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COST BENEFIT ANALYSIS FOR THE USE OF NATURAL GAS AND OTHER LOW CARBON FUELS IN THE TRANSPORT SECTOR IN LEBANON

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This document should be referenced as:
MoEW/UNDP/SODEL (2017) – Cost Benefit Analysis for the Use of Natural Gas and Other Low Carbon Fuels in the Transport Sector in Lebanon

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Executed by
Ministry of Energy and Water

Funded by
Ministry of Energy and Water – United Nations Development Programme

Implemented by
United Nations Development Programme

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Design and Printing
www.raidy.com

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FOREWORD

The world is undergoing a major and clear shift towards sustainability in the Energy consuming sectors, amongst which, transportation is rapidly transitioning to more sustainable and alternative fuel technologies as means of dealing with environmental and social challenges.

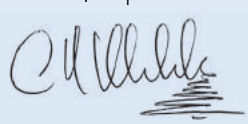
The market in Lebanon is also shifting towards a more responsible and more sustainable use and production of its energy needs but road transportation which represents more than 40% of the energy demand in Lebanon still constitutes a major environmental and social challenge.

This study plays an essential part in the efforts the Ministry of Energy and Water has been deploying jointly with all relevant stakeholders for the past few years to establish a sustainable transportation sector that will bring the people of Lebanon economic, social and health benefits, while it essentially contributes to the fight against climate change and air pollution and helps to meet the goals set in the 2030 global agenda for sustainable development.

The model and report that have been developed through this study will help inform policy makers of the timelines and transition strategies to alternative fuel vehicles that Lebanon needs to deploy so it gets the most beneficial results.

I thank the consultants, the SODEL project team and everyone who has contributed to this work, for their efforts and dedication to the greater benefit of Lebanon and encourage all relevant stakeholders to build on this accomplishment for progress on this key challenge.

Beirut, September 2017



Cesar Abi Khalil
Minister of Energy and Water

ACKNOWLEDGEMENTS

This report comes within the UNDP project "Sustainable Oil and Gas Development in Lebanon" (SODEL) under its second component "Enabling Environment for the Promotion of Alternative Fuels in the Energy and Transport Sectors". SODEL Component II was implemented for the benefit of and under the supervision and guidance of the Ministry of Energy and Water in Lebanon.

SODEL is thankful to all the project partners from the public and private sectors who contributed and assisted in developing this report particularly the Lebanon Oil Installations, Directorate General of Oil, Ministry of Environment, Ministry of Industry, UNDP Climate Change Project, Automobile Importers Association of Lebanon, Association of Petroleum Importing Companies in Lebanon, as well as IPT Energy Center (IPTEC).

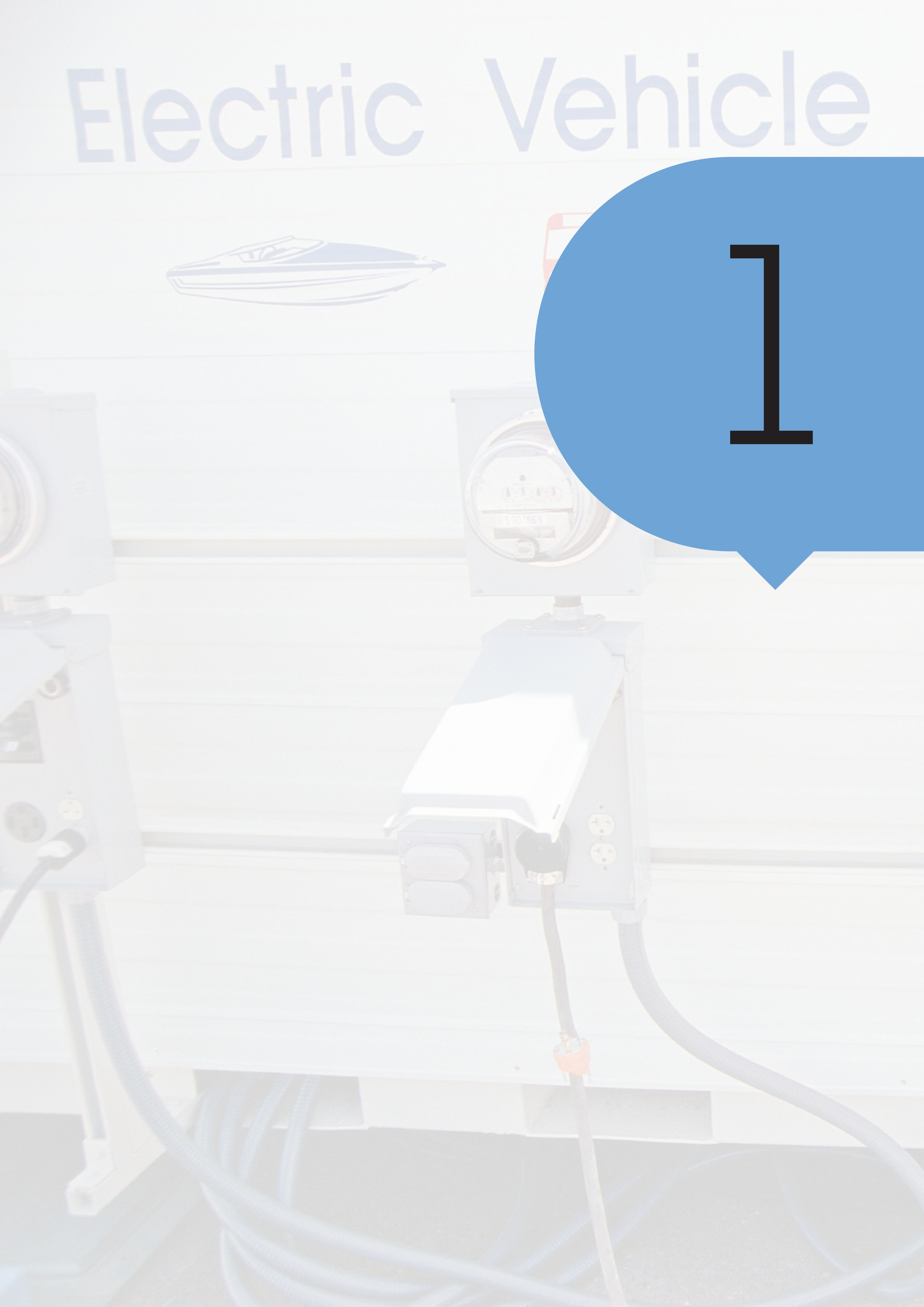
We also extend our gratitude to the United Nations Development Programme in Lebanon for all the support offered to the implementation of this project.

Last but not least, we would like to thank the main authors of this report, Dr. Charbel Mansour and Dr. Marc Haddad for their professionalism, dedication, and commendable output.

TABLE OF CONTENTS

TABLE OF ACRONYMS AND UNITS

CNG	Compressed natural gas
CO2eq	Carbon dioxide equivalent
FSRU	Floating storage and regasification unit
Gg	Gigagram
Gge	Gasoline gallon equivalent
GHG	Greenhouse gas
HEV	Hybrid-electric vehicle
HDV	Heavy-duty vehicle
ICEV	Internal combustion engine vehicle
LDV	Light-duty vehicle
Lge	Liter gasoline equivalent
LNG	Liquid natural gas
LPG	Liquid petroleum gas
Mtoe	Megatons of oil equivalent
NGV	Natural gas vehicle
PHEV	Plug-in hybrid-electric vehicle
TWh	Terawatt-hours
TTW	Tank-to-wheel
WTW	Well-to-wheel
Vkm	Vehicle-kilometer (also as Veh.km)



1

INTRODUCTION
THE ROLE OF ALTERNATIVE FUELS IN TRANSPORTATION

The use of alternative fuels in transportation is well established globally. For example, there are over 17 million natural gas vehicle (NGVs) worldwide and some 24,000 refueling stations (2014), with around 2% of total energy use in road transport (2013). Some of the main reasons for the switch away from conventional fuels are the relatively high oil prices and the environmental impacts of gasoline and diesel vehicles compared to the advantages of low carbon intensive fuels. This is especially true for natural gas which already benefits from fully developed technologies at the production, distribution and vehicle consumption stages, leading to much lower emissions at relatively low price. There is also increasing interest in LNG as a fuel for heavy duty vehicles and shipping. In Lebanon, the recent discovery potential of offshore natural gas reserves has raised interest in exploring the use of this cleaner fuel in the local transportation sector.

The study will investigate the potential pathways for the use of natural gas and other alternative fuels in the Lebanese transportation sector, and the associated environmental and financial impacts.
This report is structured as follows:

- Section 2 provides an overview of the energy usage trends and projections in the Lebanese transportation sector to estimate potential demand for alternative fuels in the local market.
- Section 3 provides a detailed assessment of the main technical, infrastructural, financial and environmental factors that make the case for each alternative fuel and vehicle option in terms of technology readiness, lifecycle costs, emissions, pathway requirements and general feasibility.
- Section 4 provides detailed pathways for the market deployment of each fuel type (including all industrial and commercial activities and processes) as adapted to the case of Lebanon. This serves as a precursor to assess the emissions, energy use and financial impacts of each fuel.
- Section 5 provides the WTW modeling and assessment of the emissions and energy use of each fuel pathway. The results of this assessment will serve as input for a cost-benefit analysis (CBA).
- Section 6 provides a detailed cost-benefit analysis (CBA) of the different fuel and infrastructure options, including vehicle costs, in order to down-select potential fuels suitable for market development in Lebanon

2

2.1.
ENERGY IN TRANSPORT – THE CURRENT STATE

2.2.
FUTURE EVOLUTION OF TRANSPORT ENERGY DEMAND IN LEBANON – BUSINESS-AS-USUAL SCENARIO

THE DEMAND FOR ENERGY IN TRANSPORTATION IN LEBANON

Transport is a major consumer of energy. This section examines the present state of demand and consumption of energy in transport in Lebanon, where oil-based fuels are still the only source. The respective shares of energy demand in the main transportation sectors (road passenger cars and freight, marine and aviation) are considered both globally and in more detail for Lebanon. Specifically for the Lebanese case, the recent growth trend of transport demand is presented in order to forecast changes in energy demand and fuel use over the short, medium and long-terms.

ENERGY IN TRANSPORT – THE CURRENT STATE 2.1.

IEA statistics indicate that transportation accounted for around 27% of global total consumption of energy in 2010 (IEA, 2010). According to Lebanon's National GHG Inventory Report for the Transport Sector (prepared for Lebanon's Third National Communication (TNC) report to the UNFCCC), gasoline is the dominant fuel in road transport, providing some 83.5% of consumption whilst nearly 16.5% is satisfied by automotive diesel (green diesel) and diesel oil (red diesel). Table 1 shows the other main fuels consumed in Lebanese transport, and Figure 1 illustrates the energy demand growth trends across all sectors in recent past. Natural gas is not reported separately and consumption figures must therefore be determined from other sources as described below.

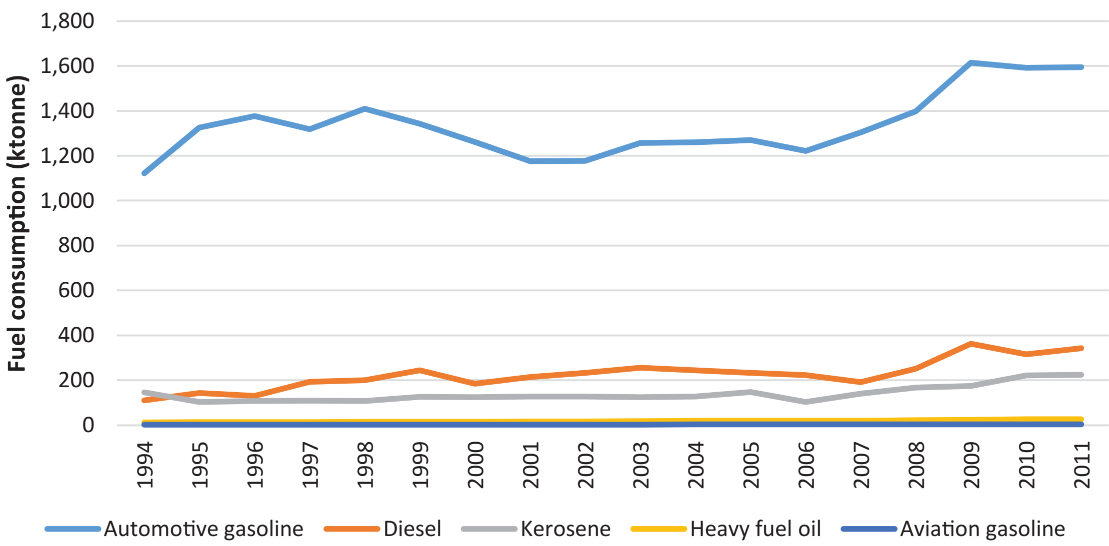
Table 1. Transportation energy consumption per fuel type in 2010.

Source: (MOEW, 2010)

	World 2010 *(ktonne of fuel)*	Lebanon 2010 *(ktonne of fuel)*
Gasoline	909,270	1,595
Diesel	807,892	315
Kerosene	235,723	221
Heavy fuel oil	2,273	26

Figure 1: Growth trends for energy demand in Lebanon.

Source: (Mansour, 2015)



For the purposes of this analysis, the transportation sector in Lebanon is sub-divided into the following modes:

- Passenger cars and taxis (PC)
- Light duty gasoline vehicles (LDV)
- Heavy duty diesel vehicles (HDV)
- Public transport diesel buses
- Commercial aviation
- Marine fisheries, yachts and commercial shipping

Rail, domestic aviation and inland water transport are not included since these services are not currently operational in Lebanon. Aviation trainers, marine fisheries and yachts are not considered further since fuel consumption for these modes is negligible compared to the total consumption.

The estimated breakdown of fuel consumption by transport mode is shown in Table 2.

Table 2. Fuel consumption per transport mode in 2010.

Source: (Mansour, 2015)

Transport Mode	Fuel Type	World 2010 *(ktonne of fuel)*	Lebanon 2010 *(ktonne of fuel)*
PC	Gasoline	1,108,727	1,324
LDV	Gasoline		280
HDV	Diesel	363,309	361[(a)]
Buses	Diesel	83,546	117[(a)]
Aviation	Kerosene	214,208	221
Marine	Heavy fuel oil	227,431	26

[(a)] *The diesel fuel consumption numbers reported by the MOEW in Table 1 differ from those given above, due to illegal fuel imports unaccounted for in the MOEW figures.*

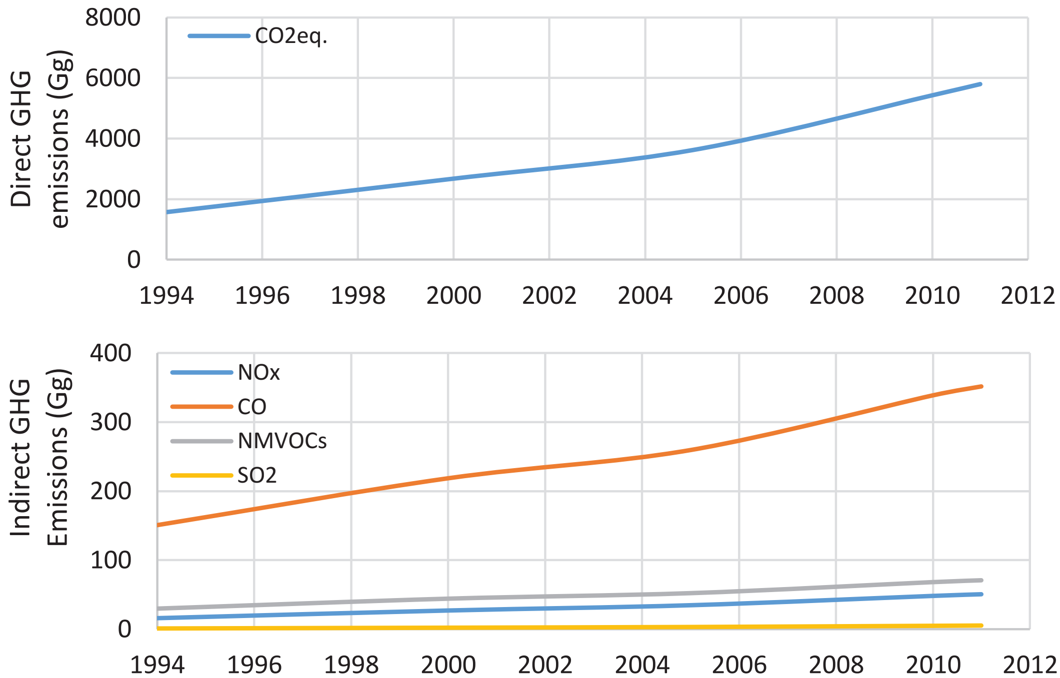
In global terms, oil usage in transport was around 2,200 Mtoe in 2010, of which 1,606 Mtoe was in road transport (WEC, 2011). In Lebanon, road transport is the dominant transportation mode with the main fuels being gasoline and diesel, and a corresponding usage of 2.15 Mtoe in 2010, in other words 0.13% of the world road transport consumption (for 0.065% of the world total population).

According to the Lebanese Technology Needs Assessment (TNA) report, the Lebanese vehicle fleet consisted in 2010 of around 1.34 million passenger cars and LDVs working on gasoline, and 33,000 HDVs working on diesel (Mansour, 2012). Despite this relatively small proportion of HDVs (2.4% of the total fleet, excluding motorcycles), they account for a significant share of fuel consumed in transport – around 23% of total road transport energy consumption in 2010.

Transport in Lebanon accounts for around 21% of greenhouse gases (GHGs) and mainly from road transport (TNC 2015). Direct GHG emissions of CO_2, CH_4 and N_2O emitted from the road transport sector significantly increased from 1994 to 2010 by over 350%, as illustrated in Figure 2.

Figure 2: Emission trends for transport in Lebanon.

Source: (Mansour, 2015)



This increase is mostly related to the upturn of the number of registered vehicles in Lebanon from 500,000 in 1994 to more than 1.2million in 2010, exceeding even the country's population growth rate. In fact, 175 vehicles per 1,000 persons were observed in 1995 and 330 in 2010 (Ministry of Environment, 2014). Among the main reasons for this significant increase is the inefficient and unreliable management of the mass transport sector, preventing the modernization and growth of the system and allowing the market to be controlled by private operators with an ad-hoc evolution strategy; consequently encouraging passengers to rely on their private cars for their daily trips, along with the lack of policy enforcement for encouraging deployment of new fuel efficient vehicle technologies (Mansour & Haddad, 2014). Table 3 shows a comparison between Lebanon and world totals for GHG emissions.

Table 3. Transportation direct and indirect GHG emissions in 2010.

	World 2010 *(Gg)*	Lebanon 2010(5) *(Gg)*
$CO2_{eq.}$	6,484,285.5(1)	5,413.6
NO_X	645,816.2(2)	48.2
CO	125,000(3)	339
NMVOC	Not available	68.4
SO_2	1,800(4)	4.8

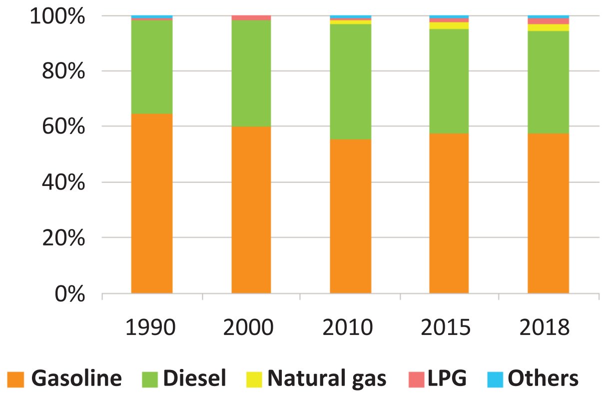
(1) (CAIT, 2010)
(2) (WB, 2016)
(3) (Granier, 2015)
(4) (Klimont, Smith, & Cofala, 2013)
(5) (Mansour, 2015)

Comparing the global demand for oil versus alternative fuels, natural gas - the primary alternative fuel - accounted for only around 2% of road transport fuel globally in 2012, growing from just 0.2% in 2000. BP (2014) forecasts gas demand to grow to 6.6% of total forecast transport energy demand and 4% of total forecast gas demand by 2035. In Lebanon, natural gas is not currently used in any of the transport modes, and there is currently (either legislation banning its use or no policy legislating its use in the transport sector), so there is no projected growth of demand for its use or that of LPG (although LPG is currently being used in an illegal and unsafe manner) in the foreseeable future under the current circumstances. This situation also applies to other alternative fuels since no current legislation or initiatives exist to reduce GHG emissions and promote the use of such fuels in the near future.

The estimated global market shares of all fuel types are shown in Figure 3.

Figure 3: Split of global road transport fuel demand.

Source: (IEA, 2013)



The countries where gas consumption in transport is significant (i.e. greater than 0.8 TWh) are shown in Table 4.
This demonstrates that with the notable exception of Italy, gas consumption in transport is still a very small proportion of the total.

Table 4. Natural gas in transportation in EU, 2012.

Source: (Eurogas, 2013)

Country	Total gas consumption *(TWh)*	Transport share *(TWh)*	Transport share *(%)*
France	492.4	1.3	0.3%
Germany	909.1	2.8	0.3%
Italy	792.6	9.6	1.2%
Poland	176.9	3.3	1.9%
Spain	362.6	0.9	0.2%
Other	2327.3	1.9	0.1%
Total for EU	5060.9	19.8	0.4%

FUTURE EVOLUTION OF TRANSPORT ENERGY DEMAND IN LEBANON – BUSINESS-AS-USUAL SCENARIO 2.2.

A projection estimation of the growth of energy consumption in Lebanon was completed in the National GHG Inventory Report and Mitigation Analysis for the Transport Sector in Lebanon, and the business-as-usual scenario is summarized in this section. This includes growth estimates for vehicle stock, transport activity and CO_2 emissions to help understand and assess trends in the evolution of the transport sector up to 2040. The projection takes into account the influence of population and GDP growth (UNECE, 2013). The estimates are only for road passenger and freight transport modes, taking into consideration the different vehicle classes, powertrains (vehicle propulsion and control components) and used fuel blends. Aviation and maritime transport were excluded.

The evaluation of energy use projection is performed using the ASIF framework (Fuel use and energy Intensity in transport Activity by Structural components) of equation (1):

The equation was first used to calculate fuel consumption in the transport system in 2010 (the base year) and the projected yearly consumptions up to 2040, in order to cover the short, medium and long-term. The associated estimates for transport activity, vehicle stock and CO_2 emission projections are also developed using a similar approach.

It was found that for both gasoline and diesel fuel use, there is a projected substantial increase compared to 2010, which is a direct consequence of the expected economic growth and increase in transport activity in Lebanon up to 2040. This economic growth is projected to trigger an increase in the number of personal passenger cars and LDVs and their corresponding annual distance traveled, with vehicle-kilometer (vkm) activity estimated to increase by 31% in 2020 and 103% in 2040 compared to the base year.

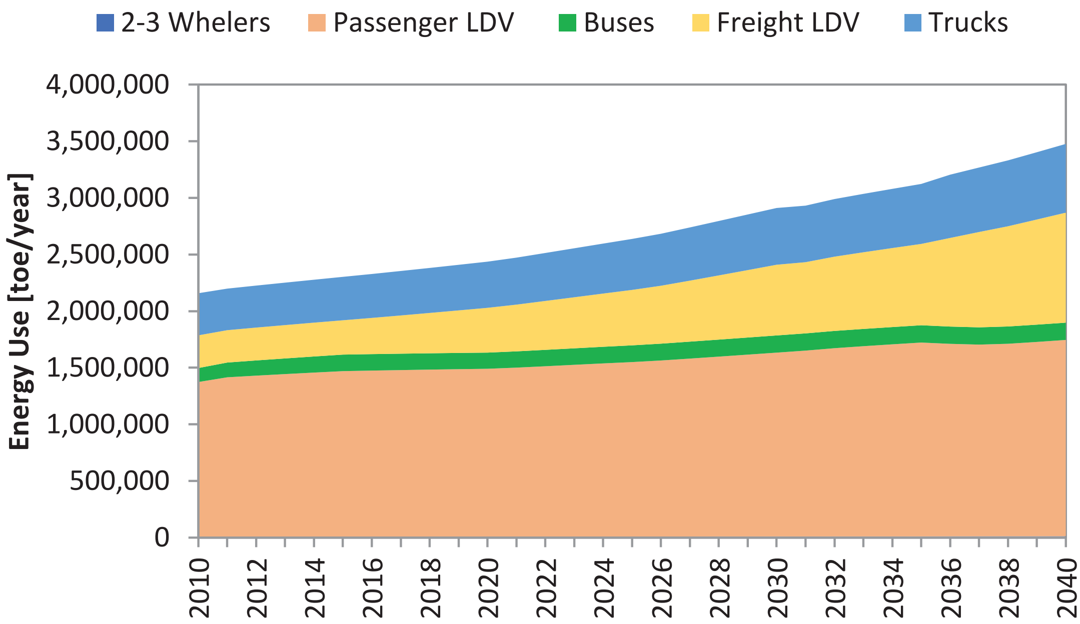
An estimated increase in CO_2 emissions follows closely the trend of the energy demand since emissions are mostly related to fuel consumption (Figure 4).

$$F = A \sum_i S_i I_i \qquad (1)$$

F	total fuel use
A	overall vehicle activity (in vehicle-kilometer (vkm))
F_i	fuel used by vehicle (i) with a given set of characteristics (by mode, vehicle class and powertrain)
S_i	sectoral structure (expressed as shares of vkm by mode, vehicle class and powertrain)
I_i	energy intensity (the average fuel consumption per vkm by mode, vehicle class and powertrain)

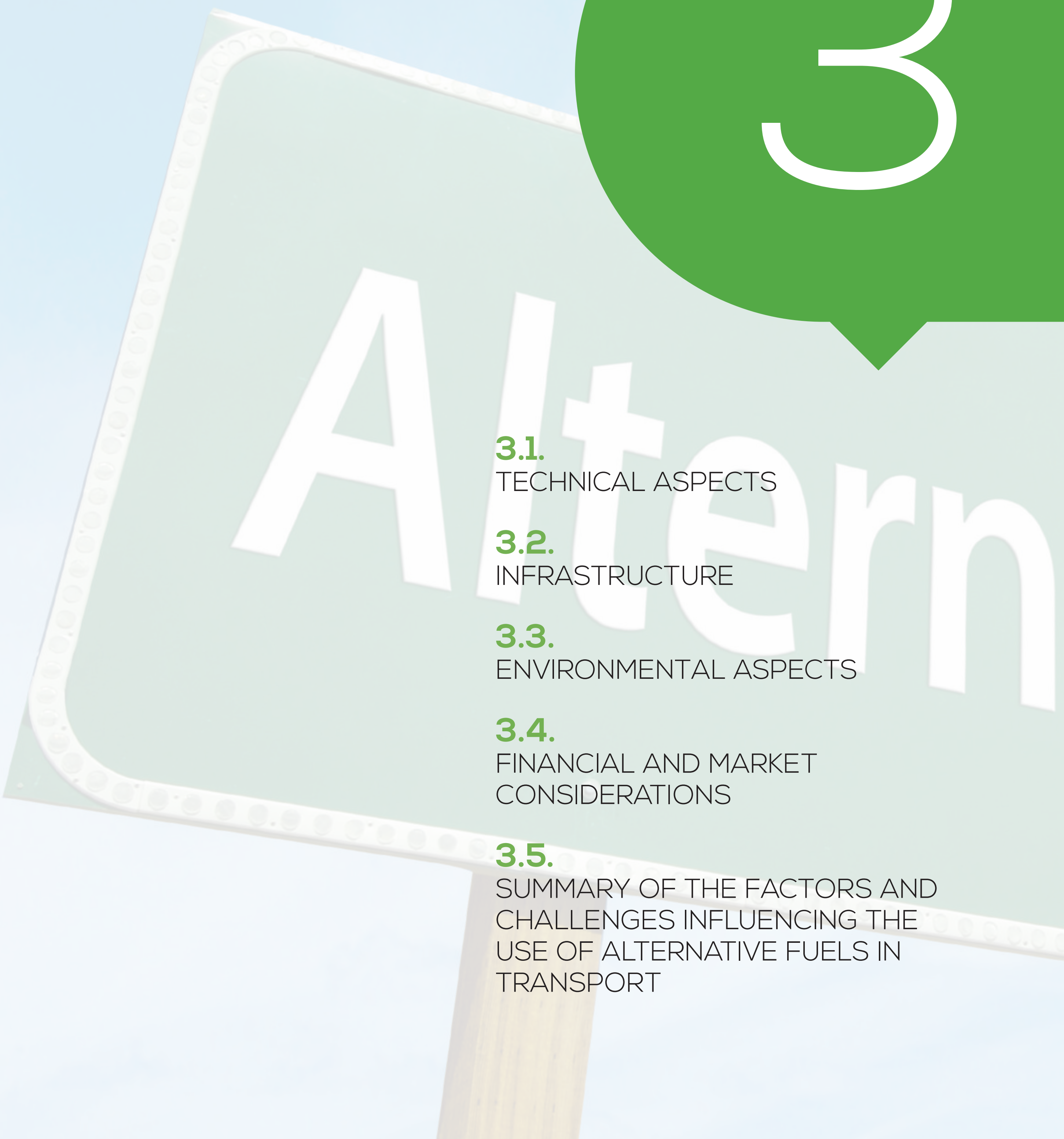
Figure 4: Baseline projection of passenger and freight energy use.

Source: (Mansour, 2015)



It is noteworthy to summarize the assumptions used in the report's business-as-usual growth estimates, as follows:

- The same preferential use of personal motorized passenger vehicles in the future is assumed as in 2010, and very low reliance on public transportation is maintained.
- The powertrain technology shares remain similar to the shares reported in 2010: 11.8% for small vehicles, 54.9% for midsize vehicles and 33.3% for large vehicles; however taking into account the improvement of the fuel consumption of each powertrain technology over time.
- Same CO_2 emission factors in 2040 as in 2010, reflecting no changes in fuel types, and therefore excluding switches towards low-carbon-intensive alternative fuels.
- A growth in gasoline and diesel fuel prices by 50% in 2040 is assumed compared to 2010 (USEIA, 2015)
- Population growth of 22% in 2040 compared to 2010.
- GDP growth four times in 2040 compared to 2010.



3

AN OVERVIEW OF THE USE OF ALTERNATIVE FUELS IN TRANSPORT

Recent developments in engine and fuel technologies involving the use of alternative fuels are receiving a lot of attention in the transportation industry, due to their sustainability promise (reference). These fuels, namely compressed natural gas (CNG), liquid natural gas (LNG), liquid petroleum gas (LPG), ethanol, biodiesel, hydrogen and electricity, are expected to bring cost and/or emissions savings when compared to the current commonly used oil-based fuels. In particular, for markets where natural gas reserves and alternative fuel production are accessible, and where pollution and traffic congestion challenges are rampant, the switch to these fuels looks to make significant economic and environmental sense. Serious investments are being considered with many initiatives already under way (example the use of natural gas and biofuels in Brazil). Such initiatives are not however without barriers and challenges, for example the potentially high up-front vehicle and infrastructure costs. In this section, we seek to explore in detail the technical, infrastructural, financial and environmental enablers and barriers relating to the use of alternative fuels, both globally and as they apply to the Lebanese context.

TECHNICAL ASPECTS 3.1.

This section provides an overview of conventional and alternative fuel characteristics and the corresponding engine technologies.

3.1.1 Fuel characteristics

Some of the main technical criteria for evaluating the use of a fuel in an internal combustion engine is the fuel's ability to ignite (burn) easily, cleanly (with relatively less emissions), and having the potential to produce sufficient power (with a high heating value) for the vehicle in a safe and reasonably inexpensive way. To make this possible, the fuelmust be readily available in quantity and easy to transport. The main existing and prospective fuels for transportation use are as follows:

- Gasoline – still the most commonly used fuel in transportation; popular for its high heating value (42 MJ/kg) and high performance in terms of mileage and horsepower. Gasoline is a readily available fuel, with a well-established infrastructure and mature engine technology. It can have a high octane rating (such as the 95 and 98 octanes used in Lebanon) when additives such as aromatic hydrocarbons are used. This allows it to withstand higher compression pressure before igniting, making it ideal for high performance engines. However, gasoline engines rely on the use of several emissions control systems, which increases costs and degrades vehicle performance. As a result, and since oil is a non-renewable resource, gasoline cannot be considered a sustainable fuel on the long term.

- Automotive diesel – known as petrodiesel, it is similar to gasoline in its energy characteristics and market and engine technology readiness, with an advantage in terms of burning more efficiently but at the expense of higher emissions, namely particulate matter (PM) and nitrous oxides (NOx) which require the use and regular maintenance of particulate filters and catalytic converters. Concern about these harmful emissions has led to a tightening of emissions standards on the use of diesel fuel in engines worldwide.

- Natural gas (NG) – Natural gas is a non-renewable fossil fuel, consisting largely of methane (CH_4) and other hydrocarbons, occurring naturally underground and often in association with petroleum. It is readily available like petroleum, and has become increasingly accessible with the recent exploration of previously untapped shale formations. Unlike oil, NG has low carbon content, meaning it burns cleaner than gasoline and diesel. As a transportation fuel, NG has a naturally high octane number of 130 (without the help of additives), which means it ignites easily and has a performance equal to gasoline and diesel, but with cleaner exhaust emissions (for example, it produces between 6% and 23% less CO_{2eq} than gasoline on a well-to-wheel basis (Marbek, 2010), (USDOE, 2015), (NGVA, 2014)). However, NG has slightly lower energy content per unit mass and unit volume than gasoline and diesel.

In natural gas vehicles (NGVs), NG can be used as compressed natural gas (CNG) or liquid natural gas (LNG). CNG is produced by compressing methane at high pressures of 200-250 bars, and it is stored safely in high-pressure cylinders. LNG is produced by cooling to -162C when methanebecomes a liquid. LNG is therefore more suitable for long range transportation since more energy can be stored onboard in liquid form, making it preferred for HDVs and buses, whereas CNG is more appropriate for smaller PCs and LDVs. LNG is however subject to boil-off during storage and dispensing when temperatures exceed -162C, so that some of the liquid turns into gas and leaks out into the atmosphere.

A new development in natural gas for use as a transport fuel is biogas, also known as bio-methane, which is extracted from renewable resources. It is typically produced from the process of anaerobic digestion of biomass, such as manure, food waste and crop residues. The resulting biogas has a high methane content which upon purification is upgraded to natural gas quality and which can then be used as a transport fuel in either compressed (CBG) or liquefied (LBG) form, similar to CNG and LNG. In this study, biogas is not considered separately since it is fully-interchangeable with natural gas in transport, both in terms of vehicle technologies as well as distribution infrastructure.

Liquid Petroleum Gas (LPG) – referred to as autogas or auto-propane or butane, it is a mix of propane and butane which are its two main constituents (in winter, LPG mix on a global average is 60% propane, 40% butane, and in summer the proportions are reversed to adjust for the evaporation point of each constituent). LPG occurs naturally in petroleum and natural gas and is recovered during extraction and refining; it is gaseous at room temperature, and must be compressed at moderate pressure to maintain its liquefied form. It is kept in pressurized storage tanks throughout the entire supply chain from the source to the fuelling station as well as in the vehicle, before it is ultimately consumed as a gas in the vehicle's engine. It has lower energy content and efficiency than gasoline and diesel, but better combustion properties than all other liquid fuels with a high octane rating of 102-108; it burns much more cleanly than gasoline and diesel, with nearly no particle emissions.

LPG is commonly used in taxis or high mileage fleet vehicles (both LDVs and HDVs) and is generally cheaper and less polluting than gasoline and diesel.

- Ethanol – ethyl alcohol is a "quasi-renewable" biofuel produced from sugar cane, wheat and maize, it can be used by itself (100% ethanol fuel) or blended with conventional fuels (so called bio-fuels or flex-fuels). Ethanol in all its forms is readily available and its supply infrastructure is well established, especially in industrialized countries; however there have been recent concerns about direct and indirect land-use change impacts from its production. These include the release of GHG emissions from crop cultivation and processing into a finished fuel, the displacement of food production to previously uncultivated land with the associated energy costs, emissions, and food price increases; as well as changes in soil characteristics, loss of forest areas and biodiversity, and displacement of populations, among others. As a result, the sustainability of ethanol and other biofuels has recently come into question, but their use in transportation remains widespread.

Most gasoline cars can run on blends of up to 10% ethanol (E10) without any engine modification, and there is even increasing use of higher blends such as E85 (85% ethanol and 15% gasoline), though they cannot be used in conventional engines. Such advanced flex-fuels have a higher octane rating of 94-97, which is only on par with unleaded 95-98 octane gasoline used in conventional engines in Lebanon.

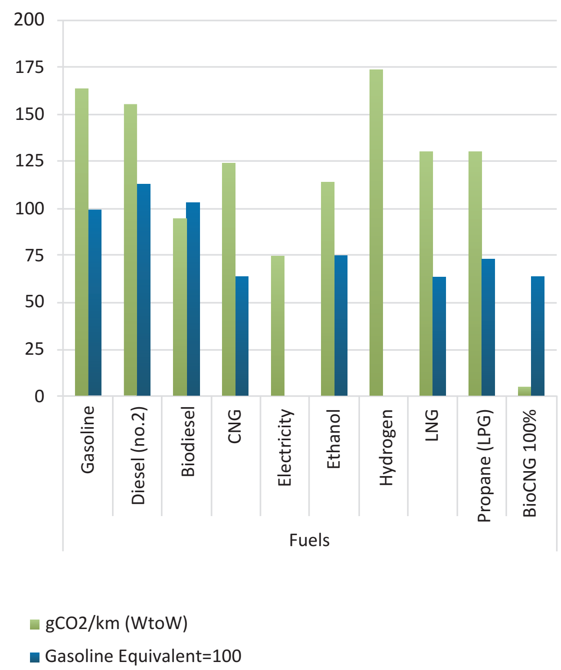
- Biodiesel – known as FAME (fatty acid methyl esters), it is produced from rapeseed, palm oil and used cooking oil. Biodiesel can be used in standard diesel engines, either alone or blended with conventional petrodiesel. Blends such as B20 (20% biodiesel and 80% petrodiesel) and lower, such as B7, can be used directly without engine modification. Biodiesel is gaining ground in transportation, especially in countries which produce oil feedstock such as Brazil, but like other biofuels it has been subject to concerns over the effects of its production on land-use change. Having the appropriate climate and land area to grow the needed feedstock is an important factor in the supply chain of biodiesel, with Brazil and Malaysia leading the low-cost production of biodiesel from vegetable oil. This makes the importing of seeds, oils or even processed biodiesel an essential part of the production lifecycle.

- Electricity – mainly used to power three types of vehicles – hybrids (HEV) and plug-in hybrids (PHEV) that have an alternative power source, and battery vehicles (BEV) that don't. HEVs charge the electric engine from the on-board internal combustion engine, and plug-ins get electricity from the grid (to be elaborated with review of Lebanese case).

- Hydrogen – can be used as a fuel directly in internal combustion engines though it is most efficient in fuel cells. Hydrogen fuel cells is a technology still in development, but promising many advantages such as zero exhaust emissions and reduced engine noise. Hydrogen is considered a third-generation fuel significantly far from commercialization, including the need for the development of an extensive production, distribution and refueling network.

Figure 5 provides an approximate comparison of the main transport fuels in terms of energy compared to gasoline and emissions performance. The CO2 emissions performance is calculated on a "well to wheel" (WTW) basis, which is discussed in section 4 of this report.

Figure 5:
Fuel comparisons: energy and CO2.
Source: (Le Fevre, 2014)



In summary, the technical aspects of vehicle fuels relate both to their physical constituents and how they perform in various engine types. In broad terms, diesel and gasoline represent the most efficient delivery of energy per unit of volume but have the potentially most damaging effect in terms of carbon dioxide and other emissions. Whilst natural gas is less energy intensive, there are no major technical obstacles to the fuel and its environmental advantages suggest it is a realistic alternative to traditional oil-based fuels.

3.1.2. Alternative fuel engines and vehicles characteristics

Since alternative fuels are not in use yet in Lebanon, this section focuses on the global current state of technology, discussing the availability of engine and vehicle technologies for alternative fuels, for both light duty and heavy duty transportation systems.

The reciprocating internal combustion engines (ICE) power nowadays almost all road vehicles and will remain holding the biggest share of the global powertrains market for the next decades despite all the efforts to substitute it with electric motors and fuel-cell stacks. They are classified under two broad combustion categories: spark ignition (SI) engines and compression ignition (CI) engines.

SI engines are well suited to light duty transportation uses, namely passenger cars. They are powered by gasoline, and can be substituted in alternative fuel vehicles (AFV) by CNG, LNG, LPG and hydrogen (called bi-fuel vehicles); or blended with ethanol (e.g. E85, called flex-fuel vehicles). These engines are relatively lightweight, and provide good performance with a broad torque over a relatively wide range of engine revolution. Although SI engines have cleaner burning capabilities compared to CI engines, they are thermally less efficient and not suitable for high torque low engine revolution transport applications such as heavy duty vehicles.

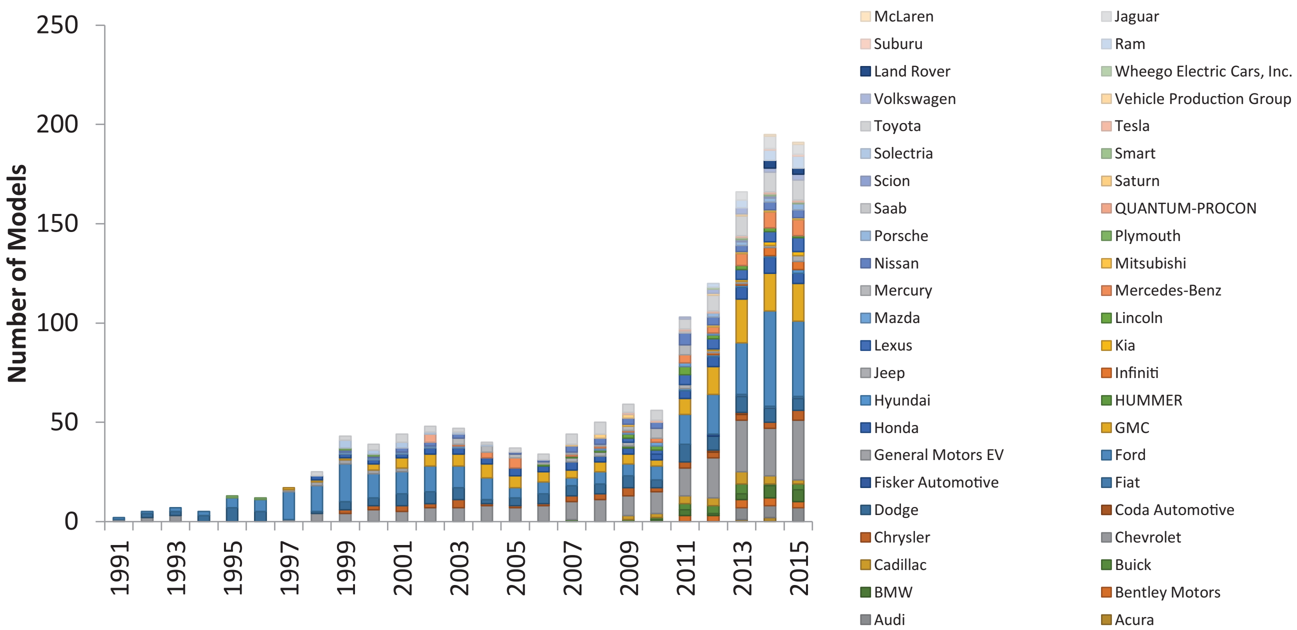
CI engines can power almost the whole range of road vehicles: passenger cars, light duty vehicles and especially heavy duty vehicles due to their high torque capabilities. They run on diesel, and can be blended in AFVs with natural gas (called dual-fuel vehicles), hydrogen and biodiesel (e.g. B7). These engines are heavier than SI engines; however, they present higher compression ratio which self-ignites the fuel without the need of a spark plug. This results in a higher engine thermal efficiency and higher torque capabilities (even at low engine speed) than SI engines.

Both types of engine technologies are available for use in AFVs. SI engines are used in bi-fuel and flex-fuel vehicles dedicated for passenger cars and light duty vehicles, and CI engines are used in dual-fuel and biodiesel-blend vehicles for heavy duty vehicles.

Bi-fuel vehicles are capable to run on two fuels: gasoline and CNG or LPG. The two fuels are stored in separate tanks and the engine runs on one fuel at a time (Nijboer, 2010). The engine has the capability to switch back and forth from gasoline to the other fuel manually or automatically. While vehicle retrofit has helped in the past to develop the CNG and LPG markets, bi-fuel vehicles retrofitting is currently forbidden in Europe and a global tendency towards original manufacturers bi-fuel vehicles is reported (reference: the contribution of NGV to sustainable transport). Original manufacturer vehicles are preferable for their quality control systems, reliability and engine optimization. Several passenger car and light duty vehicle models have become available on the market over the past years, as summarized in figure 6.

Figure 6: Alternative fuel vehicle and hybrid electric vehicle models offered by original manufacturer.

Source: (AFDC, 2015)



ORIGINAL MANUFACTURER VEHICLES ARE PREFERABLE FOR THEIR QUALITY CONTROL SYSTEMS, RELIABILITY AND ENGINE OPTIMIZATION. SEVERAL PASSENGER CAR AND LIGHT DUTY VEHICLE MODELS HAVE BECOME AVAILABLE ON THE MARKET OVER THE PAST YEARS

Flex-fuel vehicles run on any mixture of gasoline and ethanol, from pure gasoline up to 100% ethanol (E100), by automatically adjusting the engine fuel injection and spark timing according to the detected blend by a fuel composition sensor. However, despite the availability of this technology, these vehicles are optimized to run on E85 in order to reduce ethanol emissions at low temperatures and avoid cold-start problems at temperatures lower than 11 °C (reference: Ethanol vehicle cold start improvement when using a hydrogen supplemented E85 fuel). These vehicles require fundamental engine design modifications as illustrated in figure 7, namely a higher compression ratio, and the use of specific material in the engine components to prevent from corrosion and wear (such as the substitution of rubber by fluorocarbon rubber in the fuel pipes) (reference: Influence of composition of gasoline-ethanol mix on ICE). Consequently, the use of E85 is restricted to dedicated engines, and could have a limited market in Lebanon. However, E10 can be used in engines of most modern vehicles without the need for any modification on the engine or fuel system.

Figure 7: Required adjustments to gasoline engines to cope with different blends of ethanol fuel.

Source: (The Royal Society, 2008)

Ethanol blend	Fueling system[a]	Ignition system	Catalytic converter	Basic engine	Lubrica-tion oil	Intake manifold	Exhaust system	Cold start system
Up to E10	*No necessary modifications*							
E10-E25	*Require modifications*			*No necessary modifications*				
E25-E85	*Require modifications*							
E85-E100	*Require modifications*							

[a] Injection system, fuel pump, fuel pressure, fuel filter, fuel tank.

Dual-fuel vehicles are a special version of bi-fuel vehicles for heavy duty applications (such as buses, trucks, refuse trucks, off-road vehicles, forklifts and tractors), where the natural gas is ignited by an injection of diesel fuel (i.e. the diesel acts like a spark plug and is called "pilot fuel"). Thus, the natural gas injection system is electronically controlled by the engine control unit in order to monitor the engine performance. These vehicles can have variations in natural gas to diesel ratios (known as the substitution rate), depending on the engine load. When the engine is idling, only a small amount of energy is required, and it can be fully provided by the pilot fuel; thus, no natural gas is consumed. As the load increases, the energy consumption goes up and the degree of diesel that is replaced by natural gas as well. These engines used to have less power and torque than conventional diesel engines though more recent designs have closed this gap. These vehicles still lack of formal recognition, as no regulations is yet defined due to their use of multiple fuel simultaneously and consequently the difficulty to set emissions test measurement for such type of combustion application. Consequently, they are not eligible to put in use unless a local certification is provided.

Other road propulsion vehicle means using electricity as an alternative fuel to the conventional gasoline and diesel are the electrified vehicles, broadly classified under hybrid electric and battery electric vehicles. Hybrid vehicles combine the power of a SI or CI engine to an electric motor to drive the vehicle, where battery electric vehicles relies solely on the electric power of the batteries.

Hydrogen vehicles use either a fuel-cell stack or a SI engine to power the vehicle. However, these technologies are still in the development phases, and lack for a well-established hydrogen distribution infrastructure. Other possible uses of hydrogen is by mixing it with natural gas or diesel in internal combustion engines. Potential energy and emissions savings are expected; however, the technology is yet to be properly tested.

DUAL-FUEL VEHICLES ARE A SPECIAL VERSION OF BI-FUEL VEHICLES FOR HEAVY DUTY APPLICATIONS, WHERE THE NATURAL GAS IS IGNITED BY AN INJECTION OF DIESEL FUEL

INFRASTRUCTURE 3.2.

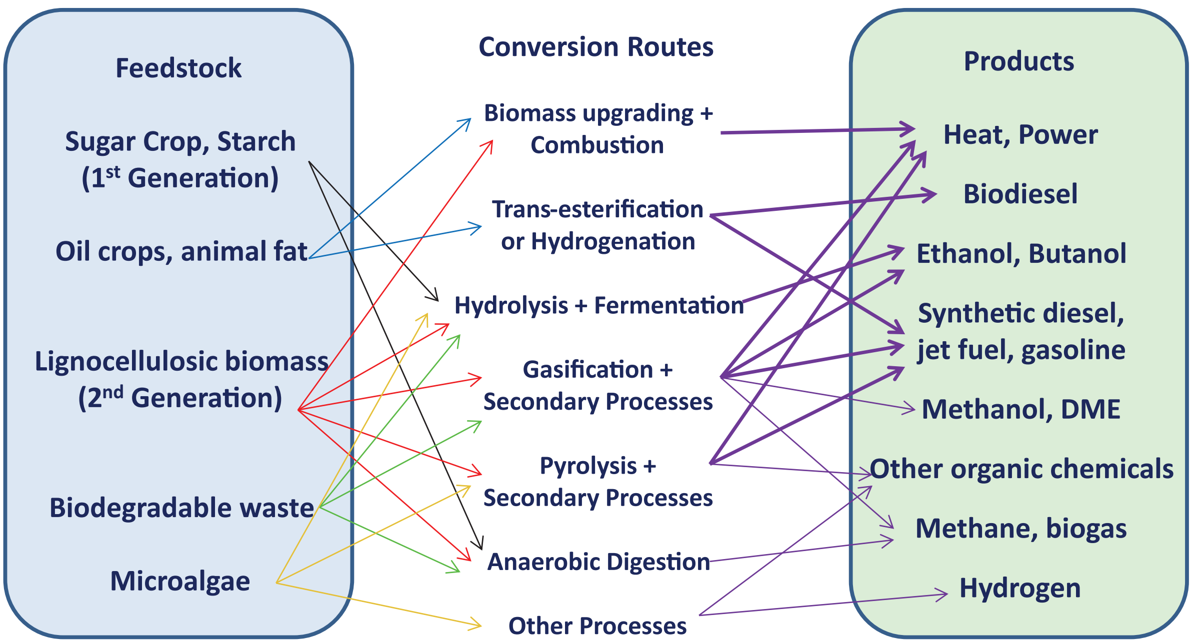
Like conventional fuels, alternative fuels require extensive critical infrastructures for production, conditioning and transformation at source, transportation to markets and in some cases, transformation near markers, before final distribution. These processes are illustrated in Figure 8 for natural gas:

Figure 8: Natural gas processes: production, transformation, transportation and usage.
Source: (IEA, 2014)

3.2.1.1. Biofuels Infrastructure

Biofuel is produced by a variety of pathways depending on the feedstock used and the type of end-product desired, as illustrated in Figure 9.

Figure 9: Major pathways for production of different types of biofuel products.
Source: Biofuel Infrastructure, DNV, 2010



Extensive infrastructure is required for each pathway type, typically involving the construction of biomass conversion facilities near where the crops are grown, along with their own pipeline and transportation networks for moving the harvested raw crops as well as distributing the converted biofuels.

Some biofuel end-products, such as biodiesel and ethanol, are sent to blending terminals through ships, tanker trucks or rail cars where they are blended with gasoline or diesel and then sent to consumer filling stations via trucks.

3.2.1.2. Natural Gas Infrastructure

The infrastructure for natural gas fuel consists of two parts: first, the connection to upstream supplies, either by pipeline (NG) or by shipping tankers (LNG); and second, the downstream transmission and distribution network connecting to different types of refueling stations for road vehicles. In the case of Lebanon over the short and medium term, it's expected that natural gas will be imported as Liquefied Natural Gas (LNG) by sea.

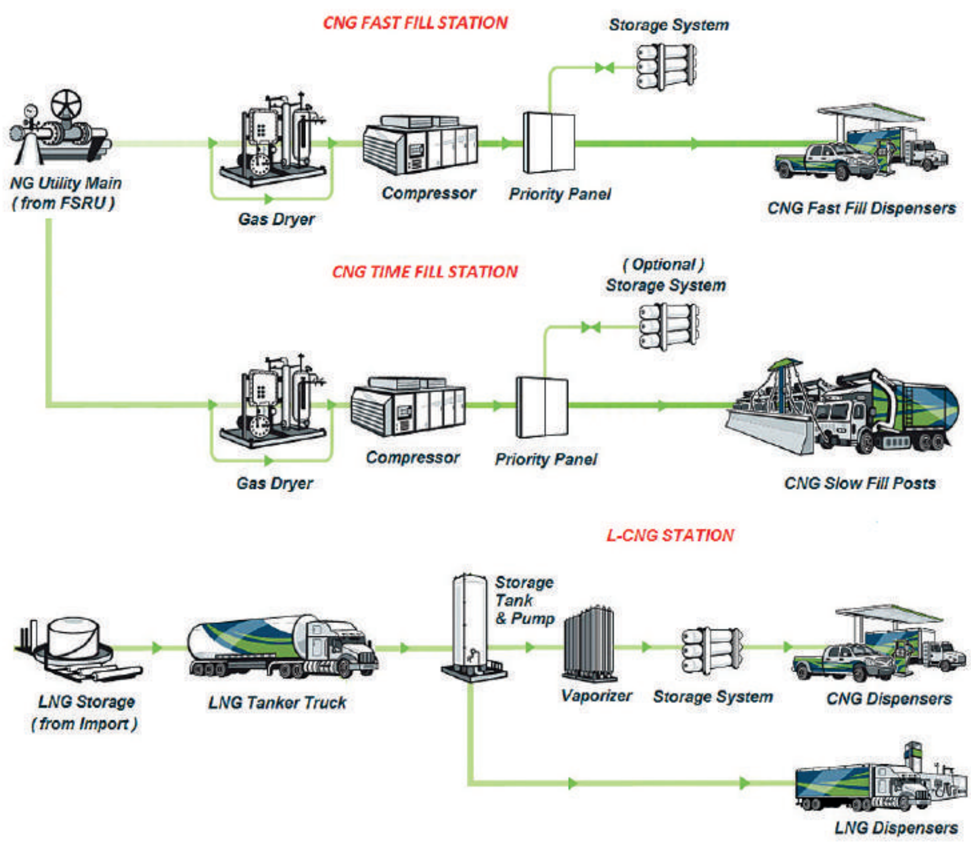
There are two potential infrastructure paths for the downstream transmission and distribution network at market, namely:

- Transmission to LNG offshore storage facilities; and distribution by tanker trucks to LNG dispensing at refueling stations.
- Transmission to a Floating Storage and Regasification Unit (FSRU), and distribution by pipeline to CNG dispensing at refueling stations.

These downstream paths and the corresponding stations are illustrated in Figure 10.

Figure 10: Natural gas station infrastructure.

Source: adapted from http://www.gowithnaturalgas.ca/



CNG stations include compressor equipment for compressing and dispensing natural gas. Fast-fill stations dispense CNG at 200 bars for a quick refill of LDVsfor their small tanks. Drivers experience similar fill times as a conventional gasoline fueling station, less than 5 minutes for a 20 gallon equivalent tank. Time fill (or slow fill) stations primarily serve HDVs and buses (i.e. vehicles with large tanks) for refueling overnight. LNG stations comprise a cryogenic tank for storing LNG at low temperatures.

The same stations providing gasoline and diesel fuels can provide LNG or CNG. A station providing both LNG and CNG is known as an L-CNG station and serves to refuel LDVs with CNG and HDVs with LNG.

3.2.1.3. Electricity Infrastructure

While alternative fuels require changes and new supporting infrastructure, electricity is generally available and can support the rapid adoption of battery-electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs). Establishing a developed infrastructure of charging stations are essential to the successful adoption of these technologies. Drivers need affordable, convenient and compatible options for charging at home, workplaces and public destinations. Different charging equipment technologies are available, classified by the batteries charging rate and summarized in table 5.

Table 5. Charging stations for BEVs and PHEVs.

	AC charging	Future AC charging	DC fast charging	Inductive charging
Power	3.3-7.4 kW	10-43 kW AC	50-120 kW	3.3-7.4 kW
Voltage	220/240 V AC	400 V AC	300-500 V DC	220/240 V AC
Charging site	Home/Office	Public area (malls, public parking, gas stations)	Inter-city service area, gas station (not suitable for home charging stations)	Home/Office
Charger type	Normal	Semi-fast	Fast	Normal
Connector type	Standard SAE J1772 connector	Standard SAE J3068 connector	CHAdeMO standard connector	Wireless charging

Note that a stable and well-established power grid, as well as an electric power load increase from power plants should be considered for the adoption of BEVs and PHEVs.

A STATION PROVIDING BOTH LNG AND CNG IS KNOWN AS AN L-CNG STATION AND SERVES TO REFUEL LDVS WITH CNG AND HDVS WITH LNG.

ENVIRONMENTAL ASPECTS 3.3.

There are two main dimensions to the measurement of emissions from road transportation:

- Fuel related factors
- Vehicle related factors

Evaluation of fuel performance depends on whether it is measured on:

- Tank to wheel (TTW) basis, (often referred to as tailpipe measurement) or
- Well to wheel (WTW) basis which incorporates the entire life-cycle of the fuel from production to combustion, including extraction, separation and treatment, transportation, refining and distribution to the tank of the relevant vehicle.

An example for the European Union (EU) of the level of emissions from a WTT assessment for a range of fuels and different pathways is shown in Table 6.

Table 6: Well to tank and combustion comparison.

Source: (Le Fevre, 2014)

Fuel pathway	WTT (gCO_{2eq}/MJ)	Total GHG incl. combustion (gCO_{2eq}/MJ final fuel)
EU supply mix (2500km pipeline) to CNG	13.0	69.3
W Siberia to CNG (7000km)	22.6	77.6
Caspian to CNG (4000km)	16.1	71.1
LNG to CNG	21.1	76.1
LNG to LNG retail	19.4	74.5
EU Shale gas to CNG	7.8	62.8
Biomethane from organic waste	14.8	14.8
Diesel	15.4	88.6
Gasoline	13.8	87.1
LPG	8.0	73.7

Note that GHGs are typically measured on a CO_2equivalence basis. For gasoline and diesel, the figures represent the emissions associated with crude oil for a typical EU source that is then transported and refined in the EU and then distributed to final customers. The pathways for natural gas reflect different sources as shown in the table and include assumptions regarding fugitive emissions of methane from production, transmission and distribution. These pathways will be different for the case of Lebanon, and therefore a pathway for each fuel type will be developed in detail and a WTT assessment will be performed.

FINANCIAL AND MARKET CONSIDERATIONS 3.4.

The economics of switching to alternative fuels are, from a user's perspective, primarily a trade-off between the price at the pump of natural gas or biofuels versus gasoline or diesel, and the additional capital and running costs of a new alternative fuel vehicle. From a national perspective, the overall economic case for alternative fuels will have to include the additional costs of building and operating the required infrastructure. This section provides an overview of these three financial components, namely the fuel pricing, vehicle costs and infrastructure costs.

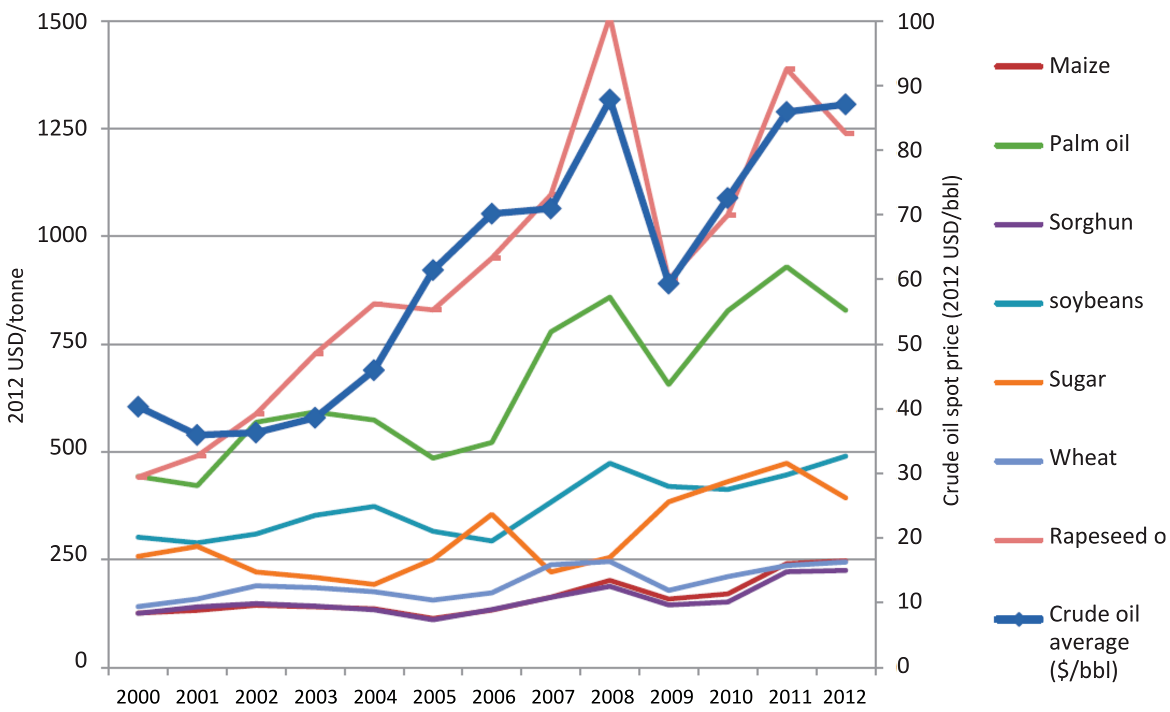
3.4.1. Fuel Price

3.4.1.1. Biofuels Prices

Biofuel prices vary depending on the fuel source, the production pathway and the market mechanisms of supply and demand as well as government taxes and charges. The world market price of biomass inputs for first generation biofuels assessed by IRENA (2013) are shown in figure 11.

Figure 11: Global prices for food-based biofuel feedstock compared to crude oil, 2000 to 2012.

Source: (IRENA, 2013)



The figure shows that the cost of each of the biofuel inputs is lower than, or comparable to, the price of crude oil, which means that biofuels can be competitive on price with gasoline and diesel as long as production costs are low.

3.4.1.2. Natural Gas Prices

There is a consensus that natural gas can compete with gasoline and diesel in all scenarios where gas transmission and distribution grids are present (Nijboer, 2010). Figure 12 compares CNG pricing in a number of countries grouped per continent, and figure 13 illustrates the CNG price percentage as of the gasoline price.

Figure 12: CNG price per liter gasoline equivalent, 2010-2013.

Source: authors, using data from (NGVA Europe, 2013)

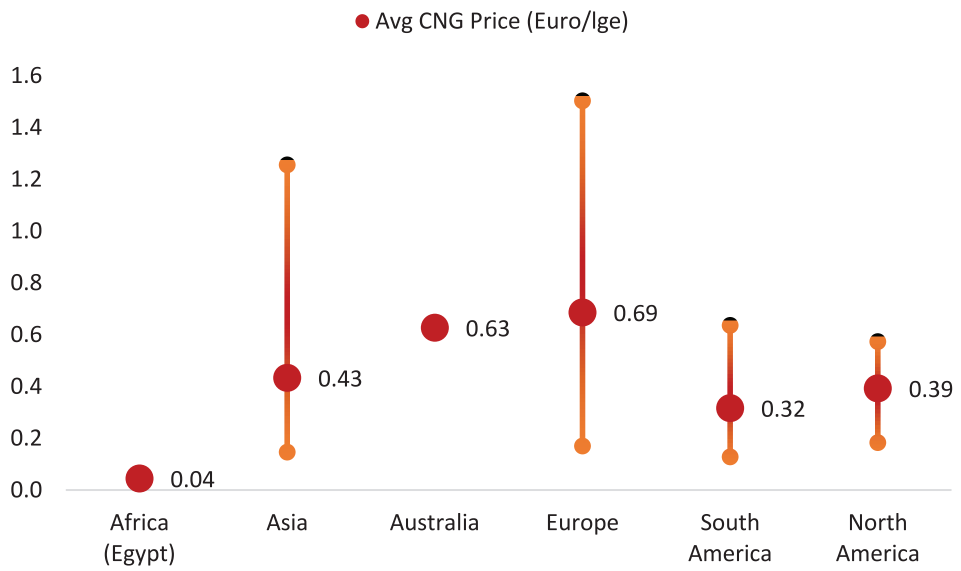
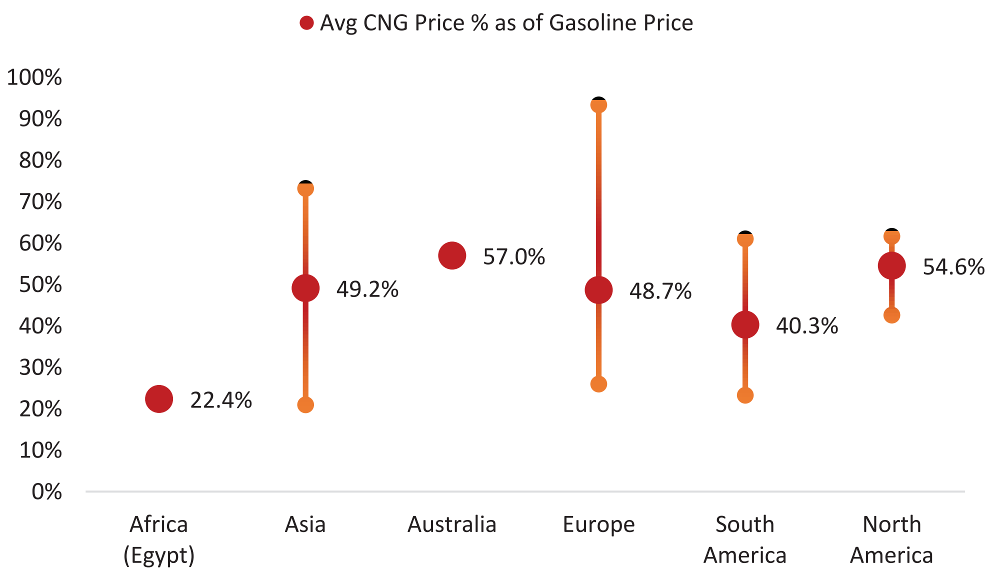


Figure 13: CNG price percentage as of gasoline price, 2010-2013.

Source: authors, using data from (NGVA Europe, 2013)



Taxation and market price fluctuation play an important role in the competitiveness of alternative over conventional fuels. Table 7 illustrates this point, where natural gas and LPG are half taxed compared to gasoline and diesel.

MUCH LIKE BIOFUELS, THE PRODUCTION COST OF LPG DEPENDS HIGHLY ON ITS PRODUCTION PATHWAY

Table 7: Taxes as percentage of end-user fuel prices in OECD countries in 2009.

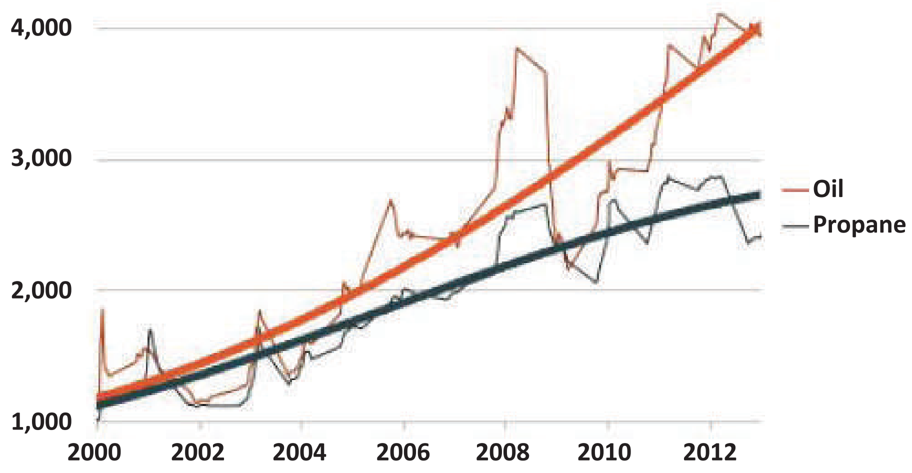
Source: (Nijboer, 2010)

	Minimum	Maximum	Average
Diesel	0.4%	64.4%	42%
Gasoline	17.2%	72.6%	57%
LPG	7.8%	48.5%	25%
Natural gas	4.7%	51.1%	18%

Much like biofuels, the production cost of LPG depends highly on its production pathway, but the price of this fuel on the end user remains very competitive. The price of LPG (or propane) relative to the price of oil in the US until 2012, is shown in Figure 14.

Figure 14: Price of propane in the US market, 2000 to 2012.

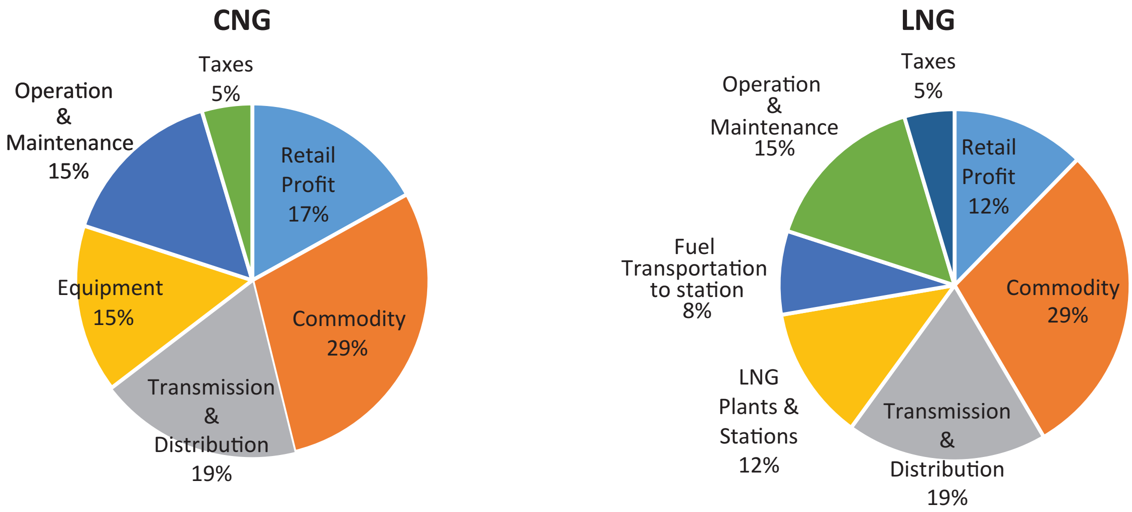
Source: (COWI, 2015)



Other costs to be considered are those related to infrastructure (pipelines, LNG terminals, stations and related infrastructure). The breakdown of price components for CNG and LNG is shown in Figure 15.

Figure 15: Components of CNG and LNG prices.

Source: adapted from (Marbek, 2010)



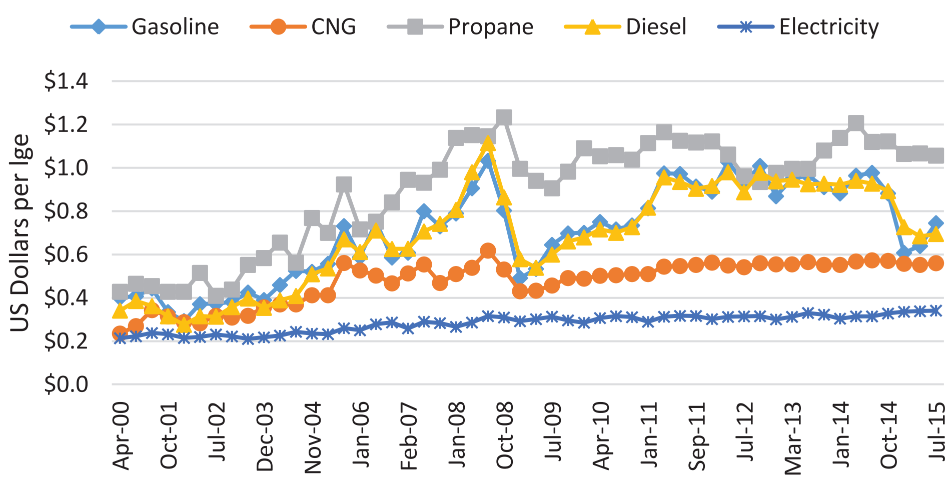
3.4.1.3 Electricity Prices

The cost of driving EVs and PHEVs depends on the electricity prices, which rely largely on the production cost, the type of fuels used, the government subsidies and the market price, among others. Consequently, electricity prices are region specific, and their tariffs even vary per region and by time-of-day, depending on the type of its use: residential, commercial or industrial. No electricity tariff is dedicated for its use in transportation as EVs and PHEVs constitute a negligible portion of its market; thus, residential electricity tariff is considered for pricing the electric mobility cost, as most of recharging stations are at home and in work parking lots.

Figure 16 illustrates the average retail price of electricity and other transportation fuels in the United-States per liter gasoline equivalent (lge). Residential electricity tariff was considered, and prices were reduced by 3.4 as electric motors are 3.4 times more efficient than internal combustion engines (ANL, 2016).

Figure 16: Average U.S. Retail Fuel Prices per liter gasoline equivalent (lge).

Source: adapted from (USDOE, 2015)



The figure shows that the electricity average tariff for transportation is cheaper than other transportation fuels. The trend is almost stable, since transportation only constitutes a negligible portion of its market, and less likely affected by the international oil markets price fluctuations and uncertainties.

Table 8 summarizes the electricity tariff in Lebanon for residential and industrial use. Assuming the highest residential slab tariff of 0.13 USD/kWh, the use of electricity as transportation fuel is very competitive compared to gasoline and diesel, as illustrated in figure 17. Although the driving cost of EVs and PHEVs is lower than for similar conventional vehicles, purchase prices can be significantly higher. However, prices are likely to decrease as production volumes increase. Moreover, the additional vehicle purchase cost can be offset by the fuel cost savings, as well as the government incentive and tax reduction.

MOREOVER, THE ADDITIONAL VEHICLE PURCHASE COST CAN BE OFFSET BY THE FUEL COST SAVINGS, AS WELL AS THE GOVERNMENT INCENTIVE AND TAX REDUCTION.

It is also important to note that much like all transportation fuels prices, it is expected that electricity tariff will increase when the share of EVs and PHEVs increases.

Table 8: Electricity tariff in Lebanon for residential and industrial sectors.

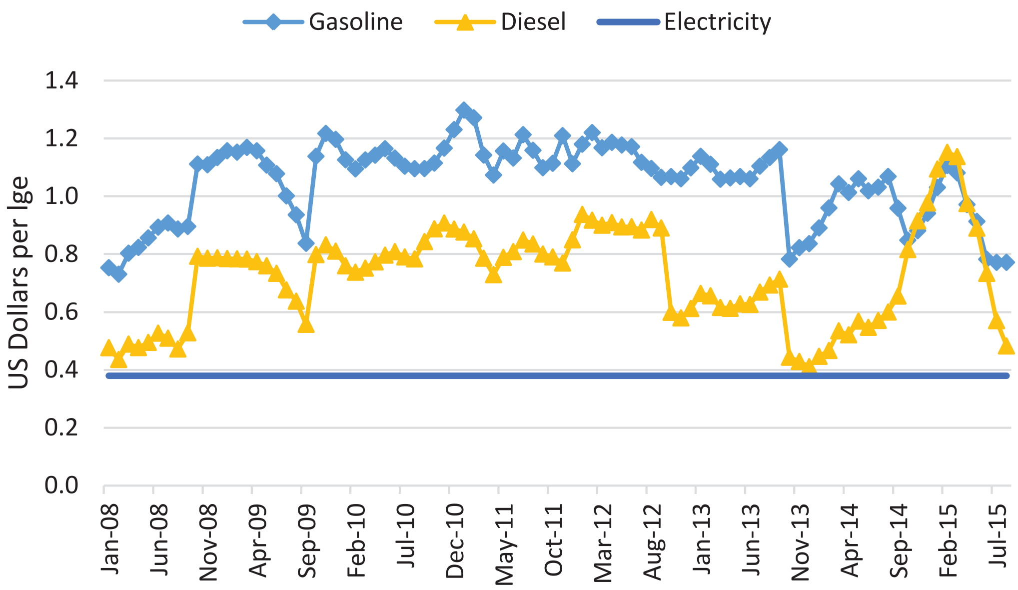
Source: data provided by MOEW

Residential*	
Consumption per month (kWh)	Tariff (LBP/kWh) (USD/kWh)
1-100	35 *0.023*
101-300	55 *0.037*
301-400	80 *0.053*
401-500	120 *0.08*
501 and above	200 *0.13*

Industrial*	
	Tariff (LBP/kWh) (USD/kWh)
Night rate	80 *0.053*
Day rate	112 *0.075*
Peak rate	350 *0.213*

** Note that electricity is subsidized by the Lebanese government.*

Figure 17: Average Retail Fuel Prices per liter gasoline equivalent (lge) in Lebanon.
Source: authors, data provided by MOEW.



3.4.2. Vehicle Costs

Vehicle costs associated with using a specific type of fuel consist of the incremental procurement cost of the vehicle and the associated costs of repairs and maintenance (meaning the additional cost of buying and operating an alternative fuel vehicle over the cost of a conventional gasoline or diesel vehicle in the same class). Third-party engine modification costs are not considered since only OEM modification is sanctioned legally; for the purpose of this study and since OEM modification in Lebanon is not regulated, only the procurement of new OEM alternative fuel vehicles will be considered.

3.4.2.1. Biofuel Vehicle Costs

There are little or no additional vehicle costs for using high blending of ethanol or biodiesel fuels with gasoline and diesel. Engine modifications are only required when using the high-blended flex fuel E85 Ethanol and the pure B100 biodiesel.

3.4.2.2. Natural Gas Vehicle Costs

CNG passenger cars have a premium of EUR 1,000 to 3,000 versus the equivalent gasoline or diesel versions; the additional cost is largely dependent on the cost of storage capacity of CNG.

The extra investment in a CNG bus is around EUR 25,000 compared with conventional diesel technology, and the incremental cost for a LNG heavy-duty vehicle is estimated at approximately EUR 25,000 to 35,000 compared with a regular diesel-fueled HDV, again depending on storage capacity of LNG and the engine output power (NGVA Europe, 2013).

The premium for an OEM LPG passenger vehicle ranges from EUR 800 up to 2,000. Note that it costs between EUR 1,400 and 3,000 to perform a conversion to LPG, which makes this option less desirable; this is why the retrofitting option was disregarded in this study, as already discussed earlier in this section.

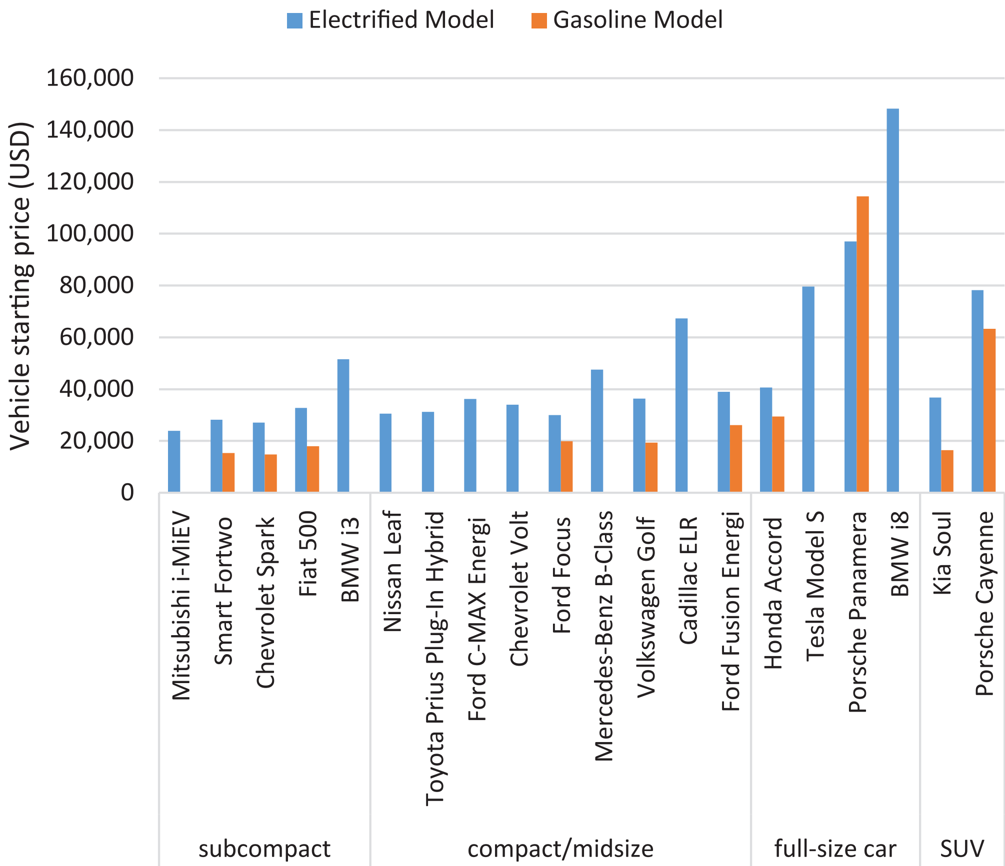
3.4.2.3 Electric Vehicle Costs

The cost of electric vehicles (EVs) is mainly affected by the battery system cost, making EV's more expensive to purchase than internal combustion engine (ICE) vehicles. EV battery costs are projected to go down from EUR 1,000 in 2010 to EUR 200 per kWh in 2020.

Figure 18 summarizes the 2015 and 2016 retail price of EVs compared to their equivalent gasoline models in the United-States. Current projections estimate that the purchase price of EV's will be competitive with ICE vehicles within 5 to 10 years. They will also have lower fuel cost (due to greater efficiency and no use of oil) and a lower maintenance cost (due to fewer moving parts, absence of catalyst and other emission control systems). This is why, the total cost of ownership of EVs is expected to converge with ICE after 2025.

Figure 18: Manufacturer's suggested retail price (MSRP) of electric vehicles and their equivalent gasoline models in the United-States, 2015-2016.

Source: (Edmunds.com, 2015)

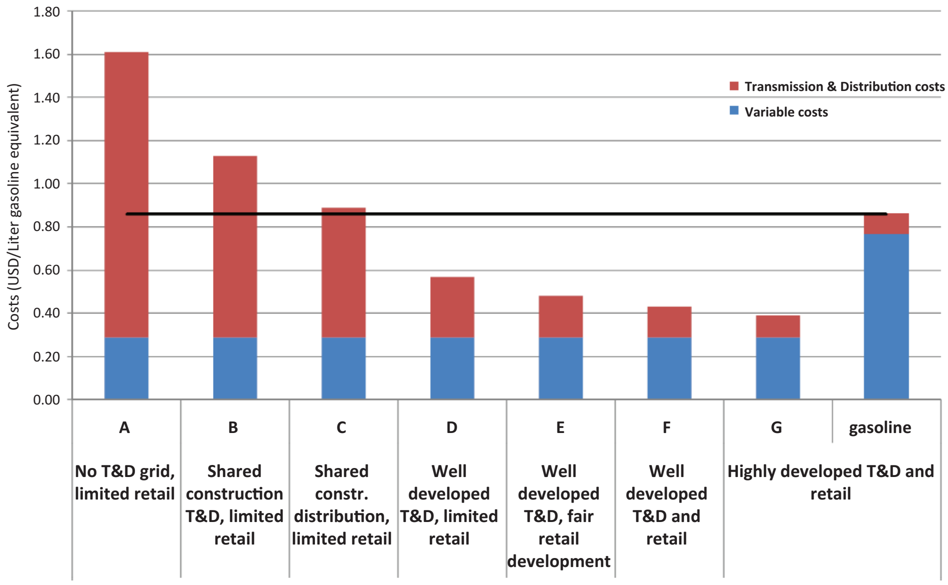


3.4.3. Infrastructure Costs

Infrastructure costs include the capital expenditure and operating costs for processing plants, pipelines, stations and other installations and equipment associated with refueling. These are considered in detail for the different fuel types in the following sub-sections. Lebanon lacks any infrastructure for alternative fuels, and as such it is expected that the infrastructure cost will be a substantial barrier to the adoption of any such fuel. Figure 19 illustrates this case for natural gas.

Figure 19: Costs of CNG versus gasoline in different scenarios of grid development.

Source: (Nijboer, 2010)



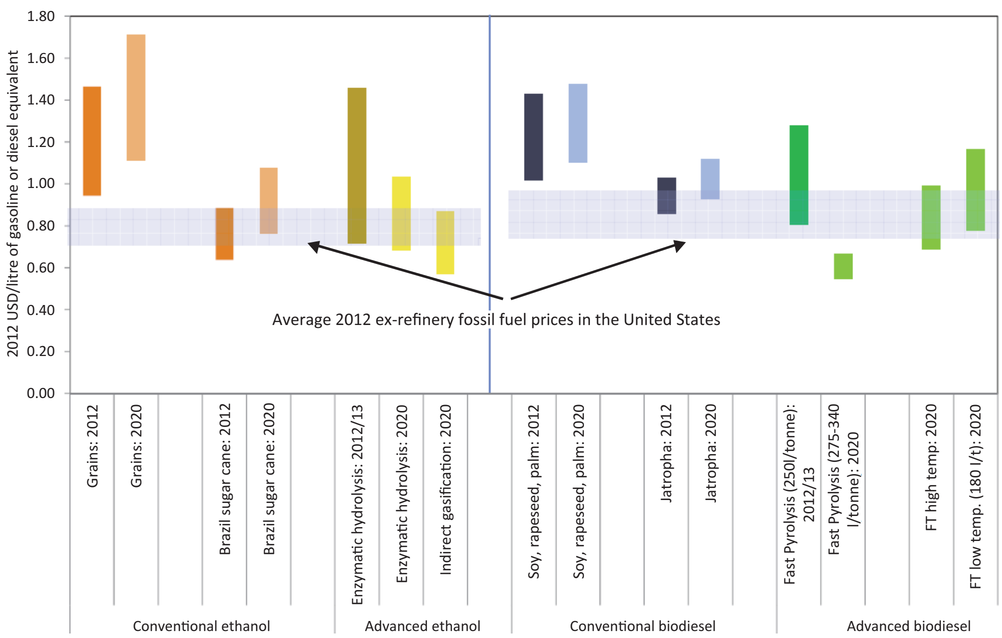
3.4.3.1. Biofuel Infrastructure Costs

The infrastructure costs for biofuels vary widely depending on the type of biofuel being considered and the distance to the feedstocknecessary for production. Infrastructure costs consist mainly of the costs of the facilities (refineries, blending and transportation systems used in production. A detailed analysis of these different production pathways will be performed in Section 4 of this report.

The US productions costs for conventional and advanced biofuels are shown in Figure 20.

Figure 20: Estimated production costs of conventional and advanced biofuels for the US market, 2012 to 2020.

Source: (IRENA, 2013)



The figure shows relatively low production costs for most biofuels, especially for conventional ethanol produced from Brazilian sugar cane. The story is somewhat different for conventional biodiesel where low cost production, such as from the Jatropha plant, is not yet feasible. This is why for countries where feedstock for biodiesel must be imported at high cost there is interest in re-using waste cooking oils as a cheaper input source that can help achieve competitively priced biodiesel fuel.

It is also important to note that the costs shown in the above figure are competitive in the US market but not equally as much in countries where there is no local production of input crops for biofuel production; these fuels will only be cost competitive when the entire alternative fuel industry has matured and become a global industry.

3.4.3.2. Natural Gas Infrastructure Costs

The costs of laying transmission and distribution pipelines for natural gas connections between supply sources and stations are expected to be very costly and can vary widely depending on land characteristics.

CNG and L-CNG stations require investments at least five times higher than for conventional liquid fuels and it can take up to 15 years to develop the necessary infrastructure. The higher spectrum of the average cost generally includes the following items: civil work, underground tank (of varying capacities), underground piping, electric and data connection (e.g. wiring to the terminal at the cashier's desk in the station), gas detection devices, and so on.

The distribution network must be sufficiently dense to have enough coverage and avoid "range anxiety" (the fear that one's vehicle will run out of fuel before there is an opportunity to re-fuel), but sparse enough to ensure economic sustainability (600 to 1,000 vehicles served per public fueling station). The European NGV industry has invested some €2 billion to establish the existing network of NG refueling stations. It is also widely accepted that without political support and binding goals, incentives and subsidy schemes, a rapid build-up of infrastructure would be difficult.

The estimated investment costs for different types of CNG refueling stations (fast-fill, time-fill) are presented in Table 9. Each cost is given as a range depending on the size of equipment, storage capacity and dispending rate.

Table 9: Estimated CNG Station Costs.

Source: (USDOE, 2014)

	Small (100-200 gge/day)	Medium (500-800 gge/day)	Large (1500-2000 gge/day)
CNG Fast-fill	\$400,000 - \$600,000	\$700,000 - \$900,000	\$1.2 - \$1.8 million
CNG Time-fill	\$250,000 - \$500,000	\$550,000 - \$850,000	--

The estimated investment costs for a standard LNG station would be in the range of \$400.000 to \$500.000, also depending on capacity, size and equipment; higher costs would apply when also taking into account acquisition of land, permits, and related costs.

These figures are higher than the estimated average cost for installing an LPG filling station which ranges between \$75,000 and \$200,000.

The station operating costs vary widely and are dependent on feed-in capacity.

The estimated costs of equipment for NG refueling stations are shown in Table 10. Each cost is given as a range depending on the size of equipment, specifications and manufacturer.

Table 10: Estimated equipment costs.

Source: adapted from (USDOE, 2014)

Equipment	Cost Range	Description
Compressor	\$4,000-\$550,000	The compressor takes inlet gas at low pressure and compresses it to the pressure necessary for filling a vehicle to 3,600 psi. Compressors that offer similar flow rates vary in price based on their horsepower rating and manufacturer.
Dispenser	\$25,000-\$60,000	At fast-fill stations, drivers use a dispenser to quickly transfer CNG to the vehicle tank. Dispensers vary in cost depending on the number of hoses, fuel management system, and other features.
Dual-hose time-fill post	\$4,000-\$7,000	At time-fill stations, vehicles are connected to a simple fill post, typically overnight. The tanks are filled as fuel is available, which depends on the compressor flow rate and the number of vehicles. Two vehicles can connect to a dual-hose time-fill post.
Storage tank	\$70,000-\$130,000	Once natural gas is compressed, it can be stored in tanks for later use.
Card reader/fuel management system	\$10,000-\$30,000	Card readers allow the driver to access fuel using a fleet card or credit card. A fuel management system is software that enables tracking of driver and vehicle fueling habits.
Gas dryer	\$10,000-\$300,000	A gas dryer removes moisture from the gas prior to compression, which is a good practice for all CNG stations.

3.4.3.3 Electricity Infrastructure Costs

Assuming a well-established nation-wide electricity generation and distribution infrastructure, EVs and PHEVs drivers need a developed charging stations infrastructure, with consideration for daily commutes and typical driving habits. According to a charging infrastructure case study from different cities in China, Japan, Europe and the United-States (The Global Electric Vehicle Insight Exchange, 2012), electric vehicle supply equipment (EVSE) is being deployed throughout these cities in key areas for public charging, and for early adopters, consumers do the majority of their charging at home and workplace.

Table 11 shows the cost of charging stations hardware for different charging locations in the United-States. The table did not include labor costs and administrative overhead.

Table 11: EVSE costs.

Source: adapted from (RMI, 2014)

	AC charging *(Home)*	AC charging *(Parking garage)*	AC charging *(Curbside)*	DC fast charging *(Station)*
Charging station hardware	\$450-\$1,000	\$1,500-\$2,500	\$1,500-\$3,000	\$12,000-\$35,000[A]

[A] excluding the cost of the 480V transformer to be installed by utility, ranging between \$10,000 and \$25,000.

SUMMARY OF THE FACTORS AND CHALLENGES INFLUENCING THE USE OF ALTERNATIVE FUELS IN TRANSPORT 3.5.

In this section, a synthesis is done for all the previous conclusions about the technical aspects of alternative fuels in transport, the infrastructure requirements for these fuels, the corresponding financial and market considerations in terms of fuel price, vehicle and infrastructure costs. This synthesis is presented in Figures 21 and 22 as a classification of the challenges facing the adoption of each fuel type in the Lebanese transport sector for the two commercially available types of vehicle technologies: the internal combustion engine vehicles (ICEV) and the hybrid electric vehicles (HEV), as used in passenger cars, buses and heavy duty vehicles. Note that due to lack of data, only passenger cars will be assessed in detail in this study.

Figure 21: Factors and challenges influencing the use of alternative fuels in passenger cars.

Transport Technology / Fuel Type	Internal Combustion Engine Vehicle				Hybrid Electric Vehicle			
Gasoline	No New Requirements					New Vehicle Acquisition ($-$$$)	New Charging Station Infrastructure (Optional)	
Diesel	No New Requirements					New Vehicle Acquisition ($-$$$)	New Charging Station Infrastructure (Optional)	
CNG	Vehicle Retrofitting - Not Advised ($$)	New Vehicle Acquisition ($$)	New Distribution Infrastructure ($$)	Refueling Station Modification ($$)	Not Commercially Ready			
LNG	Vehicle Retrofitting - Not Advised ($$$)	New Vehicle Acquisition ($$$)	New Distribution Infrastructure ($$)	Refueling Station Modification ($$)	Not Commercially Ready			
LPG	Vehicle Retrofitting - Not Advised ($$)	New Vehicle Acquisition ($$)		Refueling Station Modification ($$)	Not Commercially Ready			
Low-Blending Ethanol			New Processing Infrastructure ($-$$)		New Vehicle Acquisition ($-$$$)	New Processing Infrastructure ($-$$)	New Charging Station Infrastructure (Optional)	
High-Blending Ethanol	Engine Modification ($)	New Vehicle Acquisition ($)	New Processing Infrastructure ($$-$$$)	Refueling Station Retrofitting ($)	New Vehicle Acquisition ($-$$$)	New Processing Infrastructure ($$-$$$)	New Charging Station Infrastructure (Optional)	Refueling Station Retrofitting ($)
Low-Blending Biodiesel			New Processing Infrastructure ($-$$)		New Vehicle Acquisition ($-$$$)	New Processing Infrastructure ($-$$)	New Charging Station Infrastructure (Optional)	
High-Blending Biodiesel	Engine Modification ($)	New Vehicle Acquisition ($)	New Processing Infrastructure ($$-$$$)	Refueling Station Retrofitting ($)	New Vehicle Acquisition ($-$$$)	New Processing Infrastructure ($$-$$$)	New Charging Station Infrastructure (Optional)	Refueling Station Retrofitting ($)
Electricity	Not Applicable				New Vehicle Acquisition ($-$$$)	New Processing Infrastructure ($$-$$$)	New Charging Station Infrastructure ($-$$$)	

"$" signs indicate additional costs of vehicle and infrastructure technologies compared to conventional vehicles using gasoline as transportation fuel.

Figure 22: Factors and challenges influencing the use of alternative fuels in buses and heavy duty vehicles.

Transport Technology / Fuel Type	Internal Combustion Engine Bus and Truck				Hybrid Electric Bus	
Gasoline	*Very Limited Demand – Not Commercially Attractive*				*Not Commercially Available*	
Diesel	*No New Requirements*				New Vehicle Acquisition ($$$)	
CNG	Vehicle Retrofitting *- Not Advised* ($$$)	New Vehicle Acquisition ($$$)	New Distribution Infrastructure ($$)	Refueling Station Modification ($$)	*Not Commercially Ready*	
LNG	Vehicle Retrofitting *- Not Advised* ($$$)	New Vehicle Acquisition ($$$)	New Distribution Infrastructure ($$)	Refueling Station Modification ($$)	*Not Commercially Ready*	
LPG	Vehicle Retrofitting *- Not Advised* ($$$)	New Vehicle Acquisition ($$$)		Refueling Station Modification ($$)	*Not Commercially Ready*	
Low-Blending Ethanol	*Very Limited Demand – Not Commercially Attractive*				*Not Commercially Available*	
High-Blending Ethanol	*Very Limited Demand – Not Commercially Attractive*				*Not Commercially Available*	
Low-Blending Biodiesel			New Processing Infrastructure ($-$$)		New Vehicle Acquisition ($$$)	New Processing Infrastructure ($-$$)
High-Blending Biodiesel	*Not Commercially Ready*				*Not Commercially Ready*	
Electricity	*Not Applicable*				*Not Applicable*	

Consolidating all of the challenges identified above for the Lebanese market, table 12 presents a summary of the final selection of viable options for vehicle technologies that can be assessed in the modeling of energy use and exhaust emissions.

Table 12: Final selection of existing and potential vehicle technologies considered for assessment.

	Passenger Car				Bus		Truck
Fuel / Vehicle Technologies	ICEV	HEV	PHEV	EV	ICEV	HEV	ICEV
Gasoline	x	x	x				
Diesel	x	x	x		x	x*	x
E10	x	x					
E85	x	x					
B20	x	x			x*	x*	x*
CNG	x				x		x
LNG	x				x*		x*
LPG	x				x*		x*
Electricity			x	x			

** Shaded cells in the table above reflect that no data is available for the selected fuel-vehicle option. As a result, these options will not be considered in the modeling assessment.*

4

4.1.
MODELING METHODOLOGY AND ASSUMPTIONS

4.2.
MODELING OF EXISTING PATHWAYS

4.3.
MODELING OF POTENTIAL PATHWAYS

4.4.
MAPPING FUEL FEEDSTOCK TO VEHICLE TECHNOLOGIES IN EXISTING AND POTENTIAL PATHWAYS

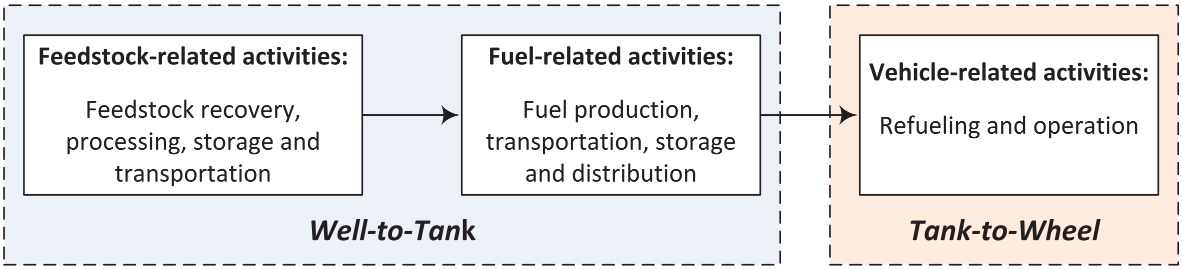
MODELING OF EXISTING AND POTENTIAL FUEL SUPPLY PATHWAYS IN LEBANON

In order to assess the environmental impacts of fuel and vehicle systems currently existing, and those potentially applicable in Lebanon, the different fuel-vehicle pathways were modeled and analyzed using the commonly adopted well-to-wheels approach. The methodology for modeling and analyzing the different pathways is discussed in this section, and the modeling results are presented in section 5.

MODELING METHODOLOGY AND ASSUMPTIONS 4.1.

A well-to-wheels (WTW) assessment of the environmental impacts of different fuel-vehicle options consists of two components: a well-to-tank (WTT) assessment of the energy use and emissions associated with fuel production and distribution activities; and, a tank-to-wheels (TTW) assessment of the energy use and emissions associated with vehicle operation activities. This is illustrated in Figure 23.

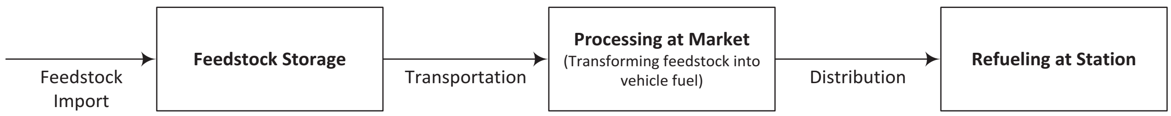
Figure 23: Overview of a Well-to-Wheels Analysis for Fuel/Vehicle Systems.



WTW calculations were based on a fuel lifecycle model developed by Argonne National Laboratory (ANL), namely the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model.

The inputs to the WTW analysis are the various fuel-vehicle pathways, which consist of a series of generic processes from fuel production to distribution at the pump, as illustrated in Figure 24.

Figure 24: Generic processes in well-to-tank pathways (reference: EU JRC Technical Report, 2014).



The processes in any pathway can be classified as either stationary or transportation processes. For stationary processes, the principal data consist of process efficiencies. For transportation processes, the principal data consist of their energy intensities. The required data for these processes were obtained from the local stakeholders concerned, where available. The remaining data was sourced from different technical sources, as referenced in the modeling of the different pathways.

The baseline year for the WTW analysis is 2010. The following table summarizes the different feedstock-to-fuel pathways considered in this assessment, as discussed in the following subsections.

Table 13: Feedstock-to-fuel pathways.

Feedstock \ *Fuel*		gasoline	diesel	CNG	LNG	LPG	ethanol	biodiesel	electricity
heavy fuel Oil									x
gasoline		x							
diesel			x						x
LPG						x			
natural gas				x	x				x
biomass	sugar beet						x		
	wheat						x		
	barley						x		
	maize (corn)						x		
	wheat straw						x		
	sugar cane						x		
	rapeseed							x	
	sunflower							x	
	soy beans							x	
	palm fruit							x	
	waste veg oil							x	
	tallow							x	
hydro									x

WTW CALCULATIONS WERE BASED ON A FUEL LIFECYCLE MODEL DEVELOPED BY ARGONNE NATIONAL LABORATORY (ANL), NAMELY THE GREENHOUSE GASES, REGULATED EMISSIONS, AND ENERGY USE IN TRANSPORTATION (GREET) MODEL.

MODELING OF EXISTING PATHWAYS 4.2.

The existing fuel pathways in Lebanon (gasoline, diesel and liquefied petroleum gas) were modeled using local data obtained from the stakeholders concerned, where available. An overview of the most relevant data is presented here.

All fuel types are imported by sea into the country and stored at various locations along the coastline, as summarized for gasoline and diesel in Table 14, and for LPG in Table 15 below.

Table 14: Gasoline and diesel fuel storage locations and terminal capacities in Lebanon.

Source: Association of Petroleum Importing Companies (APIC), 2015

Petroleum Company	Location	Region	Terminal Capacity (liters)
IPT	Amchit	North	16,648,580
Gefco	Anfeh	North	Unavailable
United Petroleum Co.	Amchit	North	Unavailable
Apec	Beddawi	North	Unavailable
Coral Oil Co.	Karantina	Beirut	69,385,993
Medco	Dora	Mount Lebanon	50,223,014
Total	Dora	Mount Lebanon	48,000,000
Uniterminals	Dora	Mount Lebanon	45,751,290
Wardieh Holdings /Mobil	Bauchrieh	Mount Lebanon	44,450,000
Hypco	Antelias	Mount Lebanon	Unavailable
Cogico	Jiyyeh	South	50,640,390
Levant Oil	Jiyyeh	South	Unavailable
Liquigas	Unknown	--	30,616,797
MPC	Unknown	--	25,142,255
Pretol Gas	Unknown	--	19,365,000
Universal Gas	Unknown	--	16,049,827
HIF	Unknown	--	14,383,285

The annual import of gasoline typically ranges between 1.8 and 2.0 million tons in total (as reported by APIC, 2015), all of which is consumed in the transportation sector, with 75% to 80% being 95 Octane. The annual import of diesel fuel amounted to 1.45 million tons in total (2014), of which only 20% is consumed in the transportation sector (trucks and buses, with some passenger cars still illegally operating on diesel).

The annual import of LPG amounted to 220,000 tons (2015), with main uses in heating, cooking, and illegal retrofitting in transport.

Table 15: LPG fuel storage locations and terminal capacities in Lebanon.
Source: Association of Petroleum Importing Companies (APIC), 2015

Petroleum Company	Location	Region	Terminal Capacity (m^3)
Nourgaz	Tripoli	North	3,313
Natgaz	Nahr El Mot	Mount Lebanon	21,340
Gazorient	Nahr El Mot	Mount Lebanon	7,000
Unigaz	Dora	Mount Lebanon	2,944
Phenicia	Dora	Mount Lebanon	2,586
Sidaco	Zahrani - Jiyyeh	South	7,485

The regional spread of legal petrol stations in Lebanon is summarized in Table 16.

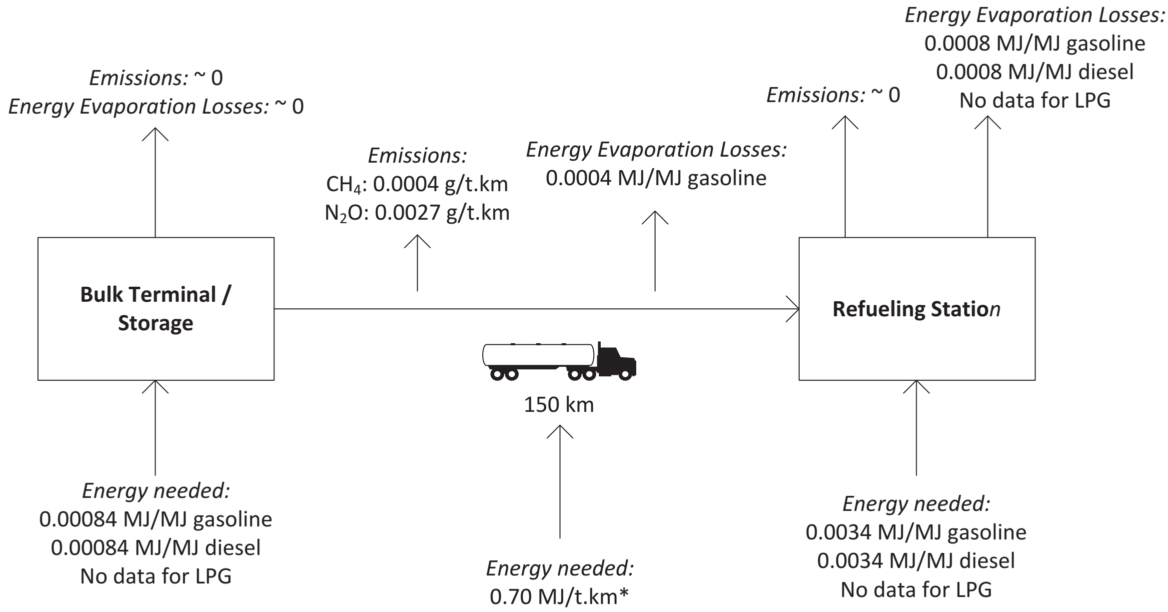
Table 16: Geographical spread of petrol stations by region in Lebanon.
Source: Association of Petroleum Importing Companies (APIC), 2015

<table>
<tr><th>Region</th><th>Number of Stations</th><th>% of Total</th><th>% of gasoline distribution to stations[(A)]</th></tr>
<tr><td>North</td><td>603</td><td>19.8</td><td>12.5</td></tr>
<tr><td>Beirut</td><td>108</td><td>3.5</td><td rowspan="2">65</td></tr>
<tr><td>Mount Lebanon</td><td>1,185</td><td>38.9</td></tr>
<tr><td>South (including Nabatieh)</td><td>568 (233)</td><td>18.6</td><td>10</td></tr>
<tr><td>Bekaa (including Baalbeck-Hirmel)</td><td>586 (241)</td><td>19.2</td><td>12.5</td></tr>
</table>

[(A)] As reported by APIC (2015).

Based on the above and other relevant stakeholder data, the existing pathways for all fuel types (gasoline, diesel and LPG) in Lebanon are represented in Figure 25.

Figure 25: Gasoline, diesel and LPG pathways in Lebanon.



Data Ref: EU Joint Research Centre Technical Report, 2014
** Ref: Greet 2015 Model, Argonne National Laboratory, USA*

The figure abstracts all three existing pathways into the main processes of storing, transporting and distributing the corresponding fuels at the station. As noted in the figure, the fuel storage process does not produce any notable emissions or losses; however it consumes energy to power fuel pumps and other loading devices, and this is expressed as the amount of energy (MJ) needed to load/unload 1 MJ of the corresponding fuel. The transportation process is done by truck (over an average distance of 150 km as per analysis of the stakeholder data), which also consumes energy and produces various emissions and losses, given per 1 ton of fuel transported over 1 km. Finally, and similar to the storage process, the refueling process at the station consumes energy but produces some evaporation losses due to various leaks and inefficiencies at the pump.

THE TRANSPORTATION PROCESS IS DONE BY TRUCK, WHICH ALSO CONSUMES ENERGY AND PRODUCES VARIOUS EMISSIONS AND LOSSES, GIVEN PER 1 TON OF FUEL TRANSPORTED OVER 1 KM.

4.3. MODELING OF POTENTIAL PATHWAYS

The potential fuel pathways for alternative fuels in Lebanon (natural gas, electricity and biofuels) were modeled using various assumptions as referenced.

LOCAL CONNECTIONS TO STATIONS WOULD BE THROUGH LOW PRESSURE PIPELINES OFF OF THE MAIN HIGH PRESSURE LINE. UNDER THIS SCENARIO, EXISTING PETROL STATIONS CAN BE RETROFITTED TO DISPENSE CNG, AND AS NOTED IN SECTION 4.2 MOST OF THESE STATIONS ARE LOCATED IN BEIRUT AND MOUNT LEBANON, WHICH WOULD BE A SHORT DISTANCE AWAY FROM THE MAIN PIPELINE

4.3.1. Natural gas pathways

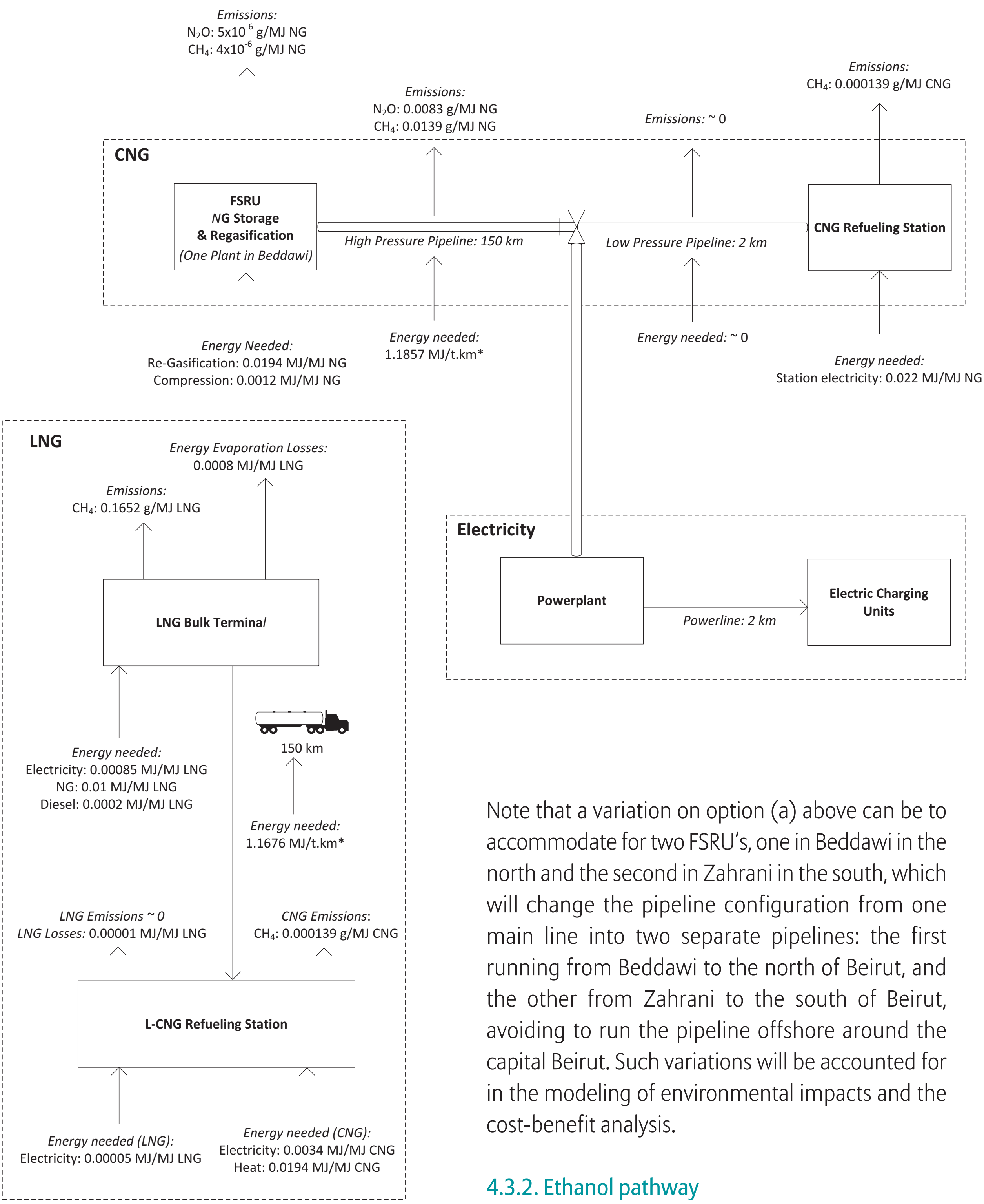
The proposed pathways for natural gas are presented in Figure 26, and include:

a) Importing liquefied natural gas (LNG) and processing it in the off-shore floating, storage and regasification unit (FSRU), proposed to be located in the Beddawi region, and transporting it in its gaseous form by high pressure pipeline to refueling stations for dispensing compressed natural gas (CNG). The pipeline would run along the coast from Beddawi to the south through Beirut in order to connect the majority of power plants in the country. Local connections to stations would be through low pressure pipelines off of the main high pressure line. Under this scenario, existing petrol stations can be retrofitted to dispense CNG, and as noted in section 4.2 most of these stations are located in Beirut and Mount Lebanon, which would be a short distance away from the main pipeline (2km on average).

b) Importing LNG and processing it in the FSRU for transportation to power plants to generate electricity, which is then distributed by power lines to electrified vehicle recharging stations. Note that the power plant emissions include numerous pollutant and GHG emissions which are not shown in the figure for brevity, but are considered in the modeling.

c) Importing LNG and distributing it by truck to L-CNG refueling stations. This configuration is considered typical for inland regions such as the Bekaa and Nabatieh regions where a pipeline connection would not be optimal.

Figure 26: Potential natural gas pathways in Lebanon.



Data Ref: EU Joint Research Centre Technical Report, 2014
** Ref: Greet 2015 Model, Argonne National Laboratory, USA*

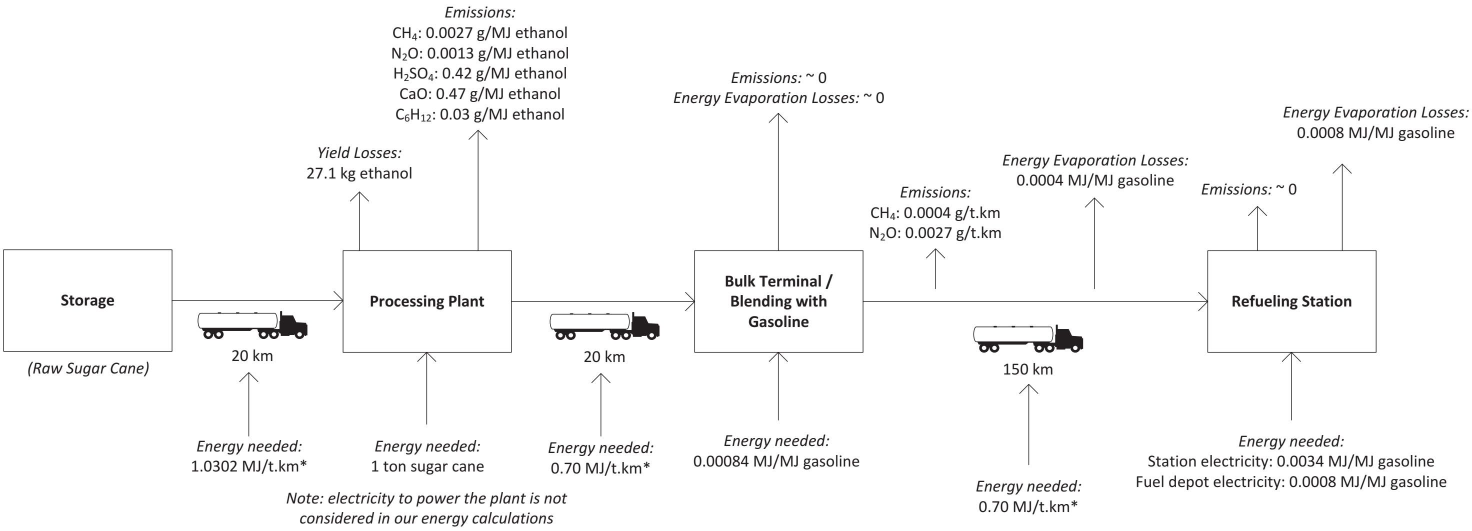
Note that a variation on option (a) above can be to accommodate for two FSRU's, one in Beddawi in the north and the second in Zahrani in the south, which will change the pipeline configuration from one main line into two separate pipelines: the first running from Beddawi to the north of Beirut, and the other from Zahrani to the south of Beirut, avoiding to run the pipeline offshore around the capital Beirut. Such variations will be accounted for in the modeling of environmental impacts and the cost-benefit analysis.

4.3.2. Ethanol pathway

The proposed pathway for ethanol biofuel is presented in Figure 27. The process starts with the import of feedstock, with Brazilian sugar cane being one of the most attractive due to the abundance of supply, relative ease of processing at market, and the relatively low direct and indirect emissions from growing the crop at the source (e.g. land-use change, impact on the soil and pollutant emissions). Sugar cane is transported by truck for processing (fermentation and distillation), and the resultant ethanol is transported by truck for blending with gasoline into E10 and E85 biofuels. These final products are then transported by truck to refueling stations.

Note that the above pathway can be simplified to directly import E10 and E85 biofuels for direct distribution to refueling stations (similar to the existing gasoline pathway); this possibility will be considered in the environmental modeling and cost-benefit analysis.

Figure 27: Potential ethanol biofuel pathway in Lebanon.



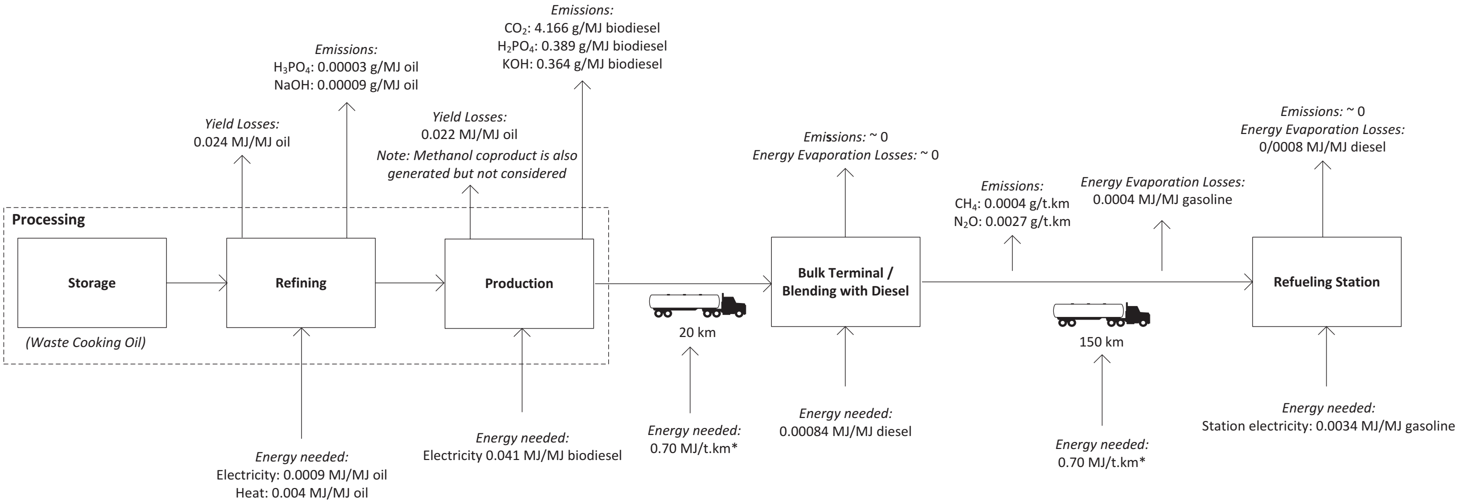
Data Ref: EU Joint Research Centre Technical Report, 2014
** Ref: Greet 2015 Model, Argonne National Laboratory, USA*

4.3.3. Biodiesel pathway

The proposed pathway for biodiesel fuel is presented in Figure 28. Similar to Ethanol, feedstock can be imported for processing at market; however, in the case of Lebanon and since biodiesel production from waste-cooking oil already exists, this possibility is selected for modeling instead. Processing of waste cooking oil consists of cleaning, refining and esterification, before transportation for blending and finally to the refueling stations as B20 and lower blends.

Note that the above pathway can be simplified to directly import B20 and lower biodiesel blends for direct distribution to refueling stations (similar to the existing diesel pathway); this possibility will also be considered in the environmental modeling and cost-benefit analysis.

Figure 28: Potential biodiesel fuel pathway in Lebanon.

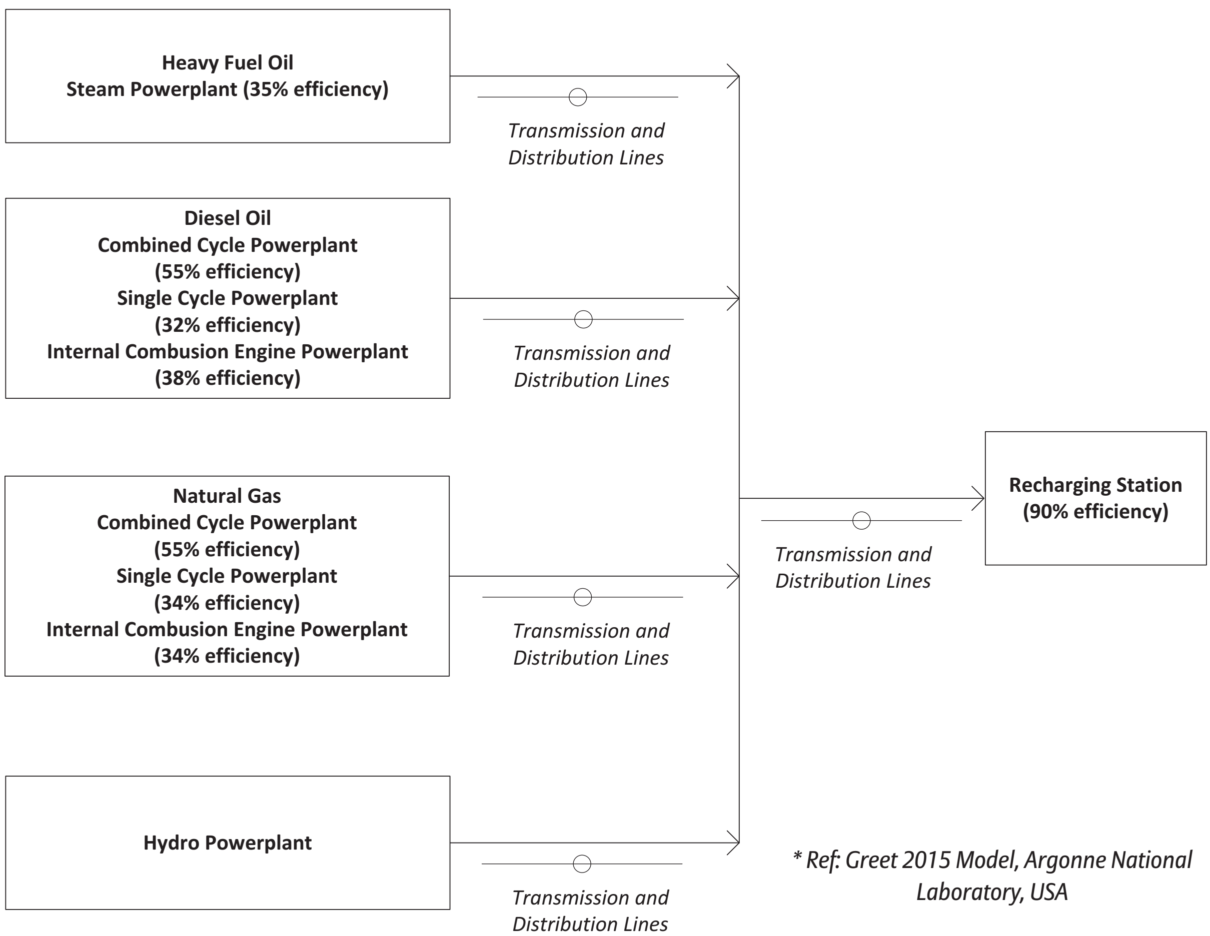


Data Ref: EU Joint Research Centre Technical Report, 2014
** Ref: Greet 2015 Model, Argonne National Laboratory, USA*

4.3.4. Electricity pathway

The proposed pathway for electricity as a fuel is presented in Figure 29.

Figure 29: Electricity pathways in Lebanon.



** Ref: Greet 2015 Model, Argonne National Laboratory, USA*

The figure includes the existing pathways using the current power plant infrastructure and fuel resource mix, which are divided as 31.3% heavy fuel oil (HFO), 64% diesel oil and 4.7% renewable (reference MOEW policy paper, 2010). It is important to note the following clarifications:

- The fuel storage process does not produce any notable emissions or losses
- The emissions from the operation of the power plant include numerous pollutant and GHG emissions which are not shown in the figure for brevity, but are included in the modeling.
- The transmission and distribution network by power lines has an estimated efficiency of 85% (reference MOEW).
- The recharging process at the station is considered to produce negligible emissions.
- The proposed electricity pathway was modeled for the currently existing power plant technologies and fuel resource mix, as well as future scenarios for 2020 and 2030 with a different power generation mix for each, as per the MOEW policy paper.

MAPPING FUEL FEEDSTOCK TO VEHICLE TECHNOLOGIES IN EXISTING AND POTENTIAL PATHWAYS 4.4.

The following table presents a mapping between each pathway described in the previous section and the corresponding vehicle technologies which can use the converted fuels from that pathway. Only the vehicle technologies which have been selected as viable for the Lebanese transport sector (as identified in Table 12) are considered. These vehicles will be included in the WTW assessment as will be detailed in the coming sections. The mapping below reflects the existing reality and potentially feasible alternatives for the Lebanese context where, for example, the upstream processing of oil-based fuel feedstock is limited to importing (i.e. no local refining).

Table 17: Feedstock and vehicle technology mix.

Imported Feedstock	End-Fuel	Vehicle Technology
Gasoline	Gasoline	ICEV, HEV
Diesel	Diesel	ICEV, HEV
Sugar Cane	E10, E85	ICEV, HEV
E10, E85	E10, E85	ICEV, HEV
Waste Cooking Oil	B20	ICEV, HEV
B20	B20	ICEV, HEV
CNG	CNG	ICEV
LNG	CNG	ICEV
	LNG	ICEV*
LPG	LPG	ICEV
Resource Mix for Local Power Generation	Electricity	EV, PHEV

** The use of LNG in passenger cars is not very viable due to the need for heavy insulation of the vehicle tank, with inevitable high evaporative losses during vehicle idle, and the need for special handling equipment at the pump. As a result, this fuel-vehicle option will not be considered further in the analysis.*

5

5.1. WTW RESULTS AND ANALYSIS

WELL-TO-WHEEL RESULTS AND ANALYSIS BY PATHWAY

A WTW analysis was done for each of the fuel pathways described in section 4, using the appropriate combination of fuels and vehicle technologies as summarized in Table 18.

Table 18: Applicable fuels and vehicle technologies for the WTW analysis.

Fuel Feedstock Category	Fuels in Use	Vehicle Technology
Oil-based	Gasoline	ICEV, HEV, PHEV
Biofuel-based	Diesel	ICEV, HEV, PHEV
Gas-based	E10 from import only	ICEV, HEV
Electricity-based	E10 from sugar cane	ICEV, HEV
	E85	ICEV, HEV
	B20 from import only	ICEV, HEV
	B20 from waste cooking oil	ICEV, HEV
	B100*	ICEV
	LPG	ICEV
	CNG from import only	ICEV
	LNG from import only	ICEV
	CNG/LNG from local extraction*	ICEV
	Electricity from current resource mix	EV, PHEV**
	Electricity from resource mix for 2020 per MOEW policy paper	EV, PHEV**
	Electricity from resource mix for 2030 per MOEW policy paper	EV, PHEV**

** Shaded cells in the table above reflect that no data is available for the selected fuel-vehicle option. As a result, these options will not be considered in the modeling assessment.*

*** Two PHEV models are considered in this fuel feedstock category: PHEV20 and PHEV60, reflecting the range of electric drive autonomy of 20km or 60km, respectively.*

Note that for all fuel feedstock including imported feedstock, the impacts of upstream processing outside Lebanon in terms of energy use and generated emissions at the source and during transportation to the Lebanese market are not considered in the WTW analysis, as they do not count towards the local impacts.

WTW RESULTS AND ANALYSIS 5.1.

The WTW analysis results summarize in this section and detailed in the appropriate appendices cover three types of impacts: energy use, greenhouse gas emissions and pollutant emissions.

5.1.1. Energy use results

The results for energy use under each of the fuel-vehicle technologies are shown in Figures A.1 to A.6 in Appendix A, presented by fuel feedstock category (oil-based, biofuel-based, gas-based, and electricity-based). The figures show the energy use from the well-to-tank and the tank-to-wheel contributions for each fuel-vehicle technology. Since the current vehicle fleet in Lebanon is made up of almost exclusively gasoline-ICEV vehicles, this vehicle type is chosen as the base vehicle against which all results are compared.

For the base vehicle, the model-year weighted average well-to-wheel energy use is a total of 330.5 MJ/100km (the vehicle model year distribution of the Lebanese fleet is shown in Figure A.7 of Appendix A).

As can be seen in figure A.1, significant reductions in energy use compared to the average base vehicle are achieved by the hybrid powertrain version for both gasoline (40.5%) and diesel (50.4%) fuels. These reductions are not improved upon by the use of biofuels, as shown in figure A.2. Indeed, the most energy efficient of all biofuel-vehicle categories is the imported biodiesel B20-HEV (163.2 MJ/100km), which is almost equal to the energy use of the diesel-HEV category. This is because the advantages of biodiesel over conventional diesel are in terms of emissions reductions for the same energy use.

For similar reasons, the imported ethanol E10-HEV fuel-vehicle category has an energy use equal to the gasoline-HEV category (196.6 MJ/100km), which makes the use of E10 less energy efficient than biodiesel. This is explained by the fact that the diesel engine has a higher efficiency than gasoline engines. However, it is important to note that diesel-based vehicles face several challenges in terms of emissions compared with gasoline and ethanol-based fuels, such as the need to have and to regularly maintain emissions-control systems (e.g. the diesel particulate filter DPF), and to ensure low-sulfur content in the diesel fuel.

It is also noteworthy that energy use for the locally converted sugar cane-to-E10-HEV vehicles (211.2 MJ/100km) is significantly higher than for imported E10 (196.6 MJ/100km) due to energy consumption in upstream well-to-tank processes.

For gas-based fuels, only ICEV vehicle technologies are considered, since no hybrid vehicles are commercially available, and as figure A.3 illustrates there is a decrease in WTW energy use compared to the average base vehicle (-3.9% for CNGand -12.3% for LPG). However, when compared with new model year gasoline-ICEV and HEV, the gas-based vehicles will actually show higher energy use (12% on average) due to a number of factors, mainly: the lower energy density of these fuels, the fact that they are used on the same conventional ICEV technology as for gasoline, and the WTT energy losses. Compared with the energy efficient diesel-based-HEV identified above, the most efficient of the gas-based vehicles (the LPG-ICEV) consumes significantly more energy (+76.9%), for the same reasons already stated.

For electricity-based vehicles under the current 2015 resource mix, the diesel-PHEV20 vehicle has the lowest WTW energy use, on par with the gasoline-HEV but still more energy consuming than the more efficient diesel-HEV, as shown in figure A.4. This is due to the low efficiency of the WTT power generation in Lebanon which currently relies on a dirty resource mix. However, the 2020 and 2030 future scenarios which have been considered show significant improvement in energy use for all electricity-based vehicles. In the 2020 scenario, and as figure A.5 illustrates, the diesel-PHEV20 and the EV have the lowest energy efficiency, but remain slightly more consuming than the diesel-HEV. In the 2030 scenario, the EV becomes the absolute lowest energy consuming vehicle compared with all other fuel-vehicle technologies, as shown in figure A.6.

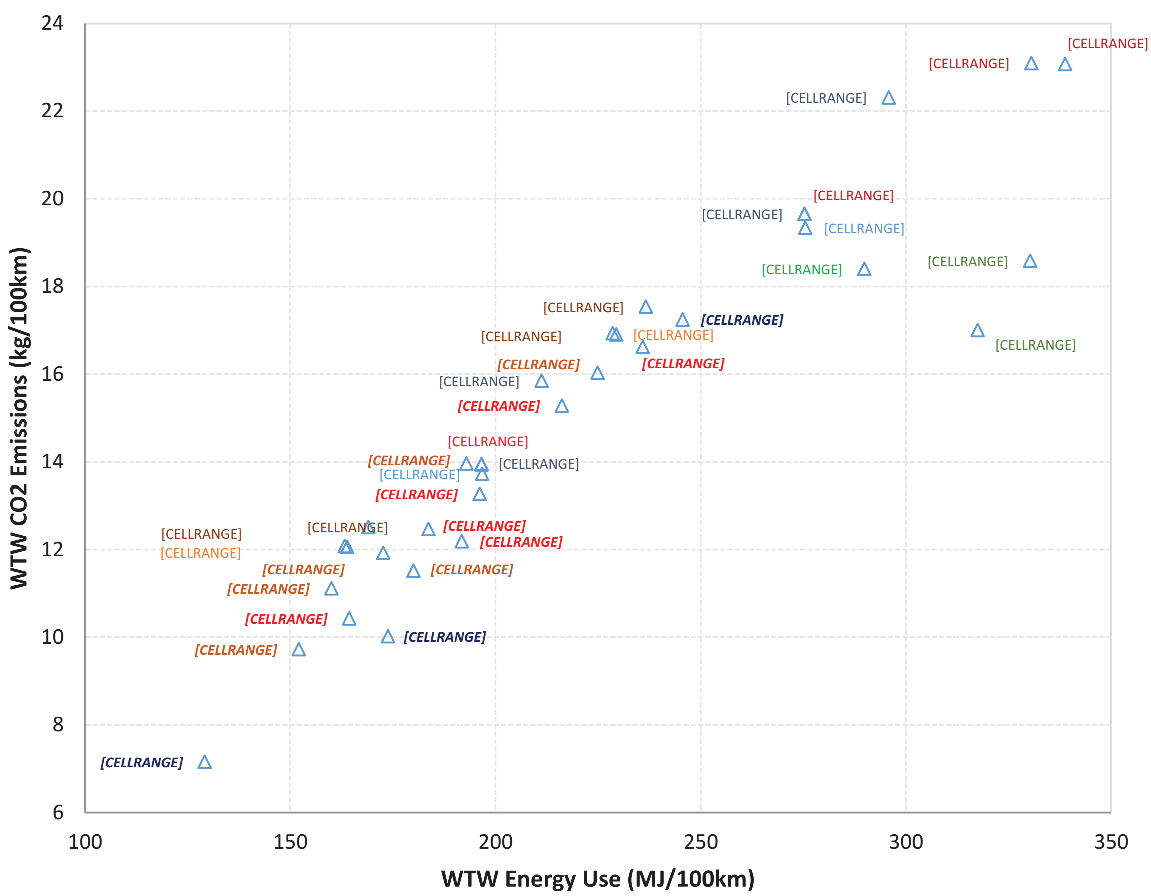
5.1.2. GHG emissions results

The GHG emissions results (CO2, CH4 and N2O) for all fuel-vehicle technologies are presented in Figures B.1 to B.6 in Appendix B by fuel feedstock category. Since CH4 and N2O emissions are almost negligible compared with those of CO2, the discussion of GHG emissions will be restricted to the levels of CO2 only.

5.1.3. Impact Assessment of fuel-vehicle technology for energy use and CO2 emissions

The CO2 emissions versus energy use for each fuel-vehicle technology are shown in Figure 30. Note that E85-based vehicles (with ethanol produced from sugar cane) are not included due to their excessively high emissions-to-energy figures.

Figure 30: CO2 emissions versus energy use of the assessed fuel-vehicle technologies.



Fuel-vehicle technologies with the lowest energy use-to-CO2 emissions are those in the lower left quadrant of Figure 30, with the best performing being the EV under the 2030 clean energy resource mix. Diesel-HEV and PHEV are the next preferred technologies, followed by gasoline-HEV and PHEV which are on-par with imported biofuel-HEV technologies, namely imported B20 and E10 HEV's. A notable mention is the locally produced B20 from waste cooking oil which has only slightly higher energy use-to-CO2 emissions than the imported B20 on the same HEV technology. Less performing technologies are ICEV vehicles, with gas-based ICEV's having some of the highest energy use, while ethanol-based ICEV's have CO2 emissions as high as the newer model gasoline cars. As expected, E10-ICEV shows only a small improvement in energy use-to-CO2 emissions as compared with the current fleet average (i.e. the base vehicle).

THE CO2 EMISSIONS VERSUS ENERGY USE FOR EACH FUEL-VEHICLE TECHNOLOGY ARE SHOWN IN FIGURE 30. NOTE THAT E85-BASED VEHICLES (WITH ETHANOL PRODUCED FROM SUGAR CANE) ARE NOT INCLUDED DUE TO THEIR EXCESSIVELY HIGH EMISSIONS-TO-ENERGY FIGURES.

5.1.4. Pollutant emissions results

The pollutant emissions results are shown in Table 19, divided by fuel-vehicle technology type. The reported emissions levels are compared to applicable emissions standards for that particular pollutant.

US Federal EPA standards for light duty low emitting vehicles (LEV-LDV) have been adopted since no local standards are available for Lebanon. No standards are available for PM and SOx, however a threshold of 5.0 g/100km for PM10 is used as per California emissions standards for LEV technology.

Numbers shown in ***bold-italics*** indicate a violation of the pollutant standard for that fuel-vehicle technology.

It is important to note that the standards used are only for vehicle emissions (i.e. the TTW portion only), while the reported emissions are for the entire WTW assessment for each fuel-vehicle technology, which includes the emissions of the WTT portion from upstream processes. In this respect, the comparison of the WTW numbers against the vehicle emissions standards is a very conservative assessment of the polluting performance of each technology.

Table 18: Applicable fuels and vehicle technologies for the WTW analysis.

	VOC *g/100km*	CO *g/100km*	NOx *g/100km*	PM10 *g/100km*	PM2.5 *g/100km*	SOx *g/100km*
Gasoline ICEV (fleet average)	***38.57***	***533.38***	***43.28***	0.70	0.63	0.94
Gasoline ICEV	13.37	***216.46***	5.61	0.55	0.49	0.78
Gasoline HEV	8.53	***216.45***	4.55	0.54	0.49	0.56
Diesel ICEV (with DPF)	10.58	31.19	5.39	0.60	0.54	2.49
Diesel ICEV (without DPF)	10.58	33.98	8.11	***5.40***	4.84	2.49
Diesel HEV	7.84	31.18	4.52	0.59	0.54	1.78
E10 ICEV (from sugar cane)	13.28	200.53	7.67	2.32	1.68	0.99
E10 HEV (from sugar cane)	8.57	198.86	5.99	1.79	1.33	0.70
E10 ICEV (from import only)	13.09	194.77	5.40	0.52	0.47	0.76
E10 HEV (from import only)	8.43	194.75	4.37	0.51	0.46	0.55
E85 ICEV (from sugar cane)	7.16	***260.96***	***31.69***	***21.17***	14.36	3.10
E85 HEV (from sugar cane)	4.25	***242.01***	***23.17***	***15.25***	10.38	2.21
E85 ICEV (from import only)	5.03	194.78	5.67	0.52	0.47	0.55
E85 HEV (from import only)	2.73	194.76	4.59	0.51	0.46	0.39
B20 ICEV (from waste cooking oil)	4.29	31.25	6.52	0.58	0.50	2.75
B20 HEV (from waste cooking oil)	4.25	31.21	4.67	0.50	0.46	2.04
B20 ICEV (from import only)	3.34	31.22	5.33	0.55	0.49	1.97
B20 HEV (from import only)	3.32	31.19	4.00	0.49	0.45	1.46
CNG ICEV (from FSRU)	4.72	174.34	12.60	0.78	0.64	2.76
CNG ICEV (LNG gasification at station)	4.46	173.23	5.95	0.56	0.50	0.60
LPG ICEV	11.78	173.18	5.70	0.55	0.49	0.49
Gasoline PHEV20	6.82	162.33	***24.81***	1.20	0.82	8.69
Gasoline PHEV60	4.61	93.79	***49.05***	1.98	1.22	18.45
Diesel PHEV20	6.33	23.82	***25.05***	1.25	0.87	9.71
Diesel PHEV60	4.35	14.34	***49.90***	2.04	1.26	19.31
EV PP10	1.52	1.40	***76.69***	2.85	1.64	29.64
EV PP20	2.12	9.56	***23.63***	1.52	1.38	13.43
EV PP30	3.48	13.37	11.48	1.46	1.46	0.05
US EPA LEV Emissions Standards*	25.48	211.27	12.43	5.0**	--	--

** standards apply to TTW emissions only, while reported emissions are for the entire WTW cycle*

*** as per California emissions standards for LEV technology*

For VOC emissions, EV's are the lowest polluters (<5 g/100km), with equivalent performance by HEV's and PHEV's for all fuel types (< 10 g/100km). Even ICEV's are well within the allowable standard when running on diesel, biofuels or gas-based fuels, and the same applies for newer model gasoline-ICEV's. It can therefore be concluded that all future fuel-vehicle technologies will be compliant for VOC emissions.
For CO emissions, EV's are again the best performing vehicle technology with emission levels well below the allowable standard.

EV's are followed by diesel and biodiesel-HEV's, PHEV's and ICEV's, all having CO emission levels less than 16% of the total allowable standard.

Gas-based fuels have much higher levels of CO emissions, primarily due to upstream WTT processes, but they still remain well within the allowable standard.

Ethanol-based fuels have CO emission levels close to the standard, with locally converted E85 exceeding the standard. This is again due to the significant contribution of upstream WTT processes.

Slightly exceeding the standard are gasoline-HEV's and newer model gasoline-ICEV's, which mirrors the global picture of performance for these technologies. However, continuous innovation in the control of tailpipe emissions is always moving these technologies in the direction of compliance with the standards.

It is also important to note that when it comes to the very well-performing diesel-based fuels, the low emissions results are contingent on the mandated use and regular maintenance of on-board emissions control systems, as well as the use of low-sulfur fuels and the ban of unauthorized vehicle retrofitting. This requires enacting new laws and regulations along with stringent enforcement in the field.
The picture for NOx is different than for the previous two pollutants, as HEV's and ICEV's become the least polluting vehicle technologies for almost all fuels, especially imported biofuels, diesel and gasoline. Only locally converted E85 biofuel exceeds the standard, which is again due to the contribution of emissions from upstream WTT processes.

In addition, EV's and PHEV's become the least performing technologies, with most being in violation of the standard due to the WTT emissions.

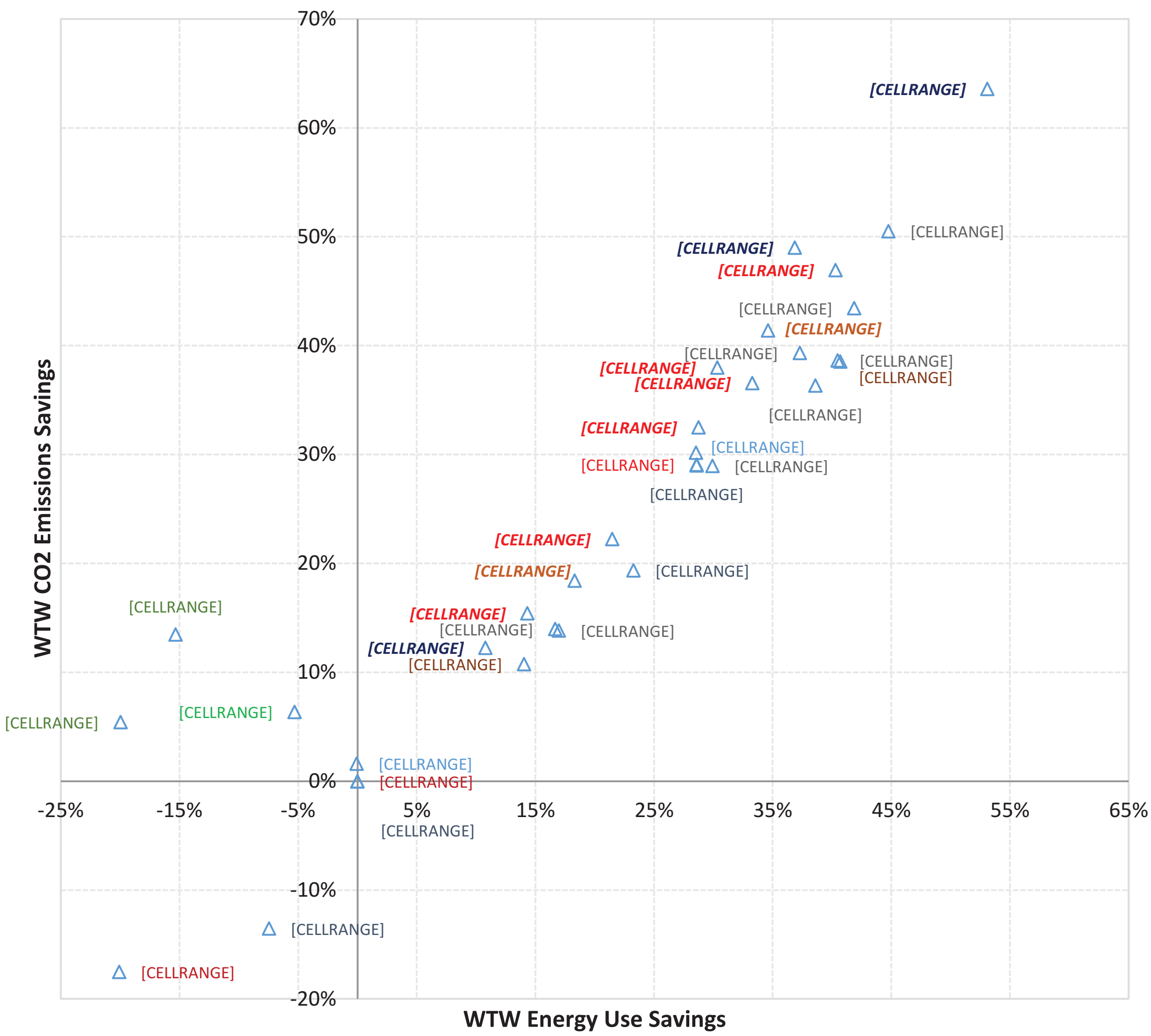
For PM10, the vast majority of fuel-vehicle technologies are well within the standard, with the only concern coming again from the WTT emissions for locally converted E85. The same picture is observed for PM2.5 which, despite the absence of a standard, shows the same exact concerns.

Finally, for SOx emissions where no standard is available, the assessment results show that emissions are very low for all fuel-vehicle technologies, with the exception of EV's and PHEV's under all but the 2030 clean resource mix, which becomes the best performing technology. This demonstrates again that the high emission levels are primarily due to the contribution from the WTT emissions.

5.1.5. Results synthesis

Since the levels of pollutant emissions did not demonstrate any significant exceedances that force the elimination of particular categories of fuel-vehicle technologies, the down-selection of the most feasible and attractive technologies was done on the basis of energy use-to-CO2 emissions, as shown in Figure 31 where all fuel-vehicle technologies are compared against the 2015 model gasoline ICEV technology.

Figure 31: CO2 emissions versus energy use savings of the assessed fuel-vehicle technologies.



As the figure illustrates, the gas-based fuel-vehicles are more energy consuming for relatively minor improvement (5-20%) in CO2 emissions. These technologies are further at a disadvantage from the standpoint of infrastructure costs and local market readiness in the near term. Even in the medium term, they remain at a disadvantage relative to HEV and PHEV technologies which may require similar investment but offer much higher energy use-to-CO2 emissions benefits.

Similarly, ICEV technologies for the other fuels (gasoline, diesel and biofuels) offer minor energy use-to-CO2 emissions improvements (<20%) relative to 2015 model gasoline ICEV technology, which leaves gasoline, diesel and biofuel HEV's as the preferred technologies for the near term due to their commercial readiness at no additional infrastructure cost.

For the medium term, electricity-based vehicles appear to have the most promise; however, the local infrastructure for these technologies is unlikely to be ready in time. As a result, high-blending ethanol and locally converted biodiesel become additional preferred options, with the possibility of having infrastructure ready for gas-based vehicles. The latter remain sub-optimal in terms of their energy use-to-CO2 emissions contributions, however they may become attractive from a cost perspective.

For the long-term scenario, the electricity-based vehicles offer much higher benefits than all other technologies and become the dominant choice under the future 2030 clean resource mix (which would consist of natural gas and renewable energies), assuming the power generation and distribution infrastructures are ready. It is noteworthy to mention here that the infrastructure needed for natural gas-based vehicles is complementary but separate from that for electricity-based vehicles, which means that one choice is typically preferred over the other depending on cost, readiness and other critical factors.

The feasible technologies identified in the analysis above are summarized in Table 20.

Table 20: Applicable fuel-vehicle technologies under near, medium and long-term scenarios.

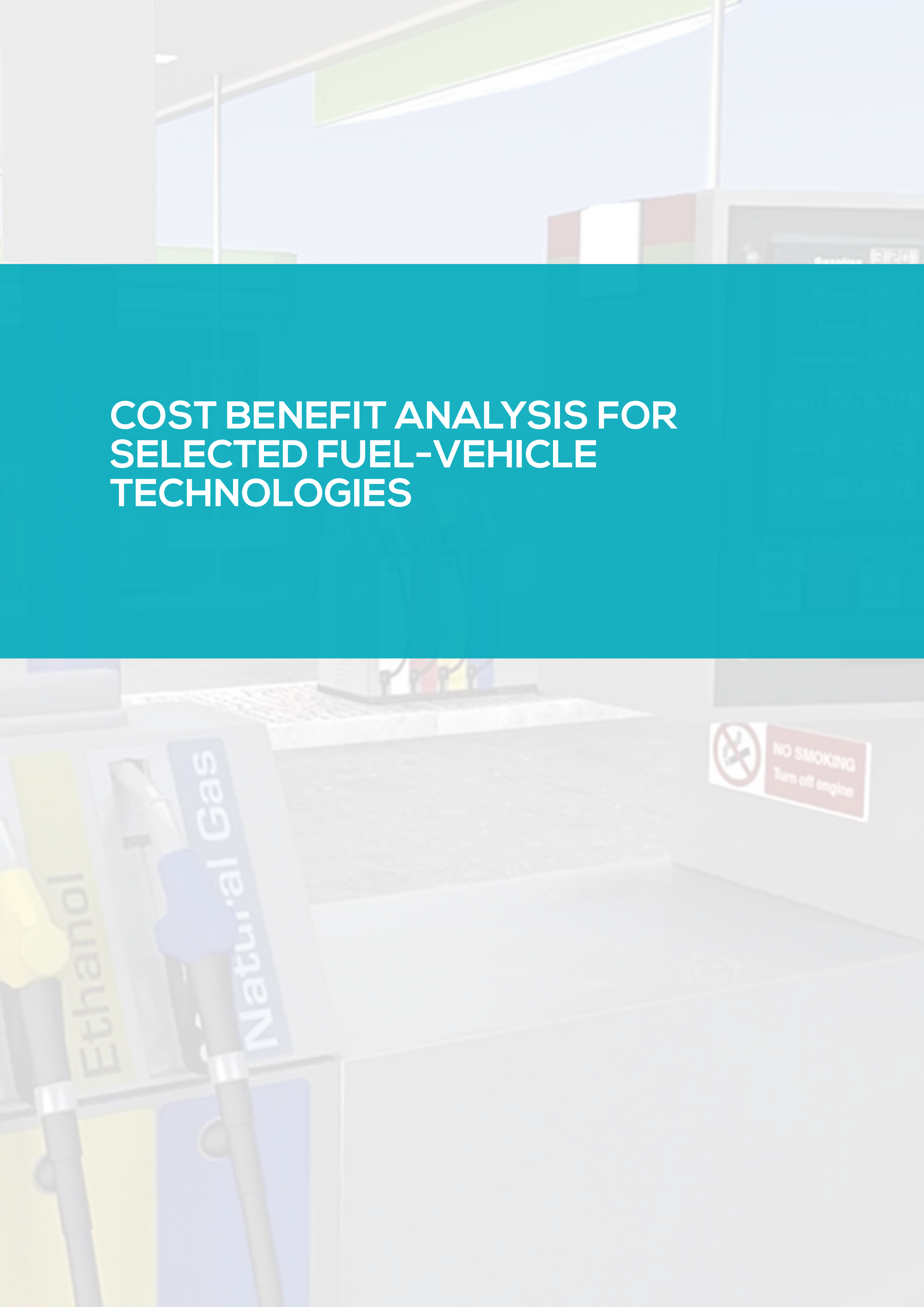
Scenario	Fuel Feedstock	Vehicle Technology
Near-term (2015)	Gasoline	HEV
	Diesel	HEV
	E10 from import only	HEV
	B20 from import only	HEV
Medium-term (2020)	B20 from waste cooking oil	HEV
	E85 from import only	HEV
	CNG/LPG	ICEV
Long-term (2030)	Electricity from resource mix for 2030 per MOEW policy paper	EV, PHEV

6

6.1. COST ANALYSIS FRAMEWORK

6.2. COST BENEFIT ANALYSIS

COST BENEFIT ANALYSIS FOR SELECTED FUEL-VEHICLE TECHNOLOGIES



COST ANALYSIS FRAMEWORK 6.1.

6.1.1. Specific transportation costs evaluated

The objective of the cost-benefit analysis (CBA)is to identify the cost value of the prioritized technologies and measures in order to support setting a beneficial transport policy, favoring cleaner and lower-cost transport technologies over more polluting or higher-cost transport technologies. The CBA is carried out in this study in order to evaluate the economic impacts of the prioritized fuel-vehicle technologies on the car users, the government and the private sector. The ultimate purpose of this economic evaluation is to minimize the ownership and operating costs on the user, and to determine the corresponding infrastructure and subsidy costs on the government, as well as to quantify the corresponding costs of transitioning to a particular fuel on the private sector. This involves quantifying the applicable fixed and variable cost components per fuel-vehicle technology, both internal and external. The specific transportation costs evaluated are summarized in Table 21.

Table 21 - Specific transportation costs assessed in the CBA.

Specific cost	Description	Cost category[1]	Market/Non market
Vehicle ownership	Cost for owning a vehicle, including the vehicle purchase cost (minus its salvage value by the end of the vehicle life estimated 10 years), insurance fees, custom and excise fees, registration fees, road-usage fees and loan financing charges.	Internal-fixed	Market
Vehicle operation	Vehicle operation costs including the cost of consumed fuel, maintenance and tires costs.	Internal-variable	Market
GHG emissions	Cost of reducing GHG emissions	External	Non-market
Operation subsidies	Financial subsidies for implementing the required measures.	External	Market
Infrastructure	Costs of alternative fuel stations and distribution networks	External	Market

[1] Cost categories are: internal/external, fixed/variable. Internal costs are directly borne by the car user; external costs are borne by others. Variable costs are dependent on external variable factors like fuel consumption or vehicle mileage; fixed costs are not dependent on these external variable factors.

6.1.2. Vehicle-fuel technology parameters and assumptions

Table 22 summarizes the total vehicle costs for a mid-size passenger car for each of the different fuel-vehicle technologies evaluated in this CBA that were prioritized in the previous environmental assessment in section 5 of this report. The individual cost component estimates under each total vehicle cost, detailed in section 6.2.1, are computed over a comprehensive timeframe to emulate the phased deployment of the fuel-vehicle technologies over time, namely under the following three scenarios: short-term (up to 2020), medium-term (up to 2030) and long-term (up to 2040). These estimates are also based on extensive research of the real local ownership and operating conditions in Lebanon.

Table 22 - Transport technologies evaluated.

Technology[(1)]	Description
Gasoline/E10/E85 ICEV	Ownership cost: 29,640/ 29,640/ 31,350 USD Operating cost: 1437/ 1437/ 1437 USD/year Fuel consumption: 8.6/ 8.6/ 8.6 lge/100km
Gasoline/E10/E85 HEV[(2)]	Ownership cost: 39,900/ 39,900/ 41,610 USD Operating cost: 1,160/ 1,160/ 1,160 USD/year Fuel consumption: 6.2/ 6.2/ 6.2 lge/100km
Diesel/B20 ICEV	Ownership cost: 37,335/ 37,335 USD Operating cost: 1,409/ 1,409 USD/year Fuel consumption: 7.2/ 7.2 lge/100km
Diesel/B20 HEV	Ownership cost: 45,030/ 45,030 USD Operating cost: 1,160/ 1,160 USD/year Fuel consumption: 5.1/ 5.1 lge/100km
CNG/LPG ICEV	Ownership cost: 35,625/ 35,625 USD Operating cost: 1,016/ 986 USD/year Fuel consumption: 9.6/ 9.1 lge/100km
Gasoline PHEV20/60	Ownership cost: 46030/ 52,015 USD Operating cost: 1,072/ 995 USD/year Fuel consumption: 6.2/ 6.2 lge/100km Electric consumption: 203.7/206.5 Wh/km Electric drive share: 28%/ 61%
Diesel PHEV20/60	Ownership cost: 52,015/ 57,145 USD Operating cost: 984/ 953 USD/year Fuel consumption: 5.1/ 5.1 lge/100km Electric consumption: 206.1/210.2 Wh/km Electric drive share: 28%/ 61%
EV PP10/ PP20/ PP30	Ownership cost: 48,595/ 48,595/ 48,595 USD Operating cost: 836/ 795/ 698 USD/year Electric consumption: 183.0 / 168.1/ 132.9 Wh/km

[(1)] The estimated average annual mileage for all passenger cars is 12,000 km. The vehicle life is considered 10 years for passenger cars.

6.1.3. Methodology for the cost-benefit analysis

The CBA in this study consists of two main parts: the user's perspective which is based on a comparison of the environmental-to-cost performance (USD/veh.km) of each fuel-vehicle technology relative to the model 2015 gasoline ICEV considered as the baseline vehicle, and where benefits are measured in terms of the cost of GHG reductions; and, the government and private sector perspective which relies on the corresponding costs of the infrastructure for fuel distribution and the foregone government revenues for each fuel-vehicle technology, which are used to evaluate the possibilities for near, medium and long-term phased implementations. The details of the CBA are presented in section 6.2.1 by quantifying the internal and external cost components of each of the considered technologies.

COST BENEFIT ANALYSIS 6.2.

This section details the individual cost components making up the specific costs considered in this CBA and presented in Table 21. From these costs for each fuel-vehicle technology, the savings that result from alternative and fuel-efficient transport means with respect to the baseline gasoline ICEV are determined.

6.2.1. Methodology and estimates of specific transport costs under local conditions

- ***Vehicle ownership and operating costs***

The computed direct user expenses to own and operate each of the considered fuel-vehicle technologies are detailed in this section.

The ownership cost components considered include:

a) Vehicle purchase cost estimated from a Lebanese market survey for conventional fuel-vehicle technologies, and from worldwide industry data adapted to the Lebanese market for alternative fuel-vehicle technologies (Edmunds, 2016; Mansour, 2012)

b) Vehicle depreciation from a Lebanese market survey estimated at 20% for the first year and 12% for the following years, with a vehicle life of 10 years (Mansour, 2012)

c) Insurance fees computed according to the locally used formula: 14.5% of the vehicle purchase cost during the loan period (5 years), in addition to 150 USD/year after loan period for the last 5 years (Mansour, 2012)

d) Custom and excise fees computed according to the locally used formulas (excise fees of 15% for the first 20 million LBP of the vehicle purchase price, then 45% of vehicle's value above 20 million LBP; and custom fees of 5% of the vehicle estimated value) (MOF, 2011)

e) Car registration fees computed according to the locally used formula (4% of the vehicle's estimated value, considered in this study similar to the vehicle purchase cost) (MOF, 2011)

f) VAT of 10%

g) Road-usage fees (or "Mécanique"). New cars are exempted from this fee for the first 3 years. Refer to (MOF, 2011) for details on the road-usage fees. All vehicles are considered in the 11-20 horsepower category. The estimated values are computed over the vehicle life (10 years).

h) Financing charges for car loans estimated locally at 4% bank interest rate after a 20% down payment of the total vehicle purchase price over a 5 year loan.

The operating cost components considered include:

a) Energy consumption costs: computed from the vehicle fuel consumption under local driving conditions, with an annual mileage estimated at 12,000 km and an appropriate average fuel cost for each fuel type (e.g. 1.0 USD/liter for gasoline; 0.5 USD/liter gasoline equivalent for natural gas; and, 0.23 USD/kWh for electricity).

b) Vehicle maintenance and repair costs estimated from professional databases in 2016 as no local data is available (Edmunds, 2016).

c) Diesel particulate filter (DPF) costs estimated from professional associations at 1,000 GBP for every 160,000 km (The Automobile Association, 2016)

d) Battery costs estimated from industry data at 450 USD/kWh every 8 years or 240,000 km (MIT Technology Review, 2011)

Table 23 and Table 24 summarize the vehicle ownership and operating costs, respectively, of the considered technologies in USD/veh.km.

Table 23 - Vehicle ownership costs of the studied transport technologies.

Fuel-vehicle technology	Gasoline ICEV/HEV	Diesel ICEV/HEV	E10 ICEV/HEV	E85 ICEV/HEV	B20 ICEV/HEV
Ownership costs	0.338/0.449	0.421/0.504	0.338/0.449	0.357/0.467	0.421/0.504
Fuel-vehicle technology (continued)	**CNG ICEV**	**LPG ICEV**	**Gasoline PHEV20/60**	**Diesel PHEV20/60**	**EV**
Ownership costs (USD/veh.km)	0.403	0.403	0.516/0.580	0.580/0.635	0.543

Table 24 - Vehicle operating costs of the studied transport technologies under GBA peak driving conditions.

Fuel-vehicle technology	Gasoline ICEV/HEV	Diesel ICEV/HEV	E10 ICEV/HEV	E85 ICEV/HEV	B20 ICEV/HEV
Operating costs (USD/veh.km)	0.120/ 0.097	0.117/ 0.097	0.120/ 0.097	0.120/ 0.097	0.117/0.097
Fuel-vehicle technology (continued)	**CNG ICEV**	**LPG ICEV**	**Gasoline PHEV20/60**	**Diesel PHEV20/60**	**EV PP10/ PP20/PP30**
Operating costs (USD/veh.km)	0.085	0.082	0.089/0.083	0.082/0.079	0.070/0.066/ 0.058

Note that these costs are borne by the user. The subsidy measures intended for hybrid, plug-in hybrid and electric vehicles will be detailed in the section *operation subsidies by Lebanese government*.

- *GHG emissions*

The cost treatment of GHG emissions in this cost-benefit analysis did not involve the assignment of a carbon cost, in order to avoid the subjective and sometimes controversial approach of monetizing this cost component. Instead, the Tank-to-Wheel (TTW) GHG emissions for each fuel-vehicle technology (previously computed and presented in section 5.1.2) were compared to the GHG emissions of the baseline gasoline ICEV and the resultant savings were attributed to the total vehicle ownership and operating cost. This allows the determination of the relative environmental-to-cost performance of all fuel-vehicle technologies, as will be illustrated in the cost-benefit analysis results (section 6.2).

Results for the saved TTW GHG emissions per fuel-vehicle technology relative to the baseline gasoline ICEV are presented in Table 25.

Table 25 - Tank-to-Wheel GHG emissions savings in g CO2 eq./veh.km.

Fuel-vehicle technology	Gasoline ICEV/HEV	Diesel ICEV/HEV	E10 ICEV/HEV	E85 ICEV/HEV	B20 ICEV/HEV
TTW Saved GHG emissions (g CO2 eq./veh.km)	0/56	27/75	0/56	3/59	26/74
Fuel-vehicle technology (continued)	**CNG ICEV**	**LPG ICEV**	**Gasoline PHEV20/60**	**Diesel PHEV20/60**	**EV**
TTW Saved GHG emissions (g CO2 eq./veh.km)	27	13	90/134	104/142	193

Note that the TTW GHG emissions presented above, while indicative for illustrating the environmental impact from the user's perspective, do not however account for the Well-to-Tank (WTT) contribution to the total GHG emissions for that particular fuel-vehicle technology. Therefore, and in addition to the CBA from the user's perspective, a separate cost assessment is also presented for the total Well-to-Wheel (WTW) GHG emissions for all fuel-vehicle technologies, thereby accounting for the additional emissions from the storage, transportation and distribution infrastructure for a particular fuel. It is common in this case to consider government mechanisms for subsidizing the vehicle ownership costs of cleaner technologies. In this CBA, such mechanisms are accounted for by considering foregone government revenues and using them in the total cost evaluation of the WTW GHG emissions, as will be elaborated in the results section 6.2.2.

- *Operation subsidies by Lebanese government*

Reviewing the possible measures to deploy the alternative fuel-vehicle technologies with highest GHG emissions savings, market and consumer incentives by the government are necessary (Mansour, 2012). Several incentive schemes to encourage the transition to hybrid, plug-in hybrid and electric vehicles as the cleanest technologies are already commonplace worldwide. The incentives mainly intend to reduce the vehicle purchase and ownership costs to encourage the creation of a market in the near term (since these schemes are typically limited to the first few years of transitioning to a new fuel-vehicle technology), through:

- exemption from customs and excise fees on vehicle purchase cost
- exemption from registration fees
- reduction of car loan interest rates

Table 26 summarizes the computed economic costs for each fuel-vehicle technology of the above government subsidy schemes assuming an average annual mileage of 12,000 km per vehicle.

Table 26 - Government subsidy for hybrid, plug-in hybrid and electric vehicles (USD/pass.km).

Fuel-vehicle technology	Gasoline HEV	Diesel HEV	E10 HEV	E85 HEV	B20 HEV	Gasoline PHEV20/60	Diesel PHEV20/60	EV
Operation subsidy (USD/veh.km)	0.151	0.174	0.151	0.159	0.174	0.175/ 0.202	0.202/ 0.226	0.187

Note that the proposed schemes have a financial impact on the government side in the form of foregone revenues, which are discussed in the results section 6.2.2.

- *Infrastructure*

The cost of the supply infrastructure is partially borne by the government, such as the cost of storage reservoirs and distribution pipelines for natural gas, or transmission lines for electricity. Such infrastructure costs should in principle be considered in the overall cost of each fuel-vehicle technology; however, it is considered in this CBA that this infrastructure is primarily built and made available for the energy sector and other sectors of industry and the economy at large, and as such the corresponding costs will not be double-counted in the CBA for the transport sector. The only infrastructure costs that will be considered are the capital and operating costs of the distribution stations (natural gas and electric) where the private sector is assumed to take up much of the provisioning role, as is currently the case for gasoline and diesel fuels. The cost components considered include the storage, compression, dispensing and metering equipment for gas, and the charging equipment (electric vehicle supply equipmentor EVSE) for electricity. The cost of land is not considered. The average cost of a station for each fuel type, shown in Tables 27 and 28 (NGVAMERICA, 2016; CRYOSTAR, 2016; USDOE, 2014), was used along with the estimated values for demand in order to calculate the average total cost of the distribution infrastructure needed for the near, medium and long-terms. This provides an indicative value for the cost of infrastructure to transition to any particular fuel.

Table 27. Average cost and capacity of medium-size CNG, L-CNG and LPG refueling stations.

Station Type	Station Size	Station Capacity (gge/day)	CNG Station Cost (USD)	L-CNG station cost (USD)	Station Capacity (gge/day)	LPG Station Cost (USD)
Fast-fill	Medium	800	900,000	1,100,000	1820	220,000

Table 28. Average cost of electricity public charging stations.

EVSE Type(1)	EVSE/EV Ratio(2)	EVSE Cost (USD)
Curbside (AC slow charger)	0.2	3,000
Fast charging station (DC fast charger)	0.01	35,000

(1) EVSE: electric vehicle supply equipment (charging station)
(2) EVSE/EV is the ratio of charging station stations to EVs, assumed similar to the US with 0.2 for slow AC public charging stations and 0.01 for fast DC public charging stations. Note that the world highest EVSE/EV ratios are 0.5 and 0.03 for slow and fast EVSE respectively.

6.2.2. Cost benefit analysis results

The CBA results are first presented and discussed in terms of their environmental-to-cost performance from the user's perspective. In addition, the financial liability from the government perspective in terms of foregone revenues after cost subsidy is discussed, and the magnitude of infrastructure investment is also illustrated.

• ***Costs and benefits from the car users' perspective***

All fuel-vehicle technologies are compared to the model 2015 baseline gasoline ICEV for an annual mileage of 12,000 km and an appropriate average fuel cost for each fuel type (i.e. 1.0 USD/liter for gasoline; 0.5 USD/liter gasoline equivalent for natural gas; and, 0.23 USD/kWh for electricity).

The results are presented in figure 32, showing various levels of savings in terms of TTW GHG emissions for different costs. As can be seen from the figure, electric vehicles provide the highest CO2 emissions savings at a lower cost than the baseline, making them the most ideal clean technology. Indeed, the only factor that prevents them from being the most cost-effective of all clean technologies is the higher purchase cost of the vehicle.

Behind electric vehicles are the hybrid and plug-in hybrid fuel-vehicles, with plug-in hybrids running on gasoline and diesel fuels providing the most benefit in terms of emissions savings, but at varying cost performance levels. Several important conclusions can be drawn from the cost-benefit results for these fuel-vehicle types, as follows:

- The cost of plug-in hybrids increases significantly with the level of electric autonomy (60km versus 20 km), making PHEV60 vehicles more costly than the baseline ICEV due to the higher purchase cost of the vehicle
- The performance of diesel hybrids and plug-in hybrids, which were found in the environmental assessment to be top performers in terms of energy use and emissions savings, is now significantly affected by the higher operating and maintenance costs of the vehicle, making them less desirable than their gasoline counterparts
- The gasoline and diesel HEVs, while not as efficient in terms of emissions savings as the PHEVs, are however much more cost effective than almost all other fuel-vehicle technologies due to the lower purchase cost of the vehicle
- Biofuel HEVs provide little environmental and cost savings relative to gasoline and diesel hybrids

For the ICEV technologies, they offer relatively minor improvement in CO2 emissions for higher costs than the baseline gasoline ICEV, due to the higher ownership costs of the alternative fuel-vehicle technology. Specifically, diesel and biodiesel ICEVs are the lowest performers, while gas-based (CNG/LPG) ICEV's were only found to be cost-effective for the higher yearly driving mileage typical of taxis and similar public transport and service vehicles, as shown in figure 33 for a mileage of 30,000 km. It is important to note that battery technologies are advancing at an accelerated pace, making EVs capable of higher electric autonomy with a longer extended battery service life. In fact, new research has shown that EV batteries continue to deliver the required functionality for the majority of drivers well beyond the standard end of service life (Saxena et al., 2015). In this case, zero battery replacement cost could be assumed over the vehicle service life, which would make the EV, PHEV and HEV technologies the most cost-effective for high mileage users, followed by gas-based ICEVs.

NEW RESEARCH HAS SHOWN THAT EV BATTERIES CONTINUE TO DELIVER THE REQUIRED FUNCTIONALITY FOR THE MAJORITY OF DRIVERS WELL BEYOND THE STANDARD END OF SERVICE LIFE

Fig. 32 – Environmental-to-cost performance of fuel-vehicle technologies relative to gasoline ICEV for yearly mileage of 12,000 km.

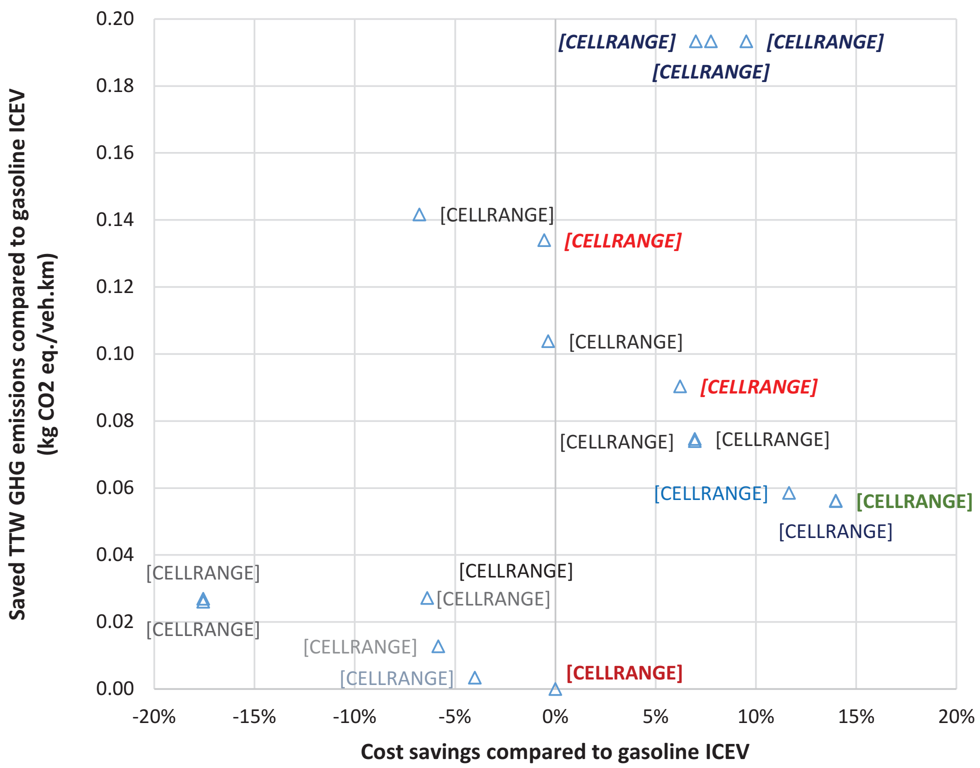
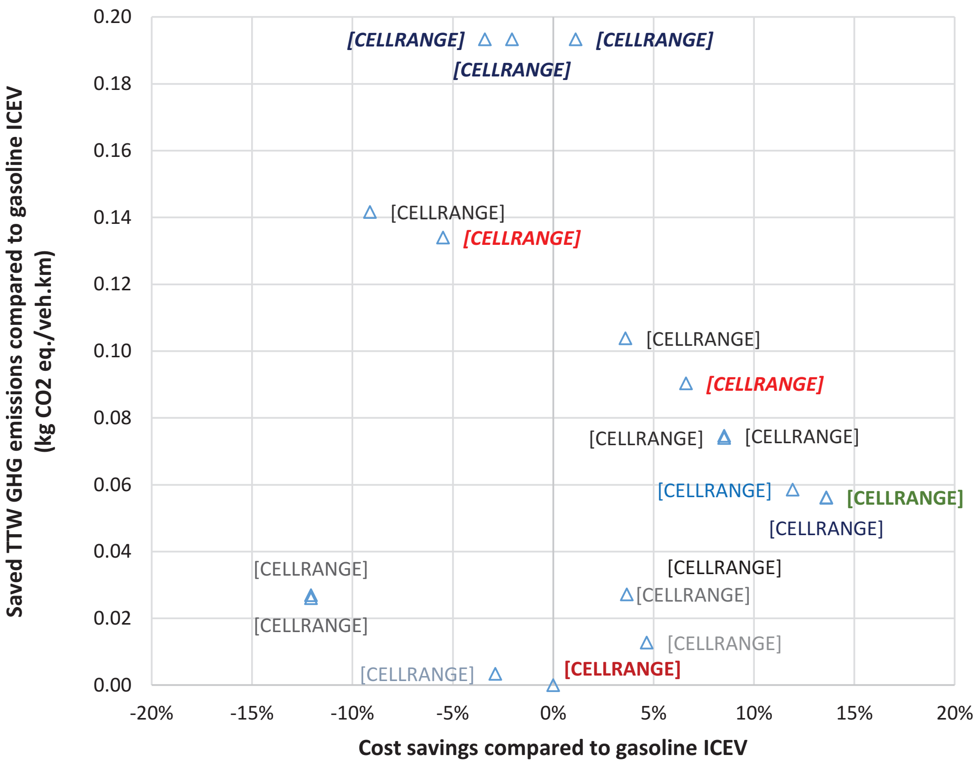


Fig. 33 - Environmental-to-cost performance of fuel-vehicle technologies relative to gasoline ICEV for yearly mileage of 30,000 km.



In summary, from the user's perspective with all else being equal and available in terms of supporting infrastructure and enabling environment, the results show that EVs are preferred when it comes to maximizing emissions savings within cost reduction constraints. However, gasoline and diesel HEVs become the cleaner fuel-vehicle technologies of choice if maximizing cost benefits is the main objective. Notably however, gas-based ICEVs are also cost-effective when it comes to high driving mileage conditions, with LNG and CNG having superior performance to LPG.

However, infrastructure costs and government incentives can have significant cost implications when it comes to transitioning to most any new fuel-vehicle technology, which can ultimately affect the preferred choices of these technologies. The relevant cost factors involved in the different supporting infrastructures and the appropriate government incentive schemes and their implications are explored further in the following section.

- *Implications of government incentive schemes and new infrastructure investments on fuel-vehicle technologies choices*

Due to the higher ownership costs of new fuel-vehicle technologies, it is common for governments to encourage the transition to these cleaner technologies through incentive schemes aimed at reducing the cost of ownership and thereby accelerating the growth of the market for such vehicles in the near term. This however naturally means that there will be an additional cost, borne by the government, in terms of foregone revenues due to these incentives.

The foregone revenues for each fuel-vehicle technology, are calculated using the economic costs per veh.km presented in Table 26, and the forecasted alternative fuel-vehicle numbers for low and high market penetration scenarios over the near-termas summarized in Figure 34. The results are presented in Table 29 and compared with the previously computed WTW GHG emissions saved for each technology compared to the baseline gasoline ICEV. Consequently, Table 30 presents the corresponding abatement cost incurred by the government in the near term (2018-2020) in the form of forgone revenues in exchange for the total saved WTW GHG emissions over the entire long-term period (2018-2040).

Fig. 34– Forecasted total number of alternative fuel vehicles over the near, medium and long-terms.

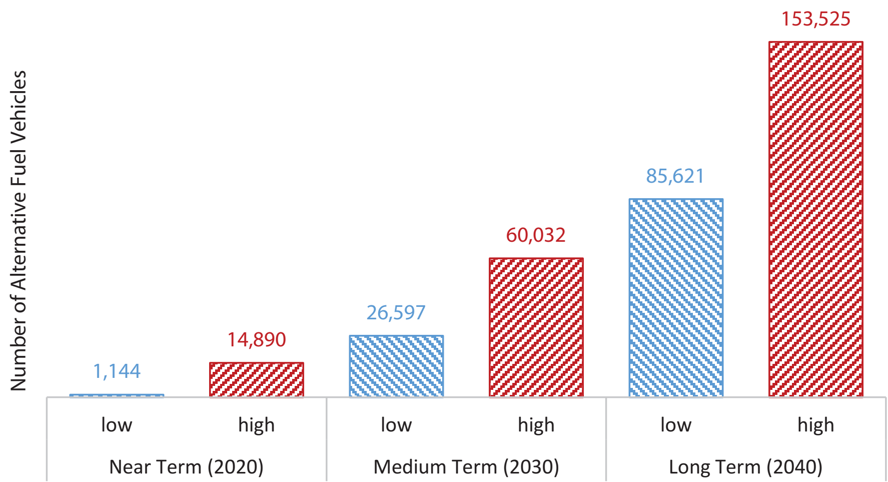


Table 29 - Government foregone revenues over the near-term and saved WTW GHG emissions over the near, medium and long-terms.

Government forgone revenues (M USD)	HEV	PHEV20	PHEV60	EV
Low market penetration	29.3	34.0	39.3	36.2
High market penetration	380.9	442.0	511.2	454.9
Near-term total saved WTW GHG emissions (tonnes/year)	**HEV**	**PHEV20**	**PHEV60**	**EV**
Low market penetration	784	600	416	330
High market penetration	10207	7809	5414	4301
Medium-term total saved WTW GHG emissions (tonnes/year)	**HEV**	**PHEV20**	**PHEV60**	**EV**
Low market penetration	18,233	20,381	23,827	30,735
High market penetration	41,153	46,001	53,779	69,371
Long-term total saved WTW GHG emissions (tonnes/year)	**HEV**	**PHEV20**	**PHEV60**	**EV**
Low market penetration	58,694	73,835	94,776	128,376
High market penetration	105,243	132,391	169,941	230,188

Table 30 – Abatement cost in (USD/tonne CO2 eq.) of saved WTW GHG emissions over the long-term.

	HEV	PHEV20	PHEV60	EV
Low market penetration	22.7	20.9	18.8	12.8
High market penetration	164.5	151.8	136.7	89.8

DUE TO THE HIGHER OWNERSHIP COSTS OF NEW FUEL-VEHICLE TECHNOLOGIES, IT IS COMMON FOR GOVERNMENTS TO ENCOURAGE THE TRANSITION TO THESE CLEANER TECHNOLOGIES THROUGH INCENTIVE SCHEMES AIMED AT REDUCING THE COST OF OWNERSHIP AND THEREBY ACCELERATING THE GROWTH OF THE MARKET FOR SUCH VEHICLES IN THE NEAR TERM.

Some important conclusions can be drawn from the above analysis, as follows:

- EVs and PHEVs with extended electric drive autonomy are preferred over the medium and long-terms when it comes to maximizing emissions savings
- HEVs become the alternative fuel-vehicle technology of choice on the near, medium and long-terms if minimizing foregone revenues is the main objective

In addition to government foregone revenues, the cost of distribution infrastructure for each fuel-vehicle technology is also considered here. The cost of distribution infrastructure was computed using the forecasted total energy demand for each fuel type, as presented in Figures 35 to 37, with the average cost and capacity of a medium-size refueling station described in Table 27, and the average cost of curbside public charging station and fast public charging station, as described in Table 28. The results are presented in Table 31 and compared with the previously computed WTW GHG emissions saved for each technology compared to the baseline gasoline ICEV, summarized in Table 32.

Fig. 35 – Forecasted natural gas demand of CNG ICEV by region over the near, medium and long-terms.

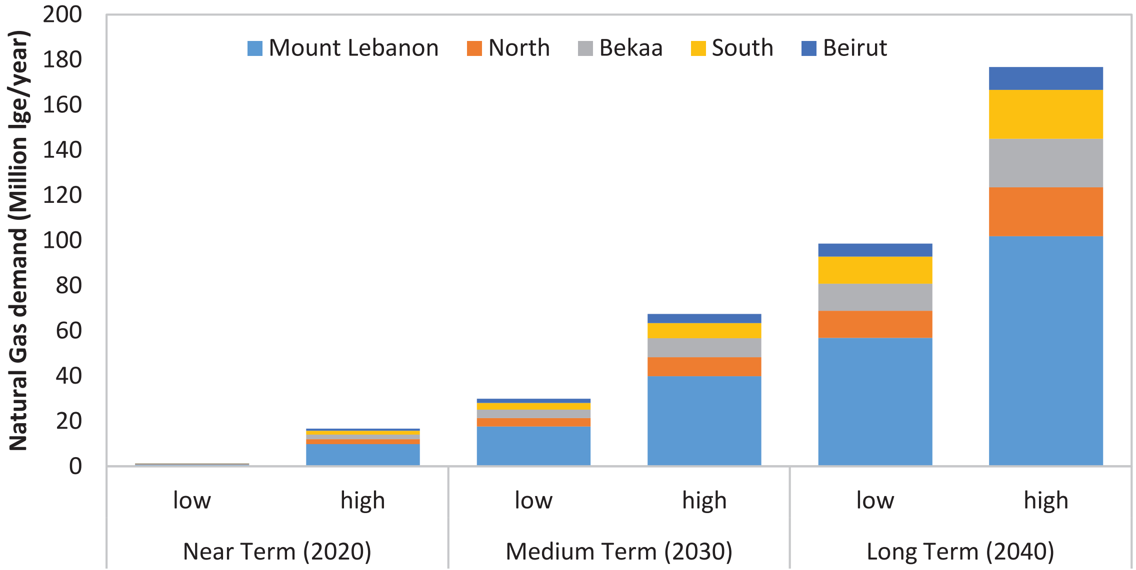


Fig. 36 – Forecasted electricity demand of PHEV20 by region over the near, medium and long-terms.

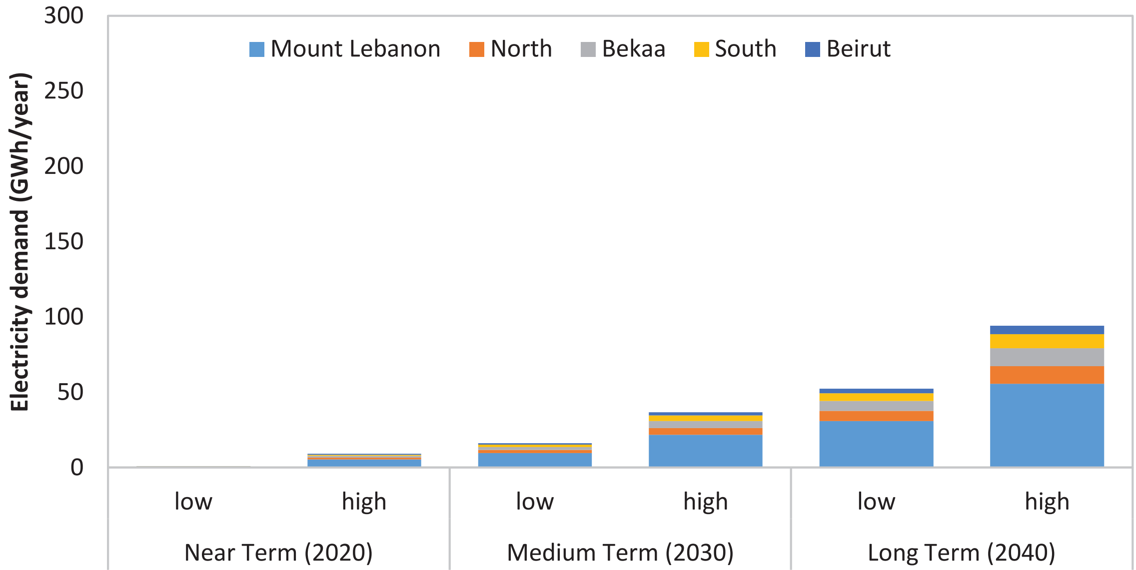


Fig. 37 – Forecasted electricity demand of EV by region over the near, medium and long-terms.

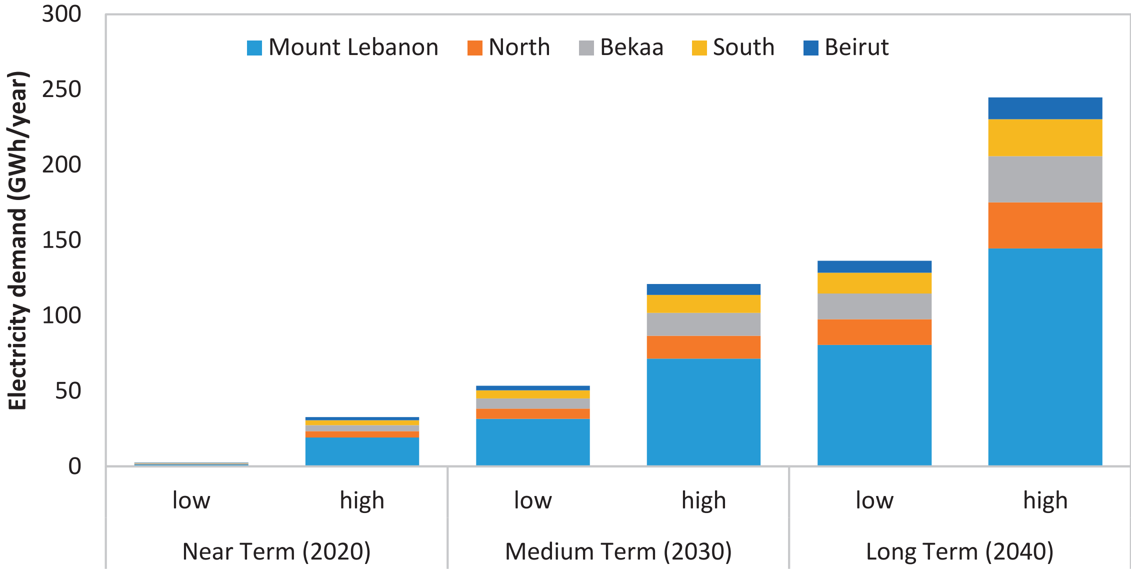


Table 31 – Capital costs of infrastructure (fuel distribution) (M USD).

Timeframe	Market Scenario	CNG	L-CNG	LPG	HEV	PHEV20	PHEV60	EV
Near-term	Low market penetration	4.5	5.5	1.1	0	1.1		
	High market penetration	14.4	17.6	3.5	0	14.1		
Medium-term	Low market penetration	26.1	31.9	6.4	0	25.3		
	High market penetration	57.6	70.4	14.1	0	57.0		
Long-term	Low market penetration	80.1	97.9	19.6	0	81.3		
	High market penetration	143.1	174.9	35.0	0	145.8		

Table 32 – Total saved WTW GHG emissions compared to baseline gasoline ICEV (tonnes/year).

Timeframe	Market Scenario	CNG	L-CNG	LPG	HEV	PHEV20	PHEV60	EV
Near-term	Low market penetration	146	146	172	784	600	416	330
	High market penetration	1,905	1,905	2,233	10,207	7,809	5,414	4,301
Medium-term	Low market penetration	3,404	3,404	3,989	18,233	20,381	23,827	30,735
	High market penetration	7,682	7,682	9,003	41,153	46,001	53,779	69,371
Long-term	Low market penetration	10,957	10,957	12,840	58,694	73,835	94,776	128,376
	High market penetration	19,646	19,646	23,023	105,243	132,391	169,941	230,188

Some important conclusions can be drawn from the above analysis, as follows:

- HEVs are the vehicle technology of choice if no infrastructure investment is to be made
- EVs and PHEVs with extended electric drive autonomy are preferred when it comes to maximizing emissions savings, making them the preferred fuel-vehicle technology in the medium and long term.

It is noteworthy to mention that the infrastructure cost for natural-gas based vehicles and electricity-based vehicles are of comparable scale, which means it is more effective to develop an infrastructure for electricity-based vehicles since they provide superior GHG emissions savings for the same cost.

7

CONCLUSION

In this report, we have shown that a host of alternative fuel technologies are feasible for the Lebanese context and offer different levels of savings in terms of energy consumption and GHG and pollutant emissions. The cost-benefit analysis performed in this work further prioritized the different technologies according to the maximum benefit achieved for the least cost, as follows:

- HEVs offer close to the highest GHG savings for zero infrastructure investment cost and moderate foregone government revenues, making them the preferred choice for the government and end user alike.
- Closely behind HEVs are PHEVs, followed by EVs, which offer the highest GHG emissions savings, for moderate infrastructure investment costs but high government foregone revenues, making these two technologies more preferred over the medium and long terms.
- LPG vehicles offer modest emissions savings for very low infrastructure investment costs , which means they becomes attractive as an alternative fuel if infrastructure investment is limited
- CNG vehicles offer the lowest emissions savings for infrastructure investment costs that are comparable to EVs, making them the least preferred technology for the typical passenger car. However, this technology becomes attractive for high mileage service vehicles.

It is important to note here that while all alternative fuel vehicle technologies are beneficial to some extent as previously demonstrated in this report, however for these benefits to be sustainable the transition to AFVs should be part of a comprehensive national transportation strategy which takes into account the need for infrastructure development including public transport, along with administrative reform and advanced systems management (Haddad, Mansour, & Stephan, 2015). To that end, a policy paper (Appendix C) and a pilot study proposal (Appendix D) have been prepared to complement this study and address the appropriate components of a comprehensive strategy.

8

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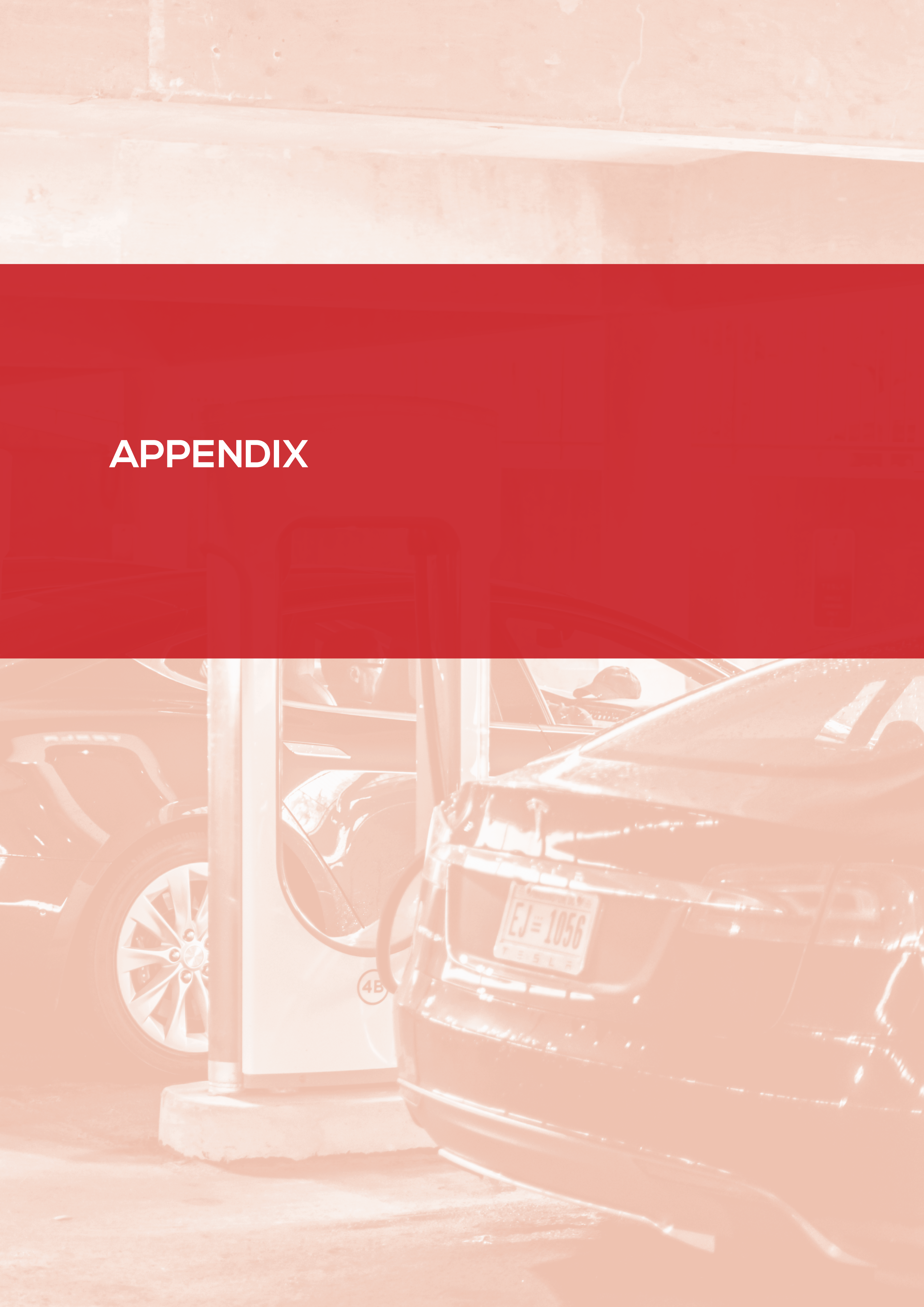
APPENDIX



APPENDIX A

WTW ENERGY USE BY FUEL-VEHICLE TECHNOLOGY.

Figure A.1: Well-to-wheel energy use by fuel-vehicle technology for oil-based vehicles.

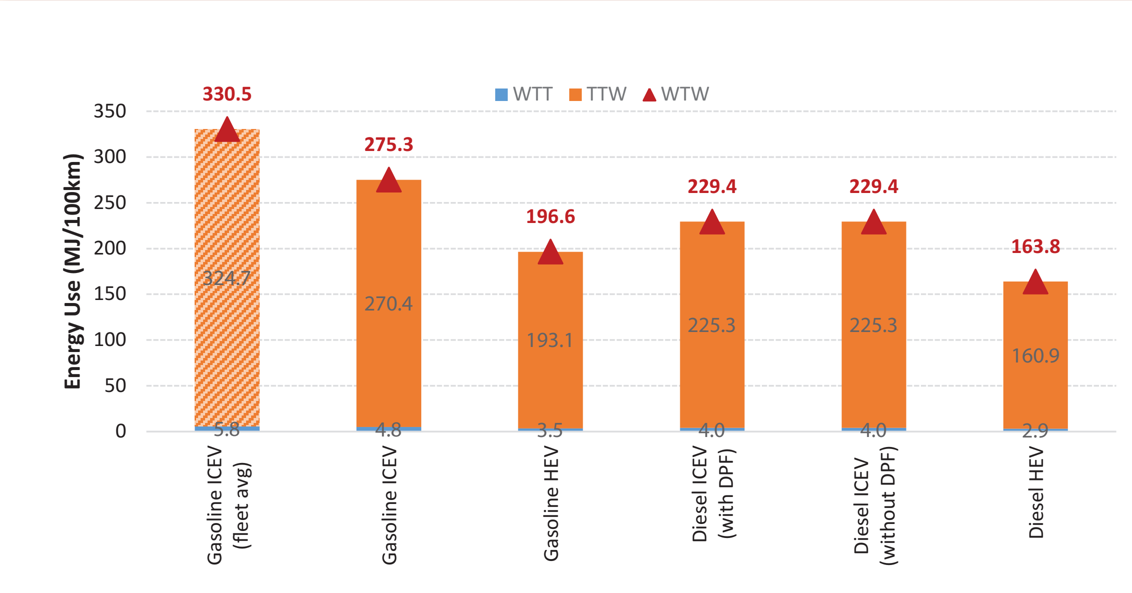
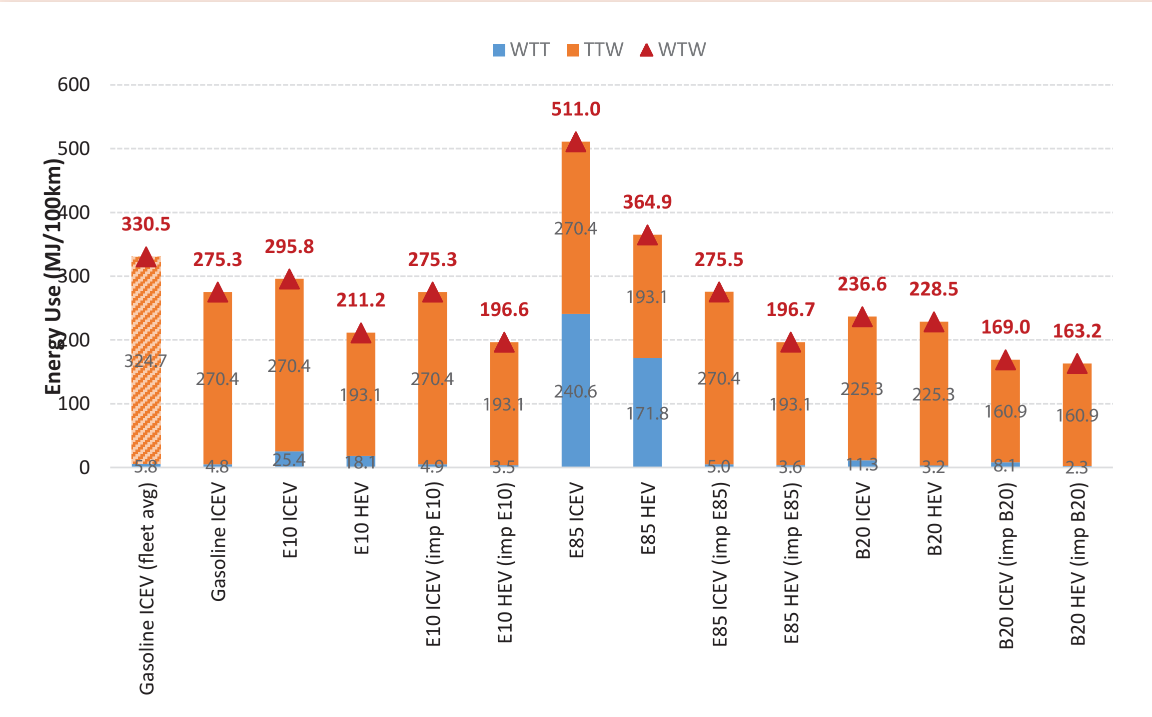


Figure A.2: Well-to-wheel energy use by fuel-vehicle technology for biofuel-based vehicles.



APPENDIX A

Figure A.3: Well-to-wheel energy use by fuel-vehicle technology for gas-based vehicles.

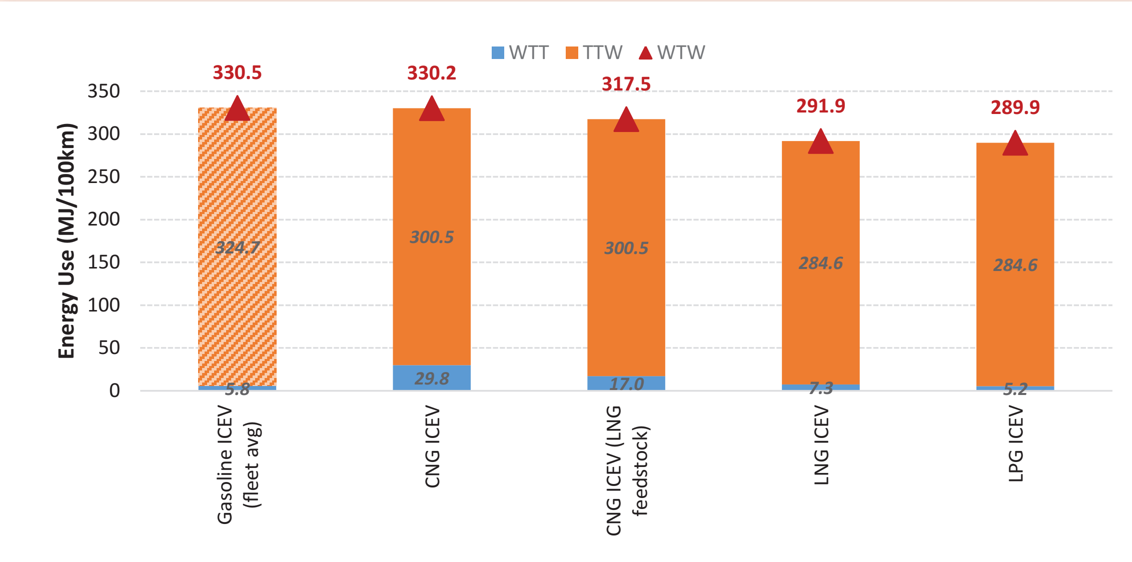
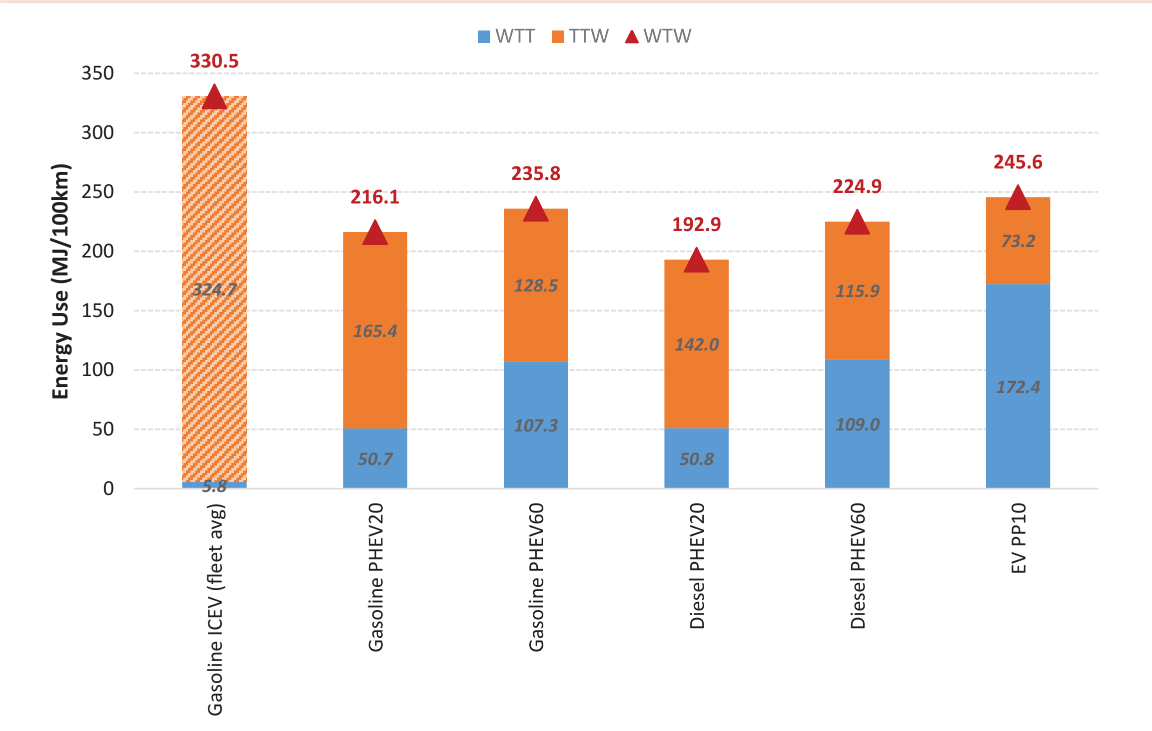


Figure A.4: Well-to-wheel energy use by fuel-vehicle technology for electricity-based vehicles under currently existing power generation mix.



APPENDIX A

Figure A.5: Well-to-wheel energy use by fuel-vehicle technology for electricity-based vehicles under 2020 power generation mix as per MOEW policy paper.

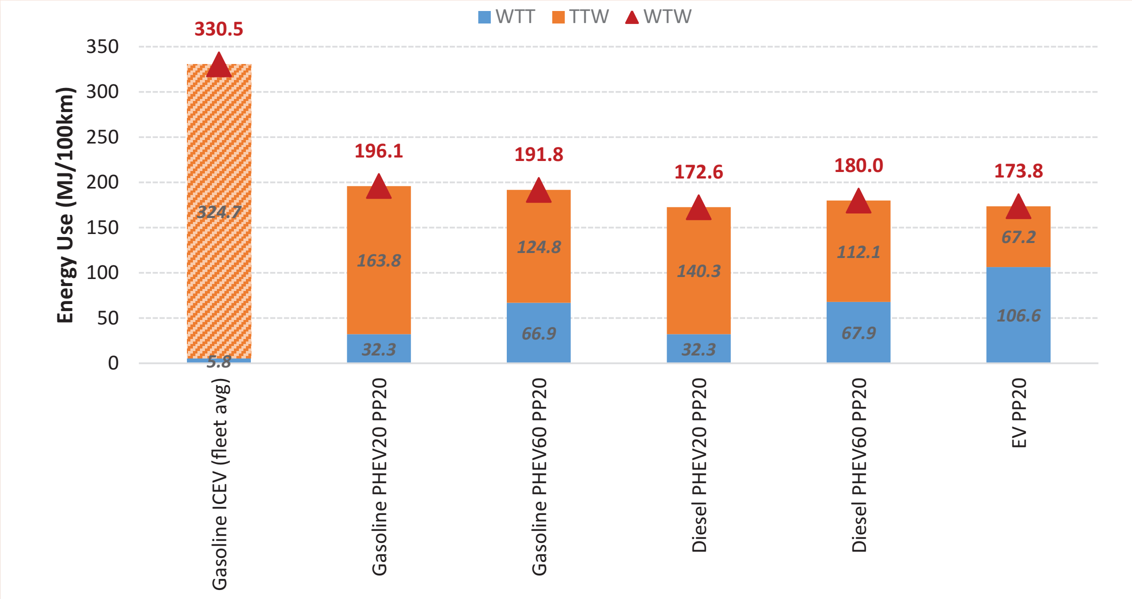
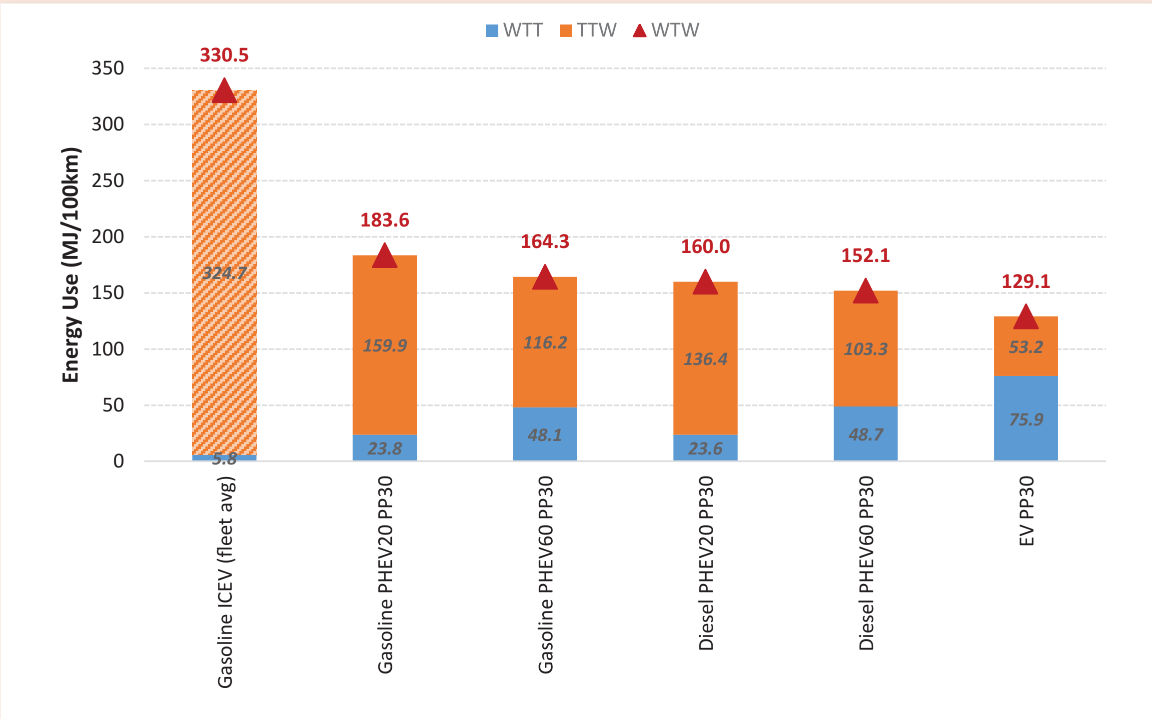
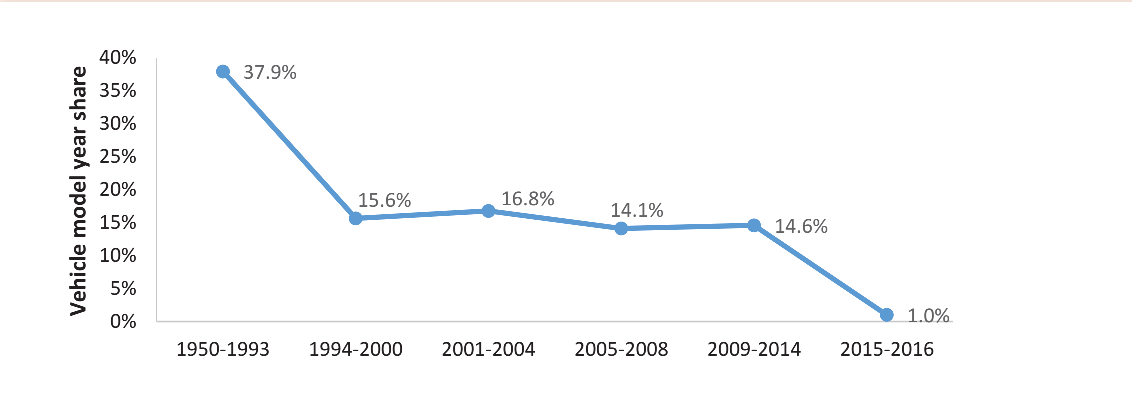


Figure A.6: Well-to-wheel energy use by fuel-vehicle technology for electricity-based vehicles under 2030 power generation mix as per MOEW policy paper.



APPENDIX A

Figure A.7: Vehicle model year distribution of the Lebanese fleet.



APPENDIX B

WTW CO2 EMISSIONS BY FUEL-VEHICLE TECHNOLOGY.

Figure B.1: Well-to-wheel CO2 emissions by fuel-vehicle technology for oil-based vehicles.

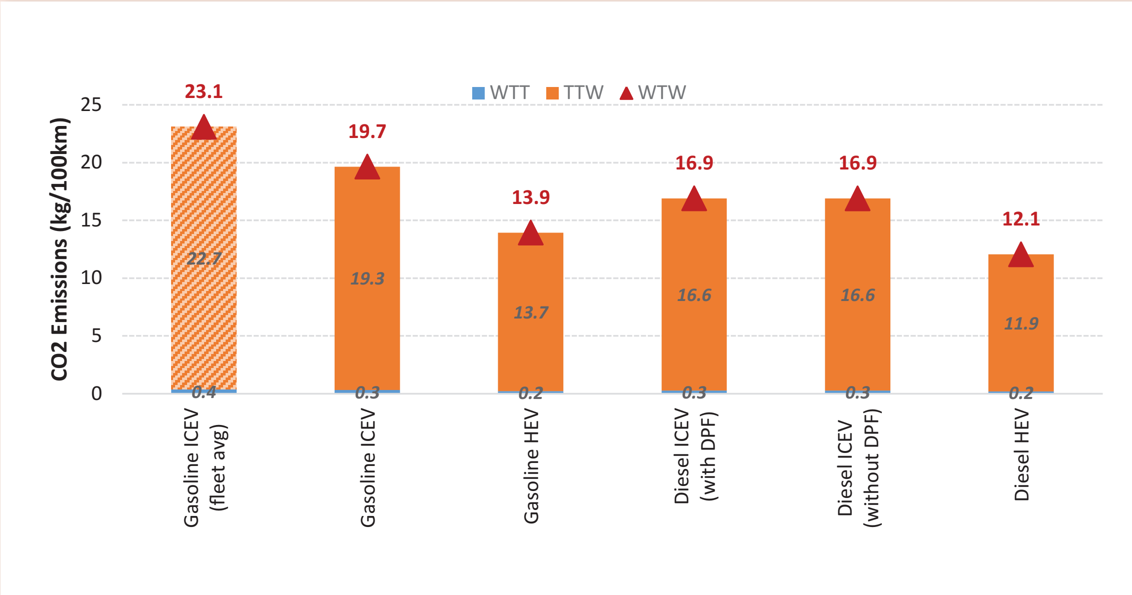
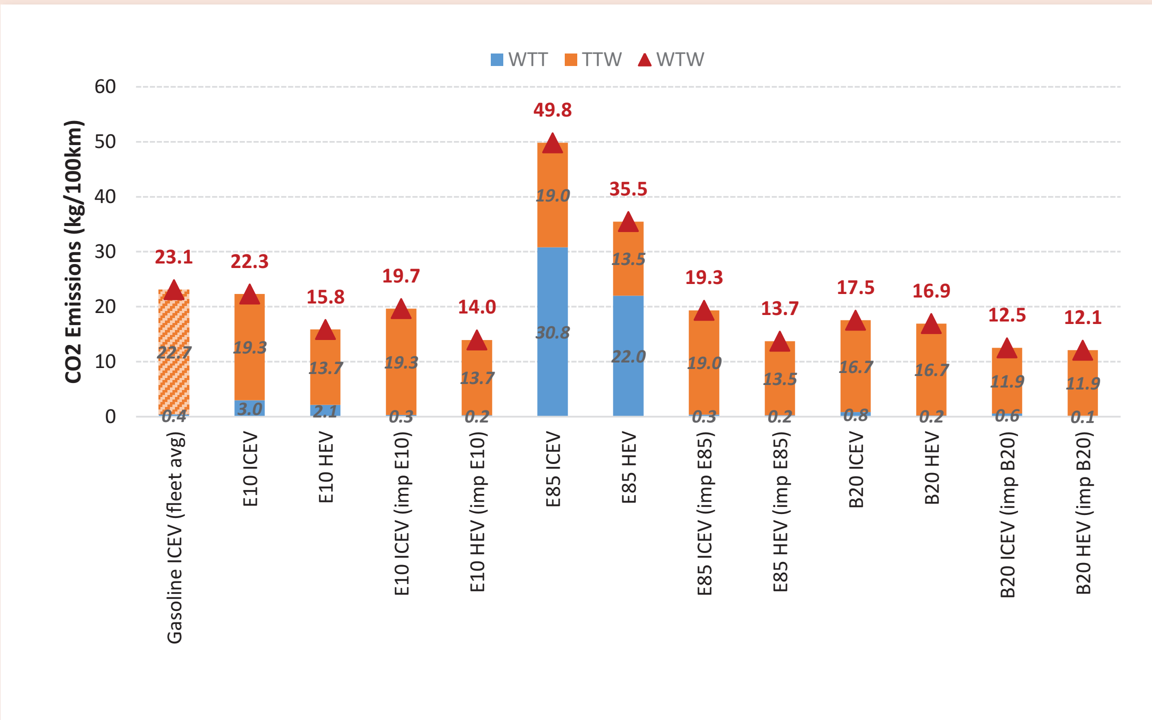


Figure B.2: Well-to-wheel CO2 emissions by fuel-vehicle technology for biofuels-based vehicles.



APPENDIX B

Figure B.3: Well-to-wheel CO2 emissions by fuel-vehicle technology for gas-based vehicles.

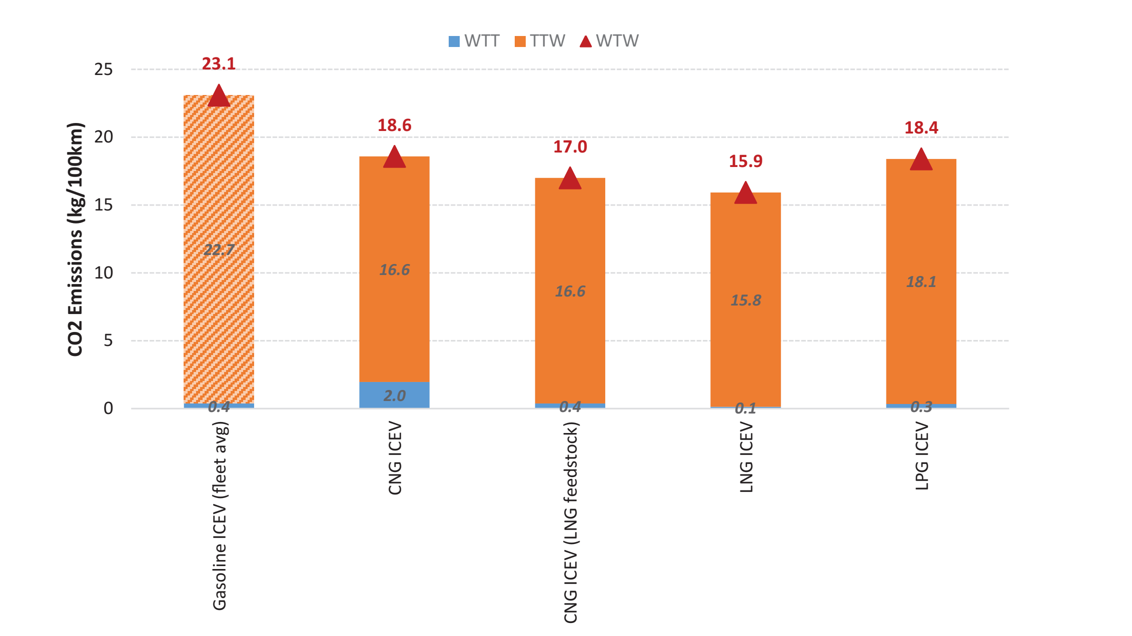
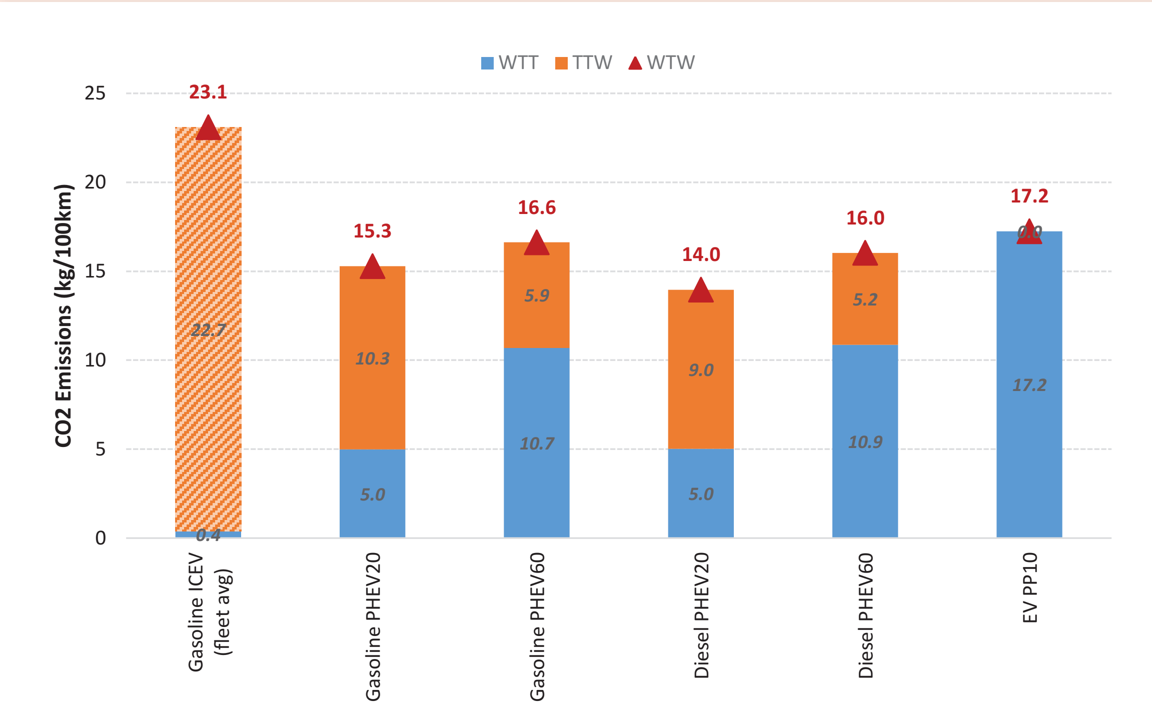


Figure B.4: Well-to-wheel CO2 emissions by fuel-vehicle technology for electricity-based vehicles under currently existing power generation mix.



APPENDIX B

Figure B.5: Well-to-wheel CO2 emissions by fuel-vehicle technology for electricity-based vehicles under 2020 power generation mix as per MOEW policy paper.

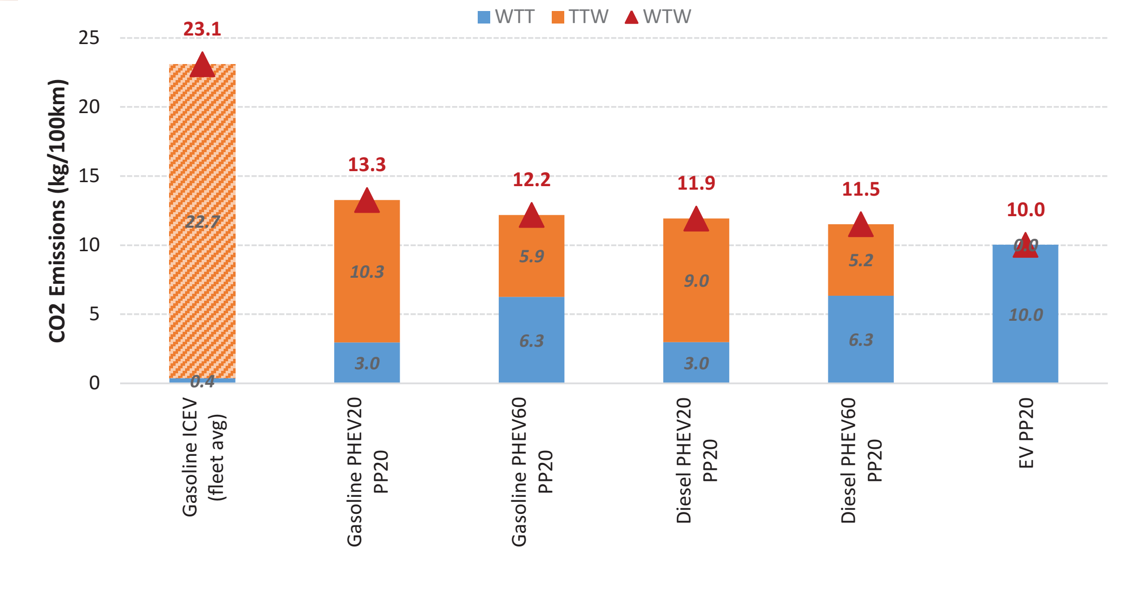
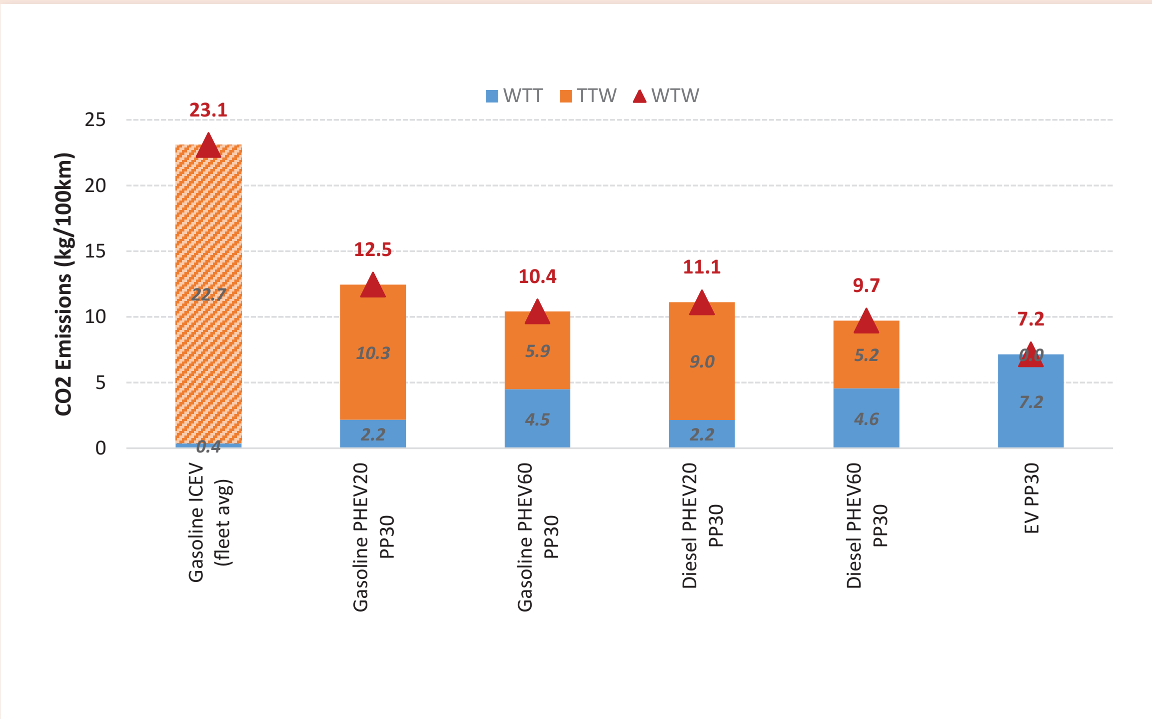


Figure B.6: Well-to-wheel CO2 emissions by fuel-vehicle technology for electricity-based vehicles under 2030 power generation mix as per MOEW policy paper.



APPENDIX C

DRAFT POLICY PAPER ON THE USE OF GAS AND LOW CARBON FUELS.

The SODEL cost-benefit analysis study for the use of gas and low carbon fuels in the transport sector in Lebanon provided recommendations for the preferred use of alternative fuel vehicle (AFV) technologies over the near, medium and long term. However, the successful implementation of these technologies and their supporting infrastructure requires new policies, structures and incentive schemes for creating and regulating a new industry around the use of natural gas and low carbon fuels.

The aim of this policy paper is to propose a policy framework that helps to guide decision makers on the efficient and effective use of natural gas and low carbon fuels in the transport sector. This includes key policy recommendations, socio-economic incentives and measures, institutional mechanisms, and market schemes, all as part of a comprehensive framework to foster an easy transition to alternative fuels and technologies and a sustainable operation of the transport sector in the future.

After discussion with key stakeholders, along with a survey of existing legal and economic structures and the analysis of institutional and market conditions, the following 6-point policy framework is proposed:

1. Economic and financial measures: the main objective of the proposed economic measures is to create a new market for alternative fuels and technologies, and to start the transition away from the current unsustainable system. Two approaches with corresponding measures are proposed.

a. Incentivize the creation of a new market by:

i. Exemption of alternative fuel vehicles (AFVs) from custom and excise fees, registration fees, and road usage fees at registration.

ii. Reduction of loan interest rates and extension of the loan period for the purchase of new AFVs.

iii. Creation of a car scrappage program based on swapping current passenger cars with AFVs.

iv. Rebalancing of existing fuel tax schemes over an initial transition period to make alternative fuels attractive and/or competitive with gasoline and diesel.

b. Incentivize the creation of a new infrastructure by:

i. Reduction of loan interest rates and extension of the loan period for the purchase of equipment and the building of infrastructure for dispensing alternative fuels during an initial transition period.

ii. Tax breaks on the import of needed equipment for the entire chain of alternative fuel processing, distribution and dispensing infrastructure over an initial transition period.

iii. Fostering the long-term creation of a local service provider industry through the enactment of local certification standards and programs concerned with the manufacturing and maintenance of needed infrastructure and equipment for alternative fuels.

c. Restrict the use of old technologies by:

i. Adoption of a Bonus-Malus tax policy where polluters pay more surcharges on vehicle purchase price, and where taxes like the road usage fees are reconsidered according to fuel efficiency and/or emissions rather than engine horsepower and vehicle model year.

ii. Gradual reduction of the maximum age and maximum mileage of imported pre-owned vehicles.

2. Vehicle and component recycling measures: the objective of these measures is to ensure that the transition to AFVs is environmentally friendly and sustainable in the long-term by:

a. Disposal of old cars: create a car termination plant that deals with the car termination process after the swap in the scrappage program

APPENDIX C

b. Setup of a recycling system for new parts and components: create an industry for recycling new car parts and components (such as batteries for electric vehicles)

3. Policy, legal and regulatory measures: these measures are intended to promote and regulate the use of natural gas and low carbon fuels in the transport sector by:

a. Regulating of new AFV car imports: update decree 6603/1995 relating to standards on permissible levels of exhaust fumes and exhaust quality to cover all types of vehicles.

b. Monitoring of AFVs: update the vehicle inspection program with special requirements for inspection of hybrid cars, monitoring of the proper maintenance of on-board emissions control systems for diesel cars, and mandate catalytic converters for conventional gasoline vehicles

c. Ban on retrofitting of old vehicles: prohibit the unauthorized (non-OEM) retrofitting of old vehicles into AFVs.

d. Update fuel standards: enact new or update existing standards to ensure the use of low-sulfur fuels and the import of appropriate grades of alternative fuels.

e. Update infrastructure security standards: enact new or update existing standards to ensure the safe installation, operation and maintenance of alternative fuel infrastructure and vehicles.

4. Institutional capacity building measures: the goal of these measures is to foster the creation of the organizational units needed to oversee the proper operation of AFVs and to ensure the sustainability of a clean transport system, by:

a. Plugging the leaks from old cars: set up a mechanical inspection unit at the port of Beirut in charge of checking up the emissions and safety standards of imported pre-owned cars before entering the country.

b. Setup of AFV inspection unit: convert current inspection facilities and/or setup new facilities with capability to inspect AFVs.

5. Social awareness measures: these measures serve to spread awareness about the benefits of switching to AFVs, and the importance of proper operation and maintenance of the new technology to sustain these benefits, by:

a. Education and awareness campaigns: establish education programs and awareness campaigns to inform people about the new technologies, their cost-savings and health benefits for individuals and society at large, and correct old perceptions.

6. Initiative monitoring and validationmeasures: the aim of these measures is to sustain the newly established structures and technologies, by:

a. Creation of a Mobility Monitoring Indicators (MMI) framework: establish a phased-implementation monitoring program with appropriate indicators at different stages of AFV implementation to ensure progress is made and sustained. These can include emissions indicators, energy consumption indicators, and AFV fleet indicators.

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