction, Asynchronous/Synchronous AC, Permanent Magnet Synchronous.
  Power generally ranges from 25kW to 240kW. The electric motor can be either a single main motor or hub–mounted (where the motor is designed within the wheel).
- **Energy Storage System**

Energy storage systems are generally based on battery packs (either NiMH or Li-ion) and/or ultra-capacitors (generally up to 100 kW). Maximum power output and storage capacity varies depending on the hybrid architecture.

- **Fuel Cell Cooling System**
  The majority of the stack manufacturers use liquid cooled systems, with radiators to dissipate heat.
- **Hydrogen Storage System**
  Hydrogen storage systems are generally based on Type III cylinder technology, storing compressed hydrogen at a pressure of 350bar.

Source: NEXT HyLIGHTS Deliverable 3.1 "Hydrogen Fuel Cell Bus Technology State of the Art Review", Element Energy

The hybrid FC bus' architecture is depicted in the 3D graph below:

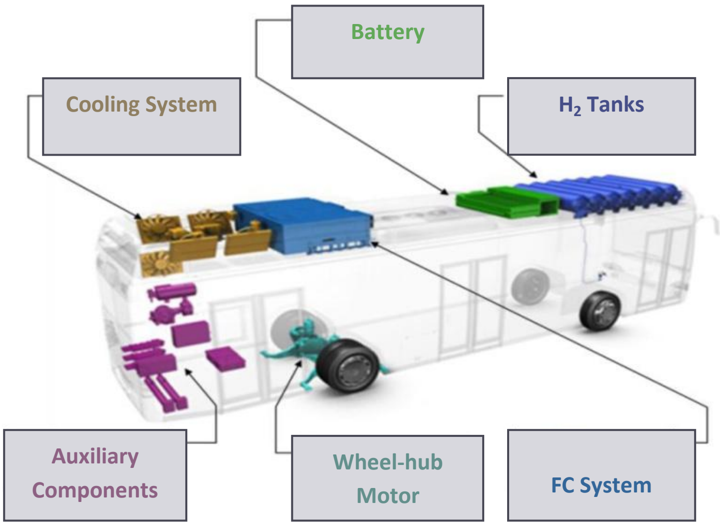

Figure 3 Typical architecture of a Hybrid Fuel Cell Bus – Model EvoBus

Source: Clean Hydrogen in European Cities project (CHIC), Presentation of emerging conclusions (December 2014)

The Fuel Cell System

The most important component is unquestionably the fuel cell system. Hybrid fuel cell buses use hydrogen-fuelled fuel cells with energy storage devices such as batteries, super-capacitors or a combination of both in order to transform hydrogen into electricity.

A fuel cell is practically a device that directly converts the chemical energy of hydrogen into electrical energy that powers the bus. Hydrogen is an energy carrier containing large amounts of usable energy. Once the hydrogen, which is stored in the tanks, is passed through the fuel cell, a chemical reaction with oxygen - which is free in the air - takes place, producing electric power and water vapour as the only exhaust gas. The electricity powers the bus' motor in a manner similar to an electric vehicle. In addition, extra features such as batteries or ultracapacitators serve as a means of storage for the electricity produced allowing the hybridized powertrain's energy storage system to buffer peak loads, boost acceleration and recover energy from braking.

The EvoBus Bus

The value chain of hybrid FC buses encompasses a large number of firms which provide the aforementioned highly specialized components and accompanying services. The common practice for the buses' original equipment manufacturers (OEMs) is to supply the basic framework for the bus chassis, as well as the conventional bus components, and collaborate with the fuel cell providers, specialty firms and the integrators in order to install the fuel cell system into the bus and make it operational. In some cases, however, OEMs can play a greater role in delivering the project by offering whole bus solutions through subsidiaries they control.

Both the bus manufacturer sector and the fuel cells market have expanded over the last years as new firms have been entering the field in order to gain operational experience of the HFC technology. However, there are 2-3 firms in each sector that stand out having engaged themselves in a respectable number of FC demonstration activities. Especially for our project's purposes, we will assume that the hydrogen bus fleet will be comprised of EvoBus Citaro hybrid buses. EvoBus is part of the DaimlerChrysler Group and, along with its subsidiary AFCC, it is one of the most active and experienced firms in fuel cell bus demonstration projects.

In particular, the bus model assumed to be deployed is a 12-metre bus, equipped with 2 Fuel Cell modules reaching a capacity of 120 kW, a 250 kW battery system and 35 kg of on-board hydrogen storage, providing a range of over 250 km. It has a carrying capacity of 76 passengers, out of which 26 can be seated. Its average speed is 12-13 km/h. A fuel economy of 9kg H_2/100 km will be considered based on the performance of current FCH bus trial projects. The bus' useful life is set at 15 years based on a lifetime mileage of 800,000 km, as set out in the Annex of Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles.

This specific type of bus was chosen primarily on the grounds of comparability as it is already being used in a CHIC demonstration project in Milan, a city whose climate and operating conditions match sufficiently those of Athens, as opposed to projects in Northern European countries.

Figure 4 An EvoBus Citaro Hybrid FC Bus in the streets of Milan, Italy
Source: Clean Hydrogen in European Cities project (CHIC), Presentation of emerging conclusions (December 2014)

2.1.2 Bus Route

With regard to the route on which the buses will be launched, we assume that the FC hydrogen bus project will be carried out on the bus line 224, which links Kaisariani with Poligono via the centre of Athens, covering an approximate length of 9.6 km with 34 stops.

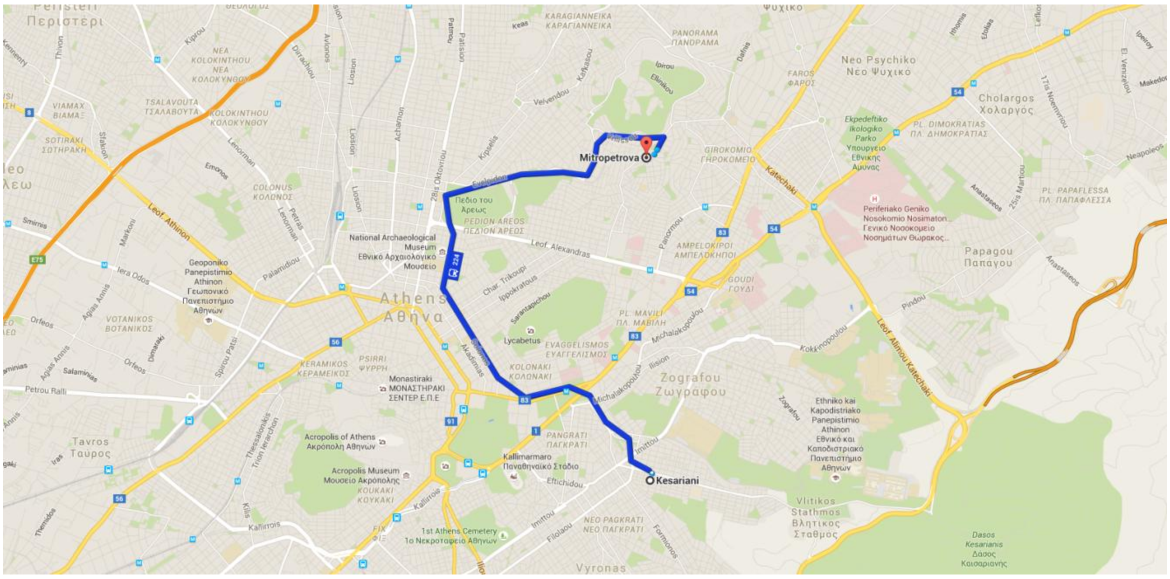

Figure 5 Bus Route 224: Kaisariani – Poligono
Sources: OASA, Google Maps

Buses on this route currently perform a daily duty of 18-20 hours with a frequency of 10 minutes and a journey time of 40 minutes. Operating hours run between 05:00 a.m. and midnight. The line currently deploys diesel fuelled buses the number of which is assumed to amount to 10.

The table below summarizes the information pertaining to the annual mileage covered by the buses servicing Route 224 based on OASA's time schedule. The required quantity of hydrogen is also estimated based on a fuel consumption rate of 9kg H_2/100 km.

Line 224		
Number of trips from Kaisariani to E.Venizelou		**28,374 trips/year**
Weekdays (252 days/year)	87 trips/day	21,924 trips/year
Saturdays (52 days/year)	68 trips/day	3,536 trips/year
Sundays & Holidays (62 days/year)	47 trips/day	2,914 trips/year
Number of trips from E.Venizelou to Kaisariani		**27,652 trips/year**
Weekdays (252 days/year)	85 trips/day	21,420 trips/year
Saturdays (52 days/year)	65 trips/day	3,380 trips/year
Sundays & Holidays (62 days/year)	46 trips/day	2,852 trips/year
Total Trips/year		**56,026 trips/year**
Length of the Line	9.6 km	**537,850 km/year**
Average Fuel Consumption (kg/100km)		**9kg H_2/100 km**
Estimation of Hydrogen used	**48,406 kg H_2 (10 buses)**	**24,203 kg H_2 (5 buses)**

Table 2 Annual Mileage information and estimated H_2 consumption for Line 224
Source: OASA

Route 224 was selected for several reasons:

First of all, it is a line largely used by university students since it passes by various faculties of the National and Kapodistrian University of Athens near Solonos Street as well as of the Athens University of Economics & Business near Pedion tou Areos. Moreover, one of its stops is right outside the Athens' Civil Courts at Evelpidon Street while it also provides two interconnections with the metro, one at Evaggelismos Station and the other at Panepistimiou Station.

Secondly, this route is currently serviced with relatively old, 12m, diesel fuelled Citaro buses, a fact that justifies their substitution with hydrogen buses and the demonstration of the latter's daily performance on a conventional diesel route.

Thirdly, it is one of the first lines making use of the Telematic Passenger Information System. Buses used on line 224 are all equipped with advanced systems technology providing passengers waiting at bus stops with real-time information indicating when the next bus is to be expected.

Overall, it is a line that fits well the length and operational profile of other bus routes participating in similar demonstration projects; it is an urban, flat route in a city known for its high temperature summers, and therefore resembles a lot the case of Milan which was mentioned earlier.

2.1.3 Bus Maintenance Facilities

According to OSY SA's website, all the vehicles currently used on route 224 are maintained, washed and fuelled either at the Depot of Votanikos, which is situated on Agiou Polikarpou Street and occupies an area of 44,390 m^2, or at ETHEL's Depot which is located on Petrou Ralli Street and extends to an area of 50,306 m^2. Both of these depots are located in close proximity to each other, in the wider district of Votanikos, a rather undeveloped area concentrating industrial, logistics and storage activities. A map of the area is provided below:

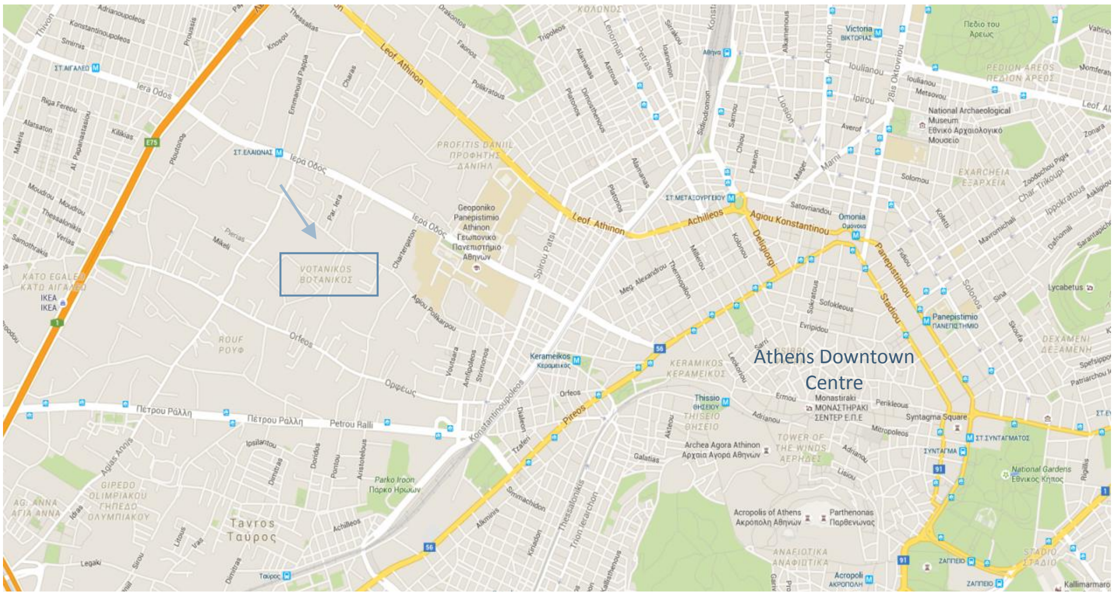

Figure 4 Map of the area of Votanikos
Source: Google Maps

A small area of one of the above maintenance depots could be converted and serve as the maintenance facility of the new hydrogen buses, as was the case with the Milan FCH bus project shown in the picture below:

Figure 6 Example of a converted bus maintenance facility in Milan, Italy
Source: Clean Hydrogen in European Cities project (CHIC), Presentation of emerging conclusions (December 2014)

2.1.4 Hydrogen Refuelling Infrastructure

The next step is to specify the infrastructure that has to be developed for the provision of hydrogen. A medium sized refuelling station with a dispensing capacity of 320 kg H_2/day is proposed. It will consist of a high pressure hydrogen storage tank capable of storing up to 3.5 tonnes of hydrogen in liquid form. The liquid hydrogen will be produced off-site and will be delivered to the station by a tanker. It will then be dispensed in gaseous phase at pressures up to 440 bar through an integrated vaporizer and compressor to two dispenser units connected with the tank. Once empty, the tanker will be replaced by a full one. The refuelling station will be able to refuel up to 8 hybrid fuel cell buses with an average fill time of 10 minutes.

Given its rather small size -less than 400 m^2 of space will be required- , the refuelling facility could be situated within one of the existing bus depots mentioned above, upon space availability. In addition, the location and design of the refuelling station must take into account certain standard safety requirements for liquid H_2. The European Industrial Gases Association (EIGA) recommends a minimum safety distance for liquid hydrogen storage of 20 m from occupied buildings. We assume that there is no constraint in meeting these prerequisites should the station make use of a part of the current depots' space.

2.1.5 Source of Hydrogen

As regards the source of hydrogen, it has to be noted that there are several production pathways, each at different stages of development. Currently, the most widely used method is steam methane reforming (SMR). This process essentially involves breaking down methane (CH_4), a hydrocarbon found in natural gas, into hydrogen (H_2) and carbon dioxide (CO_2). A first reaction between the methane and water (in the form of high-temperature steam) produces carbon monoxide (CO) and hydrogen while a second reaction involving the derived gases and -again- water generates more hydrogen and carbon dioxide (CO_2).

Another method employed for the production of hydrogen is known as electrolysis. This process refers to the use of an electric current in order to split water into hydrogen and oxygen. Being in advanced stages of technological development, this method is expected to significantly contribute to the elimination of CO_2 emissions if the electricity used originates from low-carbon sources, such as renewable technologies.

The hydrogen value chain is depicted in the following figure:

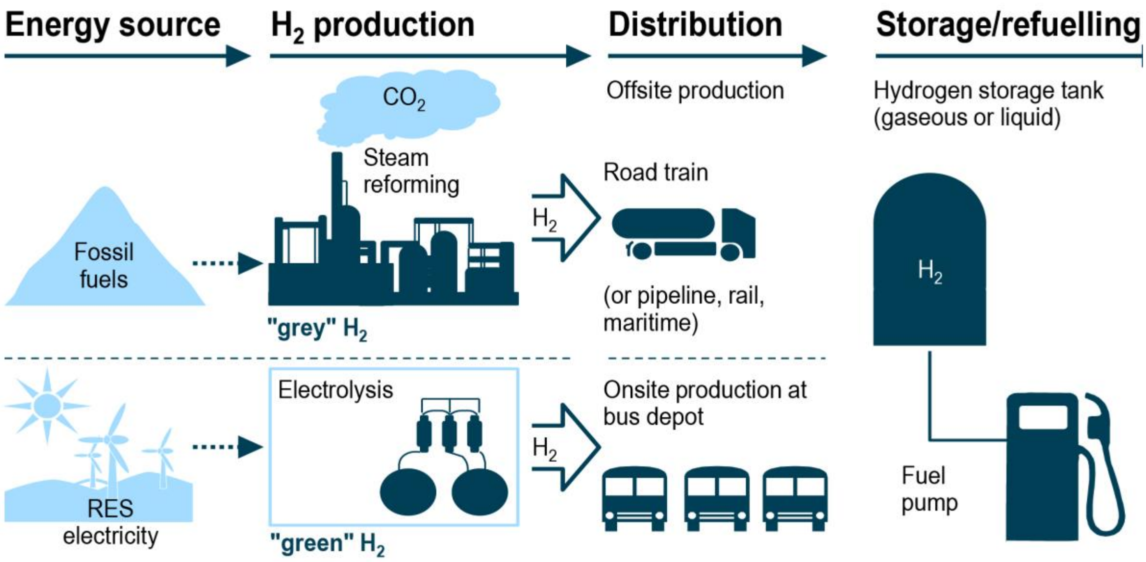

Figure 7 Hydrogen Value Chain
Source: Berger, R. (2015) "Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe", report funded by the FCH JU

Although the majority of current demonstration projects opt for a combination of an onsite electrolyser with trailer delivery of hydrogen as a backup option, in the context of our project we will assume that hydrogen will be exclusively produced via the SMR method, ruling out the option of electrolysis on the grounds of being more costly. Hydrogen, thus, will be assumed to be produced at the region of Elefsina, where industrial gas manufacturers such as Linde Hellas are located, and to be trucked to the refuelling station by road.

The technical specifications of the project are summarized in the following table:

Component	Description
Route	Line 224 (Kaisariani – El. Venizelou)
Buses	5 x 12m platform, low floor EvoBus Citaro hybrid FC buses
Characteristics	
Fuel Cell System	120 kW (2 modules)
Battery System	250 kW/26.9 kWh (Li-ion)
Energy Recuperation System	Wheel-hub motor
H_2 Storage System	7 tanks, 350bar ~ 35 kg
Performance	
Fuel Economy (kg/100km)	9kg H_2/100 km
Range	>250 km
In-service pollution (toxic emissions from exhausts)	Zero

Refuelling & Maintenance Infrastructure	
Dispensing Capacity	320 kg_{H2}/day
Hydrogen Source	Steam Methane Reforming /Liquefied Hydrogen trucked to the refuelling station through a special tanker
Refuelling Time	10 minutes / bus (35 kg of on board hydrogen storage capacity) for 8 buses in sequence
Location	Within an existing bus depot
Footprint (for the HRF)	<400 m^2

Table 3 The project's technical specifications
Source: NEXT HyLIGHTS Deliverable 3.1 "Hydrogen Fuel Cell Bus Technology State of the Art Review", Element Energy

2.2 Stakeholders of the Project

The last step in this chapter involves the identification of the body responsible for the project's implementation as well as of its final beneficiaries.

Although the public transport infrastructure in Athens is owned and operated by OASA, it is proposed that this body not be the project's sole promoter. The project deals with the application of a relatively new technology. The technological and infrastructure barriers that arise before this technology can become mature prevent individual players from entering the market. As already stated, projects, similar to the one we aim to evaluate, have been developed so far through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). A form of Public-Private Partnership led by the industry and backed by the European Commission, the FCH JU ensures the much needed collaboration between the private and the public sector, thereby efficiently addressing the aforementioned lack of economic incentives.

Several types of PPP exist, the structure of which varies depending on the degree of risk transfer to the private sector. Among the most common are: Private Operation and Maintenance, Design Build Operate (DBO), Parallel Co-finance of Capex, Design, Build, Finance and Operate (DBFO). In transport projects, the public partner is usually the owner of the infrastructure and the private partner is the operator obtaining revenues through tariff payments. However, the FCH JU's PPP structure is different: both the Industry Grouping and the Research Grouping, which constitute two of its three members -the other being the European Commission- are non-profit organisations with open membership. They partake in the undertaking by in-kind contributions and services related support.

Therefore, the following assumptions will be made:

- OASA through its subsidiary, OSY, will be responsible for the operation and maintenance of the buses.
- The Bus Original Equipment Manufacturer (OEM) will be responsible for the procurement of the FCH buses and for services relating to any maintenance issues.
- The Fuel Cell System technology provider will be responsible for the procurement of the FC stacks, their maintenance and their guarantee.
- The industrial gas manufacturers will be responsible for the refuelling infrastructure and the provision of hydrogen.

Training by each department will be provided to management, drivers, engineers and fuellers respectively.

The stakeholders participating in the project are presented in the following table. It should be pointed out that the private industry companies shown below are based on the FCH JU CHIC project, and are thus merely indicative within the current analysis.

Operator/Maintenance	OSY-Transport for Athens
Bus Original Equipment Manufacturer (OEM)	EvoBus (a subsidiary of Daimler Mercedes-Benz)
Fuel Cell System Technology Provider	AFCC (a joint venture of Daimler AG and Ford Motor Company)
HRS/H2 Producer Infrastructure	Linde or Air Liquide (delivery of liquid hydrogen)
Other organizations	Research Centres

Table 4 Stakeholders of the project

As to the beneficiaries, although the project is implemented within a local framework, the fact that it forms part of a wider EU effort lends to it a broader impact. The project's direct beneficiaries will unquestionably be the drivers and passengers who come in direct contact with this technology and enjoy the smoother, quiet driving along with the zero pollution benefits it offers. Moreover, gains in terms of in-house technological expertise will also be provided to the Transport Operator. Early engaging with the FC technology will enable the transport authority to develop the know-how and infrastructure required for future developments in the transport sector for which the EU has already started to lay the foundation. Last but not least, the technological partners will also benefit, since the project will contribute to driving down the technology costs, while research institutes will profit in terms of exchange of valuable information.

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Chapter 3: Demand & Option Analysis

3.1 Demand Analysis

Bus is inarguably the most preferred means of public transport in the city of Athens. According to a recently published survey performed by Public Issue on behalf of WWF Hellas, 33% of the Athens population chooses the bus for its daily commute, a figure closely followed by the number of those opting for the underground (31%). The results of this survey are corroborated by OASA's official figures regarding passenger traffic. Operational figures for 2014 show that 368,192,000 passenger journeys were made by bus and trolley, accounting for approximately 56.8% of total public transport journeys.

Moreover, despite the obvious decrease in the bus transport work in the last 5 years, due to a reduction in the size of fleets and number of employees owing to the ongoing economic crisis, demand for public transport in general, and bus transport in particular, has remained steady during the last 3 years. To be more exact, since 2010, public road transport services (as provided by OSY SA) have undergone the following changes:

- a 27.5% in personnel cutbacks
- a 4.3% shrinking in the bus fleet
- a 20.54% decrease in scheduled routes and a 23.81% in actual routes
- a 19.95% reduction in the transport work, as measured by the thousands of kilometres operated
- a 24.5% decline in the volume of passenger traffic

A schematic description of the last two statements is provided through the following graphs based on information presented in 2014 OASA's Report. In favour of comparing the recent trends in urban mobility, data for all public transport modes have been included. It is worth stressing that the increase in the metro transport work is partly attributed to an extension of the metro network.

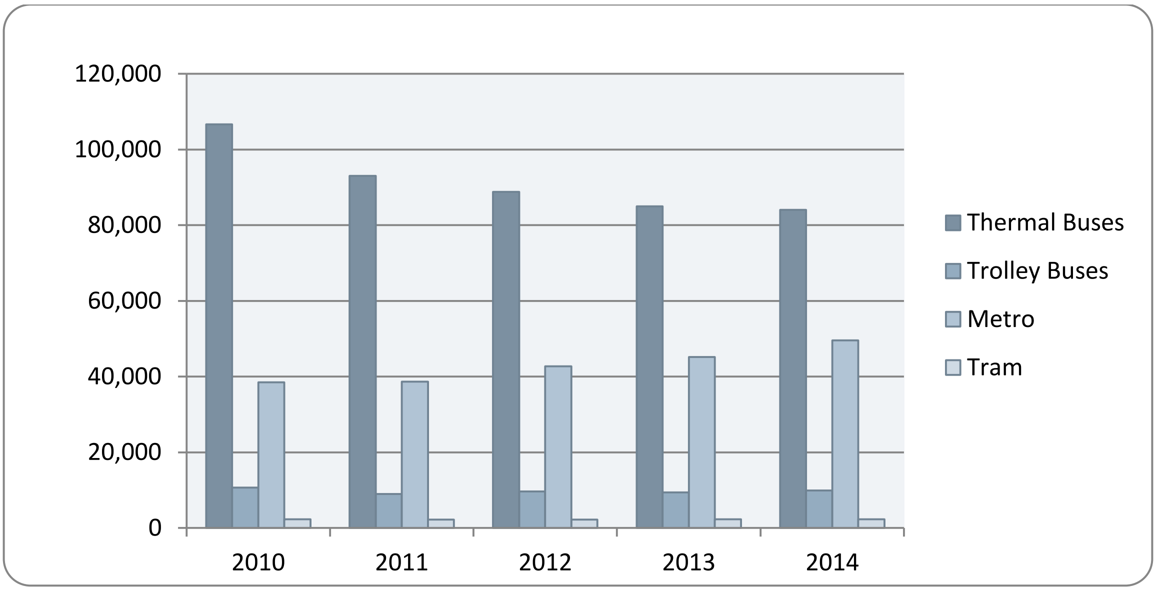

Figure 8 Transport Work (thousands of kilometres operated)
Source: OASA Report (2014)

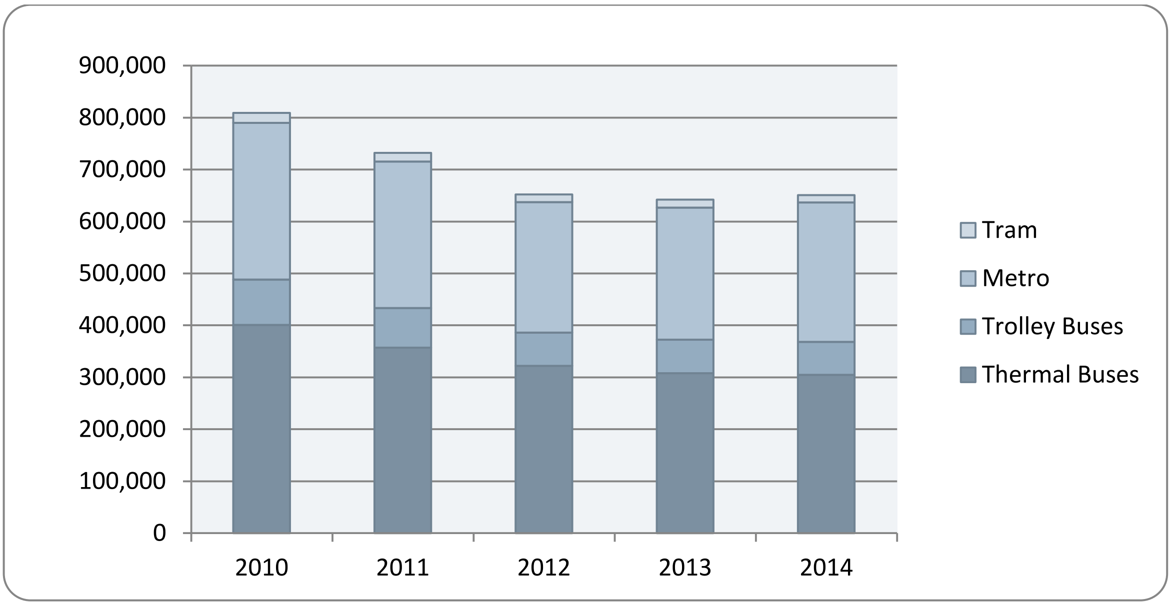

Figure 9 Passenger Traffic (thousands of passenger journeys)
Source: OASA Report (2014)

At the same time, a special Eurobarometer report conducted in 2013 regarding the attitudes of Europeans towards urban mobility reveals, among other things, the perceptions Europeans have towards problems pertaining to travelling within cities. On a 5-level scale - ranging from Very, Fairly, Not Important, Not at all, to Don't Know-, approximately 9 out of ten respondents in Greece (94%) identify air pollution as an important issue, while almost another 9 out of 10 (87%) think of noise pollution as an equally severe problem with which urban centres are faced. Both figures are above the EU28 average (which stands at 81% and 87% respectively). Furthermore, 76% of Greeks believe that the best way to improve urban travel is through better public transport, thereby assigning to the Transport Authority the crucial role of offering better quality services.

The analysis above clearly illustrates the fundamental role public transport holds to society. Technological initiatives such as the one proposed can form the basis towards the provision of improved public transport services in the near to long-term.

3.2 Option Analysis

Option analysis aims to explore different feasible options for the project, to carry out a comparison between them and, ultimately, to justify the selected option. Out of the strategic solutions available, we will choose to evaluate the alternative actions in terms of the technology that can best achieve the project's intended objectives.

Customarily, project appraisal considers the examination of the following 3 options:

1) The "Do Nothing"
2) The "Do Something" and
3) The "Do Something Else"

Following this approach, two separate bus technologies, i.e. trolley buses using electricity as their energy carrier and hybrid FC buses running on hydrogen, will be discussed and assessed against our counterfactual scenario which refers to the use of diesel-fuelled buses.

3.2.1 The "Business as Usual" Scenario

The "Do nothing" scenario, also known as the "Business as Usual" Scenario, is the without-the-project option against which the other two options will be compared. Under this scenario Route 224 will continue to be serviced by an all diesel-fuelled bus fleet.

Inarguably, diesel buses have the advantage of employing a rather mature technology; the use of diesel propulsion systems dates back to the early 20th century. Some of their distinct traits include fuel economy, power and reliability. This latter attribute is the main reason transit agencies prefer them to other propulsion systems.

At the same time, however, diesel technology presents a series of disadvantages. First and foremost, diesel-engine buses run on a fuel distilled from petroleum, a mainly non-domestic source of energy. The fact that such an important energy source has to be imported makes national economies susceptible to the swing of oil prices and aggravates the problem of energy security. Furthermore, oil is a non-renewable source; existing in finite quantities means that it will - at some future point- inevitably be depleted. Last but certainly not least, the use of diesel has significant environmental repercussions. Diesel exhaust has been blamed for containing several toxic air pollutants, which impact severely on both the environment and human health. In an effort to reduce these harmful emissions, transit buses have undergone several technological changes in recent years, mainly by incorporating to their system specially designed particulate matter filters. Nevertheless, they still compare unfavorably to other systems in terms of pollution generation.

All of the above dictate the need for a shift to other transportation technologies that can efficiently address the aforementioned problems. The continuation of the current, mainstream, diesel technology in an oil intensive sector such as the transport sector would prove catastrophic to current and, most importantly, to future societies.

3.2.2 The "Do Something" Scenario

The second scenario assumes the replacement of the 5 diesel buses with hydrogen FC buses. As we have already seen, this option presents several benefits in line with the energy and transport policy targets set in an EU level.

Hydrogen fuel cells produce zero tailpipe emissions and can, thus, contribute to the complete elimination of local air pollutants. In addition, depending on how much carbon intensive the method of hydrogen production is, they have the potential of effectively dealing with Greenhouse Gas (GHG) emissions. Moreover, the ability of hydrogen to be produced from a wide range of domestically available/renewable sources plays a crucial role in the mitigation of oil supply security issues. In addition, FC technology is able to compete with conventional fossil fuel technologies in terms of operational performance; fuel cells have been proven more efficient than conventional internal combustion engines in converting fuel to power. Lastly, another advantage worth mentioning is the reduction of noise pollution; as opposed to diesel buses, which are known for their characteristic clatter caused by the internal combustion process, FC buses can offer a quiet and smooth operation owing to the lack of an internal combustion engine.

Regarding the cons of the FC technology, a major drawback is that it has not yet reached maturity. Very high capital, maintenance and fuel costs are, thus, inevitably expected in the medium-term compared to other mature technologies which have achieved economies of scale. Nonetheless, ongoing demonstrations of FC buses have proven that they possess the potential of providing the same operational flexibility as conventional diesel buses while at the same time offering compelling environmental benefits.

3.2.3 The "Do Something Else" Scenario

The last option refers to the replacement of the 5 diesel-powered buses with trolley buses. Inarguably one of the cleanest bus technologies currently available, trolley bus powertrains present several advantages over their conventional fossil fuel counterparts: fuel economy, zero tailpipe emissions, lower noise levels, energy diversity, to name a few. At the same time, drawbacks connected with their deployment include the high cost of the overhead cabling infrastructure and the limited to particular routes operational flexibility. As a result, this technology is mainly developed for short, heavily used inner city routes. It is worth mentioning that OSY's fleet is currently comprised of 356 trolley buses, which account for approximately 15% of the total number of buses.

The table below presents the list of qualitative criteria used in order to compare the two alternatives against the operating benchmark. We have to point out that we will make no effort to rank the alternative options based on their NPV, as the usual practice suggests, since the business-as-usual scenario would clearly prevail whereas the proposed scenario would prove to be the least desirable option. FC and hydrogen technologies can in no way compare with mature technologies in terms of costs; in order to avoid biased results, a proper option analysis should take into consideration economies of scale; hence the inclusion of the 2030 Total Cost of Ownership (TCO) parameter.

Scenario / Criterion	"Business as Usual" Scenario: EURO II Diesel Buses	"Do Something" Scenario: Hybrid FC Buses	"Do Something Else" Scenario: Trolley Buses
	Fuel Availability		
Current fuel/energy source availability	High, decreasing in the long term	Currently limited	High
Possibility of bus technology to adapt to another fuel/energy carrier	Yes (biofuels)	Yes (sun, wind based hydrogen)	No
Powertrain Configuration	Conventional diesel combustion engine	Serial hybrid configuration of fuel cell system and electric drive	Electric powered bus with overhead line or ground contact
	Operational Performance		
Range (km)	>500 km	Up to 500 km	Limited by the electric supply network
Route Flexibility	High	High	Limited
Energy Consumption kWh/km	4.13	2.8*	1.8
	Infrastructure		
Need in additional	No	Yes - Need of hydrogen	Yes - Need of overhead

infrastructure		refuelling infrastructures (at bus depots) and delivery networks	contact wire networks throughout all bus route
EU coverage with fuelling infrastructure	High	Very limited	Limited
Emissions			
CO_2 Emissions (kg/km)	1.15 – 1.6 (diesel fuel carbon content: 2.3kg/litre)	Depends on the hydrogen carbon content. Up to 100% reduction over benchmark (e.g. renewable hydrogen)	Depends on the electricity carbon content. Up to 100% reduction over benchmark (e.g. renewable electricity)
Pollution from Exhausts	CO, NOx, SOx, PMs	Water vapour only	None
Noise standing (db)	80	63	62
Noise passing by (db)	77	69	72
Economy			
Indicative Purchase Price (EUR)	~ 220,000	~ 800,000	~ 400,000
Additional Infrastructure Investment (EUR)	No	100,000 per bus per station	1,000,000 /km
TCO 2012 (EUR/km)	2.1	4.6	3.1
TCO 2030 (EUR/km)	2.5	2.72	3.4

Table 5 The three scenarios screened against certain qualitative criteria.
** 1 kg H_2=3.18 litres diesel*
Sources: i) CIVITAS Policy Note "Smart choices for cities: Clean buses for your city", European Union,
ii) NEXT HyLIGHTS Deliverable 3.1 "Hydrogen Fuel Cell Bus Technology State of the Art Review", Element Energy Study on behalf of the EC

The option analysis has illustrated that FC bus technology outweighs the other two options in terms of operational performance and emissions. Furthermore, the FC bus' Total Cost of Ownership (TCO), although currently the highest by far among the alternatives, is expected to compete that of its conventional counterpart on condition that mass commercialization has been achieved. Bearing in mind the above, along with the observation that the project's aim at this stage is not commercial exploitation, rather the necessary steps that can lead to it in the near to medium term, we choose to proceed with the "Do Something" Scenario. This is the scenario that best fulfills all of the project's main objectives and is also fully aligned with the EU's strategy under Horizon 2020.

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Chapter 4: Financial Analysis

The financial analysis is of paramount importance in the context of a Cost-Benefit Analysis. By making use of certain assumptions and information surrounding the project, it aims to assess the project's financial profitability and verify its financial sustainability. Furthermore, it provides the basis for the socioeconomic analysis which follows in the next chapter.

The financial analysis will be carried out using the Discounted Cash Flow (DCF) Method. A combination of the information pertaining to the technical specifications defined earlier in Chapter 2, and of additional information and assumptions explained in this chapter, will lead to the construction of the project's Cash Flows Table. Key financial performance indicators, such as the financial Net Present Value and the Financial Rate of Return on the investment as well as on the national capital, will be computed after the discounting of the future cash flows at an appropriate discount rate.

Certain points should be highlighted prior to the analysis:

1) The investment's time horizon will be set at 11 years, of which the first one refers to the investment phase and involves the obtaining of the necessary licenses, the construction of the refuelling site and the delivery of the buses. The remaining 10 years refer to the project's operational stage. Initial capital outlays will be timed as at the start of the year, while all the rest will be timed as at the end of the year.

2) The analysis will be performed in constant prices, thus ignoring the impact of inflation. Prices will be fixed at 2015 as the base year. Accordingly, the financial discount rate will also be expressed in real terms.

3) VAT will be considered fully refundable under national legislation; therefore the financial analysis will be conducted on cash flows net of VAT.

4) Cost estimates have been largely based on and accordingly adapted from the European Commission's NEXT HyLIGHTS Deliverable 3.1 "Hydrogen Fuel Cell Bus Technology State of the Art Review" by R. Zaetta and B. Madden of Element Energy. Element Energy Limited is a consulting firm participating as a research member in the EU's FCH JU.

4.1 Total Investment Costs

The first step is to determine the project's total investment costs, which include both the initial expenditure and any equipment and machinery-related replacement costs occurring later in the project's life. As stated above, the project's life extends to 11 years. Although a typical bus' chassis and body is expected to last for 15 years, fuel cell stacks offered currently in the market have a maximum useful life of up to 10 years. Since the fuel cell system is the project's largest asset in need of replacement, the reference period was deliberately shortened to match the end of its design lifetime. This means that the bus will be in service until the original FC system fails and consequently no replacement of stacks will be considered.

As a result, our focus in this section will be the HFC bus project's initial capital costs, which can be divided into 2 components:

1) The bus purchase cost
2) The cost of the hydrogen refuelling infrastructure

4.1.1 Bus Costs

Studies surrounding the cost of fuel cell buses are still scarce. However, the research carried out by Element Energy in 2010, on behalf of the EC's NEXT HyLIGHTS programme offers the most reliable and available cost break-down data that will enable us to specify the project's costs. More specifically, Element Energy, using industry based data, provides a range of indicative costs for three different periods. Making use of moderate estimates for the period beyond 2015, and in line with the technical specifications presented in Chapter 2, we adjusted the figures selected for each component to 2015 real prices in order to determine the bus' overall cost.

The main components and indicative costs of the fuel cell bus cost structure are presented below:

Components	Indicative Range Cost beyond 2015 (2010 Euros)	Selected Values (average approach)	Indicative Cost beyond 2015 (2015 Euros)
Chassis and Body	~ €140,000 - €215,000 / bus (15 years of life expected)	€177,500	€189,652
Fuel Cell System	~ €1,000 - €2,150 / kW ~20,000 hours warranty	€1,575	€1,683 / kW X 120kW = €201,960
FC Cooling System	15,000 €/bus	€15,000	€16,027
Energy Storage System	~ €220 – €720 / kWh	€470	€502/ kWh X 26,9 kWh = €13,504
Hydrogen Storage System	~ €700 - €800/ kg	€750	€801/kg X 35kg = €28,035
Power Electronics & Electric Motors	~ €72,000 – €140,000 / bus by 2015	€106,000	€113,257
Labour for Drivetrain Integration	~ €36,000 - €50,000/ bus by 2015 As low as €3,600 / bus beyond 2015 - 2018.	€20,000	€21,369
OEM Investment Costs	Estimated at up to 26% of the final bus cost in 2010, with an expected substantial reduction over time	23%	€174,383

Table 6 Fuel cell bus cost break-down
Source: NEXT HyLIGHTS Deliverable 3.1 "Hydrogen Fuel Cell Bus Technology State of the Art Review", Element Energy

Adjustments to current prices were made using inflation rate data extracted from the European Central Bank's database.

Oct 2011	Oct 2012	Oct 2013	Oct 2014	Oct 2015
3%	2.5%	0.70%	0.40%	0.10%

Table 7 Annual Percentage Changes (19-Euro Area) HICP – Inflation Rate
Source: *European Central Bank (ECB)*

The FC bus cost break-down is depicted in the pie chart below:

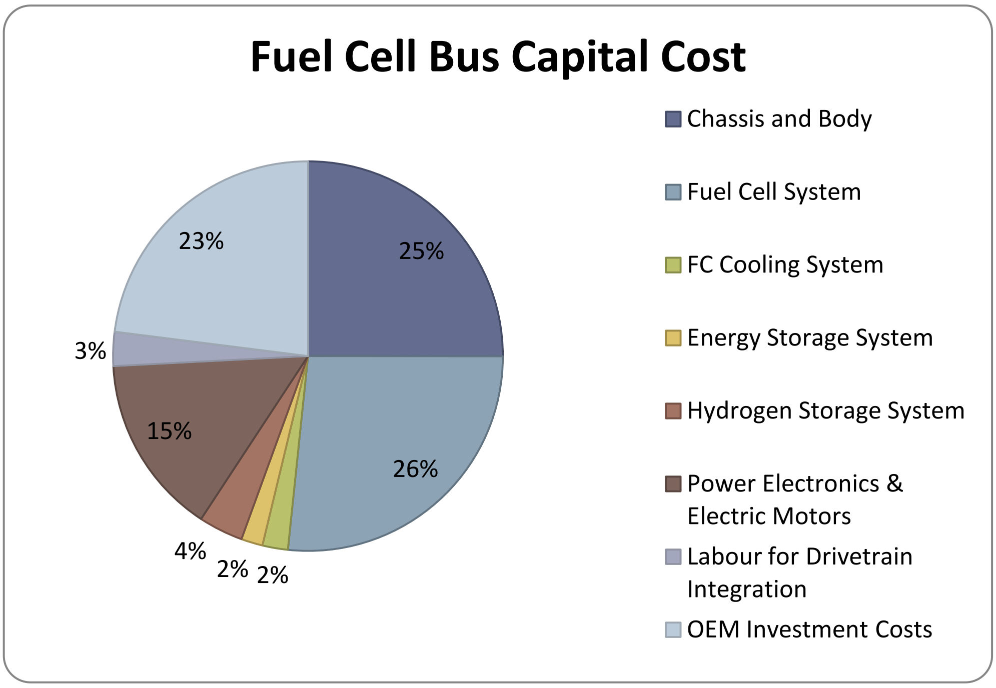

Figure 10 Distribution of the various FC Bus components costs

We observe that, apart from the cost for the bus' chassis and body, which is not expected to change due to economy of scale effects, the main cost component is the capital cost of the fuel cell system itself. The second main component which adds significantly to the overall cost refers to various factors added by bus OEMs in assembling the buses. We have to note here that these include additional labour required to hand build the FC buses, non-recurring engineering costs as well as a risk premium to cover the risks associated with selling the new technology. These costs are expected to decrease as the technology becomes more mature.

4.1.2 Refuelling Station Capital Cost

The cost for the construction of the hydrogen refuelling station is a function of its dispensing capacity as well as of the method used for the production of hydrogen. The technical specifications of the hydrogen refuelling facility were based on the EU's CHIC London project, the cost of which was estimated at approximately EUR 3 million (2010 prices). Adapting this sum to 2015 prices, the station's investment cost, including overhead costs such as permitting and planning costs, all logistics costs and staff training, amounts to EUR 3,205,381.

To sum up, the total initial cost of the project is estimated at EUR 6,996,316 net of VAT.

	YEARS										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Chassis and Body	-948,260	0	0	0	0	0	0	0	0	0	0
Fuel Cell System	-1,009,800	0	0	0	0	0	0	0	0	0	0
FC Cooling System	-80,135	0	0	0	0	0	0	0	0	0	0
Energy Storage System	-67,520	0	0	0	0	0	0	0	0	0	0
Hydrogen Storage System	-140,175	0	0	0	0	0	0	0	0	0	0
Power Electronics and Motors	-566,285	0	0	0	0	0	0	0	0	0	0
Labour for Drivetrain Integration	-106,845	0	0	0	0	0	0	0	0	0	0
OEM Investment Costs	-871,915	0	0	0	0	0	0	0	0	0	0
Fuel Cell Bus Capital Cost	**-3,790,935**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Refuelling Station Capital Cost	**-3,205,381**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total Investment Costs	**-6,996,316**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 8 Total Investment Costs (at EUR 2015 constant prices)

4.2 Total Operating Costs and Revenues

Operating -otherwise known as recurring- costs refer to all the costs needed to operate and maintain the upgraded service; these include hydrogen fuel costs, bus maintenance costs and refuelling station maintenance costs. Since the financial analysis is based on an incremental approach, costs associated with drivers' wages are not construed as operating costs, because they would occur either way, even without the replacement of the 5 buses.

Hydrogen fuel costs depend on two parameters: the fuel consumption based on the average annual distance covered by the buses and the estimated price of the fuel which is, in turn, a function of the production method used. According to OASA's timetable information presented in Chapter 2, the total number of kilometres travelled by the current fleet of 10 diesel fuelled buses in line 224 is 537,850 (53,785 km/bus). Given a fuel economy of 9kg H_2/100 km, this means that if the whole fleet was replaced, 48,406kg H_2 would be needed in order to fuel the HFC buses. Hence, the 5 HFC buses that are proposed to replace the conventional ones would run on 24,203kg H_2 per annum, i.e. on approximately 4,840kg H_2 each.

As already stated, the refuelling station will be procured with liquefied hydrogen, trucked in through a special tanker. Based on data derived from Element Energy's study, the cost of liquid hydrogen will be assumed to be €3/kg and to remain constant throughout the whole reference period. Also, in favor of simplicity, no tax on hydrogen fuel will be assumed. Therefore, the annual cost of hydrogen needed to power the fleet of 5 HFC buses is given by the solution of the following formula:

Annual Hydrogen Consumption (€) *= Average Annual Distance* ***(53,785 km)*** *x Fuel Economy* ***(9kg H_2/100 km)*** *x Hydrogen Price* ***(€3/kg H_2)*** *x No of Buses* ***(5)***

and amounts to EUR 72,610.

As far as the bus maintenance fees are concerned, Element Energy's report suggested that these would reach EUR 20,000 per bus (expressed in 2010 terms) for the period 2015-2018. Adjusting this sum to 2015 prices, we obtain a maintenance cost of EUR 21,369/bus, and an overall EUR 106,845. Lastly, the yearly maintenance fees for the hydrogen refuelling facility will be set at 3% of the station's capital expenditure, totaling EUR 96,161 per year. In total, annual operating expenses are estimated at EUR 275,616.

With regard to operating revenues, for projects of this nature, these originate primarily from user fares (tickets and subscriptions) and, depending on the institutional set-up, they accrue to the Transport Operator which in our case is the Public Transport Authority itself. However, in order to be consistent with the incremental approach, we will have to assume that there are not any revenues stemming from the project. The substitution of the conventional buses with the HFC buses does not generate any additional operating revenues. Neither the traffic levels at the line nor the pricing policy are expected to change as a result of the introduction of the new technology.

Nevertheless, certain components of the buses, such as the chassis, auxiliary equipment, power electronics and electric motors, have a residual value since they can be repurposed and reused once the buses are retired. Taking into account the operating life of the buses as well as that of their components, the residual value will be set at 5% of the acquisition cost, which includes all components except for the fuel cell system whose economic life will be completely exhausted upon the conclusion of the project.

Given the above, the residual value is calculated at EUR 27,812/bus, totalling EUR 139,060 for the 5 buses. In addition, a residual value for the refuelling station will also be set, again equal to 5% of its acquisition cost, amounting to EUR 160,269.

All the projects' relevant operating cash flows are set out in following table:

	YEARS										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Fuel Cell Bus Maintenance Fee	0	-106,845	-106,845	-106,845	-106,845	-106,845	-106,845	-106,845	-106,845	-106,845	-106,845
Station Maintenance Fee	0	-96,161	-96,161	-96,161	-96,161	-96,161	-96,161	-96,161	-96,161	-96,161	-96,161
Hydrogen Consumption	0	-72,610	-72,610	-72,610	-72,610	-72,610	-72,610	-72,610	-72,610	-72,610	-72,610
Tax on Hydrogen Fuel	0	0	0	0	0	0	0	0	0	0	0
Total Operating Costs	**0**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**
Fares Income	0	0	0	0	0	0	0	0	0	0	0
Residual Value	0										299,329
Total Operating Revenues	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**299,329**
Net Operating Revenue	**0**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**23,713**

Table 9 Operating Revenues and Costs (at EUR 2015 constant prices)

4.3 Sources of Financing

The project will adopt a public-private partnership approach (PPP) under the EC's FCH JU, so investment costs will be covered by different sources of financing. In the FCH JU framework, contributions of equal amounts are made by the European Commission and by the industry and research sector. Therefore, we will assume that the project will be co-financed at a rate of 35% from the EU and at an equivalent rate from the private sector. Private contribution will consist of both equity and in-kind contributions within the project's scope. The remaining amount, i.e. 30%, will be levied from public funds.

To sum up, Union assistance is calculated by multiplying the project's initial costs with the 35% co-financing rate and results in an EU grant of EUR 2,448,711. The same figure applies to private contribution, while the remainder of the investment will be funded by the Greek State with own contribution amounting to EUR 2,098,895. The total financing sources match the initial investment cost of EUR 6,996,316.

The financing structure of the project is as follows:

Financing Sources	m EUR	% share
Union Assistance/EU grant	2.45	35%
Private Contribution	2.45	35%
National Public Contribution	2.09	30%
Total	6.99	100%

Table 10 The project's financing structure

4.4 Financial Return on Investment

After having determined the project's costs and revenues as well as its various sources of financing, we are in a position to evaluate its financial profitability. The key indicators used in capital budgeting for this purpose are:

1) The Financial Net Present Value (FNPV)
2) The Financial Rate of Return (FRR)

It should be noted here that financial profitability will be assessed both in terms of the investment as a whole and of the national capital used. As a result, 4 indicators will be computed in total:

1) The financial net present value of the investment, FNPV(C)
2) The financial rate of return of the investment, FRR(C)
3) The financial net present value of national capital, FNPV(K)
4) The financial rate of return of national capital, FRR(K)

Both the FNPV(C) and the FRR(C) compare investment costs to net revenues in order to measure the extent to which the latter are able to repay the investment, regardless of the sources of financing.

The financial net present value of the investment, FNPV(C), is defined as the difference between the present (discounted) value of the project's cash inflows and the present value of the project's cash outflows.

The formula for calculating the NPV is the following:

$$NPV = -C_0 + \sum_{t=1}^{n} \frac{\mathrm{R_t - C_t}}{(1+\mathrm{i})^{\mathrm{t}}}$$

where

C_0: total initial investment cost
R_t: operating revenues during the period t
C_t: operating costs during the period t
i: financial discount rate (expressed in real terms)
t: number of time periods

The financial discount rate (FDR)

For the 2014-2020 programming period the European Commission recommends a 4 % discount rate in real terms as the reference parameter for the real, long term opportunity cost of capital. However, this rate is only provided as an indicative benchmark for EU Member States in general and different values can be used on the grounds of international macroeconomic trends and conjunctures as well as on the State's specific macroeconomic conditions and the nature of the project concerned.

The Commission's Notice on current State aid recovery interest rates and reference/discount rates for the 28 Member States, applicable as from 01.11.2015, sets, for most Eurozone countries, among which Greece, a base rate of 0.17. The discount rate is derived by adding a margin of 100 basis points, thereby resulting to a rate of 1.17%. Furthermore, the ECB's interest rate, which influences, inter alia, business lending rates, is currently standing at 0.050%. Taking into consideration the above, and accordingly adjusting for inflation (-0.92%), a more appropriate real discount rate should perhaps be set at around 2%; at 2.09% to be exact.

The adjustment of the nominal rate to inflation was made using the following formula:

$$(1+i) = (1+r) + \ (1+\pi)$$

where i is the nominal interest rate, r is the real nominal rate and π is the inflation rate

After applying to the project's cash flows a discount rate of 2%, the FNPV is calculated at EUR -9,217,046. Prima facie, a negative FNPV means that the project should be rejected since, from a financial point of view, there is no increase in the owners' wealth as a result of the project. However, within the scope of our analysis, the negative FNPV should rather be interpreted as proving that the project is in need of EU financial support. Let us not forget that the ultimate purpose of the CBA is to determine whether undertaking a proposed investment project is in the public interest.

Furthermore, the negative profitability should not surprise us given the fact that the project consists of mainly negative net cash flows, except for the last year of operation for which the residual value contributes to a positive net cash flow. Even if revenues were generated as a result of the project, the FNPV would still fail to take a positive value since operating expenses typically outweigh operating revenues in the urban public transport sector, let alone in a project employing a not yet commercialized technology such as the one we are trying to assess.

The other financial indicator, the financial rate of return on investment (FRR(C)), is defined as the discount rate that yields a zero FNPV and is given by the solution of the following formula:

$$0 = -C_0 + \sum_{t=1}^{n} \frac{\mathrm{R_t} - \mathrm{C_t}}{(1 + \mathrm{FRR})^{\mathrm{t}}}$$

One can easily infer from the set of predominantly negative net cash flows throughout the project's life that a financial rate of return is impossible to be derived. The project falls into one of those rare cases where the IRR isn't of any use in assessing the project's profitability.

As shown in the graph below, the FNPV is negative for every rate of return and asymptotic to the horizontal axis, hence never actually reaching zero.

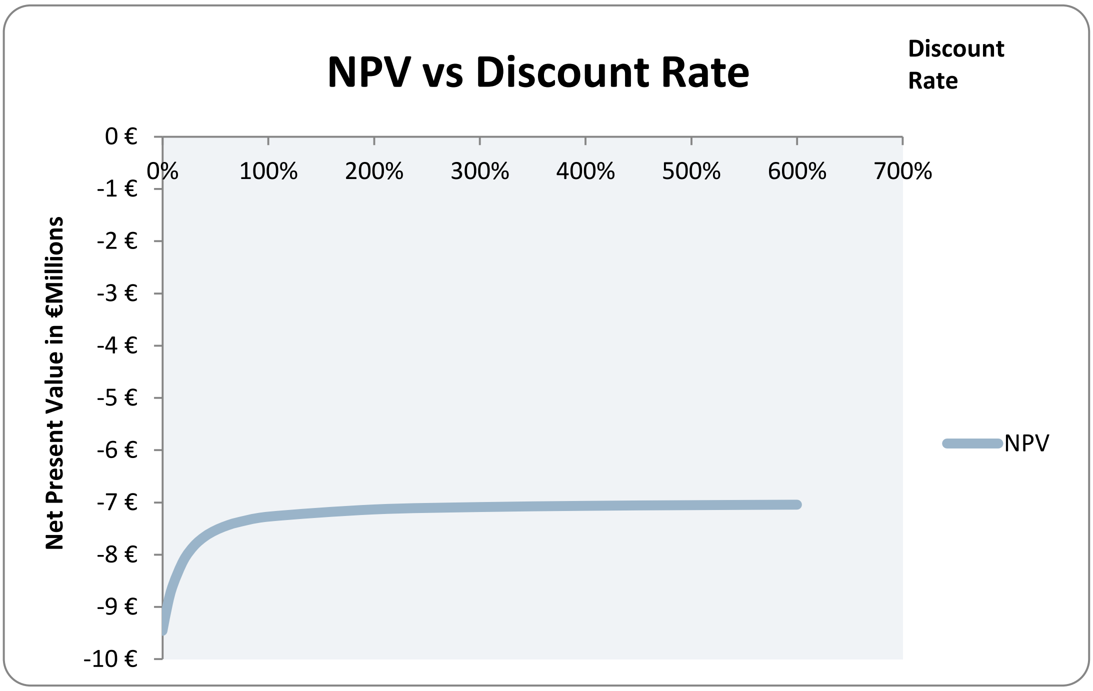

Figure 11 The project's FNPV(C) versus the Discount Rate

Note: The NPV curve would have been closer to the horizontal axis if the investment cost had been timed as at the end of the first year.

	YEARS										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Total Operating Revenues	0	0	0	0	0	0	0	0	0	0	299,324
Total Inflows	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**299,324**
Total Operating Costs	0	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616
Total Investment Costs	-6,996,316	0	0	0	0	0	0	0	0	0	0
Total Outflows	**-6,996,316**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**
Net Cash Flow	**-6,996,316**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**23,708**
Financial Discount Rate	**2,09%**										
Financial Net Present Value of the Investment -FNPV(C)	**€ -9,217,046**										
Financial Rate of Return on Investment -FRR(C)	**Cannot be defined**										

Table 11 Evaluation of the Financial Return on Investment

4.5 Financial Sustainability

A project is deemed financially sustainable when it doesn't face the risk of running out of cash in any stage during its time horizon, be it the investment or the operational stage. As stated earlier, the project implementation costs will be funded by means of an EU grant, as well as private and public contributions. However, the project will generate only negative cash flows during its operational phase, making it financially unsustainable. The absence of revenues that would be able to cover the cost of operation means that financial resources should be secured so as to avoid the discontinuation of the project. It is imperative that clear, long-term commitments be made in order to ensure that the project is not confronted with a shortage of capital. We will assume that this will be achieved through operating subsidies provided by public funds and established by law or other budgetary provisions.

Based on the assumptions made concerning the expected inflows and outflows, the table below shows the annual amount of subsidies required in order to offset the project's operating losses and to ensure its sustainability:

	YEARS										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Total Financial Resources	6,996,316	0	0	0	0	0	0	0	0	0	0
Total Operating Revenues	0	0	0	0	0	0	0	0	0	0	299,329
Subsidies	0	275,616	275,616	275,616	275,616	275,616	275,616	275,616	275,616	275,616	0
Total Inflows	**6,996,316**	**275,616**	**275,616**	**275,616**	**275,616**	**275,616**	**275,616**	**275,616**	**275,616**	**275,616**	**299,329**
Total Investment Costs	-6,996,316	0	0	0	0	0	0	0	0	0	0
Total Operating Costs	0	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616
Total Outflows	**-6,996,316**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**
Net Cash Flow	0	0	0	0	0	0	0	0	0	0	23,713
Cumulated Net Cash Flow	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**23,713**

Table 12 Financial Sustainability

4.6 Financial Return on Capital

The financial net present value of capital, FNPV(K), is, again, defined as the sum of the project's discounted net cash flows. However, as opposed to the FNPV(C) where all sources of financing were taken into account, in this case only national (public) capital contributions to the project are considered; the EU grant and foreign private funds are excluded. In addition, the subsidies granted to cover the operating costs are also excluded since they are transfers from one national source to another. As regards the project's residual value, we will only include that of the refuelling infrastructure (EUR 160,269), assuming that, under the PPP scheme, only this asset will remain under the transport authority's possession, while all other assets will be returned to the private partners.

The FNPV(K) is then computed at EUR -4,432,701. Once more, the negative NPV does not mean that the project should be cancelled. It just provides an indication that the national capital employed does not earn an adequate financial return. As for the FRR(K), once again, it cannot be determined.

	YEARS										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Total Operating Revenues	0	0	0	0	0	0	0	0	0	0	160,269
Total Inflows	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**160,269**
Total Operating Costs	0	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616	-275,616
National Public Contribution	-2,098,895	0	0	0	0	0	0	0	0	0	0
Total Outflows	**-2,098,895**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**
Net Cash Flow	**-2,098,895**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-275,616**	**-115,347**
Financial Discount Rate	**2.09%**										
Financial Net Present Value of National Capital-FNPV(K)	**-4,432,701 €**										
Financial Rate of Return on National Capital -FRR(K)	**Cannot be defined**										

Table 13 Evaluation of the Financial Return on National Capital

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Chapter 5: Economic Analysis

The economic analysis is perhaps the essence of Cost-Benefit Analysis. In contrast to the financial analysis, which is carried out from the point of view of the project owner, the economic analysis aims to appraise the project's net contribution to social welfare. In order to accomplish this, the key concept of shadow pricing is used. Shadow prices are nothing more than proxy values that properly reflect the opportunity cost of goods and services, for which either market failures lead to originally distorted prices or the absence of markets -and of prices thereof- prevents valuation of certain project related impacts.

The appraisal of the social value of the investment takes as a starting point the financial analysis preceded in Chapter 5. Adjustments to the cash flow items, along with the consideration of additional impacts and the use of an appropriate social discount rate, are made in 5 essential steps presented in the subsections below.

5.1 Conversion of Market to Accounting Prices

First of all, observed prices that do not properly reflect the opportunity cost of the project's inputs and outputs must be converted into shadow prices. The rationale behind this is that market prices, in several cases fail to capture the social value of goods and services. Monopolistic or oligopolistic forms of market structure - where a price mark-up is usually used over the marginal cost -, taxes, government subsidies and duties on imported goods provide examples of the sources of such market distortions.

As suggested in the EU guidelines, the inefficiency of observed prices/the presence of market distortions is addressed through the use of accounting or shadow prices. Appropriate conversion factors are applied to the items of the financial analysis in need of correction, creating new accounts, i.e. the shadow prices, which are able to imprint social benefits and costs.

Accounting prices are provided using the formula below:

Accounting Price = Conversion Factor x Market Price

However, no unique approach exists for the calculation of conversion factors and, consequently, of accounting prices. In practice, several approaches can be followed. The most appropriate method is customarily selected by distinguishing goods between: a) inputs and outputs of the project, b) tradable and non tradable in the international markets and c) major and minor items.

For illustrative purposes, this approach is presented in the Figure below:

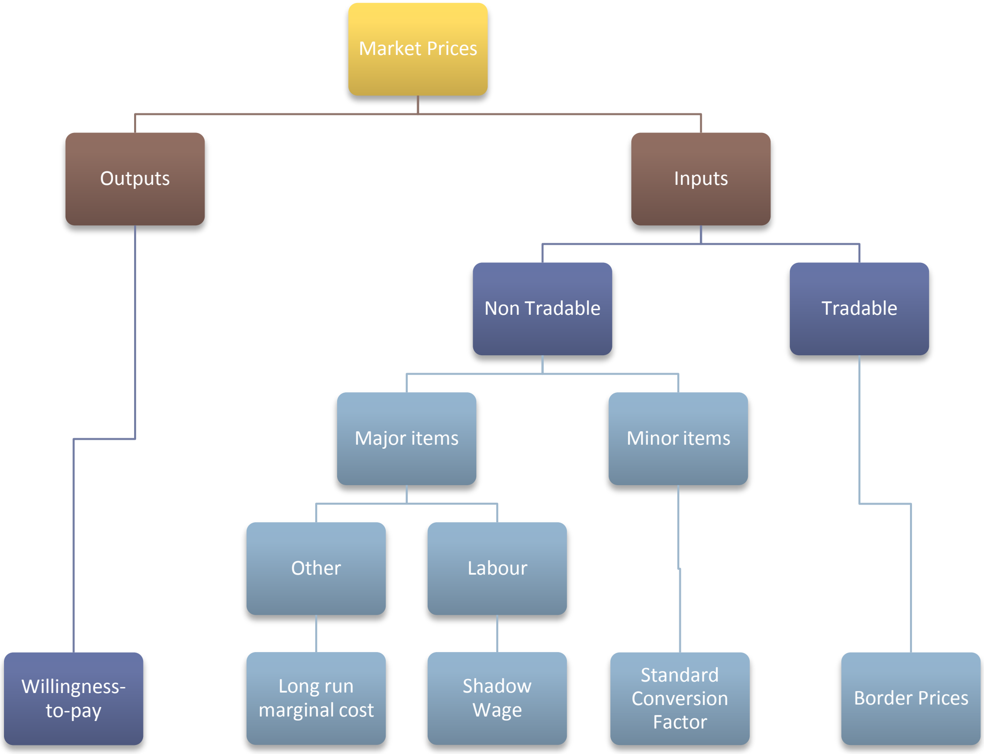

Figure 12 An overview of the transition from market to accounting prices
Source: EC's Guide to Cost-Benefit Analysis of Investment Projects (Adapted from Saerbeck (1990))

In principle, Conversion Factors should be provided by each country's planning office. However, in Greece's case such national parameters are not available. In light of this, we will proceed with the most simplified approach, i.e. with the application of the Standard Conversion Factor (SCF). The SCF is closely connected to the "border price rule", proposed by Little & Mirrlees (1974), according to which world prices properly reflect the opportunity cost of a good whereas domestic prices are considered distorted.

The most widely used formula for the calculation of the SCF, provided below, considers taxes and subsidies on imports and exports as the main factors that drive a wedge between domestic (market) and international (shadow) prices:

$$\mathbf{SCF} = \frac{\mathbf{M + X}}{(\mathbf{M + T_M - S_M}) + (\mathbf{X - T_X + S_M})}$$

where:
M is the total value of imports at shadow prices (CIF prices)
X is the total value of exports at shadow prices (FOB prices)
T_M and T_X are the values of duties on imports and exports respectively
S_M and S_X are the values of subsidies on imports and exports respectively

However, when computing the SCF for EU Member States, the following, simplified formula is assumed to be more appropriate:

$$\mathbf{SCF} = \frac{\mathbf{M + X}}{(\mathbf{M + X + T_M})}$$

The formula above manages to take into account certain particularities pertaining to the EU's trade policy, i.e.:

1) Some taxes and duties are generally imposed on imports from other - EU and non-EU – countries;
2) Import subsidies are usually not a practiced measure of EU countries;
3) Exports to other EU and non - EU countries are generally free of taxes;
4) Existing export subsidies are quite low in value and involve mainly the agricultural and food sectors, which are irrelevant to public infrastructure projects. Therefore, they can be assumed to be equal to zero.

According to data extracted from the Hellenic Statistical Authority, Greece's imports of goods and services in 2014 were valued at around EUR 62.60 billion while the value of its exports amounted to EUR 58.04 billion (at current prices). Duties on imports were calculated at EUR 22.06 billion. Inserting these figures into the simplified formula, a SCF of 0.84 is computed.

5.2 Fiscal Corrections

Certain items usually included in the financial analysis, most notably taxes and subsidies, constitute pure transfer payments from one agent to another within society, and as such should be omitted under the economic analysis.

As regard taxes, cash flow items in the financial analysis conducted have already been considered net of Value Added Tax (VAT). Moreover, no other taxes, direct or indirect, were included and, as a result, no correction is required as to this parameter.

With regard to subsidies, we have assumed that in order for the project to be financially viable, a grant would be provided by the government. Although a revenue for the beneficiary, the subsidy does not create economic value and therefore a correction should be applied in order to neutralize this fiscal impact. We will assume that this correction has already been made since, in the previous chapter's financial analysis, the subsidy was only considered in the Financial Sustainability Table and not in the calculation of the Financial Performance Indicators. Not being a part of the original cash flows table, it will also not form part of the new one. Equivalently, this could have been achieved by assigning to the subsidy a Conversion Factor value of zero (CF=0).

5.3 Monetization of Non-Market Impacts and Correction for Externalities

The next step, under the economic appraisal framework, is to account for non-market impacts generated by the project, i.e. for relevant for society effects for which no market value is available and for externalities -costs and/or benefits to society- not taken into account by immediate users but nonetheless affecting third parties. The evaluation of these impacts is made by first identifying them, then quantifying them and finally assigning to them appropriate numerical values.

It should be noted here that, given the nature and objectives of the investment, special attention is paid to the reduction in environmental externalities and the resulting gains in social benefits stemming from the application of a carbon clean technology. Externalities related to the project can be classified in the four types analyzed below:

5.3.1 Reduction in Air Pollution (Health Effects)

Air pollution is one of the most important externalities generated by transport activities. Harmful pollutants such as particulate matter (PM), namely PM10 and PM2.5, NOx and SO2 are suspended in the atmosphere as a result of the function of internal combustion engines. The social costs associated with this externality include health costs, building and material damages as well as general damage costs to the ecosystem.

The introduction of the Hydrogen FC buses is most certain to have a positive effect towards the reduction of the level of air pollutant emissions as compared to the current status quo, since, as already stated, the technology employed emits no harmful pollutants at the point of use.

Quantification of local air pollutants avoided

The first step in monetizing the external benefits associated with the reduction of air pollution is to estimate the volume of air pollutants avoided, based on the bus' characteristics and its annual mileage. To this end, we will make use of the "EURO Standards" which regulate emissions of specific pollutants depending on vehicle characteristics. Europe first introduced heavy-duty vehicle emission standards back in 1988 by the Directive 88/77/EEC. The "Euro" track was established some years later, in 1992, followed by more stringent standards implemented every few years. All EU Member States must abide to this regulation.

Table 14, below, lists the limit values for certain pollutants as set out for each EURO Standard:

Tier	Date	CO	HC	NOx	PM
Euro I	1992 (> 85 kW)	4.5	1.1	8.0	0.36
Euro II	October 1998	4.0	1.1	7.0	0.15
Euro III	October 2000	2.1	0.66	5.0	0.10
Euro IV	October 2005	1.5	0.46	3.5	0.02
Euro V	October 2008	1.5	0.46	2.0	0.02
Euro VI	January 2013	1.5	0.13	0.4	0.01

Table 14 EU Emission Standards for Heavy-Duty Diesel Engines (g/kWh)
Source: www.transportpolicy.net

As shown above, the pollutants for which limit values are placed within the Euro Emission Standards are:

a) Carbon Monoxide (CO): An odorless and colorless toxic gas, CO is the product of incomplete fuel combustion. A precursor to two significant greenhouse gases -CO_2 and ozone-, in high concentrations it can pose a threat to human health because by forming chemical bonds that inhibit the oxygenating function of blood.

b) Unburned Hydrocarbon (HC): Non-methane hydrocarbons result from partially burned fuel. They contribute to smog and can have negative health impacts.

c) Nitrogen oxides (NO_X): Nitrogen oxides are chemical substances generated by the high temperature within the engine's cylinder. They are harmful both to human health, causing asthma and breathing problems, and to the environment causing damage to buildings and materials through several corrosive processes in which they take part.

d) Particulate Matter (PM): Particulate Matter is a mixture of very fine, inhalable particles generated by the agglomeration of carbon molecules. They are classified as PM_{10} and $PM_{2.5}$ with the subscript denoting nanometers in aerodynamic diameter. They are associated with an increased risk of respiratory and cardiovascular diseases, since after penetrating the respiratory system they reach and settle on the heart and lungs.

Aside from the ones examined above, other harmful pollutants related to tailpipe emissions by diesel engines - for which no limits have been set - include Sulfur oxides (SO_2), an exhaust fume responsible for lung irritation and acidic rain, and Ozone (O3), an indirect product of fuel combustion forming in the atmosphere through the combination of NO_X and Volatile Organic Compounds (VOC), which has an adverse effect on humans as well as on the environment.

As one may notice, although a major pollutant, no limits for CO_2 emissions from single heavy-duty vehicles have been defined within the Euro Standards. As we will see later on, the impact for CO_2 emissions will be evaluated separately, since it extends to a global scale rather than a local one.

Line 224 is currently serviced with 12-metre long buses, manufactured by ELVO in 1999-2000. This specific model is based on a Mercedes chassis and features a Mercedes-Benz OM 447 HLA Euro II Diesel engine with a power of 184 kW (250 hp).

Figure 13 A Mercedes-Benz / ELVO C97.405N Mark 2 bus operating on line 224
Source: www.athensvoice.gr

The table below provides a summary of the bus' characteristics.

Bus Characteristics	
Bus Model	Mercedes-Benz / ELVO C97.405N
Length	12 metre platform
Number of Passengers	31 Seated, 71 Standing
Power	184 kW
Emissions Standard	EURO II
Engine	Diesel
Age (Year)	15 years (2000)
Average Fuel Consumption	41 l/100 km

Table 15 Description of the diesel bus model currently employed in Line 224
Source: http://leoforeia.gr/forum/showthread.php?tid=26

Conversion of kg of diesel fuel used for service in kWh equivalent

The "EURO Standards" measure pollutant emission levels in grams per kilowatt hours (g/kWh). Therefore, in order to determine the magnitude of the air pollution reduction, we will have to calculate first the equivalent energy contained in the total quantity of diesel used. The formula is based on the energy density value relative to the Lower Heating Values (LHV), i.e. 35.8 MJ/l = 42.8 MJ/kg.

Based on an annual mileage of 537,850 km and an average fuel consumption of 41 l/ 100km, the whole fleet consumes 220,430 litres of diesel per year. This translates into 7.89 TJ, and given that 1kWh = 3.6 MJ, converts into 2.19GWh.

Line 224		
Total Trips/year		**56,026 trips/year**
Length of the Line	9.6 km	**537,850 km/year**
Average Fuel Consumption	41 l/ 100km	**2.44 km/ l**
Estimation of Diesel used		**220,430 l (184,500 kg) ***
Equivalent Energy of Diesel Consumption		**7.89 TJ ****
MJ to kWh	1kWh = 3.6 MJ	**2.19GWh**

Table 16 Calculation of the fleet's total energy consumption in kWh
*Assuming a diesel density equal to: 0.837 kg/l
**Assuming an energy density equal to: 35.8 MJ/l
Source of assumptions: HIGHVLOCITY "Ex-ante evaluation of Demonstration sites", *MIT – Massachusetts Institute of Technology*

Considering that the line currently deploys 10 diesel fuelled buses and that 5 of them will be replaced with the new Hydrogen FC buses, the diesel used for 5 buses is 110,215 litres, equal to 1.095 GWh. This number combined with the amounts provided by the Standard Emissions table yields the estimated level of the reduction in emissions which is:

CO: 4 g/kWh x 1.095 GWh = 4.38 tonnes
HC: 1.1 g/kWh x 1.095 GWh = 2.14 tonnes
NOx: 7.0 g/kWh x 1.095 GWh = 7.66 tonnes
PM: 0.15 g/kWh x 1.095 GWh = 0.16 tonnes

The results are summarized in the following table:

CO	HC	NOx	PM
4.38 tonnes	**2.14 tonnes**	**7.66 tonnes**	**0.16 tonnes**

Table 17 Estimated reduction in local air pollutants for the 5 buses

Allotment of a monetary value to the estimated emissions reduction

After having determined the amount of local pollutants avoided thanks to the implementation of the project, the next step is to assign them a value. However, the quantification in monetary terms of the economic damage associated with air pollution is a rather difficult task. There is a shortage of shadow prices for every of the aforementioned pollutants, since those are a perplex function of several parameters. The scientific literature has focused on pricing the major pollutants and this is the approach we will follow based on the best available data.

In 2008, CE Delft produced for the European Commission the “Handbook on estimation of external costs in the transport sector” as part of the study “Internalisation Measures and Policies for All external Cost of Transport” (IMPACT). The handbook includes a list of recommended unit costs for externalities based on data collected from the most appropriate and extensive studies, such as the EU’s CAFE CBA (CAFE, 2005a) and HEATCO. With regard to the valuation of air pollution costs, emphasis was given on human health costs based on the “impact pathway approach” which considers resource costs and the WTP for human life. The paper includes default values per tonne of certain pollutants, namely NOx , NMVOC, SO_2 and PM, on a country-specific basis.

An update for the above handbook was issued in 2014 by Ricardo-AEA, providing air pollution costs per vehicle-km (vkm) on an EU average basis for different types of vehicles. According to this update, the costs generated by a standard 15-18 tonnes, EURO II, urban bus, such as the one we examine, amount to 17.4 c€/vkm (2010 prices). Converting from 2010 prices to 2015 prices using the Eurozone inflation rate, we arrive at a current cost of 18.59 c€/vkm. Given that each of the 5 buses to be replaced travels an annual distance of 53,785 km, air quality damage costs are estimated in total at €49,993/year.

5.3.2 Reduction of the Impact on Climate Change (as measured by the reduction in CO_2 emissions)

Climate change or global warming effects refer to climatic changes caused by emissions of certain gases known as greenhouse gases (GHGs). In the transport sector these include primarily carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Due to the global and long term nature of these external costs, two different approaches to the ones used for local air pollutants are selected. The first one, called the “damage cost approach”, evaluates GHG emissions costs under the assumption that no efforts are taken towards the reduction of the pace of climate change. The second, known as the “abatement cost approach”, evaluates the cost of achieving a specific emissions reduction target.

Both approaches present advantages as well as disadvantages. From a scientific point of view, the first approach would be the most desirable since it would allow for the full quantification of the external effects, encompassing those associated with changes in the sea level, the landscape, the flora and the fauna. Unfortunately, the complex pathways of these effects, their long-term nature and the potential existence of other impacts -not yet identified- give rise to highly uncertain cost estimations. The avoidance strategy approach, on the other hand, offers a sound alternative as long as the targets set reflect properly the society’s preferences, in the sense that Willingness-to-Pay (WTP) for a certain abatement level can be determined.

Selection of an appropriate price for CO_2

The great uncertainty surrounding climate change projections and the associated environmental damage and external costs is depicted in the wide range of carbon prices available in the scientific literature. Beside the relatively low figures for the CO_2 permit traded in the EU Emissions Trading Scheme (ETS), the values provided by most studies can be quite high. One study in particular, a meta-study by Kuik et al. (2009), using abatement cost estimates from various studies, calculates a range for emissions costs between EUR 69–241 in 2025, with a central value of EUR 129/t CO_2 equivalent, all measured in 2005 prices. This calculation, which has been made in line with the United Nations Framework Convention on Climate Change (UNFCCC) goal of stabilising global warming at 2°C, is considered to be a reliable source for average estimates and is the one we will choose to base our analysis on.

Following the appropriate discounting of these future GHG emissions and the adjustment of the values to the current price level, we arrive at a central price of EUR 96 per tonne of CO_2.

Quantification of CO_2 emissions avoided

Although the other two major GHGs responsible for climate change are also measured in CO_2 equivalent, we will proceed to the monetization of solely the CO_2 emissions avoided. Furthermore, only tank-to-wheel (TTW)/tailpipe CO_2 emissions generated during the operation of the buses will be considered. Well-to-tank (WTT) emissions induced by upstream processes such as the production and distribution of hydrogen will not be considered.

Line 224		
Total Trips/year		**56,026 trips/year**
Length of the Line	9.6 km	**537,850 km/year**
Average Fuel Consumption	41 l/ 100km	**2.44 km/ l**
Estimation of Diesel used		**220,430 l (184,500 kg)**
CO_2 per kg of diesel	3.16 kg*	**583 tons CO_2/year**

Table 18 Estimation of CO_2 Savings
Source: HIGHVLOCITY "Ex-ante evaluation of Demonstration sites"
*Given the weight of each single molecule, 1 kg of diesel generates 3.16 kg of CO_2

The quantity of CO_2 emissions produced in a year by the fleet of 10 traditionally fuelled buses currently servicing Line 224 has been computed in the table above. The 220,430 l of diesel consumed each year equal 184,500 kg, based on a diesel density of 0.837 kg/l. Considering that 1 kg of diesel generates approximately 3.16 kg of CO_2, avoided externalities from CO_2 emissions resulting from the substitution of the 5 buses amount to 291.5 tonnes of CO_2/year. Multiplication of this quantity with the assumed shadow price for CO_2, calculated earlier, provides us with the total external costs related to global warming which amount to EUR 27,984 per year.

5.3.3 Reduction in Noise Emissions

Another major external cost component arising from transport activities is noise pollution. According to the Handbook on estimation of external costs in the transport sector, "Noise can be defined as the unwanted sound or sounds of duration, intensity, or other quality that causes physiological or psychological harm to humans". Transport noise is associated with two types of costs: costs of annoyance and health costs. It has been proven that exposure to noise levels above 85 dB(A) can impair a person's hearing ability, whereas exposure to lower levels (above 60 dB(A)) are linked to an increased risk of cardiovascular diseases.

The newly introduced buses will feature a silent power-train – a fuel cell system instead of an internal combustion engine - thus mitigating external noise costs. FCH JU suggests in its 2015 Emerging Results Reports that "FC buses contribute to a reduction in the perceived noise levels by around 60% on average compared to diesel buses". More precisely, a diesel bus generates noise levels of 77 dB while in motion and 80 dB when standing still. On the contrary, an FC bus is only responsible for emitting noise pollution of 69 dB and 63 dB respectively.

There are several methods trying to assess the impact of noise, the most notable among them being the bottom-up approach, also known as the "Impact Pathway Approach", which we already mentioned in the emissions cost valuation section. However, there are substantial difficulties in measuring and pricing this type of externality. External noise costs are a function of noise emission per mode, of the number of people affected and of the damage inflicted per dB(A).

The EU's programme HEATCO (2006a) provides average noise costs per person per dB(A) for several EU countries. However, Greece is not amongst them and an inference based on data for other countries would probably lead to bias given the absence of a noise map for the municipality of Athens, which could provide the basis for the estimation of people exposed to noise as well as for the level of exposure, and thus enable comparability. Notwithstanding the project's valuable contribution towards the decrease of noise emissions, the small scale of the project possibly allows us to safely omit noise impacts from the analysis.

5.3.4 Resource Cost Savings

Another externality that we will examine refers to the fuel savings achieved by the shift in the technology that powers the buses. As shown in previous sections, the current fleet on Route 224 is estimated to consume 220,430 litres of diesel per year. Considering that the line currently deploys 10 diesel fuelled buses and that 5 of them will be replaced with the new, alternatively fuelled buses, total fuel savings correspond to an amount of 110,215 litres per year.

In order to be able to value this externality, we will have to make certain assumptions in connection with the price of diesel. According to the European Commission's Weekly Oil Bulletin No 1777 (09/11/2015), the untaxed diesel fuel price in Greece currently stands at €0.565/ litre with a range between €0.563 – €0.673/litre and an average price of €0.622/litre since the beginning of the year. Despite the sharp fall of oil prices in recent years and the rise anticipated by the markets in the medium term, long-term forecasts present inarguable difficulties. In view of this and for the sake of simplicity we will assume an untaxed diesel fuel cost of €0.70/litre, remaining constant through the whole reference period. This average figure is fairly compatible with a 3% annual increase based on conservative estimates used by several studies. However, variations in this parameter and its corresponding impact on the economic performance indicators to this parameter will be assessed later in Chapter 6. To sum up, annual diesel fuel savings are estimated at EUR 77,151.

Last but not least, there are two more externalities related to cost savings from the current diesel technology. First of all, we should account for the fact that the project will render obsolete the purchase of at least 5 new diesel buses. The buses were manufactured in 2000, meaning that their useful life approaches its end and their replacement in the near future will become inevitable. Secondly, savings from the periodic maintenance that diesel buses undergo in the course of a year should also be considered.

In a Total Cost of Ownership (TCO) comparison of the main alternative bus technologies, Element Energy has assumed that a diesel bus' capital cost ranges between EUR 170,000 - 250,000 while its annual maintenance fee falls between EUR 12,700 - 20,000. Based on these range estimates, we will assume a capital cost of EUR 220,000/bus and an annual maintenance fee of EUR 16,000/bus (2015 prices). Therefore, the implementation of the project creates additional offsets out of which EUR 1,100,000 refer to the cost of purchase of 5 diesel buses and EUR 80,000 to their annual cost of maintenance.

To sum up, the following general socio-economic benefits of the project were monetised in the economic analysis:
i) Environmental impact reductions
ii) Resource cost savings

5.4 Social Discounting

After all the project's relevant economic costs and benefits have been properly accounted for, they will now be discounted using the Social Discount Rate (SDR), which reflects the social view on how future benefits and costs should be valued against present ones.

There are 3 main theoretical approaches for the empirical estimation of the SDR. The first one, known as the "Social Opportunity Cost of Capital" (SOCC), argues that the same discount rate must apply to both private and public projects on the grounds that the latter can displace the former. The second approach, called the "Consumption Rate of Interest", maintains that the discount rate should be derived from the predicted long-term growth in the economy. The last one, the "Hyperbolic Discounting" approach, involves the application of variable -decreasing-marginal discount rates over time so as to increase the weight of the project's impacts on future generations. It is, thus, more relevant in the appraisal of long-term projects.

For our analysis' purposes, we will opt for the second approach, which is the one that has gained consensus in the scientific community since it relies not only on financial data, but above all, on social preferences. More specifically, it is based on the concept of the "Social Time Preference Rate" which can be computed through the following formula obtained from the Ramsey economic growth model (1928):

$$r = eg + p$$

where r is the real social discount rate of public funds, g is the growth rate of consumption, e is the elasticity of marginal utility with respect to consumption, and p is the rate of pure time preference. The formula is, therefore, comprised of two elements, the one related to inter-temporal preference and the other to consumption growth both of which reflect the reasons why future consumption may have a lower value than in the present.

According to Annex III to the Implementing Regulation on application form and CBA methodology, "for the programming period 2014-2020 the European Commission recommends that for the social discount rate 5 % is used for major projects in Cohesion countries and 3 % for the other Member States." At the same time, the EC strongly encourages Member States to determine their own social discount rate based on country specific circumstances.

The most recent estimates on the Social Discount Rate are provided by Massimo Florio and Emanuela Sirtori in their paper "The Social Cost of Capital: Recent Estimates for the EU Countries", a more advanced version of which was published in Florio's book "Applied Welfare Economics: Cost-Benefit Analysis of Projects and Policies". Using data obtained from the Eurostat, the OECD and the IMF, the authors have estimated the Social Time Preference Rate for 20 EU-OECD countries. The values assigned to Greece are the following:

Pure time preference rate (p)	Elasticity of the marginal utility with respect to consumption (e)	Expected per-capita consumption growth (g)
0.98%	**1.47**	**0.96%**

Table 19 Estimated Values for the Social Discount Rate Terms
Source: Florio, M. (2014), Applied Welfare Economics: Cost-Benefit Analysis of Projects and Policies

Note: The reference period for the estimation of the two first parameters is 2011, whereas for the third it is 2000-2018.

Substituting these values to the Ramsey formula, we obtain a nominal Social Discount Rate for Greece equal to 2.39%. Taking into consideration a yearly inflation rate (Oct ’14 - Oct’15) equal to -0.92 %, this rate translates into 3.34% in real terms.

5.5 Calculation of Economic Performance Indicators

The final step in the economic analysis chapter is the evaluation of the project’s economic performance as measured by certain indicators, namely:

1) The Economic Net Present Value (ENPV): the difference between the discounted total social benefits and costs
2) The Economic Rate of Return (ERR): the discount rate that yields a zero value for the ENPV
3) The Benefit/Cost Ratio (B/C): the ratio between discounted economic benefits and costs.

The programme’s new set of cash flows, including social benefits and costs, and the resulting indicators, based on the selected social discount rate of 3.34%, are summarized in the table below. It is clearly shown that despite having accounted for shadow prices as well as for positive externalities generated by the project, the NPV, although considerably improved, remains negative at EUR -4,745,127. The 0.42 B/C Ratio means that for every Euro spent on the project only 42 cents are earned. The negative economic return implies that too many precious resources are used without whatsoever equally achieving socially valuable benefits.

		YEARS										
	CF	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Operating Revenues												
Fares	**0.84**	0	0	0	0	0	0	0	0	0	0	0
Residual Value of the investment	**0.84**	0	0	0	0	0	0	0	0	0	0	251,436
Externalities												
Reduced Air Pollution		0	49,993	49,993	49,993	49,993	49,993	49,993	49,993	49,993	49,993	49,993
CO_2 Savings (291.5 tonnes/year)		0	27,984	27,984	27,984	27,984	27,984	27,984	27,984	27,984	27,984	27,984
Diesel Fuel Savings		0	77,151	77,151	77,151	77,151	77,151	77,151	77,151	77,151	77,151	77,151
Diesel Bus Purchase & Maintenance Cost Offsets		1,100,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000
Total Economic Benefits		**1,100,000**	**235,128**	**235,128**	**235,128**	**235,128**	**235,128**	**235,128**	**235,128**	**235,128**	**235,128**	**486,564**
Initial Investment	**0.84**	-5,876,905	0	0	0	0	0	0	0	0	0	0
Total Operating Costs	**0.84**	0	-231,518	-231,518	-231,518	-231,518	-231,518	-231,518	-231,518	-231,518	-231,518	-231,518
Total Economic Costs		**-5,876,905**	**-231,518**	**-231,518**	**-231,518**	**-231,518**	**-231,518**	**-231,518**	**-231,518**	**-231,518**	**-231,518**	**-231,518**
Net Economic Benefits		**-4,776,905**	**3,610**	**3,610**	**3,610**	**3,610**	**3,610**	**3,610**	**3,610**	**3,610**	**3,610**	**255,046**
Social Disount Rate		**3.34%**										
Economic Net Present Value - ENPV		**-€4,565,608**										
Economic Rate of Return - ERR		**Cannot be defined**										
B/C Ratio		**0.42**										

Table 20 Evaluation of the Economic Performance

Chapter 6: Risk Assessment

As set out in Article 101 (Information necessary for the approval of a major project) of the EU regulation No 1303/2013, risk assessment is a prerequisite of every CBA filed with the European Commission by Member States seeking EU assistance. The whole structure of a CBA essentially relies upon assumptions surrounding the most appropriate values for key parameters as well as upon forecasts for the project's future cash flows. This type of analysis is therefore used as a means of dealing with the uncertainty inherent in every investment project and thereby improving the robustness of the CBA. The process of assessing the project's risks includes various steps presented in the following sections.

6.1 Sensitivity Analysis

Sensitivity analysis is basically aimed at indicating how much the financial and economic performance indicators are expected to change in response to a given change in certain variables that affect the project's cash flows. Key tasks within this context include: a) the identification of the project's critical variables, b) the calculation of switching values and c) the performance of a scenario analysis.

6.1.1 Identification of Critical Variables

"Critical" variables are defined as those input variables whose positive or negative variations cause significant changes to the project's financial and economic performance. Conventionally, "critical" variables are considered those for which a variation of ±1 % results to a variation of more than 1 % in the value of the NPV. Although it is already known from the analyses conducted in the two previous chapters that the project produces highly negative results in both financial and economic terms, we will nonetheless try to examine the circumstances under which the project may become (economically) profitable. The sensitivity analysis will be performed for the following variables following a "ceteris paribus" approach; one variable at a time will be altered and the effect that this variation has on the NPV will be determined:

- Financial Profitability: Investment Costs, O&M costs
- Economic Profitability: Investment Costs, O&M costs, Air Pollution, Climate Change (CO_2 emissions savings)

The estimated elasticity of the ENPV and FNPV(C) with respect to a 1% increase of the abovementioned key project variables is shown in the table below:

Variable	Variation of the FNPV due to a ± 1 % variation	Criticality judgement	Variation of the ENPV due to a ± 1 % variation	Criticality judgement
Investment Costs $\pm\mathbf{1}\%$	$\pm 0.76\%$	Not critical	$\pm 1.29\%$	Critical
O&M Costs $\pm\mathbf{1}\%$	$\pm 0.27\%$	Not critical	$\pm 0.43\%$	Not critical
Hydrogen Price $\pm\mathbf{1}\%$	$\pm 0.07\%$	Not critical	$\pm 0.11\%$	Not critical
Air Pollution $\pm\mathbf{1}\%$	Not applicable	-	$\pm 0.09\%$	Not critical
Diesel Price $\pm\mathbf{1}\%$	Not applicable	-	$\pm 0.14\%$	Not critical
CO_2 Savings $\pm\mathbf{1}\%$	Not applicable	-	$\pm 0.05\%$	Not critical

Table 21 Determination of the project's critical variables

The sensitivity analysis reveals that the project's financial performance is not sensitive to any change in the tested input variables; in both cases, it remains well below the threshold of 1%. On the other hand, the economic performance seems to be quite sensitive to the project's investment cost; the ENPV exhibits an estimated elasticity of 1.10% -in absolute terms- with respect to a 1% change in the investment costs and, hence, it constitutes the only critical variable.

6.1.2 Calculation of Switching Values

Another important concept used in the sensitivity analysis, is that of switching values. The switching value of a variable refers to the value that this variable would have to take in order for the NPV to become zero. Since the only variable identified as critical is the investment costs, we will proceed to determining the extent to which it will have to be adjusted in order to reach the benchmark.

Critical Variables	Switching Value (ENPV=0)
Investment Cost	**-77.69%**

Table 22 Switching value of the project's critical variable

The above result essentially confirms the fact that a significant reduction in the investment cost is required so as to deem the project economically profitable. The break-even is reached by an almost 78% variation of this parameter, a quite unrealistic figure reflecting, among other things, the highly negative financial profile of the project. As already stated, significant efforts and high up-front investments are currently required in order for the HFC bus technology to reach critical mass and competitive deployment.

The following spider diagrams illustrate the values taken by the FNPV(C) and ENPV as a result of different variations in the tested variables, both critical and not. The more steep the line gradient, the greater the elasticity of the profitability indicators with respect to the analyzed parameter. The criticality of the investment outlays to the economic profitability is clearly depicted in the second diagram.

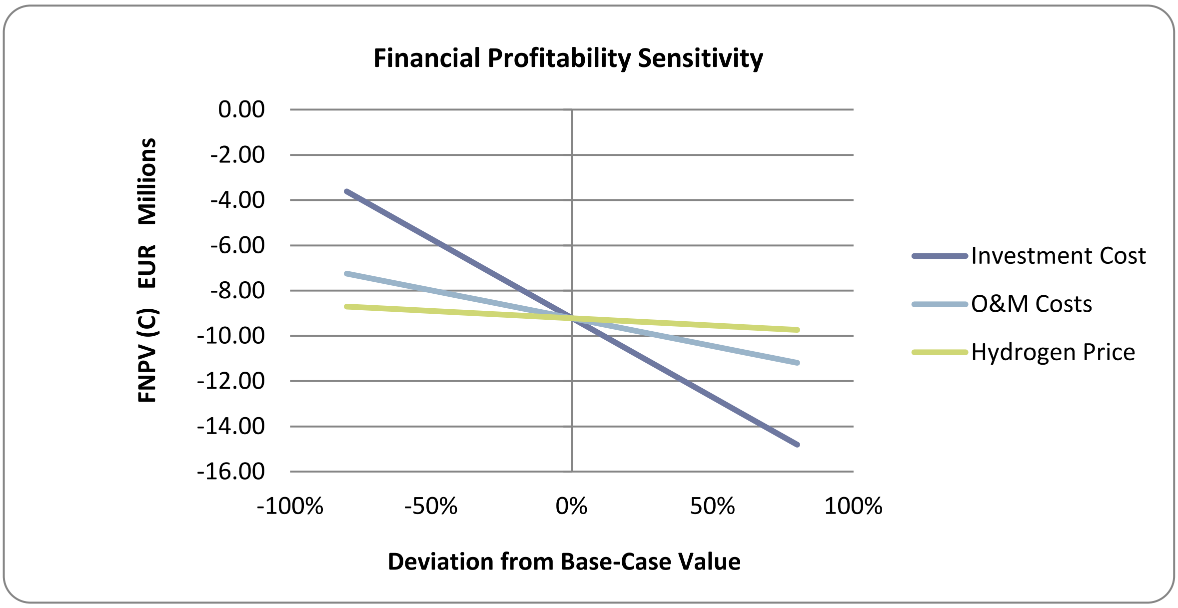

Figure 14 Financial Profitability Sensitivity

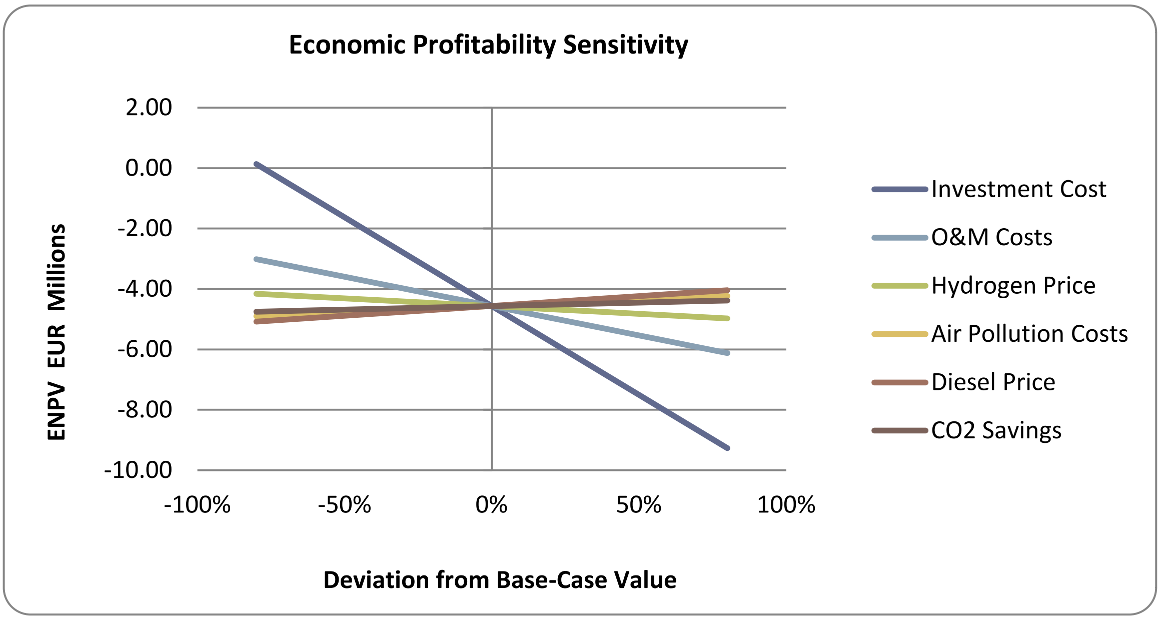

Figure 15 Economic Profitability Sensitivity

6.1.3 Scenario Analysis

The sensitivity analysis section is customarily completed with a scenario analysis which aims to study the combined impact of determined values taken by the critical variables. In particular, 'optimistic' and 'pessimistic' values - within a range defined as realistic as possible - are assigned to critical variables in order to produce a "Best Case" and "Worst Case" scenario, respectively. To each of these two scenarios, as well as to the "Base Case" scenario, specific probabilities are then allocated, leading up to the calculation of the Expected NPV.

In our case, as far as the bus' capital cost is concerned, we will make use of the upper and lower bounds provided by Element Energy (see Chapter 4). For the rest of the project's values, an ad hoc percentage of 20% will be added to and subtracted from each of the "Base Case" input values. The probabilities to be assigned to each scenario are subjectively assigned as follows: "Best Case" - 25%, "Base Case" – 50%, "Worst Case" – 25%. The results of the scenario analysis are presented in the table below:

Scenario	*Probability*	*FNPV(C)*	*ENPV*
Best Case	25%	-6,778,905	-1,903,251
Base Case	50%	-9,217,046	-4,565,608
Worst Case	25%	-11,661,786	-7,247,416
Expected NPV =	**∑(Prob x NPV)**	**-9,218,696**	**-4,570,471**

Table 23 Scenario Analysis (EUR)

6.2 Qualitative Risk Analysis and Risk Prevention

In addition to the quantitative analysis presented above, a qualitative risk analysis must also be carried out in order to identify potential obstacles in the implementation and operation of the project and to establish the most appropriate risk prevention/mitigation measures. Given the nature of the investment and based on the experience acquired from similar projects, the main risks and respective mitigation strategies are outlined in the following risk prevention matrix:

Risk Description	Probability (P)	Severity (S)	Risk Level (P*S)	Risk Prevention/Mitigation Measures	Residual Risk
			Administrative Risks		
Delays due to administrative procedures, such as the obtaining of permits for the hydrogen refuelling station and the maintenance facilities	C	III	Moderate	Establishment of a Project Implementation Unit, in charge of bringing the relevant departments together and finalise the needed procedures on time/ Harmonization of EU-wide regulations on hydrogen technologies is also under way.	Moderate
Late availability of EU grant co-financing	A	II	Low	Projects under the FCH JU are selected through open and competitive calls based on independent peer review and are concluded by formal funding agreements.	Low
			Construction Risks		
Investment Cost Overrun	C	III	Moderate	The cost budget should be compared with relevant benchmarking (see the EU's CHIC project) so as to correct possible optimism bias.	Low
Procurement – procedural delays due to contractors (failure to meet contractual deadlines, withdrawal, bankruptcy, etc.).	C	III	Moderate	The selection of contractors should be made in line with procurement legislation; emphasis should be paid to the quality of services and not only to the lowest price. The FCH JU provides advice through a Handbook called "Recommendations for delivering fuel cell buses".	Moderate
			Social Risks		
Public opposition	B	II	Low	Timely inform the public about the new technology employed in the project (benefits, safety standards).	Low
			Operational Risks		
Operation & Maintenance costs higher than expected	B	III	Moderate	The operating costs forecasts should be based on costs induced in similar projects as well as in reasonable benchmarks, in order to reduce optimism bias. Proper mechanisms should be established in order to deal with unexpected changes in costs and to ensure uninterrupted service.	Low
Staff training: underestimation of the training required	B	III	Moderate	Extensive training sessions for bus drivers, technicians and emergency services./ Increase the staff's motivation by highlighting the project's global scale.	Low
Limited bus availability due to: a) Problems in the supply chain (delays in identifying problems and providing spare replacement parts); b) Conventional component failures; c) Limited pool of maintenance staff during vacation periods	C	III	Moderate	Establish a contract exclusively with a bus OEM, who should act as the sole contractor for the project, managing all component suppliers. Ensure the availability of key personnel by training extra staff already familiar with electrical skills	Moderate

Table 24 Risk Prevention Matrix

Evaluation scale: Probability: A. Very Unlikely, B. Unlikely, C. About as likely as not, D. Likely, E. Very likely.
Severity: I. No effect, II. Minor, III. Moderate, IV. Critical, V. Catastrophic.
Risk level: Low, Moderate, High, Unacceptable.

Source: "*Guide to Cost-Benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020"*

The results of the risk analysis indicate that the project's overall risk level is moderate. Undoubtedly, the experience gained from past and current FC Bus demonstration projects under the FCH JU can help prevent the occurrence of the identified risks and mitigate their adverse effect. Nevertheless, risks associated with the immaturity of the FC technology sector are still present.

6.3 Probabilistic Risk Analysis

It has been made clear by now that the project has a highly negative financial and economic profile. In this regard, risk assessment was mainly carried out for the purpose of identifying the -albeit extreme- circumstances under which the project could become desirable from an economic point of view. Acknowledging the fact that a probabilistic risk analysis wouldn't seem meaningful given the results derived thus far, we will nonetheless proceed to this final step of risk analysis in favour of presenting an as complete as possible analysis.

As its name suggests, this type of quantitative risk analysis is centered around the probability distributions of the project's critical variables. A distribution essentially describes "the likelihood of occurrence of values for a given variable within a range of possible values around the best estimate/base value".

Among the various probability distributions, the Gaussian/Normal, is the most frequently used one. Considering that this distribution is appropriate in the context of our analysis, we will apply it to the project's sole critical variable, i.e. the investment costs, with the following assumptions:

(Mean; Standard Deviation) = (6,996,316; 1,000,000)

where, the mean of EUR 6,996,316 represents 0% changes in the base value while the standard deviation of EUR 1,000,000 depicts the degree of dispersion of the possible values around the mean.

Having determined the distribution of the critical variable, the calculation of the probability distribution of the project's socioeconomic performance indicator (ENPV) can be achieved through the use of a computerized mathematical technique known as the "Monte Carlo Simulation": multiple random extractions of a critical variable's values, taken within predefined intervals, lead to the calculation of the project's ENPV for each of this value.

The Monte Carlo Simulation was conducted for 1,000 iterations using Microsoft Excel's NORMINV(RAND();mean; standard deviation) formula. The results of the Simulation are presented in the histogram below:

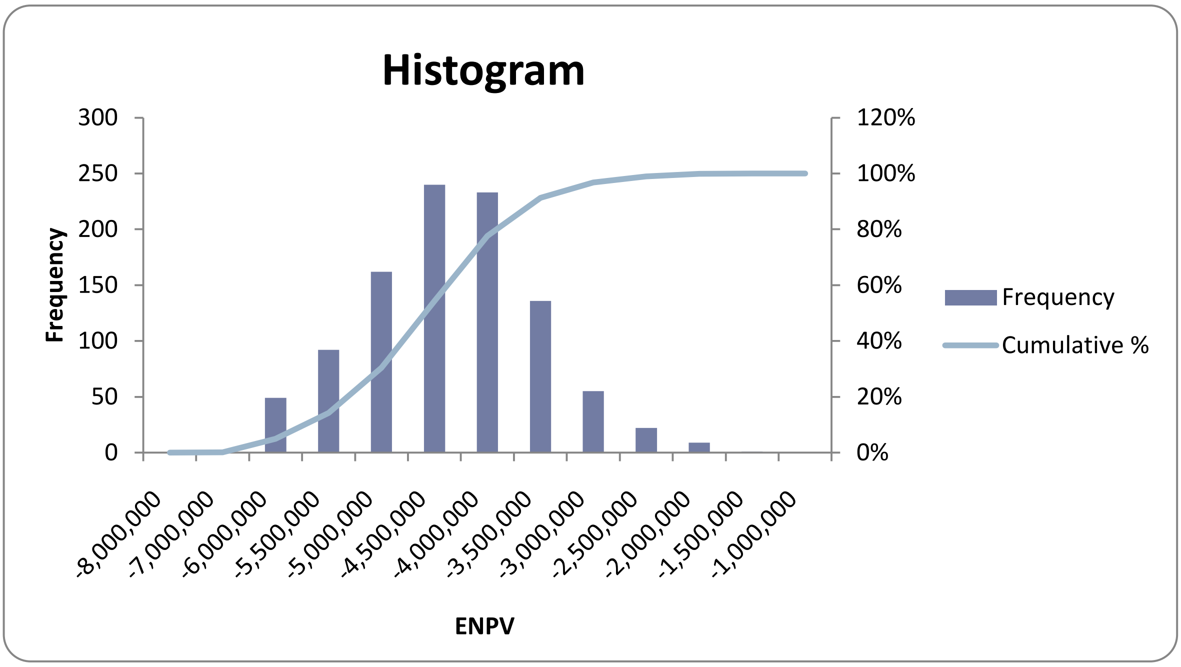

Figure 16 Monte Carlo Simulation - Probability Density & Cumulative Probability Distribution of the ENPV

The above chart indicates that, under the assumptions made, there is a nil probability for a non-negative ENPV.

Conclusions

The present thesis tried to assess a project involving a break-through technology applied in the field of public transport. The project was proposed in the framework of efforts currently made by several European countries with the aim to achieve a gradual shift towards emissions-free transport technologies and to ultimately tackle the major problems associated with the use of fossil fuels.

The analysis proved the investment's alignment with the national and European legislation and targets, and highlighted the economic, operational and environmental benefits Hydrogen Fuel Cell buses deliver in comparison with traditional diesel buses. Without a doubt, the zero emission technology that HFC buses employ holds the key to reducing our carbon footprint, leads to job creation and contributes to the preservation of our energy security.

Nevertheless, the fact that the abovementioned technology hasn't achieved maturity yet means that the start-up costs required are quite significant. As was clearly illustrated in chapter 5, despite the positive externalities arising from the implementation of the project, initial capital expenditure remains quite high and leads to a negative economic profitability. The sensitivity analysis conducted in chapter 6 came to corroborate this finding by recognizing investment costs as the only critical variable for the project's economic NPV. It is worth mentioning that the assumption of launching the buses on an existing -rather than on a new- route added to the deterioration of the profitability indicators, given that no incremental revenues would be generated from their operation.

Still, on condition that production volumes rise and that the technology advances, costs will undoubtedly decline. More specifically, according to projections based on recent and ongoing studies, HFC technology is expected to become competitive to the incumbent technologies, and most importantly to diesel, around 2030.

With regard to the FC bus purchase cost, considering that the principle cost drivers of FC buses are powertrain components, i.e. the FC system and its integration, researchers examining the future cost development of the FC bus market tend to distinguish between the following two technology pathways:

1) the "heavy-duty pathway", which refers to FC systems specifically designed and manufactured for use in heavy-duty vehicles such as urban buses

2) the "automotive pathway", which refers to the deployment of the same type of FC systems for both passenger cars and FC buses.

Current FC bus deployments are based on the first pathway, an option which has already proven viable for future market rollout. According to updated cost projections provided by Roland Berger in his study "Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe": "Overall costs for these buses are expected to decrease down to a cost premium of about 11-18% compared to conventional diesel buses on a per kilometre basis in the year 2030", while "from 2020, bus maintenance costs are expected to converge to diesel bus levels and hydrogen fuel costs are assumed to be even lower than diesel costs on a per kilometre basis". As future costs depend largely on the size of the FC bus market, two scenarios were developed in the framework of the heavy-duty pathway: the "niche scenario" and the "production-at-scale scenario".

The development of the FC bus purchase price for each scenario is depicted in the following graph. The cumulative number of buses required to be deployed in Europe by 2025 in order for each scenario to materialize is also provided.

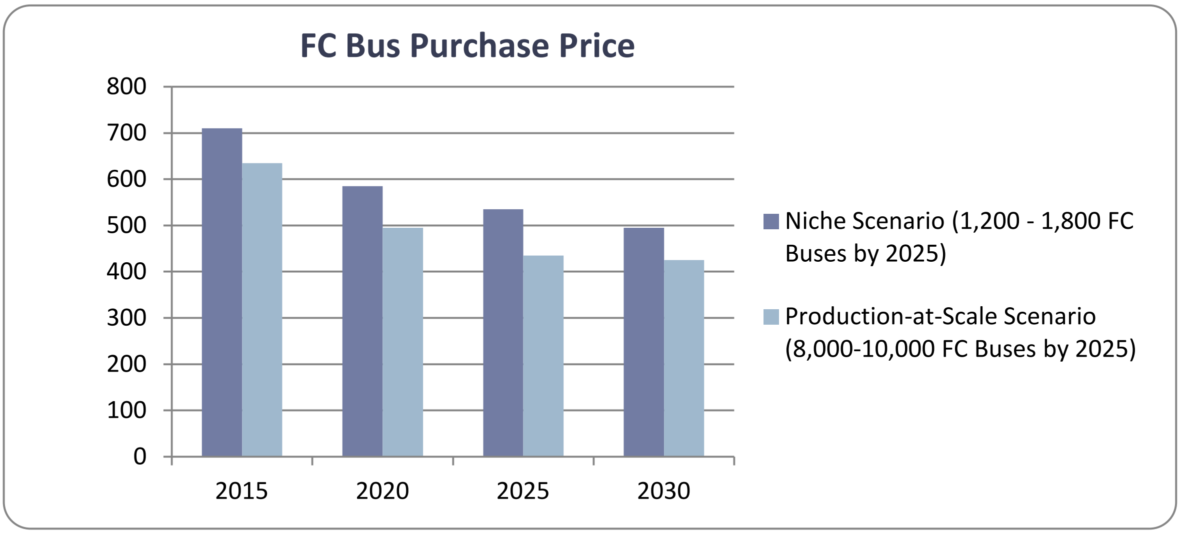

Figure 17 FC Bus purchase price development (EUR thousands) under the two scenarios of the heavy-duty pathway

With regard to the "automotive" pathway, additional, substantial cost reductions can be attained depending on the dynamics of the FCEVs' commercialization process. Should scale effects be realized in the FC passenger car market and should technical synergies be accordingly exploited, the FC buses' overall deployment costs will be able to compete with those of their diesel counterparts. More specifically, a scenario considered to be achievable before 2030 suggests an annual production of approximately 10,000 automotive FC stacks, leading to a FC bus purchase price of EUR 320,000.

Furthermore, according to the same study, cost projections for the maintenance of the buses as well as for the construction and maintenance of the Hydrogen Refuelling Station are as follows:

a) Bus maintenance costs are expected to be at a par with those for diesel buses after 2020.
b) The cost of an HRS, with off-site H_2 production, able to cater for at least 20 buses on a daily basis is expected to decrease by 24%.
c) HRS maintenance and operating costs are expected to be brought down by about 35-40%.

These cost figures are in line with the ones provided for the period beyond 2022 by Roberto Zaetta and Ben Madden in their 2010 study "Hydrogen Fuel Cell Bus Technology State of the Art Review".

Given that the second pathway is the most favorable in terms of cost reduction, it is deemed useful at this point to make a brief assessment of how these projections impact the project's profitability. Apart from substituting the original cost estimates with the above projections, certain extra assumptions must be made in order to provide plausibility to the scenario, namely:

1) The whole fleet (10 buses) will now be considered to be replaced by the FC buses in order to take advantage of the economies of scale assumed to have been already achieved.

2) An improved fuel efficiency of 7.3 kgH_2/100km will also be considered so as to be compatible with the technological developments in the FCH sector.

3) The analysis will be performed assuming a 3% annual increase in diesel fuel costs up to 2030 and beyond.

4) All other factors have remained the same.

Based on the above, and after conducting the necessary calculations, we arrive at an ENPV of EUR -67,540, very close to break-even. However, given the uncertainty as to the price of the fuel feedstock as well as to the discount rate for the period under examination, a sensitivity analysis is deemed appropriate. The results, presented below, demonstrate the sensitivity of the economic profitability particularly to changes in the price of diesel.

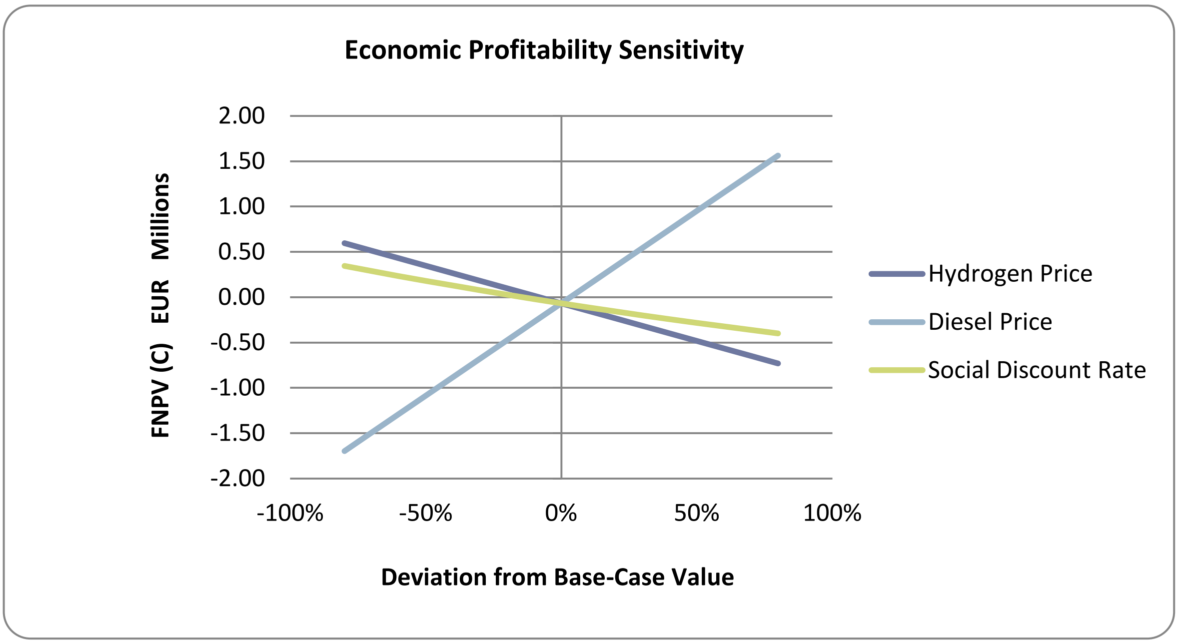

Figure 18 Economic Profitability Sensitivity using the 2030 cost projections

It can be shown that under the assumption of a slightly higher annual rate of increase in the diesel price (3.5% instead of 3%) the project's profitability can be turned around to a positive number of EUR 134,058. This assumption is a relatively plausible one, since the original rate of increase can already be perceived to be a conservative one in a future resource-limited energy system. Changes in the price of hydrogen are also deemed critical: a variation of 1 % in the price of hydrogen results to a variation of approximately 1.8 % in the value of the ENPV. In contrast, changes in the social discount rate don't seem to impact the project's economic profitability indicator.

All in all, even though current conditions are not conducive to deeming the project economically profitable, future ones certainly present that potential. Therefore, the project under consideration could be postponed and be implemented at a later stage, provided that the market uptake in the automotive sector suffices to substantially reduce initial costs, the investment's main barrier. Greece should in no way pass up the opportunity to exploit the numerous benefits that FC technology has proved to afford on multiple levels. As already stated, a project such as the one examined could undoubtedly lay the foundation for the wider adoption of this innovative technology and, ultimately, to the gradual transformation of our energy system.

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