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# *Unsustainability in Emergent Systems: A Case Study of Road Transport in the Greater Beirut Area*

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***Abstract*— The land transportation network in Lebanon faces continuing and wide-ranging challenges at the level of infrastructure development, planning and overall system management. These challenges are already significant enough to seriously hamper the network's ability to deliver an acceptable level of service within reasonable norms for environmental, health and safety impacts, especially in and around the country's major urban centers. This reality makes the road transport system in Lebanon one of the most unsustainable in the region, and as such a key candidate for closer assessment. In this paper we present a detailed case study of the passenger road transport system in the Greater Beirut Area (GBA) where we identify the root causes of the major problems facing the system today and over the long-term. We propose a framework of corresponding mitigation options as a roadmap for improving the sustainability of the system, namely by reducing the reliance on fossil fuels, decreasing pollutants and Greenhouse Gas (GHG) emissions, reducing mobility costs and increasing passenger safety.**

***Keywords*— *road transportation; sustainability; mitigation; emergent systems***

## I. INTRODUCTION

Every year, countless studies are being published about Global Warming and the need for shifting the world's energy consumption trend into one with "sustainable dynamics", which translates to reducing the dependence on non-renewable fossil fuels and controlling their negative impacts on human health and the environment. This has focused attention on road transportation worldwide since this sector boasts the highest fuel consumption of any other sector of the economy [1], with a share of 19% of global energy supplies being consumed by road transportation in 2010, the majority of which are classified as fossil fuels (gasoline, diesel and gas) [2].

Of even more concern is the growing trend of this unsustainable reality since economic growth is inevitably accompanied by an increase in energy demand in most sectors of the economy, primary of which is the transportation sector. The demand for fuel is thus expected to increase by up to 200% by the year 2050 [2]. The natural consequence of this is an increasing pressure on the supply of fossil fuel worldwide, with a corresponding increase in harmful emissions to the environment and human health affecting people everywhere, whether in industrialized or developing countries, large or small.

This unsustainable picture is vividly exposed in the functioning of the Lebanese road transport sector, where the sector is the second largest consumer of energy, dependent totally on fossil fuels (gasoline and diesel) [3]. The Lebanese vehicle fleet relies mostly on older and less efficient passenger cars as the main vehicle type for mobility, in the absence of a decently operated public transportation system [4]. And missing any other local modes of passenger transportation such as marine ferry or rail service, it becomes clear that the land transportation sector in Lebanon should be the focus of a major transformation effort to turn it into a sustainable engine of the economy, while still responding to the growing needs for individual mobility.

The focus of this paper is to describe the inefficiencies of the road transport system in Lebanon and to provide mitigation options by tackling the ad-hoc emergence of the system, its over-reliance on fossil fuels, the unchecked emissions of pollutants and Greenhouse Gases (GHG), the high costs of mobility and the lack of enforcement of passenger safety. The current state of road passenger mobility in the Greater Beirut Area (GBA) is first presented as a worst-case scenario of the challenges faced by road passenger mobility in Lebanon. Second, a roadmap for improvement is presented using an adaptation of the Avoid-Shift-Improve (ASI) approach tailored to the Lebanese case. The ASI strategy allows for moving away from unnecessary unsustainable practices, and outlines steps to decrease the use of fossil fuels and the emission of polluting substances.

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## II. OVERVIEW OF THE ROAD PASSENGER TRANSPORT PROBLEMS IN THE GBA

Local passengers commuting through the GBA suffer from daily frustrations, which stem from heavy congestion, pollution and the unwillingness of drivers to adhere to the basic driver codes of conduct and road rules in effect. The heavy congestion is due to demographic growth, the increase in the number of vehicles on the road, the unregulated and chaotic driving behaviors on major highways as well as side-roads, and the under-developed and mismanaged mass transportation system. High pollution levels originate from the dominance of old, inefficient cars in the Lebanese vehicle fleet, as well as from long idling times and very slow driving speeds in gridlocked traffic. Chaotic driver behavior and breach of driving rules paired with the absence of modern regulations and corrective actions reduce safety level on the roads, leading to further congestion in a seemingly endless vicious circle. This illustrates the current state of the Lebanese road passenger transport and it is illustrated through a multitude of observations and data presented in the following sections.

### *A. Congestion From Rapid Growth and Chaotic Driving Patterns*

There are approximately a total of 1.58 million registered vehicles in Lebanon, from the Ministry of Interior and Municipalities (MoIM) 2012 vehicle fleet database [5], for an estimated 2012 population of 4.425M people[1]. This translates to roughly 3 passenger vehicles for every person, almost double the Arab region average, as shown in Fig. 1. The GBA includes more than 40% of the Lebanese population and is a major "hub" expected to host 5 million daily passenger trips by 2015 [4]. Most of those trips are done by single drivers, as car occupancy rates in GBA were of approximately 1.2 passengers per vehicle [4], very low compared to world standards, providing a clear indication for the ever increasing number of cars on the road and the corresponding high rate of congestion. In fact, occupancy rates in the US and UK are 25% higher, at 1.55 and 1.57 passengers per vehicle, respectively [6,7].

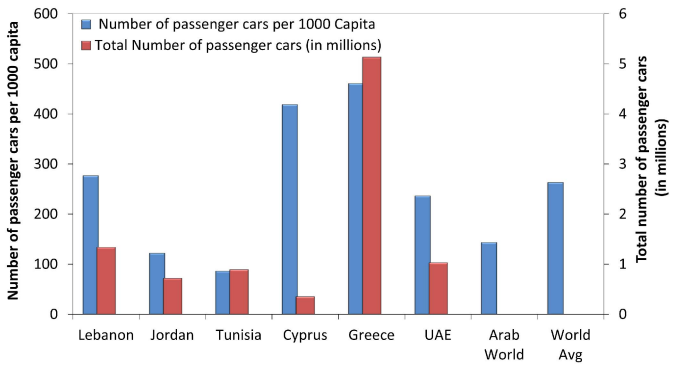


Fig. 1. Number of passenger cars in the Lebanese fleet in 2012

[1] World Bank WDI, 2014; IMF World Economic Outlook Database April 2014, 2014

To understand typical driving habits in the GBA, we equipped several vehicles with GPS equipment in order to collect data on typical driving patterns during the entire year 2011. The resulting analysis revealed that the driving patterns can be characterized by a relatively low driving range with a high rate of congestion and frequent stops at short time intervals. In fact, we found that approximately 50% of trips have a distance lower than 5 km, 25% of stops are below 2 seconds and the total stop time per trip corresponds to more than 15% of travel time. We also found that acceleration rates are significant at very low speeds, as shown in the speed-acceleration frequency distribution in Fig.2, which reflects the continuous stop-and-go driving patterns. This means there is a significant lack of efficiency in the operation of internal combustion engines and a high rate of fuel consumption and pollutant emissions.

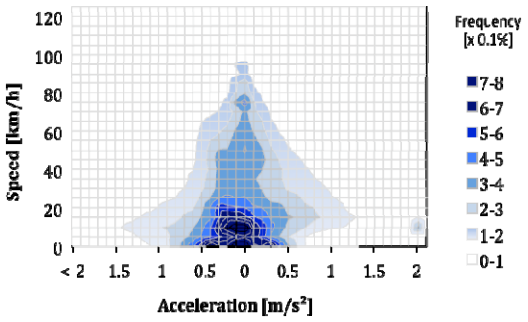


Fig. 2. Speed-acceleration frequency distribution in GBA

Consequently, the road passenger transport sector suffers from high energy demands, with deployed technologies fully dependent exclusively on fossil fuels, making it economically unsustainable especially at a time when oil supply and oil prices continue to be highly sensitive to uncontrollable external factors such as political instability in the OPEC region.

Outside of typical congestion during peak hours, driving patterns in and around the GBA are highly chaotic with drivers constantly weaving in and out of their driving lanes, breaking the speed limits both ways, such as driving too slow in the fast lane or passing traffic at high speed in the right lane, and abruptly slowing down to take an exit or to stop at commercial establishments, among many other erratic behaviors which do not conform to local traffic laws and basic norms of driver conduct. This in turn leads to more congestion during off-peak times as well as safety concerns from traffic accidents. One particularly notable driver behavior on highways is the non-adherence to lane markings, when such markings exist, which causes the crowding of two cars per lane instead of one, thereby severely restricting flow speeds and causing even more congestion. This also compromises road safety, raising the risk of serious accidents. Table 1 shows the number of fatalities per GDP/Capita for Lebanon and neighboring countries as

developed using growth ratios from publically available data for 2007 to 2010[2].

Table 1: Rate of fatalities in Lebanon 2007-2012

| | *2007* | *2008* | *2009* | *2010* | *2011* | *2012* |
|---|---|---|---|---|---|---|
| Number of crashes | 4421 | 4770 | 4644 | 4583 | 4447 | 4804 |
| Number of fatalities | 497 | 478 | 513 | 549 | 508 | 595 |
| Rate of fatalities (%) | 11.2 | 10 | 11 | 12 | 11.4 | 12.4 |

The data shows that Lebanon's fatality per capita and fatality per gross domestic product per capita (GDP/capita) are either lower or on par with neighboring countries. However, we estimated that on average, 11.3% of road crashes end in at least one fatality. The secretary general of Youth Association for Social Awareness (YASA) states that high speed driving and failure to wear seatbelts are of the most cited reasons for car crashes [8], showing a chronic lack of compliance with traffic laws, which is primarily due to insufficient enforcement as acknowledged by the Internal Security Forces (ISF) [9]. Other causes are poor roadway conditions, namely the lack of lighting on most highways, the absence of proper separation from urban construction such as that accomplished with frontage roads, inadequate traffic signs and roadway markings particularly near roadway works, in addition to poor road pavement conditions and extensive potholes, as well as slippery roads in winter weather, among other infrastructure-related and system management problems.

Another major cause for congestion in the GBA is driver behavior on narrow internal streets which make up the majority of all roads in the city, such as the common practice of double parking for a quick pick-up or delivery, or parking over sidewalks and in prohibited curbside spaces. This further reduces the space dedicated to cars and causes heavy traffic. In addition, the absence of traffic signals at minor intersections and the lack of compliance with traffic signals even at major intersections, both lead to frequent blocking of intersections and further traffic jams at all hours of the day, extending the periods of peak traffic and affecting more areas outside the normally busy business districts.

### *B. Aging Vehicle Fleet*

GBA mobility relies mainly on personal-owned passenger cars which constitute 85% of the total vehicles on the roads in Lebanon (adding up to roughly 1.34M cars in 2012), with trucks accounting for 8.9% of the total, 5.2% for motorcycles and only 0.9% for buses. The age distribution of passenger cars (public and private) illustrated in Fig. 3. reflects the old nature of the fleet, with 71% older than 10 years. These figures are reflected in the GBA where more than 315,000 of all passenger cars operate [4].

[2] Kunhadi Association website: www.kunhadi.org/en/In-Numbers

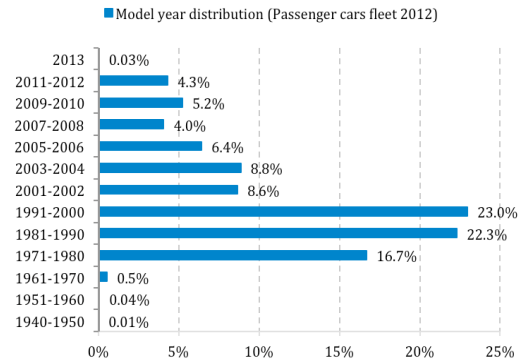


Fig. 3. Model year distribution of the fleet of private and public passenger cars in Lebanon

Moreover, the engine distribution, indicated in Fig. 4 (of the passenger car fleet in 2007), shows that the fleet is mostly inefficient, since 60% of the cars have engine displacements exceeding 2.0 liters, while only 8% have engines less than 1.4 liters. The impacts of these existing conditions are detailed in the following section.

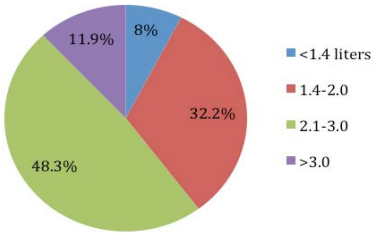


Fig. 4. Engine displacement distribution of the 2007 Lebanese passenger car fleet

### *C. Energy Consumption and Substantial Environmental Impact*

GHG emissions, mainly carbon dioxide ($CO_2$), which are responsible for Global Warming and the degradation of the environment [10], have been scientifically proven to be proportional to fuel consumption. Therefore, the more fuel is consumed in the transport sector, the more harmful emissions are discharged into the atmosphere.

According to a report of the International Energy Agency (IEA), the oil consumption in 2008 of the road transport sector constituted more than 62% of the total oil consumption in Lebanon, 99.2% depending on gasoline [11]. Consequently, the road transport sector is the second biggest emitter of GHG. It accounts for nearly 21.4% of Lebanon's GHG emissions for the year 2000, and it is the main source of CO, $NO_x$ and NMVOC emissions, with 94%, 59% and 66% respectively [11, 4]. In fact, the passenger transport sector was responsible of 25% of $CO_2$ emissions in the year 2000, and has witnessed since then an increase of 114% [3, 4], to equate 1.4 times the world average.

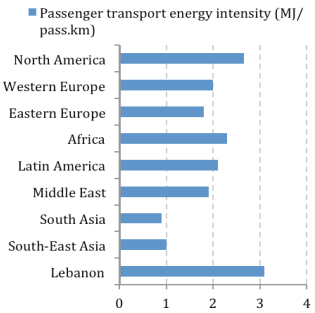


Fig. 5. Transport energy intensity (2007 for Lebanon and 2005 for the other regions)

All of these existing conditions have led the road transport sector in Lebanon to have high passenger transport energy intensity in 2007, estimated at 3.08 MJ/passenger-kilometer (Fig. 5), in addition to having a high energy demand per capita of 15.06 GJ/capita, exceeding the world average (Fig. 6) [4].

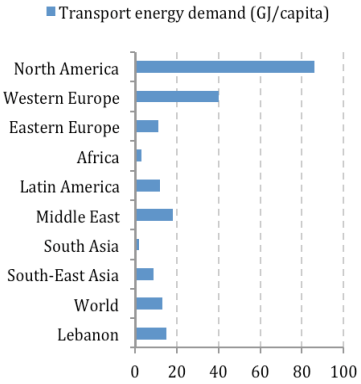


Fig. 6. Passenger transport energy demand per capita. (2007 for Lebanon and 2005 for the other regions)

It can therefore be concluded that all of the elements of an unsustainable transport system are major constituents of the current mobility model in the GBA: passengers suffer from high mobility costs, high dependence on fossil fuels, in addition to alarming pollution rates particularly in dense urban areas. Therefore, the road passenger transport sector needs to be restructured from a sustainability perspective.

### *D. Lack of Planning and Regulation*

With the high demographic growth in GBA and uncontrolled increase in car ownership, traffic congestion is likely to occur at every intersection. Several road expansion projects were undertaken; however, poor planning has led to inevitable congestion, and a quasi-impossibility of expanding current roads. Hence, new road infrastructures need to be created to accommodate for the increase in the number of cars, which is deemed as an insufficient solution given the very limited space available for new construction and the rapid growth of demand.

Lack of planning and regulation of bus and taxi transportation also plays a role in increasing traffic congestion through the lack of dedicated lanes and the absence of designated pickup/drop-off locations at specified time intervals, leading to the irregular service patterns of passenger buses. For example, the unrestrained competition between public and private mass transport operators (buses, exclusive and shared taxis) pushes drivers to abruptly switch lanes at any time and stop virtually anywhere for passenger pickup or drop-off. Consequently, additional congestion and stop-and-go patterns are generated for the other cars on the road, not to mention the increasing risks of collisions and accidents.

The consequences of the lack of planned growth of the road transport infrastructure over the past several decades is the extensive urban sprawl currently observed around the outer limits of the GBA and beyond, which in turn has prompted more unplanned expansion of the system, in a closed-loop vicious cycle of random evolution. The outcome is a system architecture typical of such complex systems, known as a "scale-free" topology [12], where there is high clustering of nodes (many short connections between nearby nodes) and few sparse links to distant nodes [13]. This means that most traffic is concentrated around a few hubs (the GBA and other major cities such as Tripoli and Sidon), with limited options for connecting to distant locations, making those few long connections equally vulnerable to rapid congestion. This is in sharp contrast to the architecture of well-planned transport systems, known as a "random network", where most nodes have the same number of links on average, making planned systems less vulnerable to congestion, all else being equal. This means that the continued unchecked evolution of the road transport infrastructure in Lebanon, as well as the lack of planning and regulation to control the unpredictable behavior of the users of the system, both combine to put this emergent system at the upper limits of unsustainability. The sustainability problem then becomes that much more challenging, as one of reversing an out-of-control trend before being able to shift towards a more sustainable path.

### *E. Inadequate Public Transport*

Mass transport in GBA consists only of public and private buses, minivans and exclusive- and shared-ride taxis, all operating ad-hoc without any coordination, resulting in very poor occupancy rates of about 1.2 passengers per vehicle for taxis, 6 for vans and 12 for buses [4]. In 2002, the mass transport market share in GBA was 31%, split between modes as illustrated in Fig. 7 [15], clearly illustrating the level of underdevelopment of mass transportation in Lebanon. This limited share of the market continues today due to the impracticality, lack of safety and restricted reach of public transportation compared to the attractiveness of owning a private automobile, an alternative that is still promoted over mass transportation in Lebanon through bank loan facilities and affordable new and used car imports.

This reality is due in large part to the chaotic, inefficient and unreliable management of the transportation sector, preventing the modernization and growth of the system and allowing the market to be controlled by private operators. For example, the

system is oversupplied with 50,000 taxi licenses (known as "red plates"), where an estimated 17,000 of these are illegally procured and operated, with a similar situation of poor forecasting and control of the number of shared taxis and minibuses relative to actual market demand.

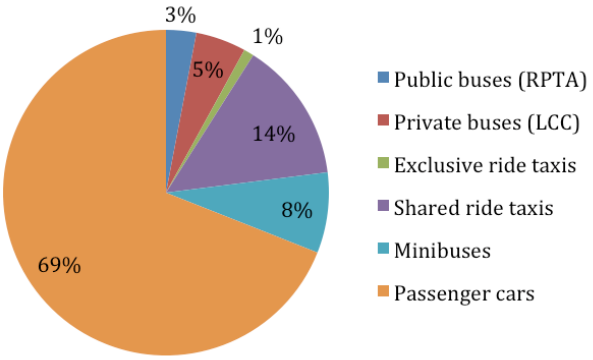


Fig. 7. Market share of passenger transport modes in GBA in 2002.

Some of the main roots of this sector's mismanagement are the limited capacities of the overseeing institutions and organizations and the fragmentation of responsibilities between them. Several governmental and institutional actors have authority over the organization and operation of various aspects of the mass transportation system, and their decisions often influence other parts of the system outside their jurisdiction or even the whole system. These actors are: the Directorate General of Land and Maritime Transport (DGLMT); the Directorate General of Roads and Buildings (DGRB), operating under the umbrella of the Ministry of Public Works and Transport (MoPWT) and responsible for the construction, rehabilitation and maintenance of public roads and government buildings; the MoIM, in charge of vehicle registration and inspection, driver's licensing and traffic code implementation; the Traffic Management Organization (TMO), in charge of the traffic management; Railway and Public Transport Authority (RPTA) and Office des Chemins de Fer et des Transports en Commun (OCFTC) in charge of public transport operations; and the local municipalities, in charge of roads within municipal jurisdiction and the associated regulation of transport and traffic. This fragmentation of responsibilities and overlapping jurisdictions along with the lack of coordination between entities has naturally led to the above-mentioned gap in the management of the mass transport system as a whole.

An additional aspect of mismanagement is related to the fiscal burden of the system on the public treasury, which can be considered to be economically unsustainable as is. Most notable is the case of the RPTA which maintains minimal services since the decommissioning of much of the network in the 1970's, but still requires heavy subsidies every year to cover its operating costs, increasing from USD 9 million in 1998 and 1999, to USD 13.3 million in 2000, more than the fare revenues earned in these years. Moreover, USD 2.2 million of the subsidies were channeled to cover railway employee salaries, when rail service has actually been suspended in Lebanon since the 1970's [15]. Along similar lines, the Lebanese government continues to subsidize the social security obligations of the 33,000 red-plate holders which are estimated at about USD 32.4 million per year [4].

On a worldwide scale of sustainable transportation (Fig. 8), the GBA ranks at the very bottom since it suffers from the same overdependence on motorized vehicles as North American cities [16], but without the equivalent GDP/capita[3] and more importantly, without any strategy towards sustainability in the horizon. Perhaps Beirut's position near Riyadh, a city where major mass transit systems are already under development, best illustrates the seriousness and urgency of the situation.

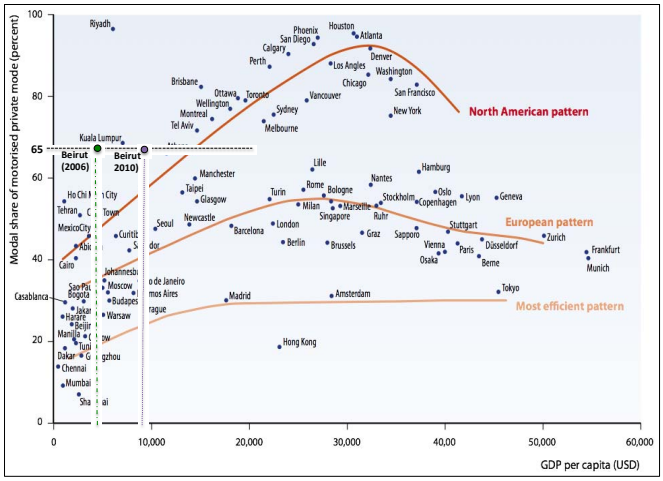


Fig. 8. Modal share of motorized private mode vs. GDP/Capita (adapted)

## III. Tackling the Problem: Current Trends towards Sustainable Road Transportation

Based on the current situation of increased mobility demand, the Lebanese passenger transport sector is far from sustainable. Until now, a traditional approach has been applied, to tackle the increase in mobility demand: it consists mainly of providing additional road space through widening existing and/or building new road infrastructure. This approach can be reviewed in detail in the Urban Transport Development Plan implemented by the Council for Development and Reconstruction (CDR).

This supply-side approach has not delivered the expected benefits, and the reasons for that are explained in a causal-loop diagram shown in Fig. 9 *(Causal-loops are a common practice in the analysis of systems, and are used to reveal connections and feedback interactions between different components of a system)*. The diagram shows two feedback loops, a large positive loop (shown in green) and a small negative loop (in red). In the negative loop we see the typical situation where traffic congestion increases the pressure to expand the road network (the top green positive arrow between "Traffic Congestion" and "Expand Road Network"), which once implemented goes back to reduce traffic congestion (the

[3] IMF World Economic Outlook Database April 2014

reverse arrow in red). However, what policymakers don't usually see is the long-term effect of this action (shown in the green loop) where road expansion encourages more people to get on the road as they get the impression that roads have improved and traffic congestion has been decreasing. This ends up canceling out the benefit of the original road expansion as congestion is increased again through the newly induced traffic.

The diagram also shows that harmful emissions and fuel consumption continue to increase despite the expansion of the road network. Therefore, the traditional supply-side approach has come to be regarded as only a short-term solution which can be counter-productive in the long-term, especially if implemented alone without other mitigating measures.

The principles of sustainability require tackling not only the supply side, but the demand side as well. On the demand side, the logic is to maximize efficiencies by the individual users of the system, namely at three levels of decision-making for a typical trip. The target is maximizing (1) the system efficiency, (2) the trip efficiency and (3) the vehicle efficiency. Hence three factors have to be considered: how far the distance to go, the mode of transport to use, and the type of vehicle to use.

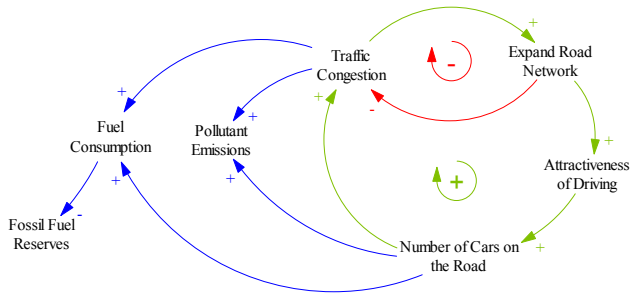


Fig. 9. Why building more roads doesn't solve the congestion-consumption-pollution problems. Adapted from [15]

One proven approach for maximizing these efficiencies is the Avoid-Shift-Improve (ASI) approach [18]. As the name implies, this approach entails a three-fold strategy for:

- *Avoiding* or reducing travel by motorized modes through, for instance, the integration of land use and transportation planning
- *Shifting* to more environmentally friendly modes such as public transport and non-motorized transport
- *Improving* vehicle and fuel technology of all modes of transport to improve the environmental efficiency from each kilometer travelled

The following sections will adapt the ASI approach to the GBA case by assessing the applicability of potential solutions under each strategy in the Lebanese case.

### A. *Avoid Strategy*

Define The Avoid strategy refers to the need to improve the efficiency of the transport system. It consists of reducing or totally cancelling the need and/or desire to travel. Several techniques and solutions were adopted in sustainable cities, among them is telecommuting to work. For the case of Lebanon, the concept of telecommuting needs to be introduced to the local work culture as it is currently an uncommon practice. Not only would this contribute to reducing congestion and fuel consumption, but it would also lead to economic benefits at the multiple levels from reduced costs, higher employee satisfaction and retention, and increased productivity from the saved travel time.

Walking and bicycle riding zones are also at the center of transportation planning [19]. These alternatives are currently not part of the daily road transportation choices taken by Lebanese commuters and can therefore have an immediate impact, particularly in the densely populated areas in the GBA. Since 35% of passenger cars trips have a distance lower than 4 km, 11% lower than 2 km [20], reserved walking and biking zones could become effective measures if the concept of environmental responsibility is promoted and enforced in Lebanese culture, at both the government and individual levels.

Another globally applied policy is to disincentive the use of motorized vehicles, such as congestion pricing in London and Singapore, air pollution pricing in Milan, and vehicle caps in Singapore [21]. Also, tolls are introduced in some areas of congested cities to relieve its traffic and motorized vehicle density. The reverse is also valid, such as giving incentives to individuals who drive "clean" cars: for example, the Swedish government implemented subsidies for eco-friendly cars in 2007, and provided free parking in cities for "clean" car owners.

Such policies and measures are worth serious consideration in some areas of the GBA in order to change the culture of dependence on the use of motorized vehicles. However, it is clear that in order to apply this "Avoid" strategy in the GBA, serious cultural changes are necessary at all levels: from decision-makers and stakeholders to passengers, in conjunction with deep and carefully considered changes to the existing infrastructure. Along those lines, capacity building and expertise are required at the level of the relevant authorities, to carry out these changes, and awareness campaigns will be needed in order to fight resistance to change at the user level. This will necessitate substantial and sustained funds to ensure success of this massive transformation. For the time being, the Avoid strategy can be considered a long-term target for Lebanon, until such time as serious governmental planning or a National Transport Strategy are enacted to organize the ad-hoc evolution of the system and prepare the ground for modern measures.

### B. *Shift Strategy*

The shift strategy seeks to improve the trip efficiency. It consists of a modal shifting from means with high energy/oil consumption to more environmentally friendly modes.

The most efficient non-motorized mean is cycling. While no data is available on the percentage of the population using bicycles as a mode of transport in the GBA, it is clearly the least popular, with no bicycle lanes or laws to protect bicyclists. Therefore, as a first step to encourage the use of bicycles, the appropriate infrastructure needs to be created in

the form of bicycle lanes, safe storage, and convenient and affordable bike rentals, among others.

A second way to push the Shift strategy is the introduction of the "Park and Ride" concept, a very popular and heavily-used facility in major cities such as Melbourne, Australia [22]. It consists of breaking the total travel distance in two parts: first using personal transport, then using either public transport or bicycles to complete the trip. People would park their cars in a public car park, which is next to a bus and/or train station, and complete the trip via buses or train. The car park is also fitted with bicycle racks if the person chooses to ride to work. "Ride2Work" is also a program for shifting mobility out of motorized means, applied for example in Victoria, Australia, and supported by the local city council [23], where the third Wednesday of every October is designated as the Ride2Work national day to encourage riding bicycles to work and to raise environmental (and physical health) awareness.

Furthermore, carpooling offers a sustainable transport alternative to single-ride passenger cars. In Lebanon, several websites and mobile applications are dedicated to match individuals, mainly students, for carpooling. The websites caused hype for a brief period of time before being forgotten. But the implications of these tools could be significant in the Lebanese context since carpooling with two or three passengers onboard gets us closer to the trip-efficiencies of local buses; and hence, lower $CO_2$ emissions per passenger-kilometer.

A last example of shifting to environmentally friendly mass transport options is the rail transport. The particularity of rail is its high transport capacity per trip compared to other modes of transportation [24]. In this case, the energy requirements per passenger-trip dramatically decrease and savings are not only in terms of energy and emissions, but in space as well since one train transporting two hundred passengers would take less space than two hundred cars, for example.

Lebanon used to have four rail lines: (1) Beirut-Damascus, (2) Naqoura-Tripoli, (3) Tripoli-Homs and (4) Rayak-Aleppo. Though the entire rail network is currently derelict, study into the feasibility of rebuilding, rehabilitating and reopening the approximately 80 km of disused railway from Beirut north along the coast to Tripoli, is under consideration by the European Investment Bank.

### C. *Improve Strategy*

The Improve strategy focuses on vehicle and fuel efficiency. It consists of improving the energy efficiency of vehicle powertrain technologies, and the use of alternative energies.

In order to comply with EURO emission regulations, car manufacturers adopted engine downsizing as a common design technique; these vehicles are also referred to as fuel-efficient gasoline cars. By decreasing the displacement of the engine and turbocharging it, fuel consumption is decreased and vehicle power is increased. Moreover, additional passive and active technology systems are incorporated in order to further reduce fuel consumption. As a result, considerable consumption and $CO_2$ emissions savings of fuel-efficient gasoline cars can be achieved relative to the current average consumption of the inefficient passenger cars fleet under GBA driving conditions.

Further advancement on powertrain efficiencies is the electrification of powertrains, combining a high efficiency electric motor to an internal combustion engine. In particular, hybrid electric vehicles (HEV) are characterized by their low consumption, with plug-in hybrid vehicles (PHEV) or range-extender electric vehicles (REEV) providing maximum fuel savings since extended battery capacities are capable of an additional 20 to 60 km of electric drive range. Once depleted, the batteries are restored to full charge by connecting a plug to an external electric power source. However, serious concerns need to be addressed like the infrastructure investment for charging stations.

Battery electric vehicles (BEV) could be an effective means for a long-term solution to today's environmental and noise pollution issues in the GBA. Technological innovations now make it possible to mass market an electric vehicle at reasonable cost if incentives are considered. In addition, changes in vehicle use make electric cars ideal for the majority of trips in the GBA, since 94% of the trips are lower than 20 km [25].

The energy efficiency of BEV is very high compared to their fossil fuel counterparts, which leads theoretically to zero GHG emissions. Nevertheless, the actual GHG emissions and total energy use associated with the use of BEVs depend largely on the way the required electricity has been produced. Therefore, the well-to-wheel (WTW) analysis must be considered in this assessment.

In terms of alternative fuels, bio- and synthetic fuels are being considered around the world, mainly blended with gasoline and diesel. The National Bioenergy Strategy, published in the *United Nations Development Programme – Country Efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon* (UNDP-CEDRO) project, indicated, under the more optimistic scenario, that 18% of the total fuel requirement for the Lebanese transport sector can be secured through sustainable bioenergy streams. However, attention as to the GHG reduction benefits require further research, as well as ensuring that they meet the sustainability criteria set.

Another alternative fuel under examination by the Ministry of Energy and Water (MOEW) for passenger cars is the natural gas (NG). NG is being used in some cities worldwide in the compressed gas form (CNG) for passenger cars, vans and buses, and liquefied form (LNG) for long range trucks. NG vehicles are well known for the air quality benefits rather than GHG and energy consumption reductions.

## IV. Mitigation Strategies: Controlling Emergent Behaviour and Promoting Sustainability

Based on the prevailing conditions in the Lebanese road transport sector, several factors need to be considered for mitigation from a sustainability perspective: (1) reduce the

number of passenger cars, (2) reduce the number and length of trips, (3) increase the vehicle occupancy rates, (4) increase mass transit means, (5) improve the vehicle efficiency, (6) increase the use of low carbon fuels, (7) increase urban average traffic speed.

Considering the suggested Avoid-shift-Improve approach to promoting sustainability and providing mitigation strategies, it is clear that no one measure will provide the solution, and action is needed simultaneously through a combination of different mitigation strategies, as summarized in Fig. 10.

Priority strategies identified for consideration in the GBA seek to:

- Promote/modernize the bus mass transit system, operable on dedicated lanes.
- Create a market for hybrid electric vehicles and promote fuel efficient gasoline-powered vehicles, in order to renew the existing car fleet through a scrappage program.

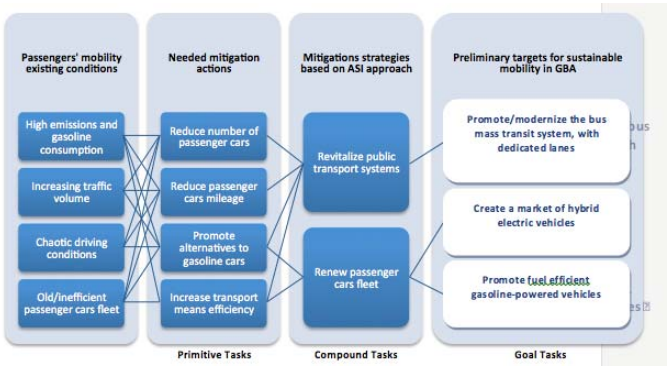


Fig. 10. Hierarchical process to setting up mitigation strategies for a sustainable mobility sector in GBA based on the ASI approach.

The two prioritized mitigation strategies are identified using a Mutli-Criteria Analysis decision-making exercise, where transport experts and stakeholders assessed the identified mitigation technologies based on their importance in meeting national mitigation goals in terms of minimizing the GHG and pollutant emissions for the transport sector and maximizing the environmental, social, and economic development benefits, on the short- and long-terms.

The selection process, selection criteria and prioritization results are fully detailed in the Technology Needs Assessment (TNA) report, prepared by the Ministry of environment and UNDP Lebanon [4].

## V. Conclusion

The long list of problems and the diverse set of challenges facing the land transportation sector in Lebanon, as discussed in this Exchange, are only the manifestations of one primary root cause: the lack of a national transportation strategy that can begin to organize the sector into a sustainable one. Such a strategy is long overdue given the current state of mobility in the country and the projected magnitude and speed of future growth in demand. The need for a comprehensive strategy is made even more pressing by the fact that the system has been left to emerge in an ad-hoc way with relatively minimal oversight for decades now, and what limited development has been done to-date has been exclusively focused on building more road capacity based on the wrong precept that capacity expansion is the solution for improving mobility. As a result, all indications are that further delay in enacting such a strategy will severely restrict future options for sustainability. Indeed, if we were to only consider the many years it takes to design and implement strategy at a national level, it would become clear how high and imminent the risk is of reaching a point of no return where we end up with a system that is continuously in "fire fighting" mode, struggling to stay functional rather than evolving to be sustainable.

The lessons learned from successful experiences in transportation planning around the world lead us to the conclusion that a national strategy for sustainable transportation in Lebanon should necessarily be based on the integration of a carefully designed portfolio of policies, mitigations, incentives and other instruments as those discussed under the avoid-shift-improve approach. It then follows that a comprehensive strategy for Lebanon should have for basic building blocks those major pillars encompassing the majority of instruments available and most critical in the Lebanese case, namely:

- Infrastructure development: the need for a modernized, inter-modal transportation system in Lebanon has been detailed in this Exchange. What remains to be emphasized is the urgent need for concurrent land-use planning in order to build the right infrastructure in the right place and to ultimately use it in a sustainable way. Attention should also be given to the speeding up of the execution of key projects since the development of the system has been exceptionally slow. For example, Public-Private Partnerships financing public works are now being explored in several cities worldwide based on the precept that transport projects bring large benefits to the economy and therefore present an incentive for industry to share in the financial responsibilities of building them quickly and efficiently.
- Systems management: the lack of regulation and planning in the transportation sector in Lebanon and the resulting chaotic state of mobility make the system an ideal candidate for "smart" management of both the technical and human parts of the system. This can be implemented with the host of options available under the "Avoid-Shift-Improve" strategies discussed previously. On the technical side, these options include the incorporation of new technologies at the vehicle level (powertrain, chassis, fuel) and the transport network level (transportation demand management, intelligent transportation systems, among others). On the user side, mechanisms for improving behaviour range from shifting demand towards more efficient modes or routes, to overcoming cultural barriers and changing driver habits.

- Administrative reform: there is no lack of government bureaucracy involved in the transportation sector in Lebanon; however, the many inefficiencies of this bureaucracy as already illustrated in this Exchange, raise a deep and immediate concern for administrative reform. Here all the typical mechanisms for transforming organizations and reducing waste in processes apply, with special emphasis on the need for inter-organizational coordination to address the deep fragmentation of responsibilities and authority between agencies, and the urgent need for a transparent process for citizen participation in transportation planning.

An illustration of the building blocks of a sustainable national strategy is shown in Fig. 11, with overlapping to indicate the needs for integration in order to accomplish a sustainable transportation system:

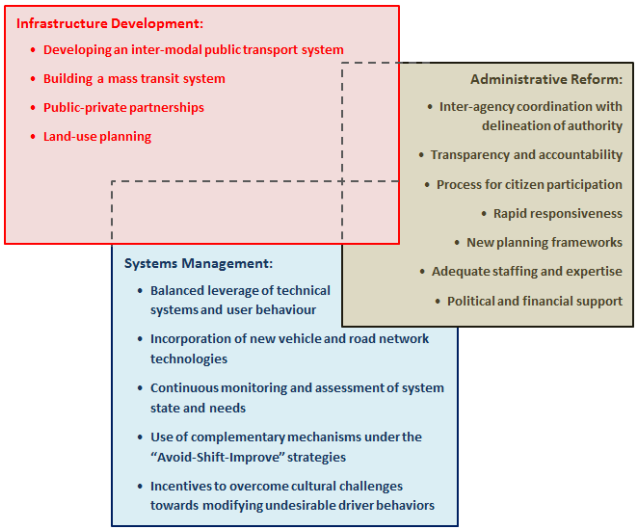


Fig. 11. Building blocks of a national strategy for sustainable transportation in Lebanon

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