Greenhouse Gas (GHG) Emissions from Land Transports in Malaysia: Modelling and Policy Analysis

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Abstract

Transportation sector is important to the economy and its rapid development has contributed significantly to the socioeconomic development of the country. The transportation sector in Malaysia accounts for approximately 35% of the total energy consumed nationally and produces nearly 50 million tonne of CO2 per year in 2015, second only to electricity power generation. Though shares only 0.3% of global GHG (Greenhouse gas) emissions, Malaysia is second largest per capita GHG emitter among the group of ASEAN countries and the major concern lies in the ever increasing trends. The aim of this work was to perform dynamic quantitative emission analysis of Malaysian vehicle fleet until year 2040, primarily on land transports including both passenger and freight transports except train. Utilizing a System Dynamic approach using Powersim Studio®, several emission scenarios were modelled in compared to current scenario (baseline model). The baseline model was used to determine carbon dioxide (CO2), carbon monoxide (CO) and nitrogen oxides (NOx) reduction for different policy scenarios in compared to baseline scenario. The complex relationships between the various components in the transport system are reflected in the dynamic model considering the vehicle technology, legislation and drivers' attitude. This work found that CO2 emission in 2040 can be reduced by up to 50%, compared to baseline scenario, without affecting the economy and vehicle demand. Carbon dioxide and nitrogen oxides pollution can also be reduced by 75% and 93% respectively with implementation of several policies compared to baseline scenario.

Keywords
System, Dynamic, Emission, Transportation, Land

1. Introduction

Malaysia has been one of the fastest growing ASEAN (Association of South East Asian Nations) countries since its independence and has significantly transformed itself from a predominantly agriculture-based country to manufacturing and, now, toward modern services and modernization towards a vision 2020 (Shahid et al. 2014). Transportation sector is important to the economy and its rapid development has contributed significantly to the socioeconomic development of the country (Mustapa and Bekhet 2016). The transportation sector in Malaysia accounts for approximately 35% of the total energy consumed nationally and produces nearly 50 million tons of CO2 per year in 2015, second only to electricity power generation. The vast majority (i.e. 85.2%) of transportation emissions comes from road transport. Due to the high rate of personal automobile ownership, cars account for about 59% of the overall emissions from transport, while freight is responsible for 27%. Although there are a roughly equal number of cars and motorcycles on the roads, motorcycles account for only 11% of the CO2 emissions from the transportation sector (Horizon Gitano Briggs and Leong Hau Kian 2016). Transportation sector is the largest pollution emitter and it is reported that energy efficiencies from this sector was merely at 20% (Bekhet and Othman 2017). Still heavily reliant on fossil fuels, the transport sector has continued to be top contributor to hazardous carbon emissions and climate damages (Sang and Bekhet 2015). One of the main concerns is the greenhouse gas (GHG) emission of CO_2 and air pollutants like NO_x and particulates (Ambrose et al. 2017).

A study by Borhan et al. (2013) and Yahoo and Othman (2017) evaluate the economy-wide impacts by implementing two different types of CO_2 emission abatement policies in Malaysia using market-based (imposing a carbon tax) and command-and-control mechanism (sector wise emission standards). Mustapa and Bekhet (2016) demonstrate that removal of fuel price subsidies can result in reductions of up to 652 000 tons of fuel consumption and CO_2 emissions can be decreased by 6.55%, which would enable Malaysia to hit its target by 2020. Another study found that mandatory implementation of fuel economy is an effective tool in controlling energy demand and greenhouse gas emission from transportation sector in many countries (Ong et al. 2012). Yu et al. (2014) analyze the impact of different transportation levels and the proportion of road and railway investment on the land transportation systems in a port city Tianjin by applying system dynamics models. Abbas and Bell (1994) evaluate the strengths and weaknesses of system dynamics (SD) with respect to its suitability and appropriateness in transportation modeling.

This article performs a system dynamic modelling for emissions from land vehicles and provides policy recommendations for formulating a comprehensive CO_2 abatement policy in Malaysia. This paper analyses the selected land transportation in Malaysia by using System Dynamic (SD) modelling approach with the help of Powersim Studio® (Powersim 2018) to compare with current scenario (baseline model). The complex relationships between the various components in the transport system are reflected in the SD model considering the vehicle technology, legislation and drivers' attitude. This paper also analyses the existing and proposed policy instruments to enhance sustainable transport and to provide dynamic quantitative analysis of Malaysian vehicle fleet emission until year 2040.

2. Methodology

2.1 Dynamic Modelling Process

A model of transportation which covers passenger road transportation in Malaysia was established using dynamic modeling software, Powersim Studio. As illustrated in Figure 1, the flowchart for this study consists of input, process, output, validation, and feedback loop for the modelling process. A baseline model was first constructed to represent business-as-usual (BAU or Base-line) scenario. Historical statistic data were primarily used for forecasting vehicle growth rate thru extrapolation. Input data used in this section represented vehicle stock quantity by types and its fuel-type distribution, collected from annual reports of Malaysian Transport Statistics from 1990 to the most recent publication.

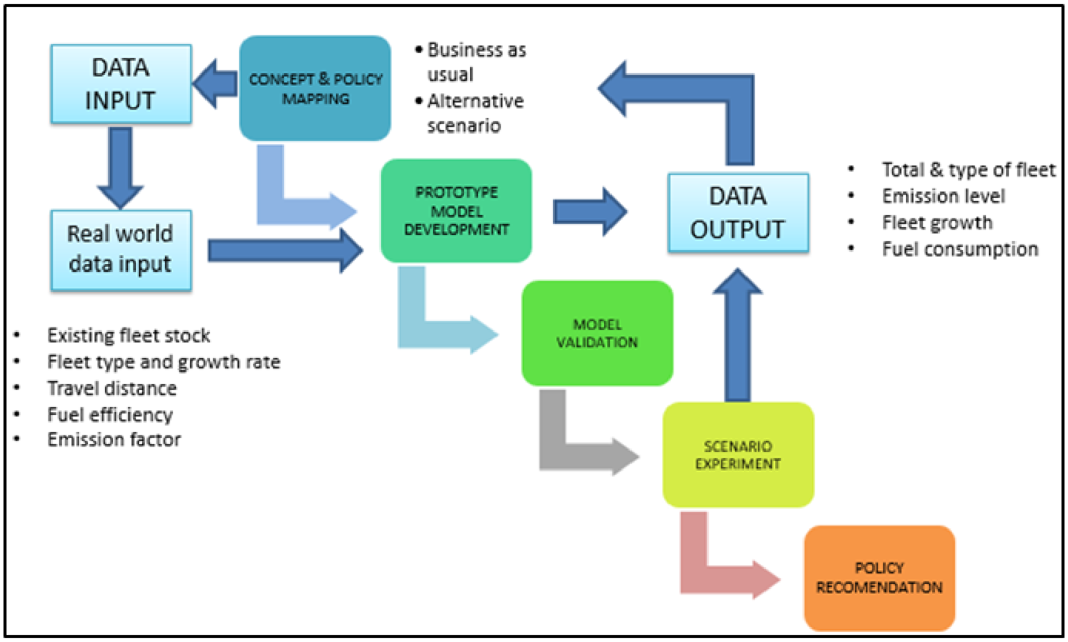

Figure 1. Flow chart of different steps to perform policy analysis

The stock flow diagram consists of vehicle stock level and emission levels were constructed using Powersim Studio (Figure 2). After the business-as-usual iteration has been completed, sets of policy scenarios are constructed by manipulating the stock flow diagram with variables and input to represent the policy scenario intended. The data generated from every policy scenario were analysed and compared to each other and to the baseline data to provide recommendations for the most effective policy and combinations of policies for actual application.

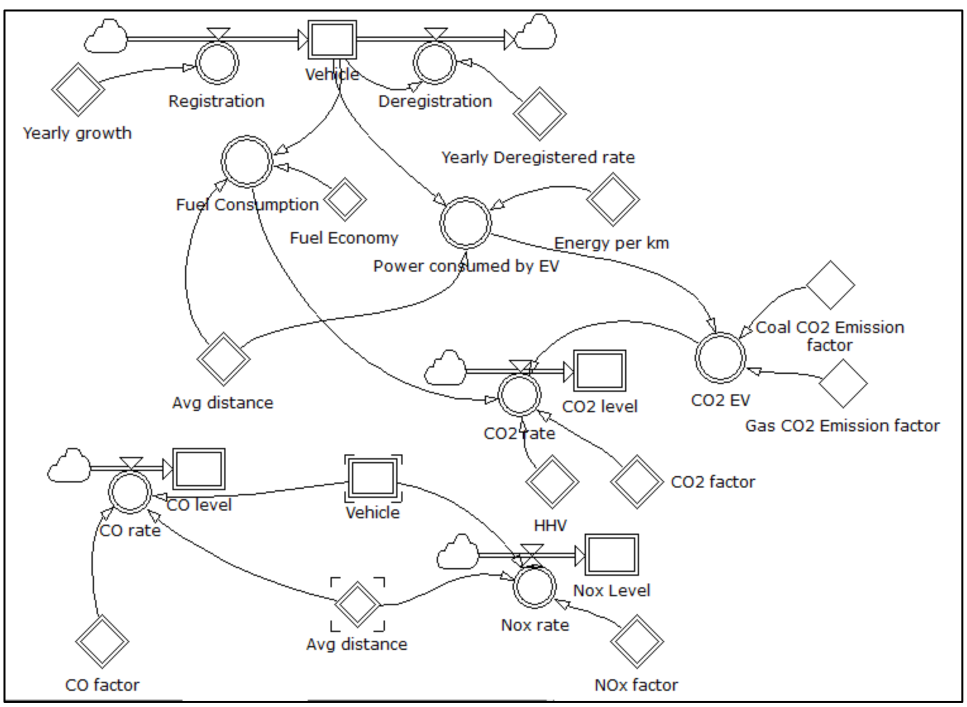

Figure 2. Baseline stock flow diagram

2.2 Data Analysis Techniques

Total Growth rate of vehicle fleet is calculated as per Equation (1) below while the growth rate is extrapolated from the statistical data.

$$TV_i(t) = TV_i(t - dt) + (V_i \cdot GRV_i) \cdot dt \qquad (1)$$

Where, TV_i = total vehicles per type, V_i = vehicles per type, GRV_i = growth rate of vehicles per type. Fuel consumption is calculated based on the multiplication of vehicle mileage and fuel economy of each type of vehicle, and is given by:

$$TFC = \sum (V_i \cdot AD_i) \cdot FE_i \qquad (2)$$

Where, *TFC* is the vehicle fuel consumption; *Vi* is the number of vehicle according to type, *ADi* is the average distance of vehicle per type and *FEi* is the vehicle fuel economy. On the other hand, CO and NOx emission for road transportation is calculated based on the volume of vehicles and total travel distance of each vehicle type, and is given by:

$$E_{ij} = \sum (V_i \cdot AD_i) \cdot EF_{ij} \qquad (3)$$

Where *Eij* is the emission in kton while *EFij* is the emission factor by fuel type. In this modelling, it is assumed that fuel consumption and air emission trends are mainly affected by vehicles growth rate, emission standard, vehicle technology and split mode between types of vehicles. Four test policy scenarios were carried out to compare the emission level as per in Table 1.

Table 1. Policy scenarios

Responsible body	Policy number	Policy acronyms
Government	Policy 1	Mandatory EV
Government and driver	Policy 2	Reduce VKT
Industry	Policy 3	Improve Fuel Economy
Government	Policy 4	Fuel quality-EURO 6 adaptation
Government, industry and driver	Policy 5	Combination of policy 1,2,3, and 4

3. Results and Discussion

Figure 3 below shows the baseline of the vehicle fleet growth. From the graph, it can be inferred that motorcycle and passenger car increased steadily from 12 540 632 units and 12 355 462 units to 19 462 619 units and 19 768 224 units respectively. Passenger cars record the highest unit followed by motorcycle, goods vehicle, taxi, bus, HEV and EV.

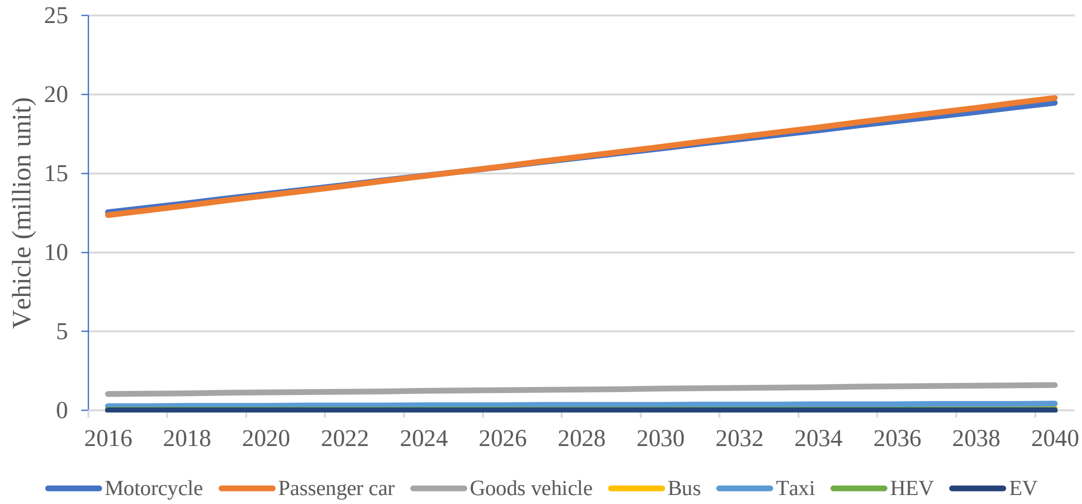

Figure 3. Baseline vehicles growth

In the baseline scenario, the current growth rate of various types of vehicles will continue to happen until the year 2040 without any major interruption from the present policy. The growth rate of each vehicle type was extrapolated from the historical data obtained from the Malaysian Transport statistic. Graph in Figure 4 below indicated growth of vehicles fleet and fuel consumed from 2016 to 2040. A 38% increase of total vehicles fleet and 53% increase of fuel consumed were projected.

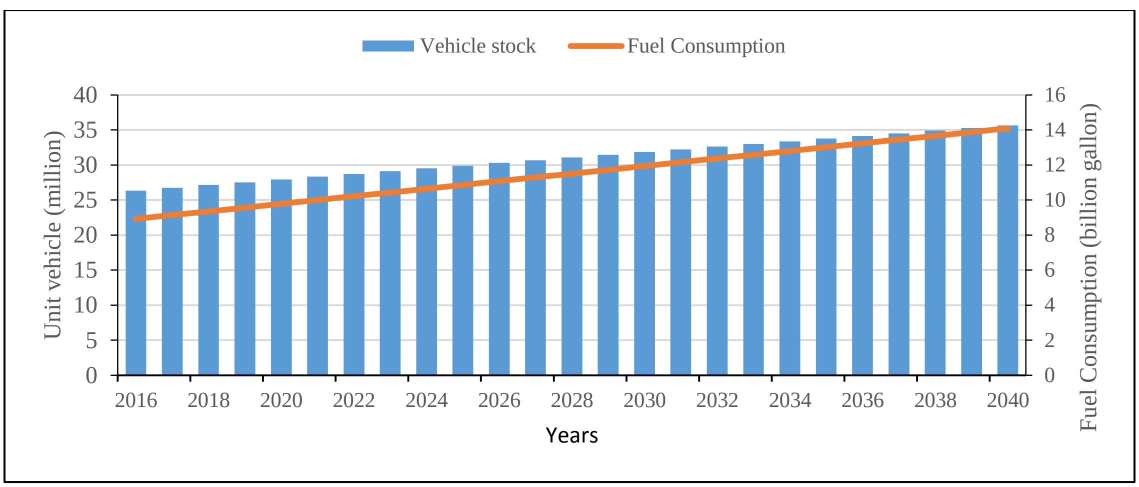

Figure 4. Total Fuel Consumption for baseline model

The individual fuel consumed as indicated in Figure 5 shows passenger vehicle is the highest fuel consumer followed by motorcycle, goods vehicle, bus, taxi and HEV. As a part of the public transportation, the growth rate of buses does not seem to be in drastic as people prefer to use motorcycle and passenger car. Due to the increasing trend of vehicle fleet, it reflected in the increasing of carbon dioxide emission for the baseline as shown in the Figure 6 below. Again, passenger car is the highest carbon dioxide emitter with 79,609 kton of carbon dioxide in 2040, a 60% increase from 2016. The second highest carbon dioxide emitter is motorcycle followed by goods vehicle, bus, taxi, HEV and EV. Clearly, it will be a significant reduction of carbon dioxide emission to formulate policies that focusing on the passenger car fleet.

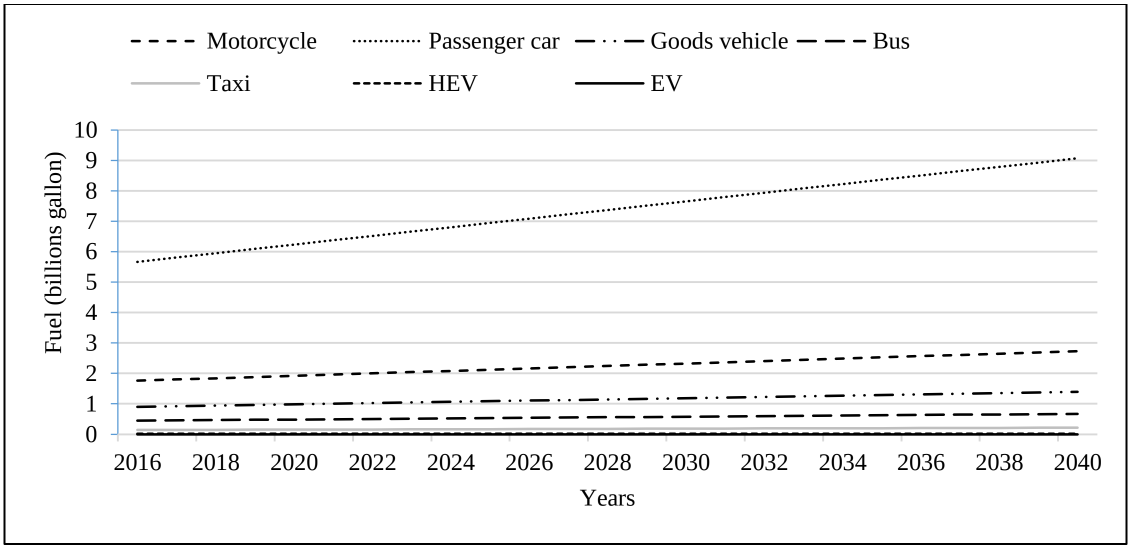

Figure 5. Fuel Consumption by vehicle type for baseline model

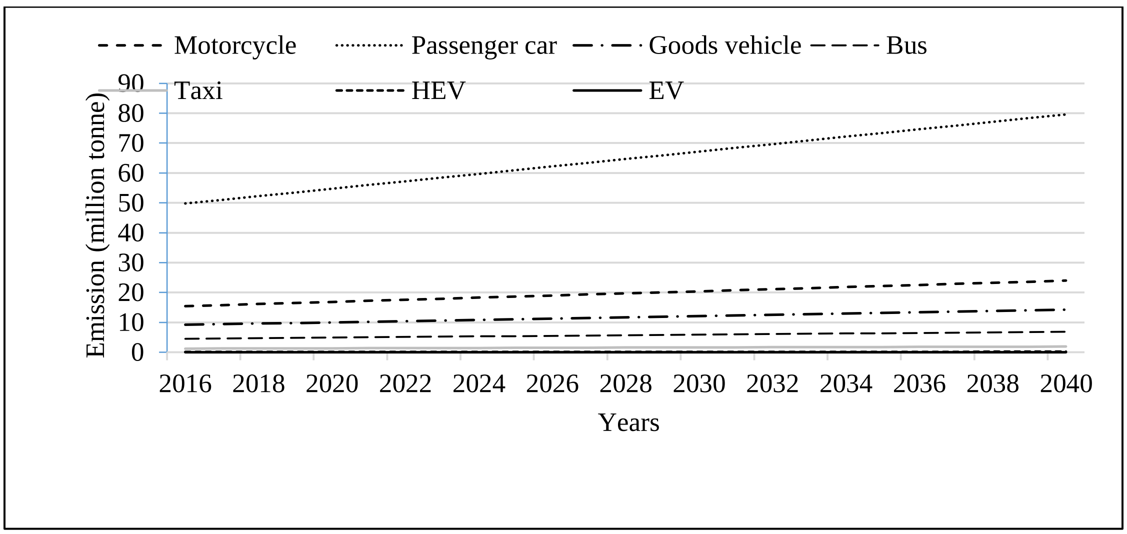

Figure 6. CO2 Emission for baseline model

Policy 1 (Increase EV) involves promoting the use of electric vehicle (EV) passenger cars while at the same time reducing the number of conventional passenger cars. Yearly growth rate of conventional passenger car was reduced by 1.9% from 2.5% started 2016 and at the same time to increase the sales of electric vehicle to 95.6% from 4.4% started 2016 with reference to the baseline model. This percentage was formulated in such a way in order to reduce 1.8% from annual baseline of carbon dioxide emission to meet Malaysia aspiration to reduce its greenhouse gas (GHG) emissions intensity of GDP by 45% by 2030 relative to the emissions intensity of GDP in 2005. In this case, 25.2% is targeted for the 14 years remaining to 2030. Targeting the passenger car, it is equivalent of removing 28000 units of conventional passenger cars annually from 2016 to 2030. The best option is to replace the conventional car with EV while at the same time to ensure no critical shortage of means transportation. This effort only represent portion in transportation sector of overall 45% national wide target. From Figure 7, only 18% of emission reduction was made possible instead of 25.2% due to low EV opening stock in 2016. However, it is a 30% reduction from 2040 with respect to 2016 baseline.

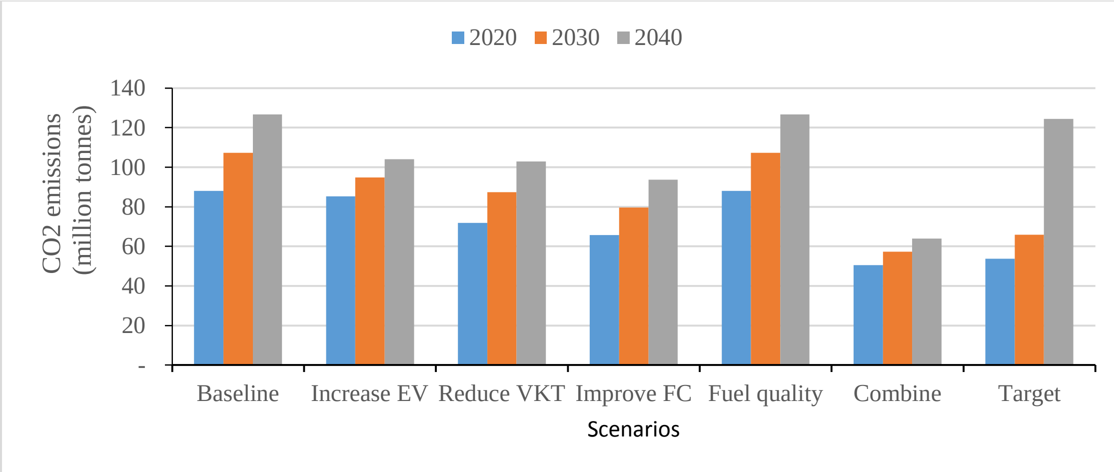

Figure 7. Comparison of CO2 emission for different policy applied

As for *Policy 2 (*Reduce VKT) average vehicle-kilometer travelled (VKT) for all fleet were reduced by 20%. This is made possible by increasing pump fuel price, providing alternative transportation system such as rail services, educate driver to plan their drive and to avoid unnecessary travel. For this policy, a reduction of 28% of total carbon dioxide emission with respect to 2016 baseline was observed. In *Policy 3 (*Improve FC) fuel consumption (FC) of passenger car was improved from 7.2 L/100km to 4.1L/100km. This can be achieved with the introduction of fuel efficient vehicle. This policy leads to 17% of total carbon dioxide emission. *Policy 4 (*Fuel quality-EURO 6 adaptation) mainly the adaptation of Euro 6 emission standard, however was only affected for carbon monoxide (CO) and NOx emission (Figure 8). *Policy 5 (*Combination) shows the lowest emission with over half of emission at 2020. The main contributor is by improving the fuel consumption and reduces the vehicle kilometre travel. Only by utilizing the *Policy 5* the target emission can be achieved.

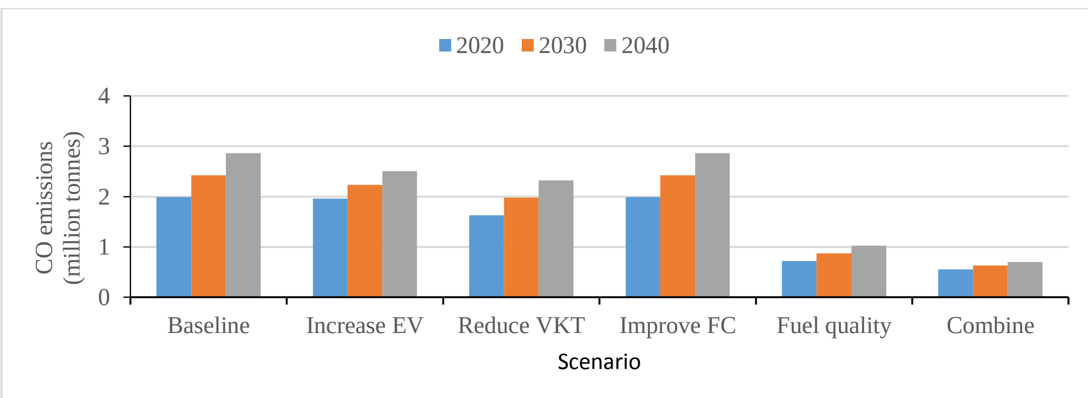

Figure 8. Comparison of CO emission for different policy applied

4. Conclusions

Fulfilling Malaysia's objective to a long-term, sustainable transport sector requires addressing a huge amount of threat to the environment. Transportation sector, as the second largest producer of carbon dioxide emission in Malaysia, it plays as an important key element for resolving this threat. Due to the high rate of passenger car ownership, cars account for about 59% of the overall emissions from transport, while freight is responsible for 27%. Although there are a roughly equal number of cars and motorcycles on the roads, motorcycles account for only 11% of the CO2 emissions from the transportation sector. As the economy continues to develop the rate of energy consumption rises, and corresponding Greenhouse Gas (GHG) emissions are also increasing, resulting in an almost constant rate of CO2 emissions, making it logical to approach better vehicle management.

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