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Title

Future trends and mitigation options for energy consumption and greenhouse gas emissions in a developing country of the Middle East region: a case study of Lebanon's road transport sector

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Keywords

Road passenger transport
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Abstract

The road transport system in Lebanon is one of the most unsustainable in the Middle East region due to, in large part, the absence of a national transportation strategy. This study proposes mitigation measures based on Lebanon's commitments for reducing fossil fuel use and CO2 emissions from road transport by increasing the share of fuel efficient and hybrid electric vehicles, and increasing the utilization of the existing bus service. Results show that increasing the market share of fuel efficient vehicles to 35% in 2040 stabilizes energy use and emissions. The addition of hybrid vehicles to the first strategy, with a target of 10% market share by 2040, leads to 11% additional savings. Increasing the share of bus passenger-kilometers traveled to 45% in 2040 leads to a reversal of adverse impacts. A combined strategy of all three measures leads to 63% reductions in 2040 compared to 2010, which is even superior to their cumulative savings.

1. Introduction

The growing concern about global warming due to greenhouse gas (GHG) emissions have focused attention on road transportation worldwide since this sector is one of the highest contributors of GHG emissions globally. In particular, the Middle East region has seen a substantial increase in energy use in transportation over the past two decades, with consumption of oil in transport almost doubling from 67.1 million tons in the year 2000 to 124.6 million in 2014 [1]. Energy outlooks for the region forecast an increase in transportation energy consumption of 1.9% annually on average until the year 2040 [2], on par with South America and almost double the rate of increase for Europe. Other projections place the Middle East transportation sector second only to that of China in the expected growth of energy use until 2030 [3]. What is also noteworthy is that the growth of overall energy use in the Middle East is the fastest of any region at 4.2%, in contrast to flat growth rates across the developed world with the exception of China [4]. Indeed, it is expected that strong economic and population growth in developing countries of the Middle East, estimated to be much higher than the global average, will see the highest growth of transportation-related activity and investments worldwide [5].

It is in this context that investigating mitigation strategies for the transport sector in this part of the world becomes important. One of the countries of interest in this respect is Lebanon which stands as having one of the most unsustainable transportation systems in the region [6]. Road transport in Lebanon is the second largest consumer of energy in the country with 40% of total oil consumption, and the second biggest emitter of GHG emissions, accounting for over 23% of annual emissions in 2012, in addition to a significant share of air-pollutant emissions [7]. This is due to a number of unsustainable practices including an almost total dependence on fossil fuels (gasoline and diesel are 97.9% of total fuels), and a substantial increase in automotive gasoline consumption of approximately 25% since 2006. This is in addition to a rapidly growing passenger vehicle fleet from 450,000 vehicles in 1994 to 1,350,000 in 2012, which are dominated by older model years, as well as a high rate of congestion, all in the absence of an effective bus transportation system or any alternative public transit modes such as marine ferry or rail service [8].

To start dealing with this unsustainable reality, Lebanon signed in 2016 the Paris agreement of the United Nations Framework Convention on Climate Change (UNFCCC) for the mitigation of GHG emissions. Under this agreement's Intended Nationally Determined Contribution (INDC), Lebanon committed to GHG mitigation targets starting in the year 2020. The minimum target is to reduce GHG emissions by 15% compared to the business-as-usual (BAU) scenario in 2030, and a more ambitious goal is to reach 30% over the same period, but conditional on receiving international support [9]. If funds are made available, Lebanon would commit to implementing a number of infrastructure initiatives, most prominent of which are to revive the role of public transport and to achieve a share of 20% fuel efficient vehicles by 2030.

Based on Lebanon's INDC commitments, this study investigates a number of relevant mitigation measures which are appropriate for the road transport sector in Lebanon, by modeling their future impacts on the transport system in terms of potential reductions of energy use and GHG emissions. This is done for near-term (2020) and long-term (2040) planning horizons and compared against a business-as-usual baseline scenario. Since passenger vehicles constitute the majority of road transport vehicles operating in Lebanon (92.3% of the total fleet in 2012), and since these vehicles are responsible for most of the GHG emissions in the transport sector (nearly 76% of total CO2 emissions in 2010), this study will only consider passenger cars (PC) and light duty vehicles (LDV) in the modeling assessment. The choice of mitigation strategies related to fuel-vehicle technology is based on the potential feasibility of each strategy and the expected benefits that can be achieved in Lebanon. This choice was further informed by a previous study [10] of the well-to-wheel energy consumption, environmental impacts and cost savings of different fuel-vehicle technologies in Lebanon that prioritized the near-term deployment of hybrid electric vehicles (HEVs).

The study is based on the system dynamics modeling approach and uses the For Future Inland Transport Systems model (ForFITS), a software tool developed in the context of a project of the United Nations Development Account (UNDA). The study can inform other developing countries in the region about the potential benefits of different mitigation strategies, since these countries share similar infrastructure and resource challenges.

This study is novel in several respects: it is the first mitigation publication on a road transport system in Lebanon and the Middle East region; it defines mitigation options that are applicable and feasible in similar developing countries; and, it is the first case study using the ForFITS modeling tool.

The rest of this paper is structured as follows: Section 2 presents an overview of relevant results from recent mitigation studies. Section 3 details the modeling methodology, including the local data and assumptions used in the modeling, an overview of the ForFITS modeling tool and the selected mitigation options. The modeling results for the baseline no-action scenario are reported in Section 4 in terms of future trends for vehicle stock, vehicle kilometers traveled, fuel use and CO2 emissions. Section 5 presents the proposed mitigation scenarios and Section 6 provides the mitigation results and a discussion of the associated impacts, including a mitigation roadmap for the context of developing countries using an adaptation of the commonly adopted Avoid-Shift-Improve-Finance (ASIF-2) framework. The study concludes in Section 7 with summary remarks.

2. Literature Review

Mitigation studies in recent years have covered a wide range of cities and regions in the Americas [11, 12], Europe [13, 14] and Asia [15, 16] with a substantial share for China due to its large-scale industrial and transportation activities [17, 18]. However, no mitigation studies have been published on the Middle East region which includes a number of developing nations with limited transportation infrastructures but rapidly growing travel demand and vehicle fleets.

Numerous strategies for the reduction of emissions and energy consumption have been proposed in the literature. The majority of studies agreed that conventional fuel hybrid electric vehicles (HEVs) are the most efficient and viable technology for the next 10-20 years even in industrialized countries [19], due to their commercial readiness, relatively lower cost and potential for reducing energy use and CO2 emissions [20]. In addition, these vehicles require no new infrastructure, which is a critical factor for developing countries. It is also established that newer model gasoline and diesel vehicles will continue to be the most cost-effective in the near-term (2020) due to lower purchase and operating costs [21].

Virtually all studies agreed that electric vehicles (EVs) are the technology of choice for the long-term thanks to their superior energy and emissions performance [22]. However, EVs are not feasible over the short and medium terms due to the high costs of the vehicle and new charging infrastructure, which in turn needs clean electricity in order to ensure that total emissions are in fact reduced instead of just displaced from the vehicle to the power plant [23, 24]. In developing countries like Lebanon where power generation relies on a dirty electricity mix based largely on heavy fuel oil, and where supply is unreliable due to insufficient production capacity [25], the feasibility of EVs may be compromised even in the long-term if such deficiencies are not addressed over the near to medium term.

Public transportation is found to have the widest reach of any other mitigation strategy [15], and can reduce the need for private cars [26], though it involves significant implementation delay, which makes it a long-term choice. This why a national policy to develop mass transport is considered a must [27].

However, the combination of multiple strategies yields higher benefits above any individual policy by itself [28, 29]. Furthermore, implementing a combination of mitigation measures is usually needed for short and long-term effects [27]. Indeed, different mitigation strategies are not mutually exclusive; they can be combined to hedge against uncertainty [13].

In summary, a host of mitigation measures were proposed in the literature, and combinations that make up a coherent strategy were found most beneficial for moving towards sustainable transport. One framework for developing such strategies is the Avoid-Shift-Improve-Finance (ASIF-2) framework [30, 31] which advocates combining measures to avoid unnecessary trips, shift to less polluting modes, improve vehicle fuel economy, and finance the development of public transport modes.

However, in developing countries, many limitations exist that make some of the desirable mitigation measures much less feasible over the near and medium terms [32]. For example, the low level of income in these countries makes it difficult for the average commuter to purchase new model year gasoline vehicles, much less to afford hybrid or alternative fuel vehicle technologies. This significantly hampers the effectiveness of "improve" strategies in developing countries and confirms findings in the literature that technological progress may not be enough to counter mobility growth [22]. As a result, it was found that government intervention in the form of increasing the market share of alternative fuel vehicles through financial incentives is necessary [16, 33]. Other limitations pertain to infrastructure which seriously limits the reach and effectiveness of mass transit systems. The main barriers in developing countries and the mitigation strategies they impact adversely are illustrated in Table 1.

Table 1: Barriers facing mitigation strategies in developing countries

	Mitigation Strategies			
Barriers	**Fuel-related (e.g. alternative fuel use)**	**Travel-related (e.g. bicycling, car restrictions)**	**Vehicle technology-related (e.g. hybrid, small engine)**	**Mass transit-related (e.g. bus, rail)**
Lack of infrastructure readiness	x			x
Lack of urban and transport planning		x		x
Lack of financial (dis)incentives	x		x	x
Lack of enforcement		x		
Low environmental awareness	x	x	x	x
Low individual income	x		x	

The vast majority of reviewed studies (with the exception of [13, 21]) have modeled mitigation impacts on energy use and GHG emissions. Many recent studies have used the system dynamics approach to build comprehensive models which include socio-economic factors and external policies to improve the reliability of the results [26, 28, 29, 32, 34, 35]. However, no specific modeling tool or approach was found dominant, with some studies using IPCC models [11, 16], Lifecycle models [23], among others.

Based on the above synthesis, this study will propose and model appropriate mitigation options for Lebanon and developing countries having limited infrastructure and financing capabilities, as detailed in the following section.

3. Methodology

3.1. Model description

In order to assess the energy use and environmental impacts of the passenger vehicles currently existing, and those potentially applicable in the foreseeable future in the road transport system in Lebanon, a baseline scenario and four mitigation scenarios were modeled and simulated using ForFITS, a comprehensive modeling tool based on the system dynamics approach and designed to assess mitigation scenarios at a national level [36]. ForFITS uses demographic and socio-economic data and assumptions, including policy inputs, to model transport activity which it then converts into estimates of fuel consumption and CO2 emissions [37]. The modeling methodology is described in this section, and the results are presented and discussed in section 6.

The modeling of the road passenger transport system covers all different types and classes of passenger vehicles currently operating in Lebanon, and the vehicle technologies proposed under future mitigation options, as summarized in Table 2.

Table 2: Transport modal characteristics considered in the ForFITS model.

Vehicle Type	Vehicle Class	Engine Type	Fuel Type
Motorcycles and scooters (MC)	Small (engine not exceeding 50 cm3) Two-Wheelers (engine exceeding 50 cm3) Three-wheelers	Internal Combustion Engine (ICE)	Gasoline
Light Duty Vehicles (LDV)	Small (unladen curb mass < 1t) Midsize (≥ 1t and < 1.5 t) Large (≥ 1.5 t) Taxi	ICE and Hybrid Electric	Gasoline
Buses and minibuses	Public transport vehicles for more than 8 seated passengers	ICE	Gasoline and Diesel

The annual estimation of energy use and GHG emissions in ForFITS is based on the ASIF decomposition framework which relies on four vehicle and fuel related components: travel Activity (passenger and/or freight), modal Structure (including vehicle class and powertrain type), energy Intensity (vehicle efficiency, characteristics and load factor), and Fuel carbon content [38]. The calculations are shown in equation (1) for total fuel use "*F*" and equation (2) for total emissions "*E*":

$$F = \sum_i F_i = A \sum_i \left(\frac{A_i}{A}\right)\left(\frac{F_i}{A_i}\right) = A \sum_i S_i I_i \tag{1}$$

$$E = \sum_i E_i = A \sum_i \left(\frac{A_i}{A}\right)\left(\frac{F_i}{A_i}\right)\left(\frac{F_{ij}}{F_i}\right)\left(\frac{E_{ij}}{F_{ij}}\right) = A \sum_i S_i \,.\, I_i \,.\, EF_{ij} \tag{2}$$

Where "*Fi*" and "*Ei*" are the tank-to-wheel amounts of fuel used and emissions generated, respectively, by vehicle (*i*) with a defined set of characteristics (by service, mode, vehicle class and powertrain); "*Fij*" is the Fuel (*j*) used in vehicle (*i*) and "*EFij*" is the corresponding emission factor; "*Ai*" is the activity of vehicle (*i*) and "*A*" is the overall vehicle activity (in vkm); "*Si*" is the sectoral structure (expressed as shares of vkm by service, mode, vehicle class and powertrain); and, "*Ii*" is the energy intensity (the average fuel consumption per vkm by service, mode, vehicle class and powertrain).

Like all models based on the system dynamics approach, ForFITS consists of a stock-and-flow model structure. Stocks capture the accumulation of quantities in the system, such as the emissions generated by vehicle activity in any given period, and flows capture the rates of change of these quantities over time, such as the influx of new passenger cars into the total vehicle stock every year. Socio-economic factors external to the transport system can easily be incorporated into the model, and policies can be readily linked to the system to test their impacts, which makes the system dynamics method a holistic modeling approach appropriate for environmental assessments in transportation [39].

An increasing number of mitigation studies in recent years have used the system dynamics method to model energy use and CO2 emissions from urban transport activities, such as private and public transport in Kaohsiung City [29], Beijing [26, 28] and inter-city passenger transport in China [40]. Other system dynamics studies have modeled environmental impacts from transportation combined with other sectors, such as pollutant emissions from urban transportation and industry in Tehran [41]; urban CO2 emissions in Malaysia [42]; and urban energy use and CO2 emissions in Beijing [34]. However, this study is the first to use the comprehensive ForFITS model, which is built on top of the popular system dynamics software tool "Vensim" [43]. ForFITS consists of an external input sheet in Microsoft Excel linked to 38 views in Vensim to represent the various technological, environmental and socio-economic aspects of the transportation system, in addition to eight output views for presenting the results. Figure 1 provides a flowchart of the overall calculation flow for the entire model, also highlighting the links associated with ASIF calculations. Further details on the ForFITS calculation methodology are presented in the ForFITS user manual [36].

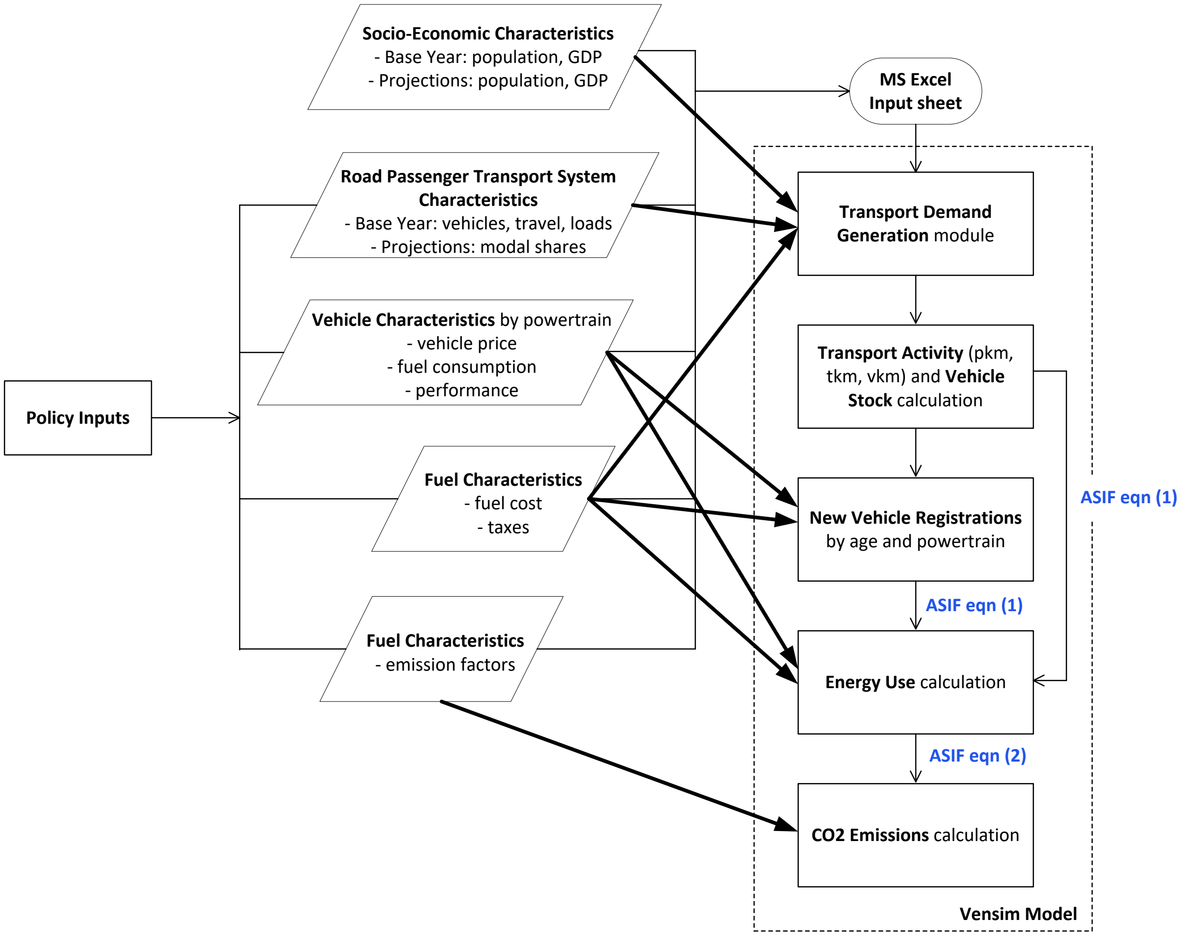

Figure 1: ForFITS simplified model structure.

(Source: Adapted from ForFITS Manual)

3.2. Local Data and Assumptions

The data required to model the Lebanese road passenger transport system in ForFITS, such as historical data about vehicle numbers, consumption, occupancy rates and travel distances, were obtained from the concerned Lebanese government ministries and authorities, as well as from meetings with local stakeholders. Socio-economic data, such as GDP and population figures, were obtained from local and international sources for previous years, and projections were made for future years until 2040. GDP figures were obtained for the years 2010-2019, while 2020-2040 values are estimated considering the average growth of 4.61% between 2012 and 2019. Figure 2 and Figure 3 show the historical and forecasted population size and GDP for Lebanon up to the year 2040.

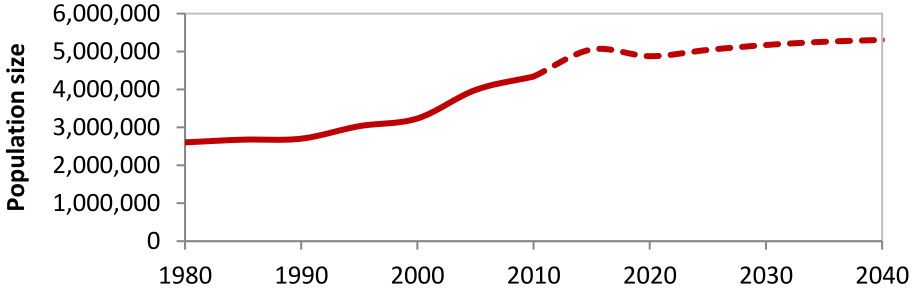

Figure 2: Population size of Lebanon, 1980-2050. (Source: United Nations Economic and Social Commission for Western Asia)

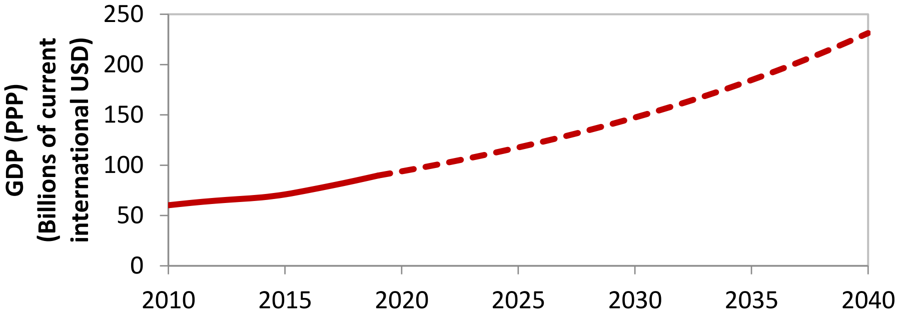

Figure 3: GDP of Lebanon based on purchasing power parity (PPP), 2010-2040. (Source: International Monetary Fund, World Economic Outlook Database, April 2014)

Before modeling future mitigation scenarios, ForFITS requires the definition and simulation of a no-action (business as-usual) baseline scenario using local data for a base year (chosen as 2010 for reasons of data availability), along with data from 5 and 10 years prior to the base year (2005 and 2000 respectively). The baseline serves as a basis for comparing the modeled results of future mitigation scenarios. The main modeling assumptions used for the baseline scenario are listed in Table 3:

Table 3: Main modeling assumptions for the baseline scenario in 2010 with future projections.

System	Parameter	Actual or Calculated Value	No-Action Projection
Transport	Passenger transport system index (PTSI) *0 = total dependence on personal vehicles* *1 = full reliance on public transport*	0.1	Maintained constant
Socio-Economic	Environmental culture index (ECI) *0 = absence of environmental awareness* *1 = strongly focused culture on protecting the environment*	0.2	Maintained constant
	Population *(actual 2010 value)*	4,341,000	Growth by 22% until 2040
	Gross Domestic Product (billion USD) *(actual 2010 value)*	60.223	Growth by a factor of 4
Vehicle	Powertrain technology share *(actual 2010 figures)*	11.8% for small vehicles 55% for midsize vehicles 33.2% for large vehicles	Maintained constant but with improving powertrain technology efficiencies
Fuel	CO2 emission factors (kg CO2/lge)	Gasoline: 2.3207	Maintained constant

(gasoline and diesel)	*(TTW only)*	Diesel: 2.4803	
	Fuel price including tax (USD/lge)	Gasoline: 1.093 Diesel: 0.624	Growth to 150% by 2040

The PTSI value of 0.1 was calculated based on the share of distance traveled by public transport out of total passenger kilometers traveled in the same year in Lebanon. The ECI value of 0.2 was derived based on local stakeholder feedback about environmental awareness in Lebanon, and benchmarked against published values for developed countries. The fuel price growth to 150% by 2040 assumes increasing fuel prices over time due to declining petroleum resources and the expected worldwide trend of imposing fuel taxes to promote fuel efficient vehicles [21, 22].

The main data used to describe the detailed characteristics of the transport system in the base year are summarized in Table 4.

Table 4: Characteristics of the road transport sector in 2010.

	Vehicle Stock	**New vehicle registrations**	**Annual distance travelled**	**Vehicle load**	**Vehicle fuel consumption**
			(vkm)	***(pass/veh)***	***(lge/100 km)***
2-3 Wheelers	60,588	13,416	5,000	1	3-6.5
Passenger LDV					
small vehicles	139,503	11,258	10,000	1.18	8
midsize vehicles	649,044	52,423	10,000	1.18	12
large vehicles	393,682	31,798	10,000	1.18	16
taxi	50,000	1,785	25,000	1.18	15
Buses	12,388	1,188	50,000	11.2	25

4. Results for the Baseline Scenario

An initial model run is performed for the baseline scenario in order to estimate the reference energy use and CO2 emissions in future years under no-action conditions. The results are presented in Table 5 for the base year 2010, the near term (2020) and long-term planning horizons (2040).

Table 5: Baseline scenario projections for passenger transport.

	unit	**Base Year (2010)**	**2020**	**2040**	**Ratio 2020/2010**	**Ratio 2040/2010**
Total passenger vehicle stock	vehicles	1,292,433	1,693,136	2,663,349	1.31	2.06
2-3 wheelers		60,587	79,632	124,268	1.31	2.05
Passenger LDV		1,219,460	1,599,130	2,523,080	1.31	2.07
Buses		12,387	14,375	16,001	1.16	1.29
Total vehicle-km	billion vkm/yr	13.68	17.98	27.74	1.31	2.03
Total energy use	toe/year	1,497,765	1,633,910	1,898,235	1.09	1.27
Total CO_2 emissions	Gg CO_2/yr	4,350	4,747	5,514	1.09	1.27

The results show that the passenger vehicle stock and the total distance traveled are projected to increase substantially, compared to the base year. In particular, passenger LDV's are responsible for the largest projected increase, by 31% in 2020 and 103% in 2040, as shown in Figure 4, with a similar growth trend in total vehicle-kilometer activity for this vehicle category. These growth trends are a consequence of the population and economic growth, and lead to a corresponding increase in fuel consumption and CO2 emissions in future years. This will therefore counter any improvements in vehicle consumption and combustion emissions from advancements in conventional vehicle technology in future years.

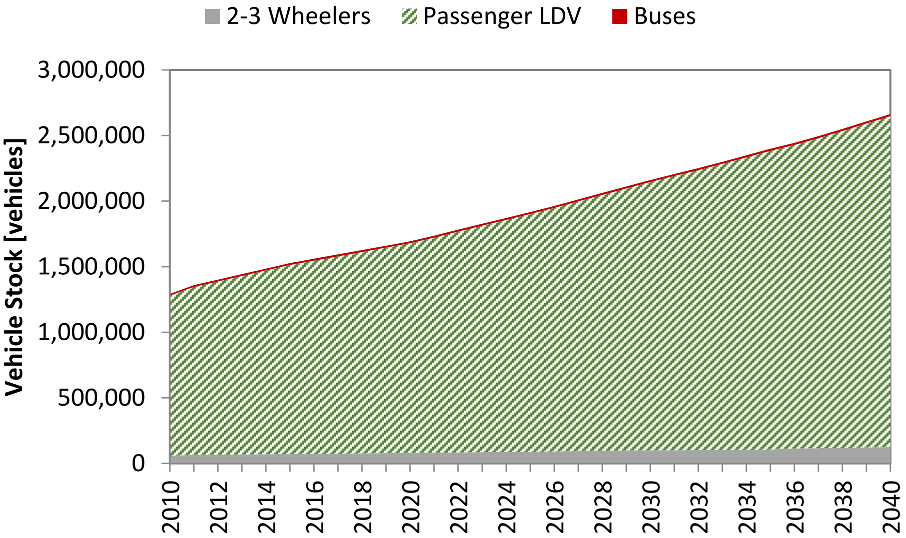

Figure 4: Baseline projection of passenger vehicle stock.

The forecasted increase in energy demand (Figure 5) dictates a similar growth trend in CO_2 emissions since the amount of generated emissions is strongly related to the amount of fuel consumption.

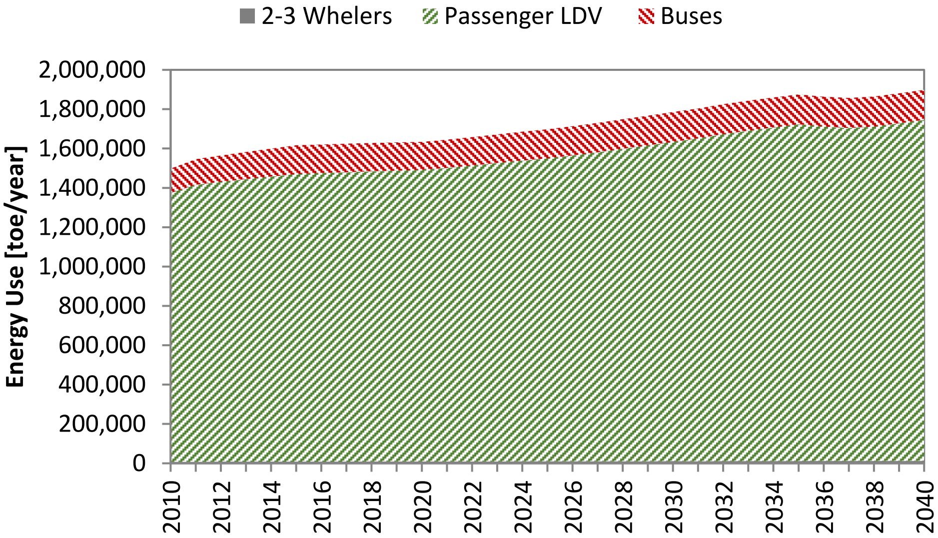

Figure 5: Baseline projection of energy use.

As the results show, CO2 emissions from the passenger road transport system are expected to increase by 27% in 2040, which works against Lebanon's INDC commitment to reduce overall emissions by 15% to 30% in 2030. These are largely dominated by emissions from midsize and large vehicles, as illustrated in Figure 6. This is due to the absence of any environmental incentives to promote the purchase of smaller vehicles, or policies to discourage the purchase of the larger fuel-inefficient vehicles, resulting in an 88% future share for midsize and large vehicles out of the total passenger vehicle fleet.

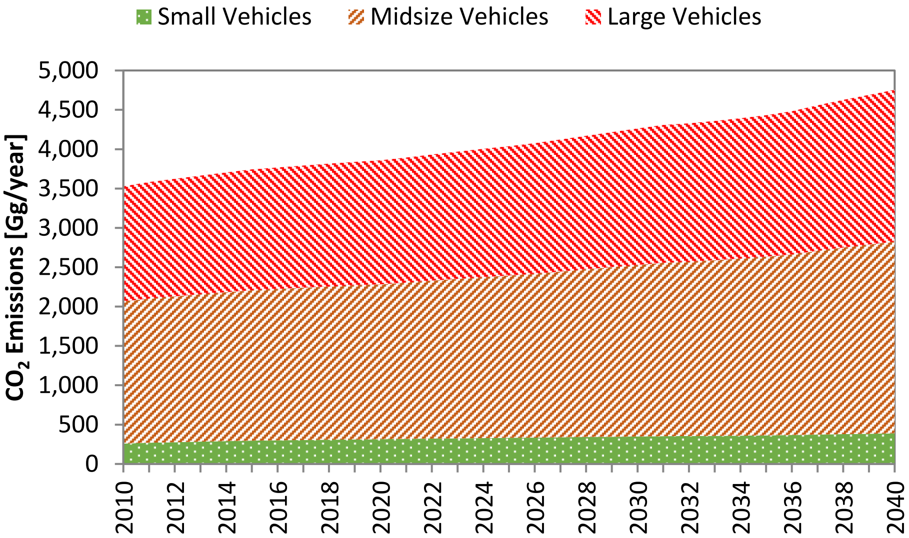

Figure 6: Baseline projection of passenger vehicles CO_2 emissions per vehicle class.

The modeling results for the baseline scenario illustrate the potential severity of mobility and environmental challenges in future years if no mitigation actions are taken. This study therefore proposes different mitigation options which are feasible in Lebanon over the near and long-term horizons.

5. Proposed Mitigation Options

Lebanon's current INDC commitments are to reduce GHG emissions by revitalizing the neglected and ineffective public transport system and promoting fuel efficient vehicles by 2030. Previous studies for the transport sector in Lebanon made similar recommendations about the urgent need to deploy an efficient mass transit system in the greater area of Beirut, the nation's capital, and to renew the passenger cars fleet with fuel efficient and hybrid electric vehicles, as the top two mitigation options prioritized by transport experts and stakeholders [44].

Consequently, the proposed mitigation options in this study are those already considered the most appropriate and feasible in Lebanon in the 2020 to 2040 planning horizon, which consist of three measures: 1) increasing the share of fuel efficient conventional vehicles (FEVs); 2) increasing the share of hybrid electric vehicles (HEVs); and, 3) increasing the share of mass transport. These options were modeled using local assumptions developed in a similar manner as for the baseline scenario. Table 6 provides details on the appropriate data and modeling assumptions as used in ForFITS.

Table 6: Assumptions for modeling the mitigation scenarios.

	Fuel price (including tax)	Transport system and Environmental indices	Passenger LDV powertrain shares in 2040	
			Conventional	**Hybrid**
Mitigation option 1: *Increase share of Fuel Efficient Vehicles (FEV)*	Growth to 150% by 2040	Transport: 0.1 assumed constant over time Environmental: 0.7 in 2040	35% for small vehicles 55% for midsize vehicles 10% for large vehicles	0%
Mitigation option 2: *Increase share of FEVs and Hybrid vehicles*	Same as option 1	Same as option 1	Same as option 1	10% of new vehicle registrations
Mitigation option 3: *Increase share of mass transport*	Same as option 1	Transport: 0.15 in 2040 Environmental: 0.7 in 2040	Same as actual (11.8% small, 55% midsize, and 33.2% large vehicles)	0%

The transport index value of 0.15 in 2040 was derived in a way so as to reflect Lebanon's INDC commitments which are supposed to reduce the gap between the current index for Lebanon (*0.1*) and the typical index for mass-transport-oriented sustainable European cities (*0.45*) [36]. The environmental index of 0.7 was derived through the analysis of data from interviews with local stakeholders about the increasing trend of environmental awareness in Lebanon.

5.1. Mitigation option 1: increase the share of FEVs

FEVs are already in use in Lebanon in the form of small, late model year conventional gasoline powered vehicles. They have become increasingly popular in recent years due to the low vehicle purchase price, high fuel economy and practicality of driving and parking in narrow and crowded urban areas. This constitutes an opportunity to reduce fuel consumption and emissions at a national scale by speeding up the adoption of these vehicles in the market through appropriate policies and incentives [33].

Therefore, the first mitigation option proposed in this study is to increase the share of FEVs to about a third of the total vehicle fleet, at the expense of the large fuel inefficient vehicles. This was implemented in the modeling by setting an FEV target of 35% in 2040, combined with a progressive increase in gasoline prices up to 150% of the 2010 base year levels by 2040. This is to reflect the expected increase in prices due to market conditions, and the need to impose additional fuel taxes in order to speed up the adoption of these vehicles.

5.2. Mitigation option 2: Increase the share of FEVs and HEVs

The second proposed mitigation option adopts the same assumptions as the first mitigation scenario, which is the increase in the share of FEVs to 35% of all vehicles in 2040, in addition to the introduction of HEVs to the market. Since hybrid technology has yet to be adopted in the Lebanese market, it is assumed that the annual share of HEV sales out of all newly registered vehicles can increase to a relatively conservative figure of 10% by 2040. This assumption was further validated with the local stakeholder community as a realistic target given the current and projected market conditions.

HEVs considered in the model include micro-hybrid, full-hybrid, plug-in hybrid and range-extender electric vehicles. However, the shares of micro and full hybrid models were strongly favored in the modeling due to the current absence of charging infrastructure and additional electricity capacity necessary to operate plug-in and range extender models [25]. These limitations are not expected to change quickly enough to accommodate a mass deployment of advanced electric vehicles over the considered planning horizon.

5.3. Mitigation option 3: Increase the share of mass transport

The deployment of a mass transit system covering the greater Beirut area is an integral part of a public transport plan prepared by the government. The plan includes support for the provision of high-quality public transport services, in addition to policies favoring mass transport over personal vehicles, such as parking and access restrictions for passenger vehicles and dedicated lanes for buses.

While the government plan is yet to be implemented, the shift to mass transport in Lebanon is an inevitable scenario which is long overdue since there is currently no operational rail or light rail service or even a reliable bus system in place. As a result, the third mitigation scenario proposed in this study consists of increasing the share of passenger-kilometers traveled from 31% in 2010 [44] to 45% by 2040, determined so as to be consistent with the derived PTSI of 0.15.

6. Mitigation Results

To allow for a comparison of the benefits of each mitigation measure relative to the other scenarios, **Error! Reference source not found.** presents the modeling results of the total distance traveled (vkm), energy use (toe) and CO_2 emissions (Gg), respectively, of all three considered mitigation scenarios. In addition, a combined scenario of options 2 and 3 being applied together (without option 1 since it is already included in option 2) was modeled and the results included in the figures as “Mitigation option 2+3”. This reflects the fact that the proposed options are complementary and not mutually exclusive, making it possible to combine them so as to achieve improved mitigation results. The figure also includes the results of the baseline scenario, discussed separately in section 4, for the purpose of comparing the benefits of each mitigation option against the no-action, business-as-usual conditions.

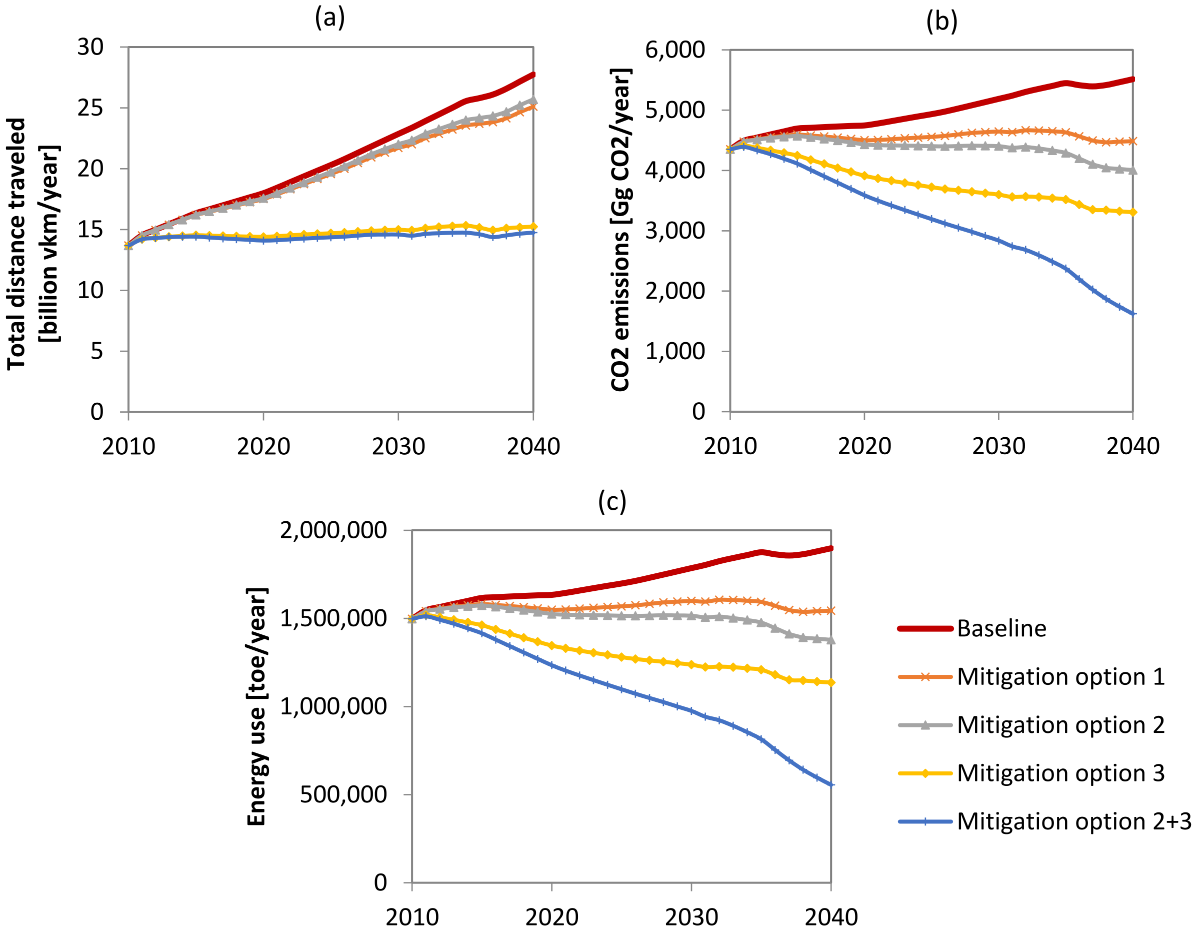

Figure 7: (a) Change in total distance traveled, (b) CO2 emissions and (c) energy use under the different scenarios.

The results for each mitigation scenario are discussed in the following subsections, followed by a discussion of the overall impacts on the road transport system.

6.1 Impacts of mitigation option 1

Boosting the share of FEVs under the first proposed mitigation option reduces the passenger transport energy use and CO_2 emissions in 2040 by 19% compared to the baseline scenario. The benefits achieved are attributable to the improved fuel economy of these vehicles and, in parallel, the decrease in the share of the large fuel consuming vehicles. In addition, the fuel price increase by 50% over the 2020 - 2040 evaluation period naturally impacts the number of trips compared to the baseline scenario, thereby reducing the total distance traveled, and with it the corresponding energy consumed and the emissions generated from these trips.

Table 7 presents the values of the main outputs of this scenario for 2020 and 2040. Note that the energy use is stabilized under this scenario, with a small increase of 3.4% from 2010 to 2020, followed by a slight decrease by 0.3% between 2020 and 2040 due to the improved fuel economy, keeping the energy use stable over the entire planning horizon. CO_2 emissions follow the same trend. This is again due to the larger share of fuel efficient vehicles at the expense of larger fuel-inefficient vehicles, as well as the reduction of vehicle kilometers traveled due to increasing fuel prices.

Table 7: Passenger transport projections of the mitigation option 1 scenario.

	unit	Base Year (2010)	2020	2040	Ratio 2020/2010	Ratio 2040/2010
Total passenger vehicle stock	vehicles	1,292,433	1,652,426	2,425,655	1.28	1.88
2-3 wheelers		60,587	77,797	113,503	1.28	1.87
LDV		1,219,460	1,560,650	2,297,710	1.28	1.88
Buses		12,387	13,978	14,442	1.13	1.17
Total vehicle-km	billion vkm/yr	13.68	17.50	25.10	1.28	1.83
Total energy use	toe/yr	1,497,765	1,549,395	1,543,931	1.03	1.03
Total CO_2 emissions	Gg CO_2/yr	4350	4502	4486	1.03	1.03

6.2 Impacts of mitigation option 2

Since the second proposed mitigation scenario includes mitigation option 1 in addition to the deployment of the more fuel efficient HEVs, more reductions in energy use and CO2 emissions are achieved compared to mitigation option 1. These improvements are achieved despite the slight increase in vehicle-kilometer activity in this scenario, as shown in **Error! Reference source not found.**. This is explained by the fact that the highly fuel efficient HEVs are able to counter the increasing fuel prices in future years, allowing more passenger trips to be made than under the first mitigation scenario without HEVs.

The improvements made by introducing HEVs are substantial compared to the first scenario and the baseline, with 11% additional reductions in energy use and CO2 emissions in 2040, for a total reduction of 27% compared to the baseline (Table 8). More importantly, this scenario sees a first decrease in 2040, below the 2010 base year levels , instead of only controlling the increasing trend over time, showing how beneficial hybrid technologies can be in the long-term. It is also important to remember that this is achieved with only a conservative HEV share of 10% and no new infrastructure construction or any additional investments needed, making this technology easily deployable in the near term.

Table 8: Passenger transport projections of the scenario shift powertrain technology to FEV and HEV.

	unit	Base Year (2010)	2020	2040	Ratio 2020/2010	Ratio 2040/2010
Total passenger vehicle stock	vehicles	1,292,433	1,653,549	2,437,284	1.28	1.89
2-3 wheelers		60,587	77,838	113,950	1.28	1.88
LDV		1,219,460	1,561,750	2,308,995	1.28	1.89
Buses		12,387	13,961	14,339	1.13	1.16
Total vehicle-km	billion vkm/yr	13.68	17.57	25.70	1.28	1.88
Total energy use	toe/yr	1,497,765	1,525,047	1,378,665	1.02	0.92
Total CO_2 emissions	Gg CO_2/yr	4,350	4,431	4,007	1.02	0.92

6.3 Impacts of mitigation option 3

Shifting to mass transport under this proposed mitigation scenario results in a significant 45% reduction of vehicle-kilometer activity in 2040 compared to the baseline, which obviously reflects a net decrease in vehicle trips as those who shift to mass transport no longer need to rely as much on their personal vehicles for mobility. As a result, the energy use and CO_2 emissions are substantially reduced, by a net 10% in 2020 and 24% in 2040 compared to the base year (Table 9). Therefore, this scenario sees the first early improvement below the 2010 base year levels, as of the near-term in 2020.

Table 9: Passenger transport projections of the scenario shift to mass transport.

	unit	Base Year (2010)	2020	2040	Ratio 2020/2010	Ratio 2040/2010
Total passenger vehicle stock	vehicles	1,292,433	1,515,801	2,163,453	1.17	1.67
2-3 wheelers		60,587	71,099	99,530	1.17	1.64
LDV		1,219,460	1,429,350	2,040,880	1.17	1.67
Buses		12,387	15,352	23,043	1.24	1.86
Total vehicle-km	billion vkm/yr	13.68	14.40	15.24	1.05	1.11
Total energy use	toe/yr	1,497,765	1,345,957	1,135,994	0.90	0.76
Total CO_2 emissions	Gg CO_2/yr	4,350	3,912	3,308	0.90	0.76

6.4 Impacts of combined mitigation options and discussion

The interest in combining multiple mitigation options together is obviously to try and combine the benefits from each mitigation type alone, especially that the proposed mitigations are complementary and not mutually exclusive, as previously explained.

Table 10 summarizes the results of this scenario, and as expected the level of reductions of CO2 emissions and energy use achieved under this scenario is greater than for any of the mitigation options alone, due to the cumulative benefits from the improved fuel economy of the FEVs and HEVs and the reduced vehicle use from the shift to mass transport. This result is in agreement with similar conclusions about combined strategies in the literature [28].

Table 10: Passenger transport projections of the combined scenario shift to FEVs, HEVs and mass transport.

	unit	Base Year (2010)	2020	2040	Ratio 2020/2010	Ratio 2040/2010
Total passenger vehicle stock	vehicles	1,292,433	1,477,860	1,978,225	1.14	1.53
2-3 wheelers		60,587	69,393	90,558	1.15	1.49
LDV		1,219,460	1,393,615	1,867,814	1.14	1.53
Buses		12,387	14,852	19,853	1.20	1.60
Total vehicle-km	billion vkm/yr	13.68	14.09	14.74	1.03	1.08
Total energy use	toe/yr	1,497,765	1,234,523	555,686	0.82	0.37
Total CO_2 emissions	Gg CO_2/yr	4,350	3,589	1,623	0.83	0.37

Even more noteworthy is the observation that the environmental results of this scenario exceed in magnitude the sum of the individual results from mitigation option 2 and mitigation option 3 when applied alone. For example, the reduction in energy use from mitigation option 2 in 2040 compared with the base year is 8% (Table 8), and the corresponding reduction from mitigation option 3 is 24% (Table 9), which implies that the total reduction from mitigation option 2+3 should be a cumulative 32%. However, the achieved reduction is actually 63% (Table 10). This means that there are new benefits which are achieved from the combination of mitigations, as a result of possible synergy between the options when applied together. From a systemic view, this is commonly referred to as the whole being greater than the sum of its parts.

Indeed, the results show that the total vehicle stock in option 2+3 is reduced below the sum of reductions from each option alone. This is explained by the fact that implementing a mass transport system alone (option 3) will reduce vehicle trips but will not dissuade the majority of people from continuing to own their old cars or from purchasing new conventional-engine vehicles as before since the vehicle market is not addressed in this scenario. On the other hand, combining mass transport with the introduction of FEVs and HEVs (option 2+3) will allow more people to opt-out of buying these relatively expensive new vehicles, and will even encourage them to abandon their old cars since the introduction of new technology is typically supported by disincentives against the older inefficient vehicles. Conversely, introducing FEVs and HEVs alone (option 2) will not discourage as many people from buying these expensive vehicles since in this scenario they have no other alternative but to rely on the use of their cars.

The analysis of the modeling results illustrates the importance of adopting a holistic approach in the development of a mitigation portfolio, and the need to enable these measures with the appropriate policy framework that ensures a successful outcome. A holistic approach also calls for a comprehensive modeling of the system under consideration, such as extending the scope of the modeling beyond the passenger transport sector to include other important activities in the overall road transport system. Since freight activities consumed 30.6% of total transport energy and were responsible for 31.4% of total GHG emissions in this sector in 2010 [7], a separate modeling of freight activities was done for the baseline scenario to assess their impact on the overall system as compared to passenger transport. Results showed that freight vehicle stock is expected to almost triple in 2040, and is estimated to consume 45.4% of total energy at that point. It can therefore be concluded that the proposed mitigation options for the road passenger transport sector, even when combined effectively, will not be enough to control the substantial growth trends of adverse environmental impacts for the entire road transport system.

To help guide the development of an effective mitigation portfolio, Figure 8 provides a sample roadmap based on the comprehensive ASIF-2 approach, with a focus on navigating the barriers identified in Table 1 for the context of developing countries. This translates to lesser reliance on financial incentives and investments (indicated by dotted arrows for weaker effect), due to limited resources in developing countries. In addition, the roadmap illustrates a focus on “Shift” and “Improve” strategies over the near and medium terms since the “Avoid” strategies are less applicable in this timeframe in the developing context. This is due to the traditional nature of the work culture in these countries and the lacking information and communication infrastructure necessary for wide scale telecommuting and e-trading.

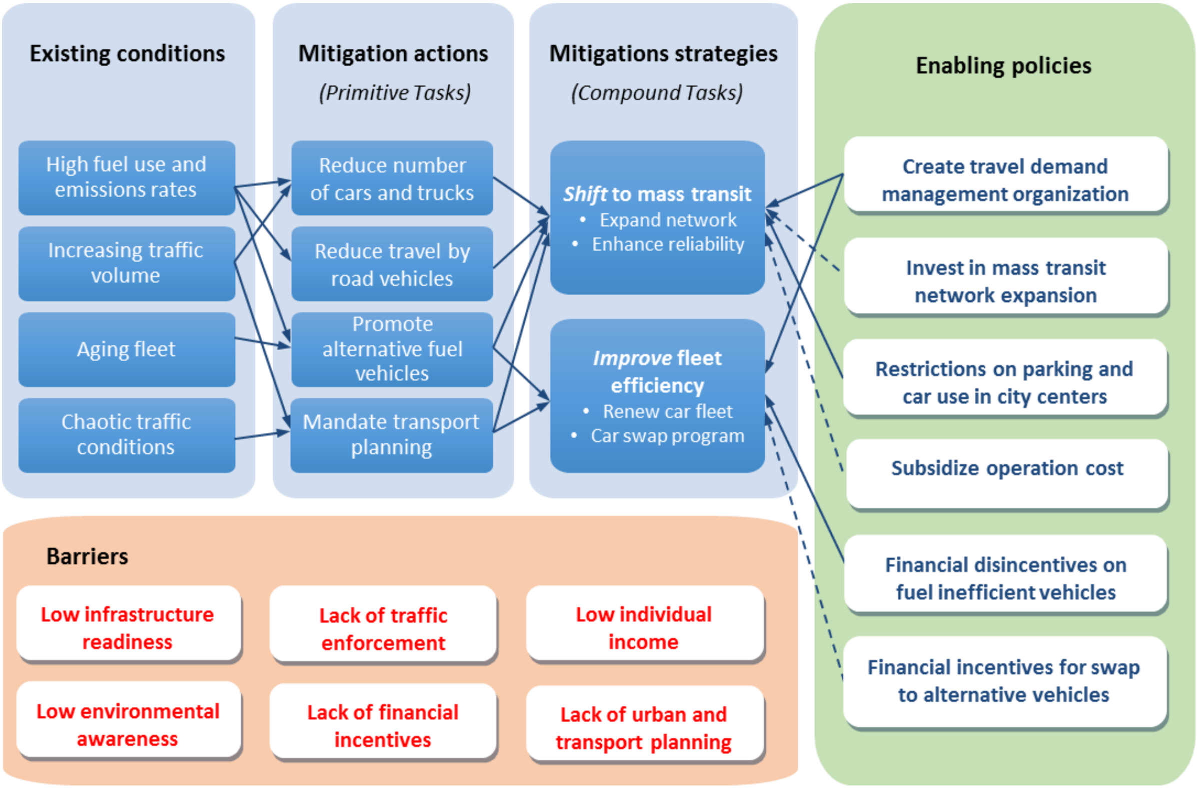

Figure 8: Process for defining mitigation strategies for a sustainable mobility based on the ASIF-2 approach.

7. Conclusion

A modeling of the energy use and CO2 emissions from the road passenger transport system in Lebanon was conducted using the "For Future Inland Transport Systems" (ForFITS) model based on the system dynamics approach. Results showed that renewing the fleet with fuel-efficient and hybrid electric vehicles leads to significant reductions of energy use and CO2 emissions by 27% in 2040 compared to the business-as-usual scenario. However, the vehicle stock and vehicle travel distances are estimated to almost double in 2040 compared to the base year 2010. Therefore, problems pertaining to traffic congestion will continue, and the growth trends of energy consumption and GHG emissions will at best be stabilized or slightly reduced. Therefore, relying on vehicle fuel economy alone is a good first step but not enough to reverse the current unsustainable trends in Lebanon. This can be a beneficial conclusion for similar developing countries in the Middle East region where mass transport infrastructure is limited and there is a culture of heavy reliance on personal vehicle use.

Increasing the share of bus transport led to higher reductions of emissions and energy use (40% each by 2040 compared to the business-as-usual scenario), and more importantly reduced the vehicle-kilometers activity, indicating clear potential to overturn the growth trends of adverse impacts. Combining all three mitigation options naturally gave rise to the highest savings, with 71% reductions achieved by 2040 compared to the business-as-usual scenario in the same year (or the equivalent of 63% reductions in 2040 compared to the baseline year 2010). And while other studies have also confirmed that combined mitigation strategies provide higher benefits than any individual strategy alone, this study illustrated the counterintuitive feedback effect where the overall benefit from combined mitigation policies can be even greater than the sum of the parts.

The diverse challenges facing the road transport sector in Lebanon are only the manifestations of one primary root cause: the absence of a national transportation strategy that can begin to organize the sector into a sustainable one. Such a strategy is long overdue given the fact that the system has been left to emerge in an ad-hoc way with relatively minimal oversight for decades now. This study demonstrated that such a strategy should necessarily be based on the integration of a carefully designed portfolio of mitigations measures and enabling policies under the avoid-shift-improve-finance framework. This would ensure that the road transportation system can get out of the perpetual struggle to stay functional and evolve to become sustainable in the long-term.

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References

1. OECD/IEA. (2016). *World Energy Statistics 2016*. Paris, France. doi:10.1787/9789264263079-en
2. U.S. EIA. (2016). *International Energy Outlook 2016*. *International Energy Outlook 2016* (Vol. 0484(2016)). Washington, DC. doi:www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf
3. UNEP. (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication (p. 407). Crowthorne, United Kingdom: United Nations Environment Programme. Retrieved from http://web.unep.org/greeneconomy/resources/green-economy-report
4. BP. (2016). *BP Statistical Review of World Energy*. *BP Statistical Review of World Energy*. London, United Kingdom. Retrieved from http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
5. WEC. (2011). *Global Transport Scenarios 2050*. *World Energy Council*. London, United Kingdom. doi:10.1016/j.enpol.2011.05.049
6. Haddad, M., Mansour, C., & Stephan, J. (2015). Unsustainability in Emergent Systems : A Case Study of Road Transport in the Greater Beirut Area. In *Industrial Engineering and Operations Management (IEOM), 2015 International Conference on* (pp. 1–10). Dubai, UAE: IEEE. doi:10.1109/IEOM.2015.7093899
7. MoE/UNDP/GEF. (2016). *Lebanon’s Third National Communication to the UNFCCC*. Beirut, Lebanon. Retrieved from http://climatechange.moe.gov.lb/viewfile.aspx?id=239

8. Mansour, C., Zgheib, E., & Saba, S. (2011). Evaluating impact of electrified vehicles on fuel consumption and CO 2 emissions reduction in Lebanese driving conditions using onboard GPS survey. In *Energy Procedia* (Vol. 6, pp. 261–276). Beirut, Lebanon: Elsevier B.V. doi:10.1016/j.egypro.2011.05.030
9. MOE. (2015). *Lebanon's Intended Nationally Determined Contribution under the United Nations Framework Convention on Climate Change*. Beirut, Lebanon. Retrieved from http://climatechange.moe.gov.lb/Library/Files/Uploaded Files/Republic of Lebanon - INDC - September 2015.pdf
10. Mansour, C. J., & Haddad, M. G. (2017). Well-to-wheel assessment for informing transition strategies to low-carbon fuel-vehicles in developing countries dependent on fuel imports: A case-study of road transport in Lebanon. *Energy Policy*, *107*(August 2017), 167–181. doi:10.1016/j.enpol.2017.04.031
11. Solís, J. C., & Sheinbaum, C. (2013). Energy consumption and greenhouse gas emission trends in Mexican road transport. *Energy for Sustainable Development*, *17*(3), 280–287. doi:10.1016/j.esd.2012.12.001
12. McCollum, D., & Yang, C. (2009). Achieving deep reductions in US transport greenhouse gas emissions: Scenario analysis and policy implications. *Energy Policy*, *37*(12), 5580–5596. doi:10.1016/j.enpol.2009.08.038
13. Månsson, A., Johansson, B., & Nilsson, L. J. (2014). Assessing energy security: An overview of commonly used methodologies. *Energy*, *73*, 1–14. doi:10.1016/j.energy.2014.06.073
14. Dedinec, A., Markovska, N., Taseska, V., Duic, N., & Kanevce, G. (2013). Assessment of climate change mitigation potential of the Macedonian transport sector. *Energy*, *57*, 177–187. doi:10.1016/j.energy.2013.05.011
15. Aggarwal, P., & Jain, S. (2016). Energy demand and CO2 emissions from urban on-road transport in Delhi: current and future projections under various policy measures. *Journal of Cleaner Production*, *128*, 48–61. doi:10.1016/j.jclepro.2014.12.012
16. Ong, H. C., Mahlia, T. M. I., & Masjuki, H. H. (2012). A review on energy pattern and policy for transportation sector in Malaysia. *Renewable and Sustainable Energy Reviews*, *16*(1), 532–542. doi:10.1016/j.rser.2011.08.019
17. Hao, H., Wang, H., & Ouyang, M. (2011). Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet. *Energy*, *36*(11), 6520–6528. doi:10.1016/j.energy.2011.09.014
18. Shen, W., Zhang, A. L., & Han, W. J. (2007). Alternative vehicle fuels strategy in China: Well-to-wheel analysis on energy use and greenhouse gases emission. *Proceedings of 2006 International Conference on Management Science and Engineering, ICMSE'06 (13th)*, 1735–1739. doi:10.1109/ICMSE.2006.314070
19. Williamson, S. S., & Emadi, a. (2005). Comparative assessment of hybrid electric and fuel cell vehicles based on comprehensive well-to-wheels efficiency analysis. *IEEE*

Transactions on Vehicular Technology, *54*(3), 856–862. doi:10.1109/TVT.2005.847444

20. Ong, H. C., Mahlia, T. M. I., & Masjuki, H. H. (2011). A review on emissions and mitigation strategies for road transport in Malaysia. *Renewable and Sustainable Energy Reviews*, *15*(8), 3516–3522. doi:10.1016/j.rser.2011.05.006

21. Streimikiene, D., Baležentis, T., & Baležentiene, L. (2013). Comparative assessment of road transport technologies. *Renewable and Sustainable Energy Reviews*, *20*, 611–618. doi:10.1016/j.rser.2012.12.021

22. Morgadinho, L., Oliveira, C., & Martinho, A. (2015). A qualitative study about perceptions of European automotive sector's contribution to lower greenhouse gas emissions. *Journal of Cleaner Production*, *106*, 644–653. doi:10.1016/j.jclepro.2015.01.096

23. Orsi, F., Muratori, M., Rocco, M., Colombo, E., & Rizzoni, G. (2016). A multi-dimensional well-to-wheels analysis of passenger vehicles in different regions: Primary energy consumption, CO2 emissions, and economic cost. *Applied Energy*, *169*, 197–209. doi:10.1016/j.apenergy.2016.02.039

24. Huo, H., Wu, Y., & Wang, M. (2009). Total versus urban: Well-to-wheels assessment of criteria pollutant emissions from various vehicle/fuel systems. *Atmospheric Environment*, *43*(10), 1796–1804. doi:10.1016/j.atmosenv.2008.12.025

25. MOEW. (2010). *Policy Paper for the Electricity Sector*. Beirut, Lebanon. Retrieved from climatechange.moe.gov.lb/viewfile.aspx?id=121%0A

26. Wen, L., & Bai, L. (2016). System Dynamics Modeling and Policy Simulation for Urban Traffic: a Case Study in Beijing. *Environmental Modeling & Assessment*. doi:10.1007/s10666-016-9539-x

27. Pongthanaisawan, J., & Sorapipatana, C. (2013). Greenhouse gas emissions from Thailand's transport sector: Trends and mitigation options. *Applied Energy*, *101*, 288–298. doi:10.1016/j.apenergy.2011.09.026

28. Liu, X., Ma, S., Tian, J., Jia, N., & Li, G. (2015). A system dynamics approach to scenario analysis for urban passenger transport energy consumption and CO2 emissions: A case study of Beijing. *Energy Policy*, *85*, 253–270. doi:10.1016/j.enpol.2015.06.007

29. Cheng, Y.-H., Chang, Y.-H., & Lu, I. J. (2015). Urban transportation energy and carbon dioxide emission reduction strategies. *Applied Energy*, *157*, 953–973. doi:10.1016/j.apenergy.2015.01.126

30. Chavez-Baeza, C., & Sheinbaum-Pardo, C. (2014). Sustainable passenger road transport scenarios to reduce fuel consumption, air pollutants and GHG (greenhouse gas) emissions in the Mexico City Metropolitan Area. *Energy*, *66*(2), 624–634. doi:10.1016/j.energy.2013.12.047

31. Dalkmann, H., & Brannigan, C. (2007). *Transport and Climate Change Initiatives*. Eschborn, Germany. Retrieved from http://www.sutp.org/files/contents/documents/resources/A_Sourcebook/SB5_Environment and Health/GIZ_SUTP_SB5e_Transport-and-Climate-Change_EN.pdf

32. Acharya, S. R. (2005). Motorization and Urban Mobility in Developing Countries Exploring Policy Options Through Dynamic Simulation. *Journal of the Eastern Asia Society for Transportation Studies*, *6*, 4113–4128.

33. Brand, C., Anable, J., & Tran, M. (2013). Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. *Transportation Research Part A: Policy and Practice*, *49*, 132–148. doi:10.1016/j.tra.2013.01.010

34. Feng, Y. Y., Chen, S. Q., & Zhang, L. X. (2013). System dynamics modeling for urban energy consumption and CO2 emissions: A case study of Beijing, China. *Ecological Modelling*, *252*(1), 44–52. doi:10.1016/j.ecolmodel.2012.09.008

35. Wang, J.-F. J., Lu, H.-P. H., & Peng, H. (2008). System dynamics model of urban transportation system and its application. *Journal of Transportation Systems Engineering and Information Technology*, *8*(3), 83–89. doi:10.1016/S1570-6672(08)60027-6

36. UNECE. (2013). For Future Inland Transport Systems (ForFITS) User Manual. Retrieved from http://www.unece.org/trans/theme_forfits.html

37. Andrejszki, T., Gangonells, M., Molnar, E., & Török, Á. (2014). ForFITS: A new help in transport decision making for a sustainable future. *Periodica Polytechnica Transportation Engineering*, *42*(2), 119–124. doi:10.3311/PPtr.7442

38. Millard-Ball, A., & Schipper, L. (2011). Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries. *Transport Reviews*, *31*(3), 357–378. doi:10.1080/01441647.2010.518291

39. Abbas, K. A., & Bell, M. G. H. (1994). System dynamics applicability to transportation modeling. *Transportation Research Part A*, *28*(5), 373–390. doi:10.1016/0965-8564(94)90022-1

40. Han, J., & Hayashi, Y. (2008). A system dynamics model of CO2 mitigation in China's inter-city passenger transport. *Transportation Research Part D: Transport and Environment*, *13*(5), 298–305. doi:10.1016/j.trd.2008.03.005

41. Vafa-Arani, H., Jahani, S., Dashti, H., Heydari, J., & Moazen, S. (2014). A system dynamics modeling for urban air pollution: A case study of Tehran, Iran. *Transportation Research Part D: Transport and Environment*, *31*, 21–36. doi:10.1016/j.trd.2014.05.016

42. Fong, W. K., Matsumoto, H., & Lun, Y. F. (2009). Application of System Dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emissions from cities. *Building and Environment*, *44*(7), 1528–1537. doi:10.1016/j.buildenv.2008.07.010

43. Ventana Systems Inc. (2013). Vensim® User Manual. Ventana System, Inc. Retrieved from http://www.vensim.com

44. MOE/URC/GEF. (2012). *Lebanon Technology Needs Assessment Report For Climate Change*. Beirut, Lebanon.