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Energy saving and CO_2 mitigation through restructuring Jordan's transportation sector: The diesel passenger cars scenario

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Abstract

The transportation sector is responsible for 37% of the total final energy consumption in Jordan, with passenger cars taking a share of 57% in this sector. Improvement of the energy efficiency of the transportation sector can help in alleviating socio-economic pressures resulting from the inflating fuel bill and in lowering the relatively high CO_2 emission intensity. Current legislations mandate that all passenger cars operating in Jordan are to be powered with spark ignition engines using gasoline fuel. This paper examines potential benefits that can be achieved through the introduction of diesel cars to the passenger cars market in Jordan. Three scenarios are suggested for implementation and investigated with a forecasting model on the basis of local and global trends over the period 2007–2027. It is demonstrated that introducing diesel passenger cars can slow down the growth of energy consumption in the transportation sector resulting in significant savings in the national fuel bill. It is also shown that this is an effective and feasible option for cutting down CO_2 emissions.

Keywords: Energy; Transportation; Jordan

1. Introduction

From a global perspective, transportation is the single most important sector for oil demand. At 34.5 million barrels of oil equivalent per day (mboe/d), the transport sector accounted for 47% of the world oil demand in 2001 (Shihab-Eldin et al., 2004). In the countries of the Organisation for Economic Co-operation and Development (OECD), the transport sector accounts for 54% of primary oil demand while it drops to around 33% in the developing world. This difference is primarily due to the relatively larger share of the industrial sector in developing countries and the reliance on oil in electricity generation. Within the transportation sector, road transportation is the most important source of demand, accounting for over 80% of the global transportation oil demand (IEA, 2002).

In the next two decades, transport is expected to grow faster than any other sector and the growth of energy demand in non-OECD countries is expected to be three times higher than in OECD. The International Energy Agency's (IEA) World Energy Outlook base case projection, which assumes stable fuel prices and no new policy action, foresees total transport energy demand growing 40% in the OECD and nearly 140% in non-OECD countries from 1997 to 2020 (IEA, 2000). Accordingly, the transport sector's share of oil demand will grow to 62% in OECD countries and 42% of non-OECD countries by 2020.

Growth of energy demand is mainly due to increasing vehicle ownership levels combined with growth in transport activity, which in turn is tightly linked to income growth. Trends in transport activity are rising steadily and show few signs of saturation that might moderate growth in the future. World vehicle ownership has been growing steadily, reaching 800 million vehicles in 2000. Over the past three decades, the developing countries witnessed the highest rates of growth in vehicle ownership. This trend is expected

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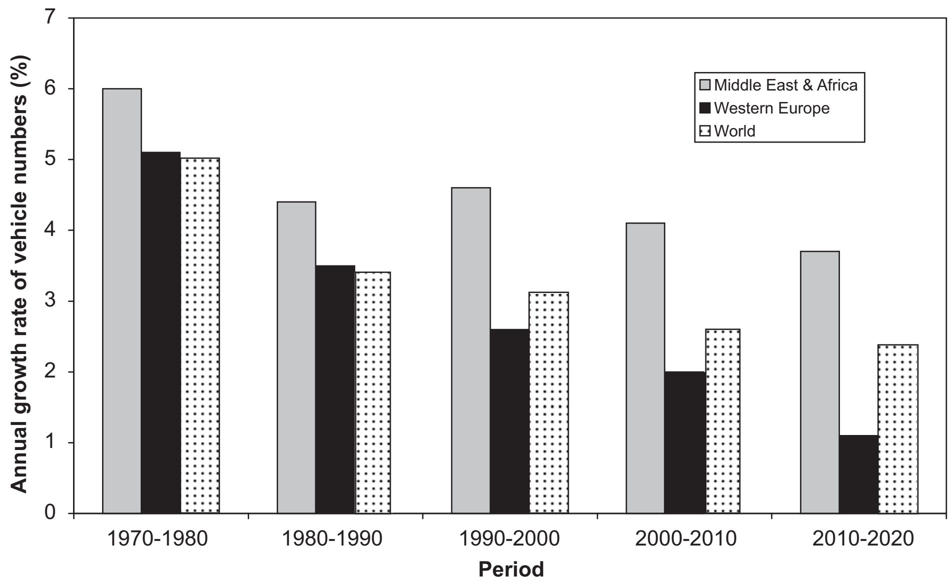

Fig. 1. Documented and projected annual growth rates for vehicle ownership for 'Western Europe' and 'the Middle East and Africa' regions against world rates.

to continue in the future due to the current low levels of vehicle ownership in developing countries which provide obvious scope for increases. Fig. 1 shows the documented and projected annual growth rates for vehicle ownership for Western Europe and the Middle East and Africa regions against world rates (Shihab-Eldin et al., 2004). It is beneficial here to note the stark difference in vehicle ownership levels between OECD and developing countries. For example, in year 2000 vehicle ownership in Western Europe was around 0.444 vehicle/person compared to only 0.033 vehicle/person in the Middle East and Africa region.

Although CO_2 emissions were not initially included in most emission legislations, this has started to change over the past few years. Currently, CO_2 is regulated in many parts of the world either directly as in the case of Japan, or indirectly as in the case of the European Union (EU) countries. This is mainly due to the belief that CO_2 is responsible for around 80% of the anthropogenic climate change and global warming effects (Ritter, 1998). Since the 1960s tropospheric CO_2 concentration has been increasing at an annual rate of 0.45% (Lenz and Cozzarini, 1999). Road transportation has been playing an important role in this steady increase. In the EU countries, it is responsible for around 21% of the total anthropogenic CO_2 emissions (Ritter, 1998). These concerns have been addressed in Rio and Kyoto summits leading to the adoption of the "Kyoto Protocol" which demanded a worldwide reduction of CO_2 emissions by at least 5% compared to the 1990 level by year 2010 (UNFCCC, 1997). The effective Kyoto Protocol does not have binding commitments for developing countries to reduce their greenhouse gas emissions. However, there is increasing pressure for developing countries to adopt some kind of target. As most developing countries are not currently in the position to make absolute emission reductions, the most immediate and realistic challenge is lowering the CO_2 intensity (How many tons of CO_2 emissions are emitted per US dollar of the Gross Domestic Product (CO_2/GDP)?) (Kuntsi-Reunanen, 2007).

2. National energy and emissions status

Jordan is a lower-middle income Middle Eastern country, of about 5.8 million inhabitants, that suffers from a chronic lack of adequate supplies of natural resources including water and oil. Jordan depends heavily on imports of oil from neighbouring countries as the main source of energy. Its current imports of around 100,000 barrels of crude oil per day are placing the country under extreme economic pressures. The annual fuel bill has been rapidly increasing over the past few years due to population and economic growth combined with the consecutive increases in oil prices.

In 2005, Jordan's consumption of primary energy[1] amounted to 7.028 million Ton Oil Equivalent (TOE). Nearly 95% of this consumption came in the form of imports of crude oil, natural gas and petroleum products. The remaining 5% came in the form of renewable energy and imported electricity. The final energy[2] consumption for the same year amounted to 4.802 million TOE, an increase of 6% on the 2003 consumption (Ministry of Energy and Mineral Resources (MEMR), 2005). Fig. 2 illustrates the growth in total primary and final energy consumption over the period 1995–2005, while Fig. 3 shows the cost of consumed energy and its proportion to the national GDP (MEMR, 2005). The relatively high growth rates of energy consumption, cost and proportion to the GDP are evident,

[1]Primary energy refers here to the energy products provided by nature in their direct form, such as petroleum, natural gas, coal, etc.

[2]Final energy designates the energy as received by the users in different sectors, such as gasoline, diesel, kerosene, etc.

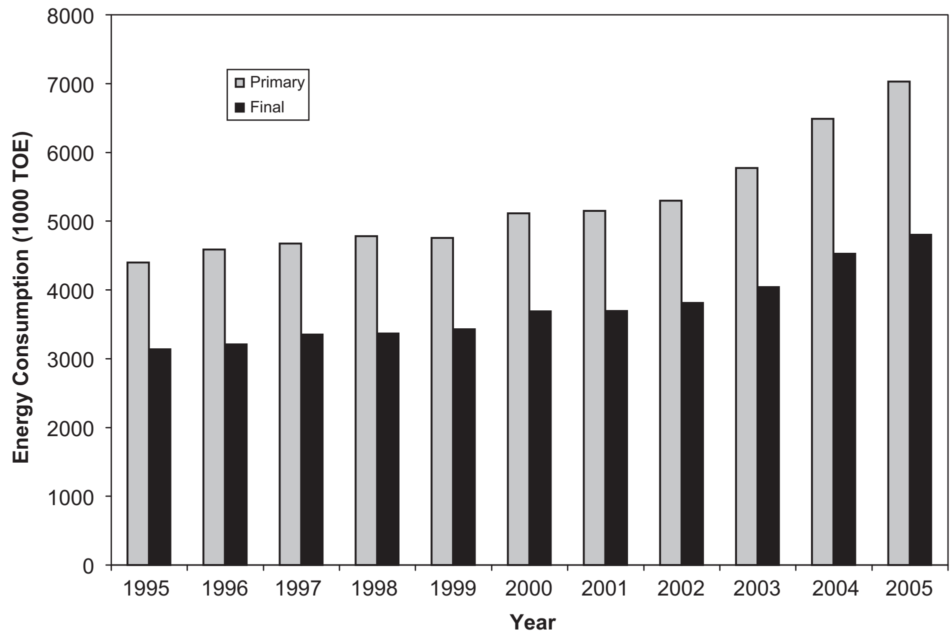

Fig. 2. Primary and final energy consumption in Jordan over the period 1995–2005.

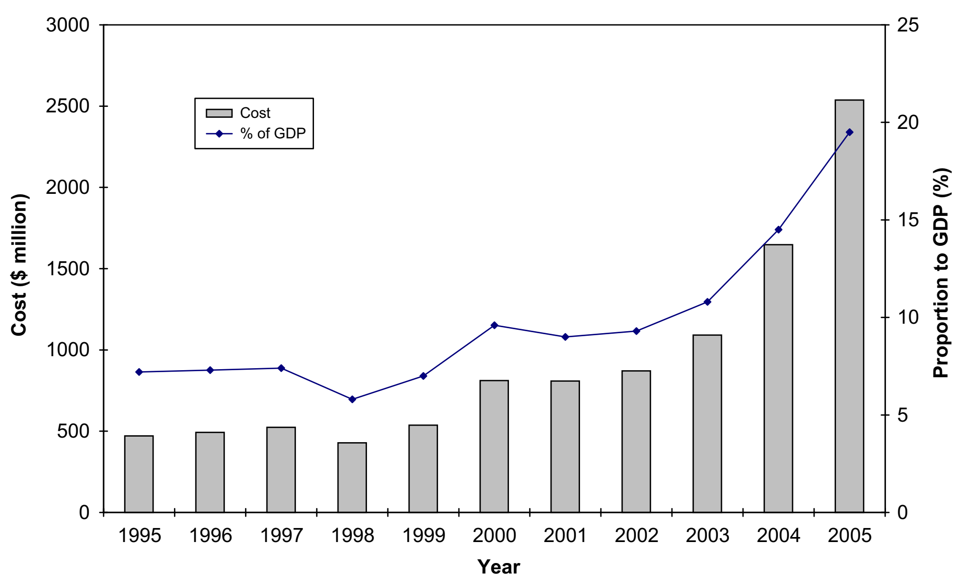

Fig. 3. Cost of consumed energy in Jordan and its proportion of the GDP over the period 1995–2005.

especially over the past few years. These rates are due to a mixture of factors including strong economic growth, increasing population demand and inflating energy prices.

Examination of how final energy consumption was distributed in Jordan in 2005 reveals that the transportation sector had by far the highest share at 37%, followed by the industrial sector at 24% and the residential sector at 22% (MEMR, 2005). The share of the remaining sectors (commercial, agricultural, street lighting, etc.) was limited to 17%. Although the share of the transportation sector in Jordan is slightly higher than the average share of other developing countries (33%), it is still much lower than the world average share (47%). Implementing the IEA base case projection, it is expected that this share will rise to around 45% in 2020.

Jordan's annual CO_2 emissions were estimated in 2004 to be 16.70×10^6 tonnes (IEA, 2006). Although this constitutes less than 0.1% of the world's annual CO_2 emissions, the CO_2 intensity is considerably high, not only compared to OECD countries but also in comparison with other Middle Eastern countries, as indicated in Fig. 4. This implies that there is much room for energy efficiency and emissions reduction improvements in all sectors in order to lower the emission intensity. Jordan's CO_2 emissions are mainly attributed to three sectors: energy production, industry, and transportation where they are responsible for 39%,

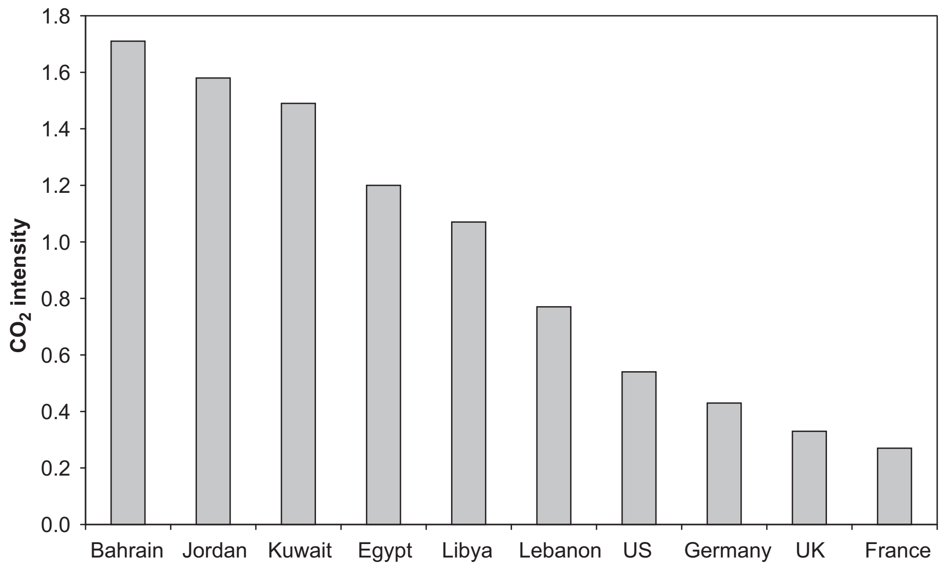

Fig. 4. CO_2 emissions intensity in selected Middle Eastern and OECD countries.

25%, and 21% of the national CO_2 emissions, respectively (Ministry of Environment, 1997). The share of the transportation sector is equivalent to 3.51×10^6 tonnes/year.

3. Jordan's transportation sector

Jordan's transportation sector is dominated by road transportation since there are no rail networks and marine transportation is negligible due to the geographical location of the country. The national network of roads covers nearly 8.6×10^3 km. Of which over 3.1×10^3 km are main roads, while the remaining are either side or rural roads (Ministry of Public Works and Housing, 2005). In 2000, the number of registered vehicles was around 4.73×10^5, with passenger cars taking a share of around 56% of this number. In 2005, the number of registered vehicles increased to over 6.80×10^5 vehicles with the share of passenger cars slightly rising to around 57% (Department of Drivers and Vehicles Licensing, 2005). This translates to a vehicle ownership ratio of 0.117 vehicle/person. Although this ratio is much higher than the average ratio for the Middle East and Africa region, it still gives much room for potential increase.

All of passenger cars operating in Jordan are powered with spark ignition (S.I.) engines using gasoline fuel. This is mandated by legislation that does not permit the registration of passenger cars powered by compression ignition (C.I.) engines using diesel or any other fuel. This legislation dates back to the late seventies when diesel engines were associated with very high levels of noise and polluting emissions, especially particulate matter emissions.

4. Advantage of diesel engines

From a thermodynamic point of view, the diesel engine is a very efficient reciprocating prime mover due to the relatively high compression ratios that can be achieved with it. Under typical conditions, the compression ratio in diesel engines is about double that of gasoline engines (Ferguson and Kirkpatrick, 2001). The superior efficiency of the diesel engine becomes even more evident at part load, which is most common during urban driving conditions. While lower output in gasoline engines is obtained by throttling the intake mixture, power is modulated in diesel engines by simply injecting less fuel into the cylinder, resulting in very lean air/fuel mixtures without affecting the volumetric or the overall efficiency of the engine (Haddad and Watson, 1984). The high thermal efficiency of diesel engines is manifested by its well-known superiority in fuel economy in comparison with gasoline engines.

In order to quantify the fuel economy advantage of diesel engines, a comparative survey was carried out between diesel and gasoline powered passenger cars covering seven different 2006 models with engine displacements ranging from 1.3 to 2.0 l. This survey was based on published manufacturer's data of fuel consumption under urban and extra-urban driving conditions. The results of this survey are summarised in Table 1. Although results vary according to variations in model and size, they all illustrate that the fuel consumption, on the basis of litres/100 km, for diesel cars is 20–30% less than comparable gasoline cars. Similar results have also been reported by other studies and surveys (Grant, 1992; Waters, 1992; Schindler, 1997). The significant fuel consumption advantage of diesel cars becomes more evident under urban driving conditions. This superiority was recently recognised by the 2006 fuel economy guide, which was prepared jointly by the U.S. Department of Energy and Environmental Protection Agency to identify most efficient vehicles available in the American market. All diesel cars included in the guide came either first in their category or second only to hybrid cars (EPA and DOE, 2006).

Table 1
Specifications and fuel consumption data for selected commercially available passenger cars

Model	Engine	Ignition	Capacity (cm^3)	Power (kW)	Fuel consumption (l/100 km)		
					Urban	Extra urban	Combined
Ford Focus	1.6 Duratec	Spark	1596	74	8.9	5.7	6.9
Ford Focus	2.0 Duratec	Spark	1988	107	10	5.6	7.3
Ford Focus	1.6 Duratec TDCI	Compression	1560	66	6	4.1	4.8
Ford Focus	2.0 Duratec TDCI	Compression	1997	100	7.6	4.8	5.8
Peugeot 206	1.4 16v	Spark	1360	65	8.2	4.9	6.1
Peugeot 206	1.6 16v	Spark	1587	80	8.7	5.5	6.7
Peugeot 206	1.4 HDi	Compression	1398	50	5.7	3.7	4.4
Peugeot 206	1.6 HDi	Compression	1560	80	6	4.1	4.8
Peugeot 407	2.0 16v	Spark	1997	103	11	6.4	8.1
Peugeot 407	2.0 HDi	Compression	1997	100	7.7	4.9	5.9
Volkswagen Polo	S 1.4	Spark	1400	56	8.7	5.3	6.5
Volkswagen Polo	S 1.4 TDI	Compression	1400	60	5.7	4.1	4.6
Volkswagen Golf	GT FSI 2	Spark	1984	112	10.8	6.1	7.8
Volkswagen Golf	GT TDI	Compression	2000	105	7.4	4.8	5.7

As a direct result of high efficiencies and low fuel consumption, diesel engines produce much less CO_2 emissions compared to gasoline engines. Two correlations relating the average CO_2 emissions with the vehicle weight for diesel and gasoline vehicles were presented in a recent study (Zervas, 2006). These correlations indicate that for a given vehicle weight, CO_2 emissions from diesel vehicles are 20–25% less than that of gasoline vehicles.

Over the past two decades, major developments in diesel engine technologies have resulted in impressive reductions in diesel emissions. Table 2 summarises the Euro IV and Euro V emission standards for diesel and gasoline passenger cars. Euro IV came into effect in 2005, while Euro V is proposed for implementation in 2009. It is clear that although the allowable particulate and NO_x emission levels from diesel cars are still generally higher than those from gasoline cars, CO and HC emission levels are slightly lower. The introduction of new after-treatment technologies such as diesel particulate filters, lean NO_x catalysts, and selective catalytic reduction has been effective in closing the emission gap between gasoline and diesel cars.

The Association of European Automobile Manufacturers (ACEA, 2005) has proposed a voluntary reduction of their vehicle fleet average CO_2 emissions from the current level of 175 to 140 g/km in 2008. Although there has been some scepticism about the usefulness of increasing the share of diesel engines in the passenger car market in reducing CO_2 emissions (Rijkeboer et al., 1998; Candace and Mark, 2000), it is still the most effective and practical solution in sight. This is encouraging car manufacturers to increase the share of diesel cars in their production lines. As a result of this and due to the clear fuel economy advantage, diesel passenger cars are enjoying a growing popularity in European markets. In fact, the share of the diesel passenger cars in the European new passenger car market has been growing at a steady rate over the past decade. Fig. 5 shows the development of the share of diesel passenger cars of new passenger car registrations in EU (ACEA, 1995). It can be seen that the share of diesel has grown from only 22% in 1995 to nearly 50% in 2005. This share is the average for the original 15 member states of EU and differences exist from one country to another due to differences in taxation policies and diesel fuel prices (Walsh, 1999). For example, while the share of diesel was just under 10% in Sweden in 2005, it exceeded 70% in both Belgium and Luxemburg.

Table 2
Summary of the current and proposed European emission standards for diesel and gasoline passenger cars

Emission (g/km)	Euro IV (2005)		Euro V (2009)	
	Diesel	Gasoline	Diesel	Gasoline
CO	0.5	1.0	0.5	1.0
HC	–	0.1	–	0.1
$HC+NO_x$	0.3	–	0.23	–
NO_x	0.25	0.08	0.18	0.06
Particulate matter	0.025	–	0.005	0.005

5. Analysis model

The clear fuel economy and emission advantage that diesel passenger cars have over their gasoline counterparts can be one of the answers offered to alleviate the worsening energy crisis in Jordan on one hand and to improve the CO_2 emission intensity. In order to quantitatively examine potential benefits from introducing diesel passenger cars into the Jordanian passenger car market, five different scenarios are suggested:

- *Scenario A*: The policy of banning diesel passenger cars will continue.
- *Scenario B*: Diesel passenger cars will take a constant share of 30% of the new passenger car sales from 2007 until 2027.

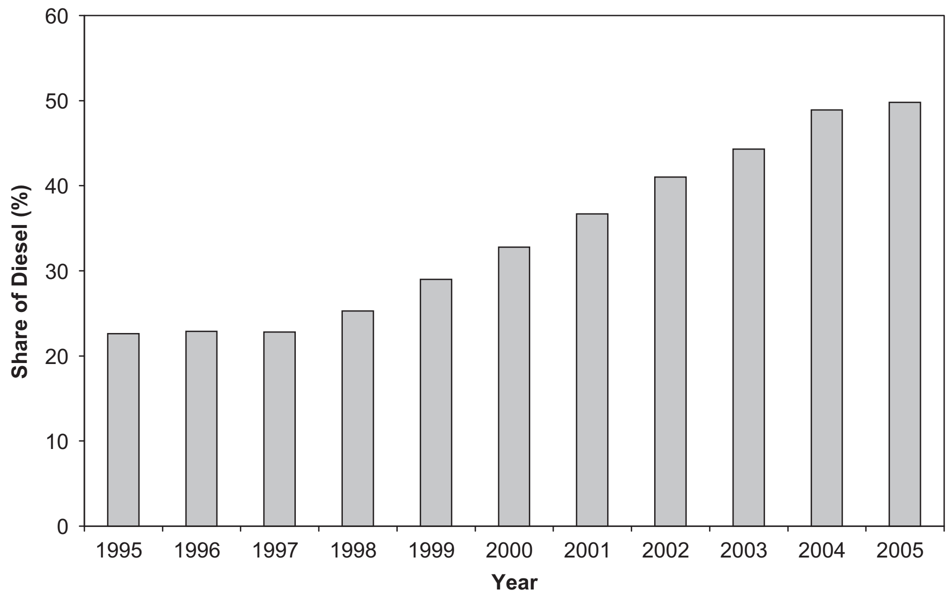

Fig. 5. Share of diesel in new passenger car registration in the European Union over the period 1995–2005.

- *Scenario C*: Diesel passenger cars will take a constant share of 50% of the new passenger car sales from 2007 until 2027.
- *Scenario D*: The share of diesel passenger cars will linearly increase to 30% of the new passenger car sales from 2007 until 2012 and then remains constant at 30% afterwards.
- *Scenario E*: The share of diesel passenger cars will linearly increase to 50% of the new passenger car sales from 2007 until 2014 and then remains constant at 50% afterwards.

The suggested shares for scenario B and C are justified by the popularity diesel cars are currently enjoying in Europe along with the relatively high fuel prices in comparison to local income levels in Jordan. Scenarios D and E assume a more gradual and conservative approach in introducing diesel cars to the Jordanian market. For all five scenarios, the following assumptions are made:

- Diesel passenger cars have an average 20% advantage on fuel economy and CO_2 emissions in comparison with comparable gasoline passenger cars. This is consistent with the discussion presented in the previous section.
- The share of passenger cars in the transportation sector will remain constant at 57% over the projected period.

To evaluate the potential savings at period t (ES_t), the following model is proposed:

$$(ES)_t = SF \times CP \times MS \times \left[\left(\frac{E_0 \times t}{T}\right) + (E_t - E_0)\right]. \quad (1)$$

In Eq. (1), SF represents the saving factor resulting from introducing diesel passenger cars (20%), CP the coverage percentage of passenger cars within the transportation sector (57%), MS the proposed market share of diesel passenger cars, E_0 the energy consumption of the transportation sector at the base year 0 (2007 in this study), E_t the predicted energy consumption of the transportation sector for period t, and T is the study period length (in this study 20 years, from 2007 to 2027).

In order to use this model, the predicted future energy consumption of the transportation sector (E_t) is required. This data can be generated using a forecasting tool based on time series technique. The analysis of historical final energy consumption of the transportation sector over the period 1995–2005 shows an evident long-run trend similar to that seen in Fig. 2. The double exponential smoothing forecasting time series method is recommended in such situations (Claycombe and Sullivan, 1977). The double exponential forecasting equation can be expressed as follows (Claycombe and Sullivan, 1977; Makridakis et al., 1983):

$$E_{t+m} = a_t + b_t m, \quad (2)$$

where E_{t+m} is the final energy consumption forecast after m number of periods ahead, m the number of periods ahead to be forecasted, a_t the intercept of forecasting, and b_t the slope of forecasting. The intercept a_t and the slope b_t are estimated as follows:

$$a_t = 2S'_t - S_t, \quad (3)$$

$$b_t = \frac{\alpha}{1-\alpha}(S'_t - S_t), \quad (4)$$

$$0 \leqslant \alpha < 1, \quad (5)$$

where α is the smoothing constant and used to weight current and past observations, S'_t and S_t the single and double exponential smoothing values, respectively, for time t. These $S_t^{'}$ and S_t values are calculated as follows:

$$S_t^{'} = \alpha X_t + (1 - \alpha) S_{t-1}^{'}, \tag{6}$$

$$S_t = \alpha S_t^{'} + (1 - \alpha) S_{t-1}, \tag{7}$$

where X_t is the observation at time t.

The higher the value of α, the more weight is given to the most recent observations. Before running the analysis, α should be selected. This was done by calculating historical final energy consumption using different values of α. The value that resulted in the minimum mean square error was found to be equal to 0.62 and was therefore selected. In addition to choosing appropriate α, values of $S_{t-1}^{'}$ and S_{t-1} must be available when $t = 1$ (the initial estimates). These values can be found by running a linear regression of the data using the obtained parameters in the following equations (Claycombe and Sullivan, 1977):

$$S_0^{'} = a_{est} - \left(\frac{1-\alpha}{\alpha}\right) \times b_{est} \tag{8}$$

$$S_0^{''} = a_{est} - \left(\frac{2(1-\alpha)}{\alpha}\right) \times b_{est} \tag{9}$$

where a_{est} and b_{est} are the y-intercept and independent variable's coefficient of the linear regression model, and $S_0^{'}$ and S_0 are the initial simple and double exponential smoothing values to be used in the forecast. The use of linear regression is justified here since the sample size is less than 15 (Claycombe and Sullivan, 1977). Minitab tool was used to calculate the regression coefficients, a_{est} and b_{est}, and were found to be 1114.38 TOE and 49.62 TOE, respectively.

6. Results and discussion

Using the double exponential forecasting model described in Eq. (2), the projected final energy consumption of the transportation sector can be calculated over the period 2007–2027 for scenario A. Potential savings from introducing diesel passenger cars according to scenarios B, C, D, and E are then calculated for each year over the same period. Consequently, the final energy consumption can be calculated for all scenarios. Fig. 6 shows the projected final energy consumption of the transportation for scenarios A, B, and C. Results for scenarios D and E were not included in the figure to avoid confusion. It can be seen that following scenario A (business as usual) will result in an increase of 106.7% in the transportation sector by 2027 to reach around 4120 TOE. The growth can be slowed down to 99.7% and 95% if scenarios B or C are adopted, respectively. Similarly, scenarios D and E will result in a growth of 100.4% and 96.8%, respectively.

The resulting savings in million US dollars ($) as a result of the saving in the final energy consumption, can be calculated depending on the following assumptions:

- Steady prices of crude oil at an average of $55/barrel over the projected period. It is needless to emphasise that prices of crude oil are subject to an array of factors that are extremely difficult to predict. Additional surges

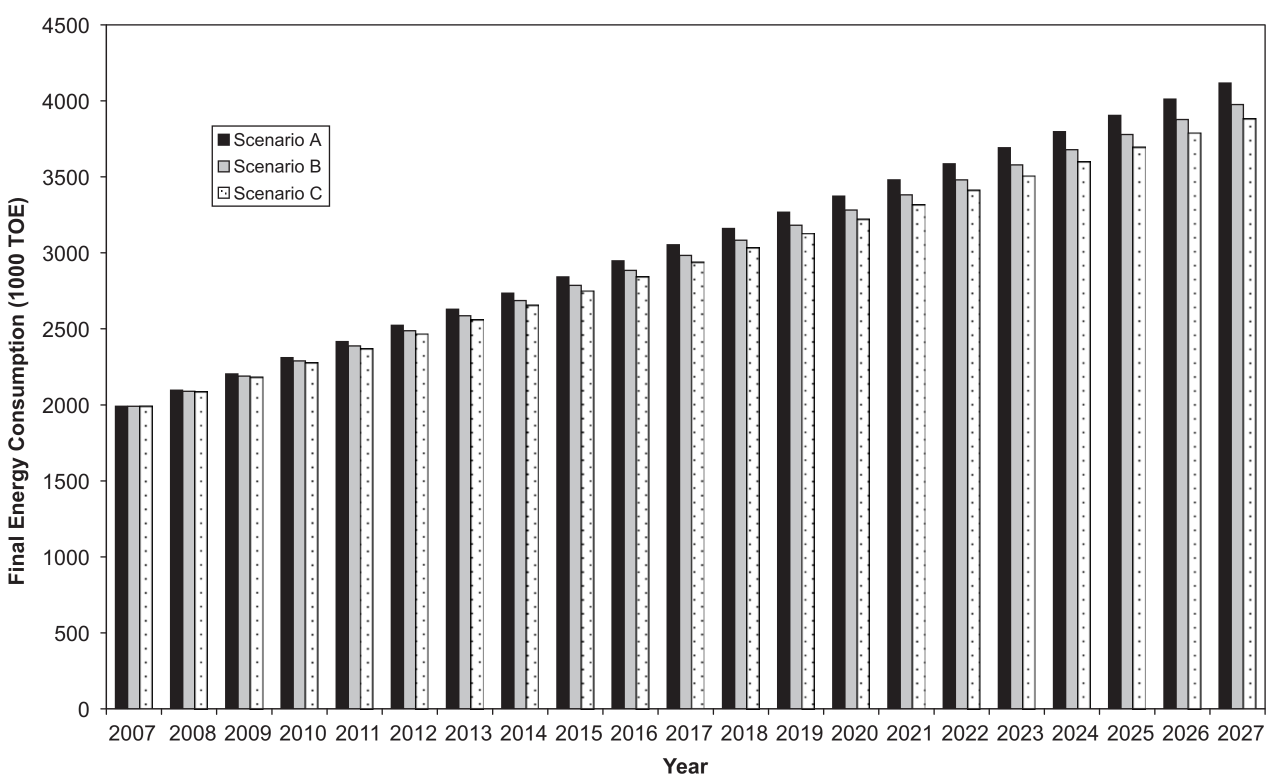

Fig. 6. Projected final energy consumption of the transportation for scenarios A, B, and C.

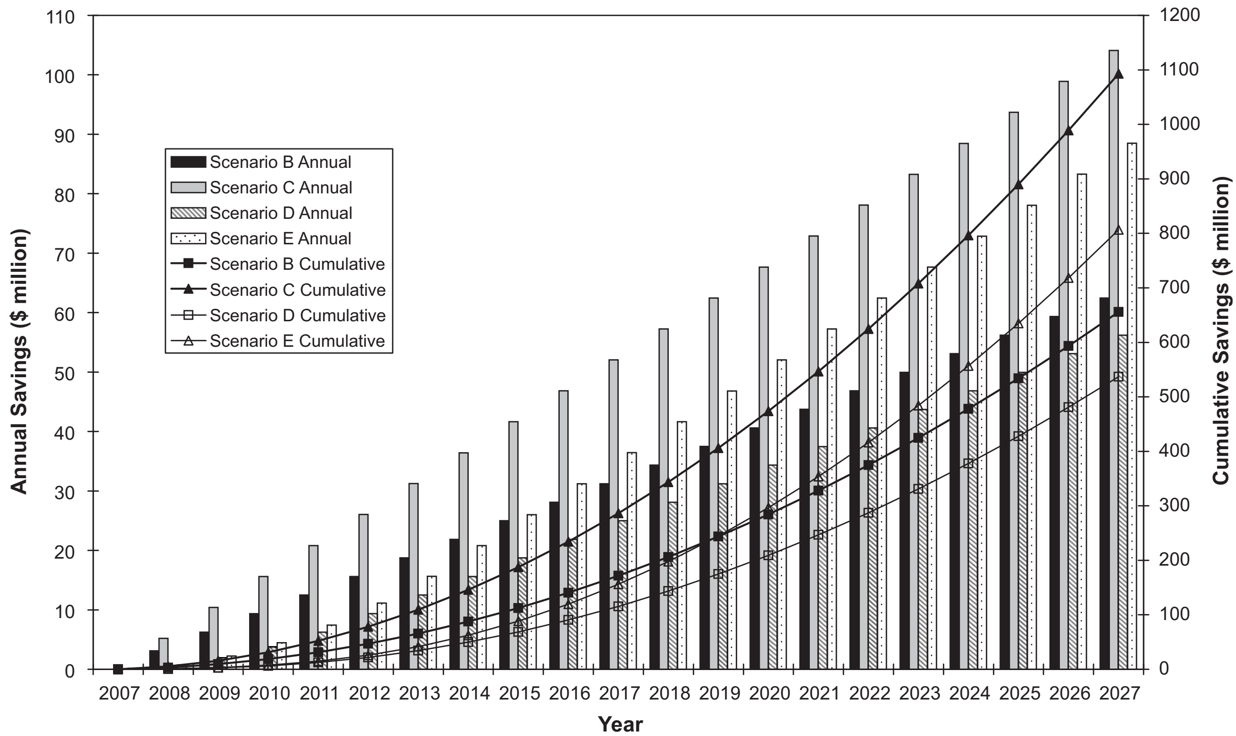

Fig. 7. Projected annual and cumulative savings in the cost of consumed energy in the transportation sector for scenarios B, C, D, and E.

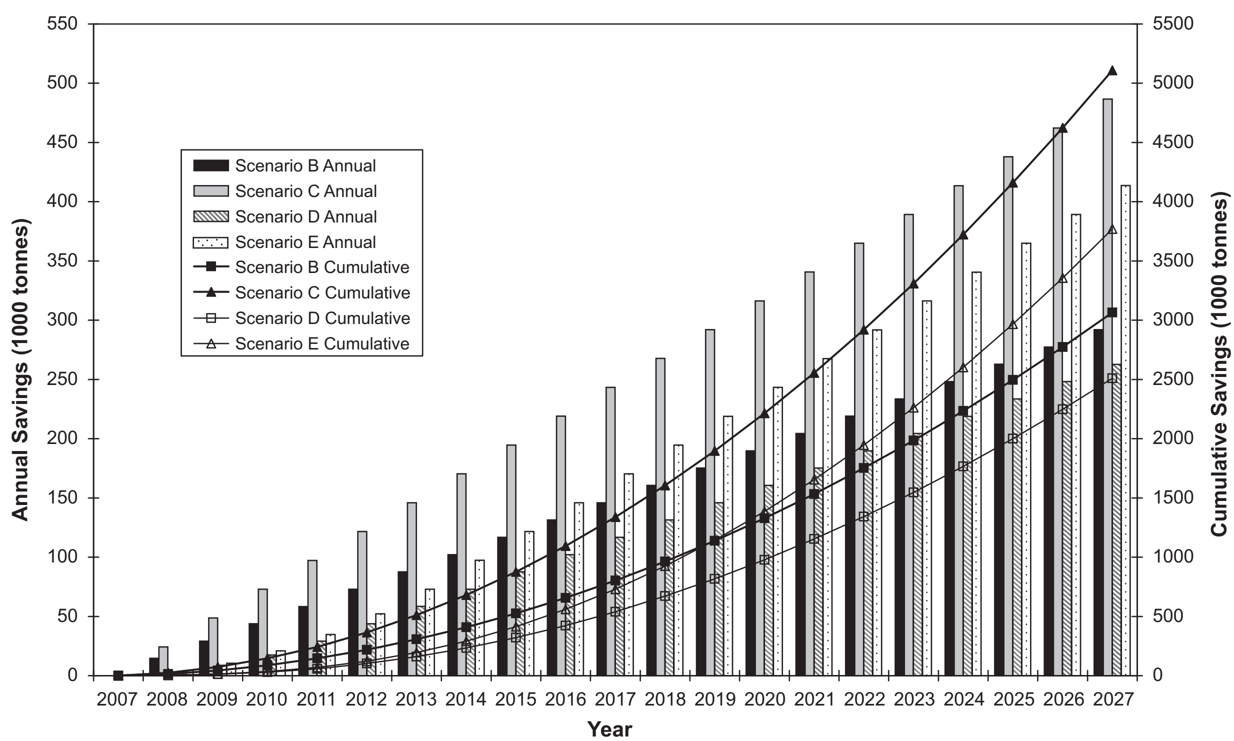

Fig. 8. Projected annual and cumulative savings in the CO_2 emissions from the transportation sector for scenarios B, C, D, and E.

in oil prices such as those witnessed over the past two years can significantly increase potential savings.

- The unit price for diesel and gasoline fuels is equal.
- The efficiency of conversion process from primary to final energy is 72%.

Fig. 7 shows the annual and cumulative savings in the national fuel bill for scenarios B, C, D, and E. Although the annual savings are limited during the first years of implementation due to the limited penetration of diesel passenger cars, they continue to increase at a steady rate with the increase of the diesel share in the passenger car market to reach $62.5 million in the case of scenario B and $104.1 million in the case of scenario C in 2027. The cumulative resulting savings by 2027 will reach $656 million for scenario B and $1093 million for scenario C. Scenarios D and E which represent a slower and more conservative introduction of diesel will result in slightly reduced annual savings of $56.2 million and $88.5 million and cumulative savings of $537 and $807 million, respectively.

The projected reduction in CO_2 emissions can also be calculated using the available emission data for 2004 and assuming a direct relationship between the energy consumption and CO_2 emission. Fig. 8 illustrates these potential reductions on both annual and cumulative basis for scenarios B, C, D, and E. Scenario B can result in an annual reduction of 2.92×10^5 tonnes in 2027 in comparison with Scenario A, while scenarios C, D, and E can result in a reduction of 4.87×10^5, 2.62×10^5, and 4.13×10^5 tonnes, respectively, for the same year. These reductions are, respectively, equivalent to 8.3%, 13.9%, 7.46%, and 10.74% of the 2004 CO_2 emissions from the transportation sector. The cumulative savings by 2027 will reach 3.07×10^6 tonnes for scenario B, 5.11×10^6 tonnes for scenario C, 2.51×10^6 tonnes for scenario D, and 3.77×10^6 tonnes for scenario E.

7. Conclusion

For a country that depends nearly totally on imported fuel and suffers from a worsening energy crises, an all out approach aiming at improving energy efficiency is mandatory. Examination of the national CO_2 emission intensity in Jordan reveals that there is much room for improvement. Since transportation is by far the largest energy consuming sector and is expected to grow faster than other sectors, more attention should be directed towards the provision of feasible and effective options in this sector. Due to the inherent efficiency advantage enjoyed by diesel engines over other combustion engines, their introduction into the Jordanian passenger car market can significantly slow down the growth of energy consumption and CO_2 emissions from the transportation sector.

An introduction scenario based on diesel passenger cars taking a share of 50% of the new passenger car sales over the next 20 years can slow down the projected growth of energy consumption in the transportation sector in 2027 from 106.7% to 95%. This will result in cumulative reduction of $1093 million in the fuel bill and 5.11×10^6 tonnes of CO_2 emissions by 2027. These reductions are significant in comparison with the current national fuel bill and the current emission levels.

This requires the adaptation of new legislation that would allow for such introduction, which can even be encouraged if the legislation includes tax exemptions for diesel car buyers and for replacing older cars. It should be emphasised here that the introduction of diesel passenger cars should also be accompanied with updated emission legislation so as to ensure that this energy solution does not result in new health and environmental problems.

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