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ASSESSING THE SUSTAINABILITY OF TRANSPORTATION AS CRITICAL INFRASTRUCTURE: A PREDICTION MODEL FOR ENVIRONMENTAL DIMENSIONS USING JORDAN AS A CASE STUDY

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ABSTRACT

Sustainable development, for various sectors, aims to achieve a balance between several objectives, maintaining the environmental, economic, and social dimensions to allow development to continue invariably over time. The planning processes for sustainability to improve civilization and urban development must include urban infrastructure and transportation since they are the major sectors that provide a continual flow of goods, materials, products, services, and information to improve living conditions and protect a country's defence, economic viability, prosperity, awareness, safety, and security. The right transportation mode will allow the provision of good levels of service, thus increasing the satisfaction of current and future potential users. The development of sustainable transportation infrastructure is key in modern societies. If the sustainable transportation system is well planned and managed in developing countries, it will improve and facilitate living conditions in a way that is compatible with the next generation's needs and will facilitate progress, prosperity, environmental, social, and economic welfare; if it is not well planned, it will hinder such progress. This article aims to assess sustainability dimensions for transportation as a critical infrastructure in terms of social, economic, environmental, technological, and energy aspects, with emphasis on environmental aspects. Measures of performance indicators for each dimensional goal are developed based on the data and statistical findings. The study uses models, an analytical descriptive style, and a methodology based on previous studies, as well as secondary data sources. Recommendations for enhancing transportation sustainability and potential reforms are proposed that can be applied to Jordan and generalized for other developing countries with similar circumstances.

KEY WORDS

critical infrastructure development, transportation sustainability, economic, energy, environment

CLASSIFICATION

JEL: R40, R42, R48

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INTRODUCTION

Sustainability implies the provision of more efficient services that maintain public health and welfare, are cost-effective, and reduce negative environmental impacts, both now and in the future. A definition of sustainable development provided by an ASCE/UNESCO working group on developing sustainability asserts that sustainable development is truly about achieving a balance between several objectives (environmental, economic, and social) over dynamic time and spatial horizons. Accordingly, research in the area of sustainable urban infrastructure reflects the need to design and manage engineering systems in light both of environmental and socioeconomic considerations. A principal challenge for the engineer is the development of practical tools for measuring and enhancing the sustainability of urban infrastructure over its life cycle [1, 2].In order to assess environmental sustainability performance, two major aspects (technology and energy) must be taken into consideration, in addition to the known three dimensions of transportation sustainability, since they affect the economy not only through operational processes but also through the manufacturing of vehicles and the construction of the infrastructure [3]. The development of environmentally sustainable transportation is vital since the modes of transportation that depend on fossil fuels are causing all kinds of pollution, emissions, waste, etc. Adopting the suitable planning and modelling strategies for the development of transportation system infrastructure is the main goal for any study, since this will improve the current and long-term situation. However, as the population has increased over time, cities have grown, and globalization and free trade have increased the regional and international movement of people and goods, leading to the dramatic expansion of our transportation infrastructure and systems. The cars, trucks, buses, subways, trains, airplanes, ships, and ferries that we use to move ourselves and our goods today have significant implications in terms of energy and material resource use, environmental pollution, noise, and land use at local, regional, and global levels. Transport is a vital sector for the Jordanian economy and an important component of the daily life of Jordanians. In the past decade, the country has heavily invested in expanding the road network, which constitutes the backbone of the national transport system, improving urban transport, and enhancing the logistics industry and international connections. In parallel, the transport sector has seen a gradual process of liberalisation, opening the market to private operators and private investors. To face these new tasks, the institutional set up has been, and is still being, gradually transformed [4]. Transport demand, both for passengers and freight, is growing rapidly, due to the growing population and the economic development within the country and in the region. This growth is concentrated on parts of the transport networks near the main urban areas and along the key corridors. As a consequence, parts of these networks are under pressure, and performance is below that required. This situation is predicted to worsen to the end of the next decade, with the system becoming unable to perform as needed to support the Jordanian economy and the daily life of citizens. Like any other developing country, the infrastructure and transportation sector in Jordan suffers from short-sighted planning and lacks a comprehensive and integrated vision, which has left Jordan with serious problems related to high levels of congestion, especially at rush hours, poor safety procedures, high incremental traffic accident figures, and low-quality requirements for transporting goods and passengers. The remainder of this article is structured as follows: the next section provides a literature review related to sustainability and transportation. The subsequent section provides an analysis of Jordan's infrastructure and transportation. This is followed by an explanation of the methodology adopted in this research. The subsequent section presents and analyses the results. Conclusions, including predictions and recommendations are provided in the final section.

LITERATURE REVIEW

Defining sustainability and the sustainable development of transport systems in the current research climate is not easy since it incorporates global aspects related to meeting present needs without reducing the ability of future generations to also meet their needs; for example, “There are no common opinions also about city public transport safety systems and controlling the public transport system in a whole, it is necessary to remember also about sociological factors. Europe needs professionals and also young professionals especially in the field of sustainability, sustainability in transport including energy efficiency, ecology and other aspects”. Achieving energy efficiency and reducing global pollution is possible if, and only if, sustainability is implemented in each field. A re-examination of the definition of sustainability will be key for new scientific ideas and ways of thinking about public transport systems and their sustainable development. Public transport systems can be sustainable based on the type of impact they have on the environment and society. They can also be a means of helping to achieve sustainability in other aspects of human life [5]. There is much discussion about sustainability and about transportation indicators. Jeon, Amekudzi and Guensler [6] developed 11 indicators to determine environmental, social, and economic impacts, as well as the sustainability performance of the transportation system for different scenarios in Metropolitan Atlanta. The 11 quantified indicators were aggregated into four dimensions of sustainability indices (environmental, social, and economic impacts, and transportation performance). Scenarios were evaluated based on a composite sustainability index encompassing the indices for the four sustainability categories. Maoh and Kanaroglou [7] developed a tool as an add-on module in an integrated transportation and land-use model for assessing urban sustainability. The indicators were based on large-scale simulation models such as SPARTACUS, PROPOLIS, and PROSPECTS to reflect aspects of the environment, society, and economy, grouped into three sustainability categories. The weights for the individual criteria were developed through a Delphi process using four experts in the field of transportation planning. The weights of the indicators were based on the relative costs to society for those indicators. The tool thus provides information on identifying appropriate performance measures for sustainable transportation (see Figure 1).

Sustainability dimension	Goals	performance measures
Social	Max Mobility	Travel Rate
	Max Safety	Accidents per VMT
Economic	Max Affordability	Point-to-Point Cost
Environmental	Min Air pollution	VOC, Car on CO and NO_x Emissions
	Min Energy Use	Fuel Consumption

Figure 1. Maoh and Kanaroglou’s sustainability categories for assessing urban sustainability [7].

According to Haghshenas and Vaziri [8], although there has been numerous studies about indicators and their application, few studies uses sustainability indicators to compare systems. Previous studies that have applied this concept include Jeon [9], Kennedy [10], Haghshenas and Vaziri [8], Miller [11], and Jeon, Amekudzi and Guensler [12], considered sustainability in terms of dimensions that can be quantified.

JORDAN’S INFRASTRUCTURE

Jordan is unlike other neighbouring Arab countries; it is a non-oil-producing country with limited natural resources and minerals. The country faces persistent unemployment, in addition to a growing budget deficit and inflation. Jordan is known as a politically stable country;

however, the area surrounding Jordan currently is not. Like many other developing countries, it has experienced rapid population growth. Furthermore, the nation is experiencing increased pressure on natural resources, widening income disparities, and growing poverty. Countrywide, access to fresh water represents the most pressing challenge, both in terms of quantity and quality [13]. Since Jordan enjoys conditions of security and political stability, Jordan has been subject to many waves of forced migration since 1948, which were mostly for political reasons due to wars and revolutions in several neighbouring countries. Jordan experienced four major immigration waves, which caused unexpected increases in the population; the population has increased 10 times in the last 65 years. [14]. Infrastructure has been affected by these unexpected increases in population, the major effects were on water, transportation, energy, education, and health. The civil war in Syria, which began in 2011, is still having serious impacts on the region, while the situation in Iraq, dating back to 1990, can still be valued as unstable [4].

ENERGY

Jordan imports 96 % of its energy from other countries, which constitutes a high percentage (8 %-20 %) of the country's GDP. This has led to scaling up the development of alternative energy sources and enhancing energy efficiency in buildings and industrial processes; this is critical since demand for energy is increasing year on year (driven largely by the population increase discussed above) (see Figure 2).

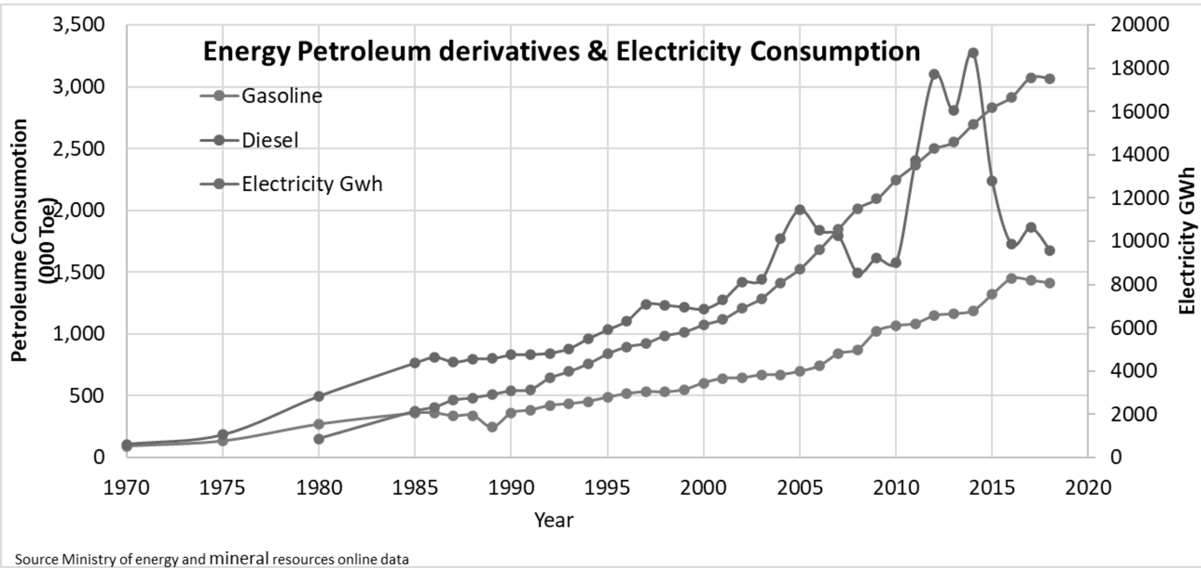

Figure 2. Jordan's energy consumption, petroleum derivatives and electricity consumption [16].

Jordan enjoys an atmosphere that meets many of the criteria for successful renewable energy investment. One of the most crucial perquisites for renewable energy success in Jordan is that it enjoys 300-320 days of full sunshine a year. It also has an above-world-average wind speed of 7 meters per second (as high as 7,5 meters to 11,5 meters per second in hilly areas) and has among the highest per capita ratios of engineers in the world.

TRAFFIC, MOBILITY, AND SAFETY

Jordan has one of the highest per capita and per vehicle ratios for traffic accidents involving fatalities in the world coinciding with low pedestrian safety procedures. Based on Jordan's Long Term National Transport Strategy, transport safety is a critical issue in Jordan. Although the Jordan National Transport Strategy encompasses all transport modes, the most significant improvements in Jordan's transport-related safety challenges need to be achieved mainly in the road sector. The proposed relevant measures cover three fields of action: road users' behaviour;

vehicles characteristics; and infrastructure characteristics. Although a national strategy for transport safety is still missing, there is a separate National Transport Safety Programme, which complements the strategy document and aims to fill this gap, suggesting several integrated measures to mitigate the major risk factors affecting road safety [4].

ENVIRONMENT

Car ownership rates have increased in Jordan, leading to more passenger trips by motorized vehicles and thus more pollutants and greenhouse gases are emitted and more noise is generated. Similarly, in freight transport, alternatives to transporting goods by road vehicles (heavy or light duty vehicle [HGV/LGV]) barely exist. Therefore, the Jordan freight industry depends heavily on road transport (trucks). Both passenger transport by car and freight transport by truck have serious environmental impacts, including the emission of pollutants and greenhouse gases and increased noise levels. Air quality is already deteriorating in Jordan, particularly in urban areas, and is predicted to continue to do so. Other environmental impacts of cars and trucks in Jordan have costs for other users, economic processes, natural and man-made, or social environments. The costs resulting from these impacts on other individuals or other processes are usually called externalities or external costs [15]. As well as aiming to improve the competitiveness of alternative private road transport, both for passengers and freight, Jordan's Long Term National Transport Strategy and Action Plan [4] is also aiming to reduce the impact of the transport sector in relation to the environment (pollutant emissions, greenhouse gasses, and fuel consumption). Transport model simulations show that the vehicle kilometres in private transport are predicted to increase by 56 % (road freight transport by 44 %) in the long term (by 2030), fuel consumption is predicted to grow by approximately 30 %, CO_2 emissions will increase by 26 %, and NO_x emissions are predicted to decrease by 14 %. Figure 3 shows the growth rate for several years [4].

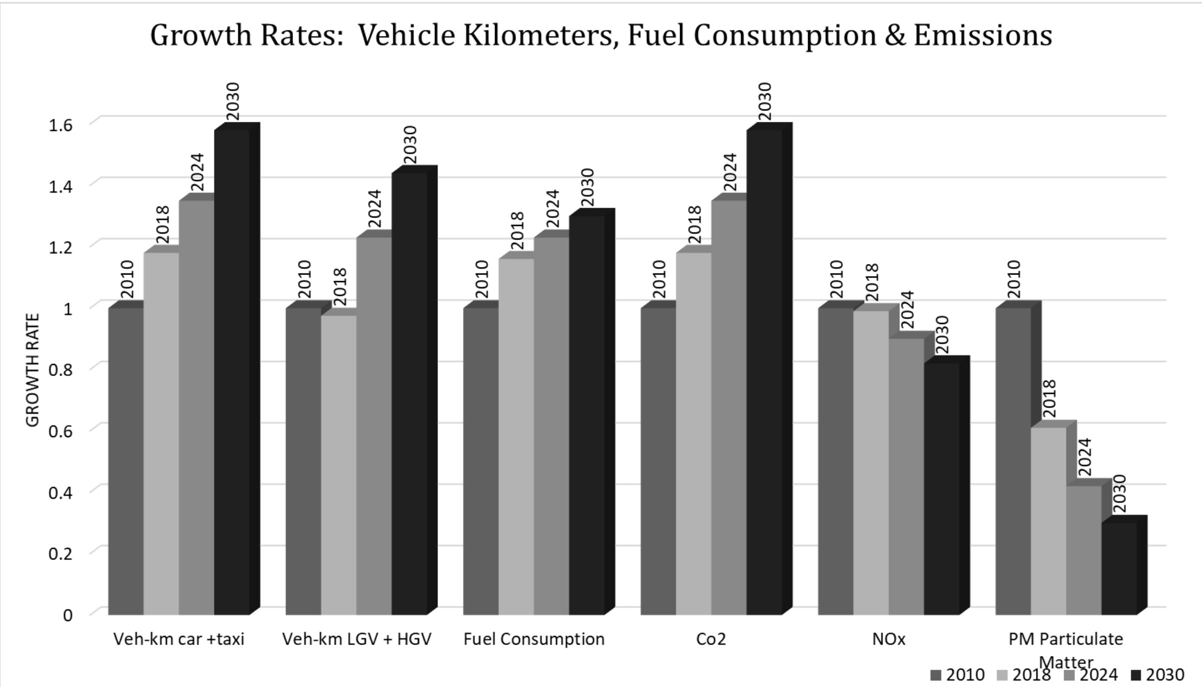

Figure 3. Growth rates in Jordan vehicle kilometres, fuel consumption and emissions [4].

Transportation is one of the major contributors to climate change, which is caused by the so-called greenhouse gases (GHGs) that trap heat reflected from the surface of the planet in the lower atmosphere causing the greenhouse effect. The primary GHG is carbon dioxide, which is responsible for about two-thirds of human-induced climate change.

METHODOLOGY

The quantitative methodology adopted in this article uses data retrieved from various prior studies (individual authors, institutions, organizations, and companies, both public and private) as well as from secondary sources, such as periodicals, brochures, articles, and relevant regional, local, and international studies. Regression analysis is used as a form of predictive modelling to forecast the future demands related to transport. As is well known in the field of transportation, data analysis is probably the most important and widely used research tool available for demand analysis.

ANALYSIS

Jordan imports almost 96 % of its primary energy and this equals to 7-10 % of the country's GDP. The primary energy consumption for the transportation sector was 50 % of the total throughout the years 2013 to 2018, so it is vital to carefully analyse this sector. Jordan's transport system is primarily based on individual transport, with almost no public transport system, and the high growth rate in the number of vehicles, combined with the high growth rate of the population is creating pressure on the country's infrastructure and seriously affecting the country's economy. In this analysis, the transportation system will be evaluated with respect to sustainability, based primarily on the number of registered vehicles, energy consumption and its effect on the environment. Statistics shows that the consumption of primary energy has followed the same trend over the last 27 years, with energy consumption growing from 3 million equivalent tons to 10 million equivalent tons over this period. The country's population followed a similar upward trend, as has the number of registered vehicles, the vast majority of which are privately registered. It is difficult to predict the future growth in the number of vehicles since it is linked to the growth in population, which is governed by geopolitical issues in the region, even though in making future predictions the curve behaves perfectly, with the straight-line regression with a high R^2 value of 99,85 % (see Figure 4).

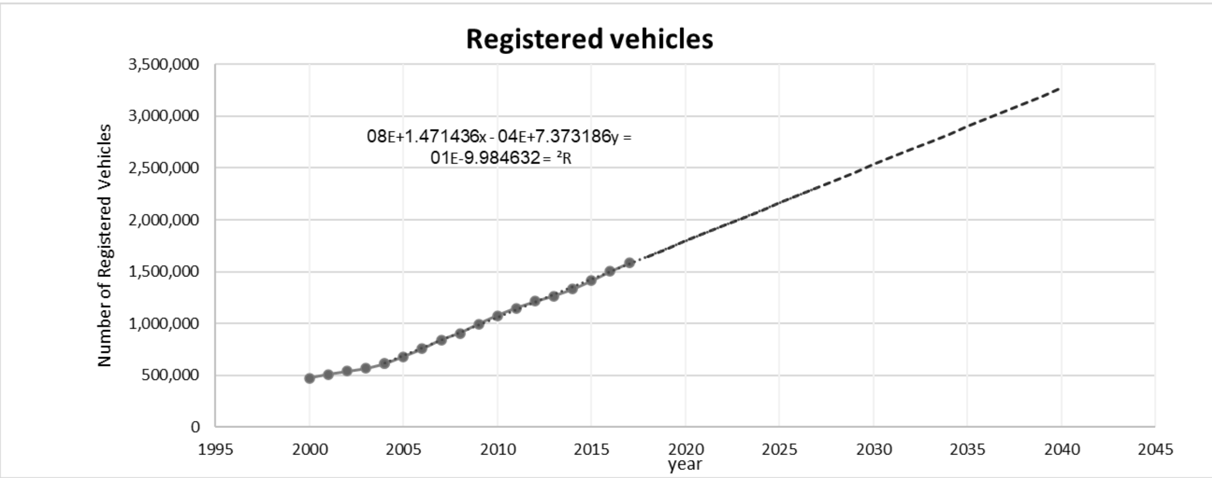

Figure 4. Vehicles registered in Jordan, current trends, and predictions [4].

The trend for buying hybrid and electric cars in Jordan is not high enough; although, unfortunately, there is no adequate information available on the number of vehicles based on fuel type. Yet, it is common to see hybrid and electrical cars on the streets because of the continuous rising in fuel prices has encouraged people to buy hybrid cars, also supported by adequate maintenance and spare parts availability. The future is possibly more encouraging for electric vehicles than for hybrid vehicles, as shown by recent trends. Figure 5 shows recent trends for vehicles (and their types) imported into Jordan.

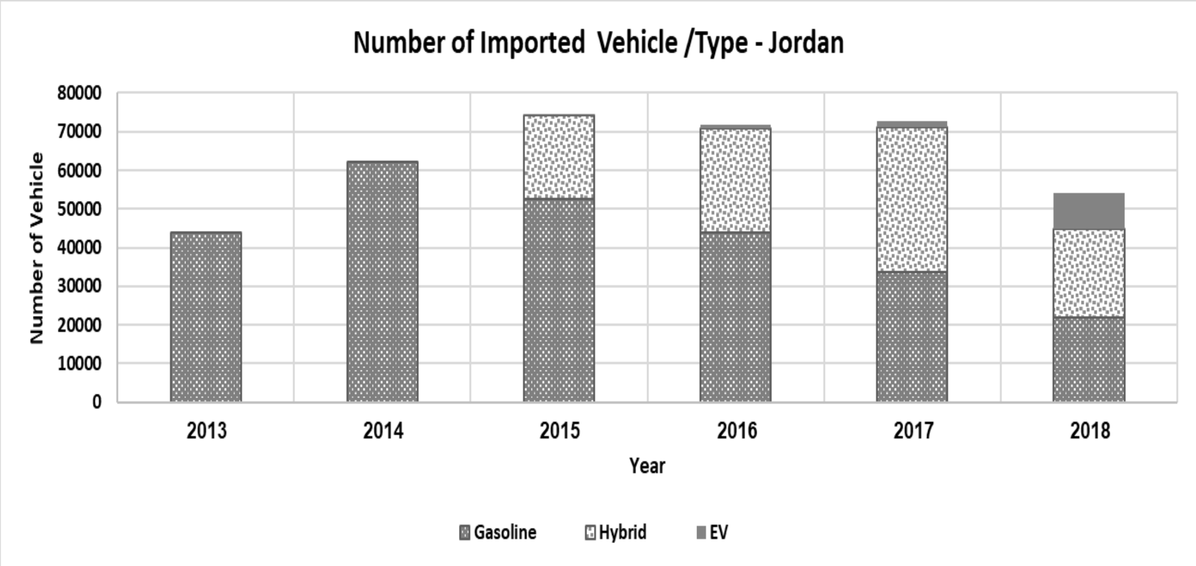

Figure 5. Number of imported vehicles by type in Jordan [4].

FUTURE PREDICTIONS

To predict the future growth of the transportation sector, this article has used the available historical data that has an influence in this sector, starting with historical population growth, which is hard to predict, as it is controlled by external issues. The population has increased by 50 % in the last seven years. Prediction is to focus on electricity and gasoline consumption since almost all of the vehicles in Jordan run by gasoline, unlike diesel, which is used by other sectors such as heating, pumping, and electricity generation in areas with no natural gas supply. Gasoline consumption demonstrates the best fit, historically and for future predictions, showing a linear regression relationship with an R^2 value of 98,9 %. Assuming that the use of the internal combustion engine in vehicles is to be replaced by hybrid and electric vehicles, we should take into consideration the electricity consumption (see Figure 6) and make predictions for the future demands with and without electric cars to see if extra generation capacity is required.

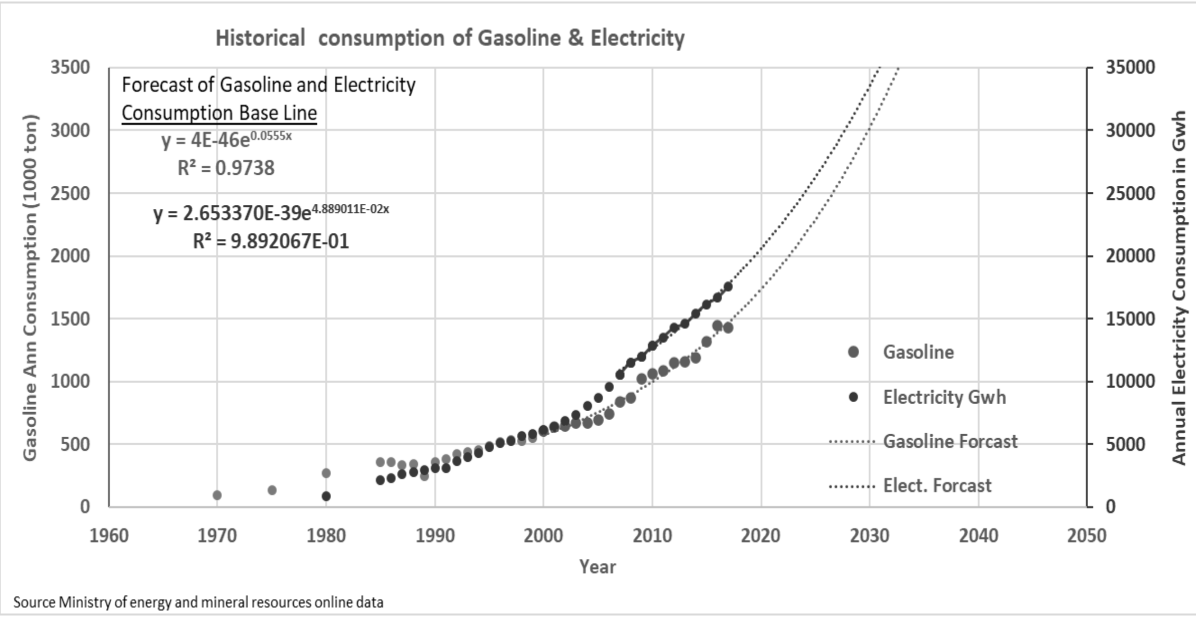

Figure 6. Historical consumption of gasoline and electricity [4].

To predict the number of electrical vehicles and the rate of replacement, this article assumes three different scenarios, compared to what happens if we do nothing:

- **scenario (1) best case:** 90 % of vehicles will be electric in 2040.
- **scenario (2) most likely case:** 65 % of vehicles will be electric in 2040.
- **scenario (3) worst case:** 40 % of vehicles will be electric in 2040.

To predict the number of vehicles and engine types, a forecast model (Figure 7) was made at the above three different scenarios for the replacement rate of internal combustion engines by electric engines by 2040 with a constant rate of growth linked to the forecasted number of vehicles.

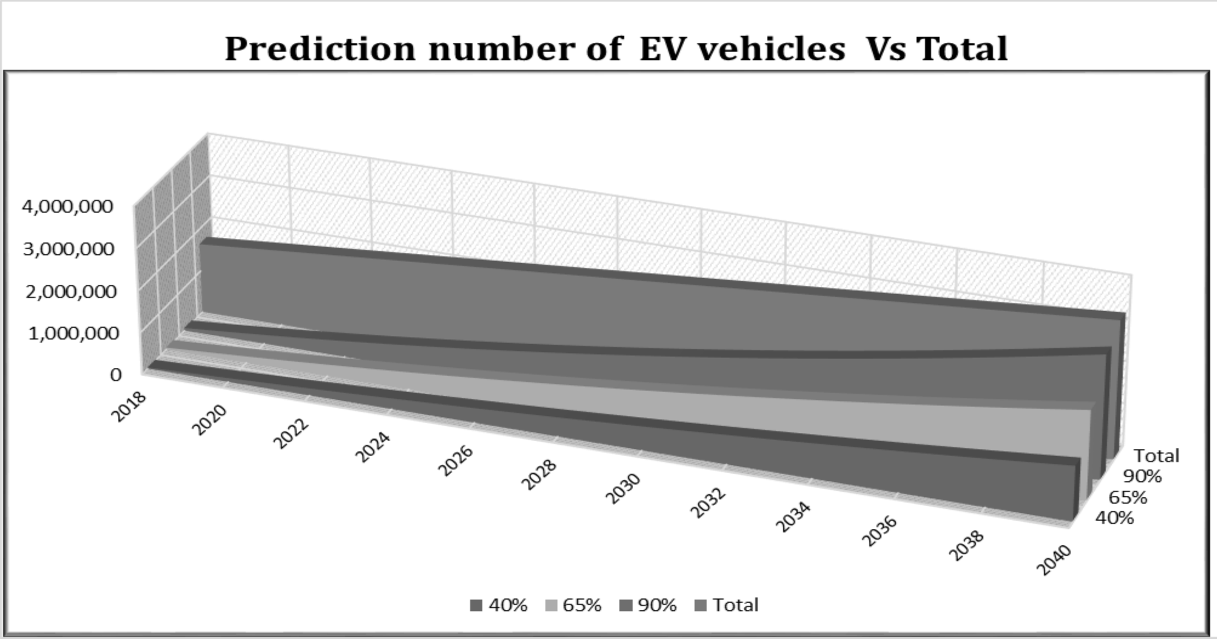

Figure 7. Predicted number of electric vehicles VS total.

Based on the number of vehicles, the modelling was performed for gasoline consumption as internal combustion engines are being replaced, and the quantity of gasoline was estimated for each scenario (Figure 7).

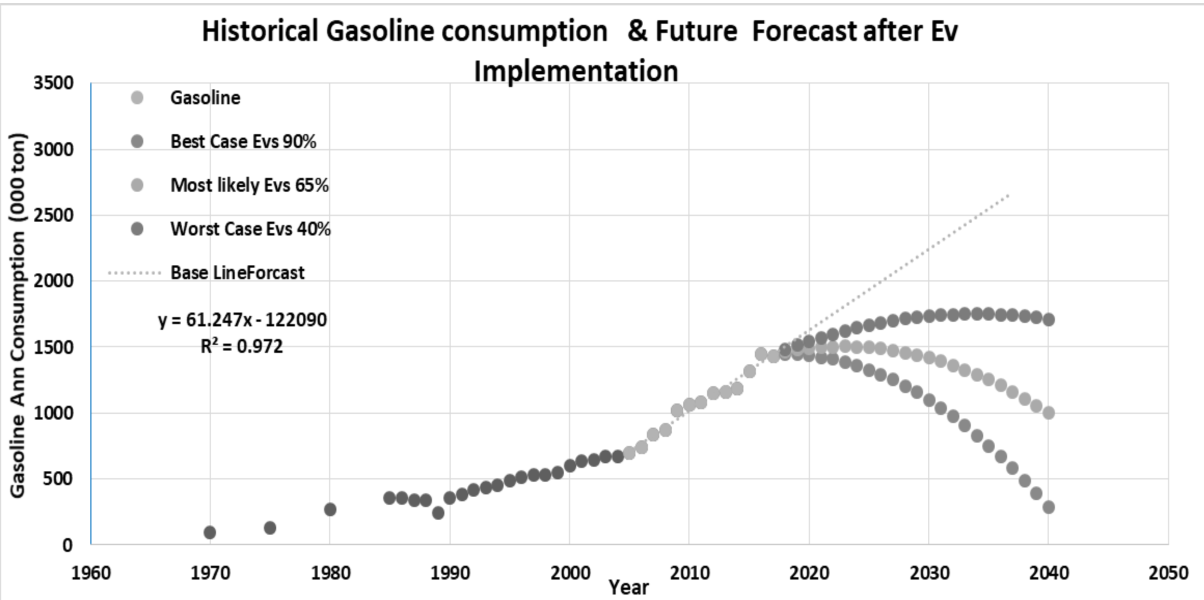

Figure 8. Gasoline consumption, historical and predicted after EV implementation.

Similarly, based on the number of electric vehicles compared to the total number of vehicles as for the electricity capacity, the future electricity demand was estimated from the base line, and the power requirements were estimated for each scenario based on the assumptions of average annual distance of each electric vehicle of 15 000 km, and an average electricity consumption per vehicle of 0,2 kWh/km. As shown in Figure 9, the effect of the extra load consumed by electric cars in the three scenarios is negligible.

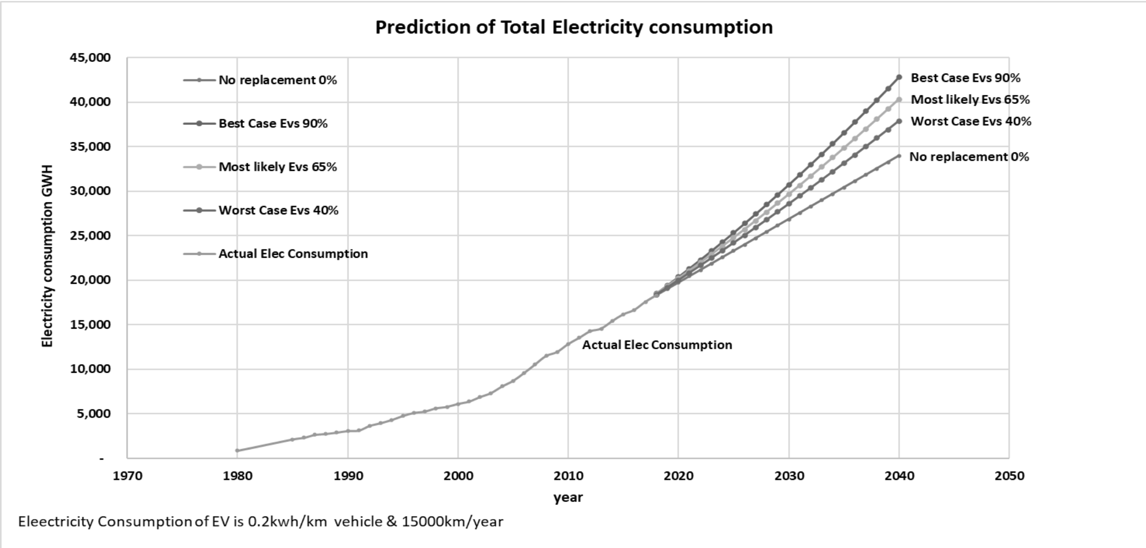

Figure 9. Electricity consumption (historical and predicted).

All the results of the scenarios are presented in Table 2, it shows a significant Annual savings in gasoline consumption compared to the base line

			Year 2040			
	Unit	Base Line Year 2017	No replacement	Best Case 90%	Most likely 65%	Worst Case 40%
Population	Millon	10.05	15 - 20			
# of Gasoline Vehicles	Millon	1.58	3.27	0.33	1.14	1.96
# of Vehicles EV	Millon	-	-	2.942	2.13	1.31
Gasoline *	000 teo	1,431	2,854	285	999	1,712
Gasoline Saving	000 teo		-	2,569	1,855	1,142
Electricity **	Gwh	17,574	33,963	42,790	40,338	37,886
Electricity Increase	Gwh		-	8,827	6,375	3,923

*Gasoline consumption in 2040 is predicted to be 2,854 thousand Teo if no replacement is assumed
** Ev electricity consumption assumed as 0.2kwh/km vehicle & 15000km/year

Figure 10. Electricity consumption (historical and predicted).

CONCLUSION AND RECOMMENDATION

Based on the results of prediction models, huge savings can be seen in terms of gasoline consumption. In year 2040 the savings in gasoline in best case scenario will be 2 569 000 teo, whereas the savings in worst case scenario will be 1142 000 teo. The transition to electric vehicles will cause an increase in electricity consumption of 8 827, 6 375 and 3 923 GWh in the assumed three scenarios respectively. The increase in electricity consumption and the decrease in gasoline consumption will encourage the use of renewable energy and reduce the import of fossil fuels. This will also have a significant impact on the environment due to reduced emissions. To encourage the shift to electric vehicles, it is recommended that the government adopt new policies and measures by accelerating the replacement and imposing taxes on cars with internal combustion engines. Moreover, the infrastructure for electric vehicles should be improved accordingly, which would have a significant impact both on the economy and on the environment.

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