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Energy consumption and emission projection for the road transport sector in Malaysia: an application of the LEAP model

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Abstract This study has attempted to estimate the energy consumption and emission of pollutants namely carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOC) from the road transport sector in Malaysia from the year 2012 till 2040. This was done using the long-range energy alternatives planning (LEAP) model. Estimates of energy consumption and emissions were evaluated and analysed under a business-as-usual scenario and three other alternative fuel policy scenarios of biodiesel vehicles (BIO), natural gas vehicles (NGV) and hybrid electric vehicles (HEV). The aim of this study has been to identify the potential alternative fuel policies that would be effective in reducing the future growth of road transport energy consumption and emission in Malaysia. Results indicate that the NGV scenario contributes towards the highest reduction in road transport energy consumption followed by BIO and HEV. The NGV scenario also achieves highest mitigation of emission of all the four pollutants. In the case of CO_2 emission, BIO scenario attains second highest mitigation,

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whereas in the event of CO, NOx and NMVOC emission, HEV scenario achieves second highest mitigation.

Keywords Road transport · Malaysia · Energy consumption · Emission · Energy forecast · Energy policies · LEAP

1 Introduction

Malaysia is a developing nation that has seen outstanding economic performance with an average annual GDP growth rate of about 6 % since 1980, making it one of the fastest growing economies in the world (World Bank 2014). Successful and consistent economic growth has led to rapid urbanization and significant rise in income per capita. Malaysia's annual GDP per capita has increased by about three times in the last three decades. As a result, final energy consumption in Malaysia has grown at an average annual rate of 6.23 % from year 1990 to 2012 and reached 46.7 Mtoe in 2012. Transportation sector is the highest energy consuming sector in Malaysia accounting for 36.8 % of the total final energy consumption in 2012 (National Energy Balance 2012). This can be attributed to the massive rise in vehicle ownership throughout the country (Mohamad and Kiggundu 2007). The total number of on-road vehicles in the country has increased from about 5 million in 1991 to 23.7 million in 2013 registering an average annual growth rate of 7.5 % during this period (Ministry of Transport Malaysia, Land Statistics 2013).

Transportation sector is also one of the most energy intensive sectors in Malaysia depending primarily on petroleum products which accounts for about 98 % of the total energy consumption in this sector. The prime fuels used in the transportation sector include petrol, diesel, aviation turbine fuel (ATF) and aviation gasoline (AV) (Al-Mofleh et al. 2010). Road sector energy consumption has been growing with an average rate of 6.24 % per year since 1971 and in 2011 equalled 14,432 ktoe accounting for almost 19 % of the total final energy consumption in this country (World Bank 2014). The share of petrol and diesel consisted of 95 % of the total road sector fuel consumption in 2011 (World Bank 2014). So there seems to be a persistent increase in non-renewable sources of fuel consumption in the transportation sector in Malaysia. Malaysia has proven oil reserves of 4 billion barrels as of 2014. Malaysia is the second largest producer of oil and natural gas in Southeast Asia and has the fourth highest oil reserves in Asia–Pacific after China, India and Vietnam (U.S. Energy Information Administration 2014). Malaysia's total oil production in 2013 was 669.53 thousand barrels per day, and consumption was 623 thousand barrels per day. Production has been declining since its peak in 2003 due to natural depletion of existing fields, while domestic consumption has been rising incessantly. As a result, net export of petroleum has been declining for Malaysia over the past few years, generating a loss in national revenue. With the ever increasing huge demand of fossil fuel, it is calculated that Malaysia's oil reserves will be depleted in the next 21 years (Ong et al. 2012). Malaysia has remained a net exporter of crude oil and petroleum products thus far, but in early 2015, the government of Malaysia announced that the country had turned into a net importer of crude oil and petroleum products since 2014 (Kok 2015).

Since petroleum products are the primary source of energy in the growing transportation sector in Malaysia, this sector has become a major contributor of GHG emissions in the country. Transportation sector is a primary contributor of various local air pollutants such as carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NOx), non-methane volatile organic compounds (NMVOC) and total suspended particulates (TSP) (Ong et al. 2011). Carbon dioxide (CO_2) emissions from the transport sector in Malaysia have been steadily increasing with an annual growth rate of 6.5 % since 1980, reaching 43.02 million metric tons in 2011. These emission rates are considered to be comparatively high among emerging nations. Furthermore, road transport CO_2 emission in 2011 equalled 42.5 million metric tons which accounted for almost 99 % of the total transport sector CO_2 emission in Malaysia for that year (International Energy Agency 2013). Per-capita CO_2 emission from road transport in Malaysia increased by a 88 % during the period 1990–2007 (International Transport Forum 2010), and in 2011 per-capita CO_2 emission from road transport stood at 1.47 metric tons (International Energy Agency 2013). The rising emissions from the transportation sector in Malaysia may contribute to domestic pollution and global climate change. The catastrophic impacts of climate change include heating of the atmosphere causing sea level to rise, intensifying extreme weather events such as storms and droughts, altering natural habitats and ecosystems making it inhospitable for some species, threat to agriculture and ground level ozone formation creating negative consequences to human health.

It has become necessary for Malaysia to implement appropriate energy planning and policies to reduce the demand for fossil fuels in the transportation sector, thereby reducing GHG emissions. It is important to understand how alternate fuels other than traditional petroleum products would affect road transport energy consumption and emission in Malaysia. This study has attempted to estimate the energy consumption and emission of pollutants (CO_2, CO, NOx, NMVOC) from the road transport sector in Malaysia from 2012 till 2040 under various alternate fuel policy scenarios. The aim is to analyse the potential of alternative fuel policies to reduce energy consumption and emission from the road transport sector in Malaysia.

2 Rationalization of alternative fuel policies for the road transport sector for Malaysia

The lack of fuel diversification in the fuel basket and the almost absence of clean fuel, i.e. fuels that create less pollution in the road transportation sector, is perhaps the fundamental factor for the high emissions from this sector in Malaysia (Mustapa et al. 2011). In 2011, motor petrol had the largest share with 52.76 %, followed by diesel with 42.11 % of the

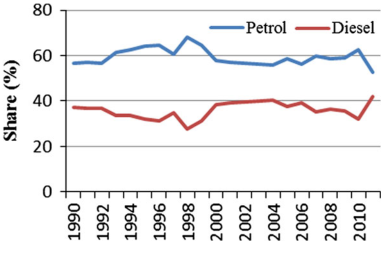

Fig. 1 Shares of petrol and diesel in total road transport fuel consumption. *Source*: World Bank Data

total road transport energy consumption (World Bank 2014). The share of petrol and diesel in the total road transport energy consumption in Malaysia is shown in Fig. 1. It clearly depicts the dominance of non-renewable petroleum products in the road transport sector in Malaysia over the years. In the case of other sources of energy in the entire transport sector, natural gas and electricity had a share of a mere 1.7 and 0.12 %, respectively, in 2012 (National Energy Balance 2012). There is therefore a clear need to search for alternative fuels beside fossil fuel.

Natural gas is an alternative fuel source that addresses the problem of oil shortage and produces lower emissions than traditional fossil fuels. There have been a number of studies carried out examining the effect of natural gas on environmental emissions. Natural gas is found to decrease emission of hydrocarbons (HC), CO and CO_2, but increase NOx emission compared to that of gasoline (Jahirul et al. 2010). In contrast, usage of natural gas in engines reduces NOx and CO_2 emission, but produces higher HC and CO emission than normal diesel engines (Korakianitis et al. 2011). However, the share of natural gas in the total transport fuel consumption in Malaysia has been rather low as demonstrated in Fig. 2. Many countries are adopting natural gas vehicles (NGV) as an alternative fuel vehicle. The countries with the largest market share of NGV in total fleet are Bangladesh (61 %), Armenia (30 %), Pakistan and Bolivia (26 %), and Argentina and Colombia (24 %). Market share of NGV in Malaysia is 11 % (International Energy Agency 2010). Compressed natural gas (CNG) can be used to power vehicles ranging from light delivery trucks to full-size urban buses, and it has been used in vehicles since 1930. In Malaysia, natural gas is used in all classes of vehicles starting from motorcycles, private and public use motorcars to goods vehicles and buses (Ministry of Transport Malaysia, Land Statistics 2013). Malaysia's current natural gas proved reserves stand at 83 trillion cubic feet. Malaysia is the second largest producer of natural gas in Southeast Asia and 12th largest in the world. Total natural gas production in Malaysia in 2012 was 2176 billion cubic feet, and consumption was only 1104 billion cubic feet (U.S. Energy Information Administration). Therefore increased usage of natural gas in the transport sector is highly prospective. The use of NGV is promoted by the Malaysian government by providing economic incentives to vehicle owners who use natural gas. The government of Malaysia exempts import duty and sales tax on NGV conversion kit and other necessary components for natural gas conversion of vehicles. Furthermore, the government provides a 50 % discount on road taxes for NGVs to induce more use of NGVs (Mahlia et al. 2010).

Hybrid or electric vehicles are also another source of clean fuel vehicles for the road transport. Hybrid electric vehicles (HEV) have an improved fuel economy which allows it to consume less energy and therefore reduce GHG emissions. HEV or Plug-in HEV emit less CO_2 and other pollutants over their entire fuel cycle than conventional vehicles. In Malaysia, emission from hybrid or Plug-in HEV are also assured to be less because the

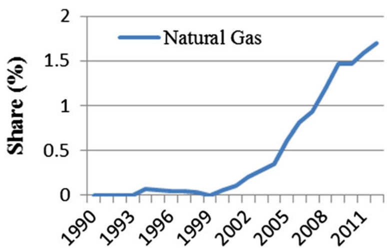

Fig. 2 Share of natural gas in total transport sector fuel consumption. *Source*: National Energy Balance (2012), Malaysia

primary fuels for electricity generation in this country are natural gas and coal with natural gas having the highest share of 46 % followed by coal with a share of 41 % in 2012 (Energy Commission 2014). However, there are several studies that suggest that subsidies are necessary to promote clean vehicles. The share of hybrid and electric vehicles in Malaysia is very negligible. As of mid-2012, there were only 8000 hybrid and 21 electric cars on the road in Malaysia (Ministry of International Trade and Industry 2012). Starting from 2009, hybrid cars receive a 100 % tax exemption of import duty and a 50 % exemption of excise duty. Under the National Automobile Policy of 2009, investments in the assembly or manufacture of hybrid and electric vehicles will be granted 100 % investment tax allowance or pioneer status for a period of 10 years (Ministry of International Trade and Industry 2009).

In the Eighth Malaysia Plan, renewable energy was announced as the fifth fuel in the energy supply mix under the fifth fuel policy. In order to promote the demand for palm oil as a renewable energy source, national biofuel policy was launched in 2006 to support the fifth fuel policy. Biodiesel is a renewable energy, and commercially these blends are named as B10, B20 or B100 where the numbers represent the volume percentage of biodiesel component in the blend with diesel fuel. A key component of the National Biofuel Policy is to produce a biodiesel fuel blend of 5 % processed palm oil with 95 % petroleum diesel (Hashim and Ho 2011). This mixture is called Envo Diesel which is different from conventional biodiesel B5 blend. Utilizing this in the transportation sector can save Malaysia up to 0.5 million tonnes of diesel imports or equivalent to USD 380 million a year (Lim and Teong 2010). Moreover, usage of biodiesel can reduce greenhouse gas (GHG) emissions by as much as 80 % depending on the feedstock employed. Results from tests conducted indicate that biodiesel can decrease HC, CO and particulate matters from exhaust emissions compared to fossil fuels. Abundance of palm oil in Malaysia is the principal driving force for its development of biodiesel industry. Malaysia is one of the largest producer and exporter of palm oil in the world currently accounting for 39 % of world palm oil production and 44 % of world palm oil export (Malaysian Palm Oil Council). Hence Malaysia would not need to rely on foreign import of raw materials to develop its biodiesel industry. Producing biodiesel from palm oil has several other advantages; for example, the yield of vegetable oil from oil palm plant is almost 5 times and 10 times higher than rapeseed and soybean, respectively, with the same area of land, and moreover, the palm oil production cost per unit is the lowest among other oil crops (Lim and Teong 2010).

Palm oil production in Malaysia has increased over the years from 4.1 million tonnes in 1985 to 19.4 million tonnes in 2012 (Malaysian Palm Oil Board). However, the survival of the biodiesel industry in Malaysia depends on various factors. Production of biodiesel can only be economically feasible if its price is close to petroleum-derived diesel and also if the price covers cost of production. When the price of crude oil reduced drastically and due to the sluggish and inefficient policy response of the Malaysian government to the changing market scenario, most of the 91 licensed biodiesel plants had to either reduce or cease their production operations altogether. This has hindered the efforts of the Malaysian government to mandate the application of B5 biodiesel blend in private diesel-powered transportation. The plan now is to fully implement the B5 biodiesel program nationwide by December 2014 (Pakiam 2014). The key ways for the survival of biodiesel industry in Malaysia would be for the government to incentivize demand for biofuel and most importantly provide subsidies. Subsidies for biofuel are a common practice in countries such as the USA, Brazil and Germany where their production is substantial (Timilsina and Dulal 2011).

3 Methodology

3.1 Empirical analysis by long-range energy alternatives planning (LEAP) model

This study used the long-range energy alternatives planning (LEAP) model to estimate the energy consumption and emissions from the road transport sector. The LEAP model was developed by the Stockholm Environment Institute. It is an integrated energy modelling tool, widely used to track energy consumption, production and resource extraction in all economic sectors. It can be used to account for both energy sector and non-energy sector GHG emission sources and sinks. It can also be used to analyse emissions from both local and regional air pollutants (SEI 2011). Using LEAP, policy analysts can generate and then evaluate alternative scenarios by comparing their energy requirements, environmental impacts and their social costs and benefits. The model requires data for the base year and any of the future years. Using functions such as interpolation, extrapolation or the growth rate method, future energy consumption and emissions are estimated. In this study, 2012 was chosen as the base year and future energy consumption and emission of pollutants (CO_2, CO, NOx and NMVOC) were projected till 2040 under four policy scenarios.

The principal concept of LEAP is an end-use-driven scenario analysis. The LEAP framework is disaggregated in a hierarchical tree structure of four levels: sector, subsector, end-use and device (Dhakal 2003). Energy consumption in this study was calculated from the products of two factors: the levels of activity and energy intensity. Emission was calculated from the product of the energy consumptions and the emission factors, which depend on the technology of vehicles and the fuel types.

3.2 Calculations, data and sources

Energy consumption from the road transport sector in Malaysia in this study is calculated in two steps. First, the total travel demand and energy intensity are estimated. Travel demand is calculated in terms of passenger kilometres (pass-km), while energy intensity is calculated in terms of litres per passenger kilometre (litres/pass-km).

$$\text{Travel demand (pass-km)} = \sum Vi(t) \times \text{VKT}i(t) \times \text{VO}i(t) \quad (1)$$

where V is the total number of vehicles of category i, VKT is the average annual vehicle kilometre travelled (mileage) of vehicle category i (kilometre) and VO is the vehicle occupancy rate of vehicle category i (passenger kilometre/vehicle kilometre) in year t.

$$\text{Energy intensity (litres/pass-km)} = \sum 1/\{\text{FE}ij(t) \times \text{VO}i(t)\} \quad (2)$$

where FE is the fuel economy of fuel category j under vehicle category i (vehicle kilometre/litre) and VO is the vehicle occupancy rate of vehicle category i (passenger kilometre/vehicle kilometre)} in year t.

Finally, energy consumption is calculated using the following equation:

$$\text{Energy consumption} = \sum \text{TD}i(t) \times \text{EI}ij(t) \quad (3)$$

where TD is the travel demand (pass-km) of vehicle category i and EI is the energy intensity of fuel category j under vehicle category i (litres/pass-km) in year t.

Emissions are estimated using the following method:

$$\text{Emissions} = \sum \text{EC}j(t) \times \text{EF}jk(t) \quad (4)$$

where EC is the energy consumption of fuel category j and EF is the emission factor of pollutant type k under fuel category j in year t.

Collecting data for all the required variable inputs has been a challenging task due to the unavailability of requisite statistical data in Malaysia. All the data required for the estimation of energy consumption for 2012 have been tabulated in Table 1. Data for the total number of registered vehicles for the 2012 base year for each mode are obtained from the Ministry of Transport Malaysia. The share of each type of fuel usage for each vehicle mode is based on the "New Registered Vehicles in 2012 by type of Fuel Usage" section due to the absence of fuel share data for the entire stock of vehicles for 2012. Data for annual vehicle kilometre travelled or mileage are taken from a study by Aizura et al. (2010) and are assumed to be the same for all modes of vehicles. Vehicle occupancy rate is taken from Shabbir and Ahmad (2010). Fuel economy data for the vehicles in Malaysia are taken from Jacobsen and Blarke (2007). Fuel economy data for alternate fuels such as electricity and biodiesel are taken from a number of published literatures namely Samaras et al. (1998) and Kalam and Masjuki (2002).

Emissions are calculated for CO_2, CO, NMVOC and NOx. Emission factors for these gases from the use of petrol, diesel and natural gas came from the IPCC Tier 1 Default Emission Factors for road transport. These emission factors have already been integrated in the Technology and Environment Database (TED) in the LEAP system. Emission factors of pollutants from biodiesel are obtained from the IPCC Emission Factor Database (2013) under the "Fuel 2006-Energy Industries" Category and also from a report prepared by Eastern Research Group, Inc. (2007). Further, emission factors for pollutants from HEV are taken from Samaras et al. (1998). The emission factors of all the four pollutants for each fuel are given in Supplementary Materials: Section A.

The activity level in the LEAP model is expressed in terms of travel demand per person or passenger kilometre (pass-km) per person. The Malaysian population data for 2012 were sourced from the World Bank Database. It should be noted that population and the total number of vehicles for each mode for the baseline scenario were forecasted from 2013 through 2040 using univariate first-order autoregressive AR(1) procedure. This estimation method is provided in the Supplementary Materials: Section B. Thus values of travel demand per person for each mode of road transport from 2013 till 2040 for the baseline scenario were forecasted accordingly and inserted into the LEAP system. Annual vehicle kilometre travelled for all modes of road transport is assumed to remain the same for all future years due to data constraints.

3.3 Definition of scenarios

The four policy scenarios that have been considered in this study are defined below. The rationale behind the assumptions in these policy scenarios are based on the discussion in Sect. 2. The justification for the chosen diffusion share of alternative fuels is grounded on the current status of these fuel shares in Malaysia and future planning and prospects for the country which has also been elaborated in Sect. 2.

Scenario 1: business as usual (BAU)
This scenario is the baseline scenario where current trends and policies will be maintained. There will be no interventions or no introduction of new policies or measures to reduce energy consumption or emissions for the future. The number of vehicles for each mode of

Table 1 Variables for energy consumption estimation in 2012

Type of vehicle[a]	Total registered vehicles[a]	Fuel[a]	Fuel share (%)[a]	Mileage[b]	Load factor[c]	Fuel economy (km/l)
Motorcycles	10,589,818	Petrol	100	19,660	1.6	30.8
Passenger cars	10,354,678	Petrol	99.5	19,660	2.6	11.4[d]
		Diesel	0.48	19,660	2.6	14[d]
		Natural gas	0.015	19,660	2.6	11[d]
		Electric	0.005	19,660	2.6	0.588235294[e]
		Biodiesel	0	19,660	2.6	12[f]
Bus	73,536	Petrol	1	19,660	50	5[d]
		Diesel	88	19,660	50	6.3[d]
		Natural gas	11	19,660	50	5[g]
		Biodiesel	0	19,660	50	5[g]
Taxi	93,040	Petrol	22.2	19,660	2.6	11.4[d]
		Diesel	0.14	19,660	2.6	14[d]
		Natural gas	77.66	19,660	2.6	11[d]
		Electric	0	19,660	2.6	0.588235294[e]
		Biodiesel	0	19,660	2.6	12[f]
Hire and drive cars	19,296	Petrol	98.6	19,660	2.6	11.4[d]
		Diesel	0.8	19,660	2.6	14[d]
		Natural gas	0.6	19,660	2.6	11[d]
		Electric	0	19,660	2.6	0.588235294[e]
		Biodiesel	0	19,660	2.6	12[f]
Goods vehicles	1,032,004	Petrol	25.8	19,660	12	3.7[h]
		Diesel	73.8	19,660	12	3.7[d]
		Natural gas	0.4	19,660	12	3.7[h]
		Biodiesel	0	19,660	12	3.7[h]
Other vehicles	539,849	Petrol	14	19,660	18	11.4[d]
		Diesel	84	19,660	18	14[d]
		Natural gas	0	19,660	18	11[d]
		Electric	2	19,660	18	0.588235294[e]
		Biodiesel	0	19,660	18	12[f]

[a] Data obtained from Ministry of Transport Malaysia, Land Statistics (2013)

[b] Data obtained from Aizura et al. (2010)

[c] Data taken from Shabbir and Ahmad (2010)

[d] Data obtained from Jacobsen and Blarke (2007)

[e] Fuel economy of hybrid electric vehicles obtained from Samaras and Meisterling (2008) and expressed in km/MJ

[f] Fuel economy of biodiesel passenger vehicles obtained from Kalam and Masjuki (2002)

[g] Fuel economy of natural gas and biodiesel bus are assumed to be the same as that of petrol bus due to data constraints

[h] Fuel economy of petrol, natural gas and biodiesel goods vehicles are assumed to follow that of diesel goods vehicles due to data constraints

transport and travel demand per capita for the 2013–2040 period will simply be a continuation of the past trajectory.

Scenario 2: natural gas vehicles (NGV)
This scenario assumes that petrol and diesel engines each for all passenger cars, buses, taxis, hire and drive cars, goods vehicles and other vehicles (with the exception of motorcycles) will be substituted for natural gas with the percentage share of NGV reaching 15 % by 2025 and 30 % by 2040.

Scenario 3: hybrid electric vehicles (HEV)
This policy scenario assumes that by 2025, 5 % of all on-road vehicles (passenger cars, buses, taxis, hire and drive cars, goods vehicles and other vehicles with the exception of motorcycles) will be HEV and by 2040 this share of HEV will increase to 10 %.

Scenario 4: biodiesel vehicles (BIO)
The business-as-usual (BAU) scenario assumes no penetration of biodiesel in the fuel mix. However, in this policy scenario, it is assumed that there will be a mandatory implementation of the mixture of 10 % processed palm oil with 90 % diesel for all road transports running on diesel by 2025. This would be a mandatory B10 Program.

These assumptions of fuel share for each vehicle type under each of the alternative fuel policy scenarios have been provided in Supplementary Materials: Section C.

4 Results and discussion

The first part of this section provides the results of energy consumption. The second part discusses the results of emission of pollutants (CO_2, CO, NOx, NMVOC) from the road transport sector in Malaysia that has been attained from the LEAP model.

4.1 Forecast of energy consumption

The forecast of road transport energy consumption from 2012 till 2040 obtained from the LEAP model for the BAU, NGV, HEV and biodiesel vehicles (BIO) scenarios is presented in Figs. 3, 4, 5, 6 by sub grouping it under each vehicle running on each fuel category. Energy consumption in the base year 2012 for all four scenarios is estimated to be 25,172 thousand tonnes of oil equivalents (ttoe). In the BAU scenario, the energy consumption increases to the value of 94,170 ttoe in 2040. The compound annual growth rate (CAGR) of Malaysian road transport energy consumption from 2012 till 2040 in the BAU scenario is 4.8 %. Two other works have been identified in the existing literature for the purpose of comparing the CAGR value obtained from this study. An assessment report of the Intergovernmental Panel on Climate Change (Kahn Ribeiro et al. 2007) states that transport energy consumption in Malaysia would have a growth rate of above 3 % per year between 2002 and 2025 in a non-intervention scenario. Also another report by the International Energy Agency (2013) indicates that energy demand of the Malaysian transport sector will have a CAGR of 2.1 % from 2011 to 2035 in a continuation of existing policy scenario. These annual growth rates differ slightly from the rate attained in this study. The slight

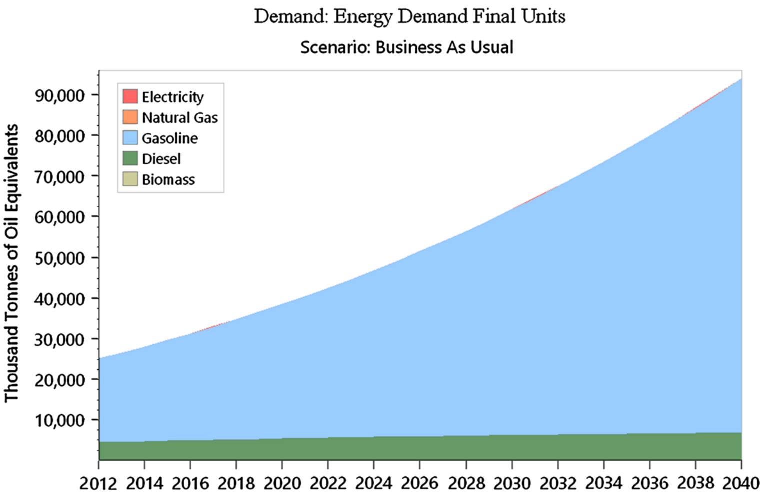

Fig. 3 Road transport energy consumption forecast in BAU (thousand tonnes of oil equivalents)

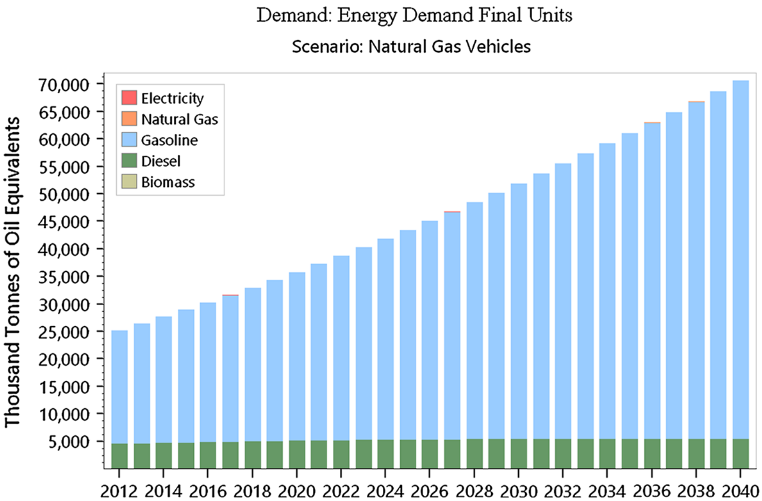

Fig. 4 Road transport energy consumption forecast in NGV (thousand tonnes of oil equivalents)

dissimilarity could be because these two studies took into consideration the entire transport sector of Malaysia, whereas this study only works with road transport energy consumption. Also the differences in the forecast time period considered can be attributed for the different growth rates.

It is also seen in the figures that energy consumption in BIO, HEV and NGV in the end year 2040 increases to the amount of 89,429, 90,488 and 70,608 ttoe, respectively. Among the alternative policy scenarios, the highest amount of increase in energy consumption during the forecast period takes place in HEV followed by BIO and NGV. Energy consumption in BIO, HEV and NGV has a CAGR of about 4.6, 4.7 and 3.8 %, respectively,

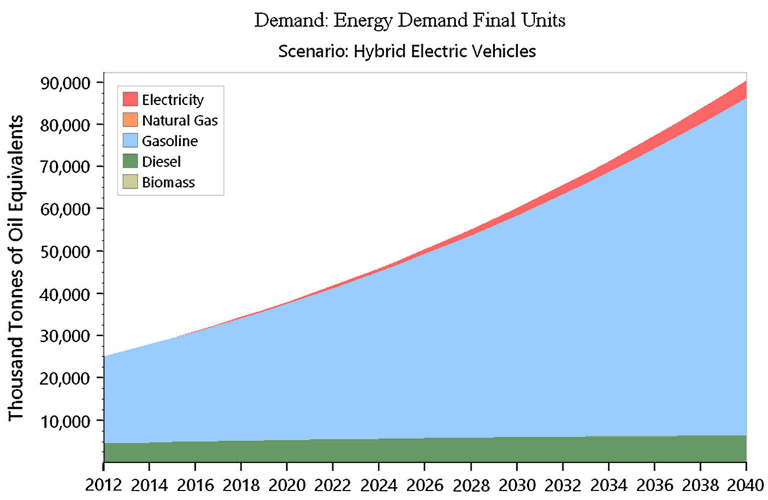

Fig. 5 Road transport energy consumption forecast in HEV (thousand tonnes of oil equivalents)

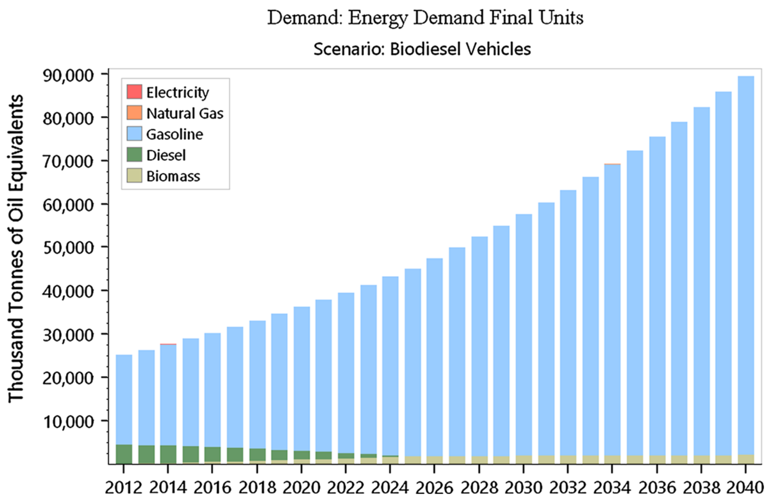

Fig. 6 Road transport energy consumption forecast in BIO (thousand tonnes of oil equivalents)

between 2012 and 2040. Results from LEAP evidences the fact that road transport energy consumption in Malaysia is projected to increase substantially in a BAU scenario or in other words if no policy interventions are introduced. This massive growth rate of energy consumption in the road transport sector in BAU is intuitive owing to rising income and vehicle ownership demand in Malaysia while maintaining reliance on the use of conventional fuel (Kasipillai and Chan 2008). If intervention policy measures are taken on the other hand, which is demonstrated by the outcomes from the alternative fuel policy scenarios, this growth rate can be limited to varied levels as has been specified above.

The volume and fuel composition pattern of road transport energy consumption in each of the scenarios are also depicted in Figs. 3, 4, 5, 6. The share of petrol and diesel in the total fuel consumption in the BAU in 2040 is poised to remain at 99.9 %. The implementation of HEV and NGV policies reduces this share to 95 and 99.8 %, respectively, in 2040. Electricity consumption from road transport in HEV reaches a share of 4.7 % of total fuel consumption by 2040. This percentage share in HEV is substantially larger than its BAU corresponding value of a mere 0.02 %. The share of natural gas as part of total energy consumption in NGV in 2040 is almost 0.04 %. Although substantially higher than the corresponding share in BAU, the diffusion of natural gas as a fuel source for road transport vehicles in the NGV scenario is highly minute and therefore more penetration would be required to see substantial increase in its share. In the BIO scenario, 2.3 % share of fuel consumption in 2040 comes from biodiesel. It is seen that the penetration of biodiesel is still quite low by the end of the forecast period. This is due to the fact that the portion of vehicles running on diesel is much lower than the portion of vehicles running on petrol in Malaysia, thus leaving out very few vehicles capable of utilizing biodiesel. Therefore another way to increase penetration of biofuel for road transport vehicles in Malaysia could be through blending biogasoline with gasoline such as bioethanol (Zhang et al. 2010).

Table 2 shows the mitigation potential for energy consumption for the alternative scenarios in comparison with the BAU scenario. The mitigation potential here is quantified as the reduction and percentage reduction in energy consumption in the alternative scenarios compared to the BAU scenario. It can be seen from the table that the highest reduction in energy consumption by 2040 relative to BAU is obtained in the NGV scenario, followed by BIO and then HEV.

Increasing the share of NGV offers the highest mitigation potential with a 25.02 % energy consumption reduction in 2040 relative to BAU scenario. When comparing with other end-year energy consumption reductions conducted in separate studies relating to a substitution to NGV scenario, Shabbir and Ahmad (2010) in their study in Pakistan estimated a decline of about 10.02 %. Also Ahanchian and Biona (2014) concluded that energy consumption would fall by approximately 5.5 % in the end year in Philippines. Results from this study indicate that the amount of energy savings through switching to NGV is substantial. Substitution to NGV would reduce its heavy reliance on traditional petroleum products. Additionally, due to the abundance of natural gas resource in Malaysia, the widespread usage of NGV would help to put a stop to the gradual decline of

Table 2 Reduction of road transport energy consumption in alternative scenarios compared to BAU (unit: thousand tonnes of oil equivalents)

	2015	2020	2025	2030	2035	2040
Business as usual	29,716.3	38,568.9	49,223.4	61,907.6	76,830.3	94,169.8
Biodiesel vehicles	28,937.8	36,259.7	45,153.3	57,573.3	72,275.5	89,428.6
Reduction	778.5	2309.2	4070.1	4334.3	4554.8	4741.2
Percentage reduction (%)	2.62	5.99	8.27	7.00	5.93	5.03
Hybrid electric vehicles	29,569.9	38,076.2	48,225.2	60,260.4	74,306.1	90,488.3
Reduction	146.4	492.7	998.2	1647.2	2524.2	3681.5
Percentage reduction (%)	0.49	1.28	2.03	2.66	3.29	3.91
Natural gas vehicles	28,918.9	35,774.4	43,347.4	51,889.2	61,045.6	70,608.1
Reduction	797.4	2794.6	5876	10,018.4	15,784.7	23,561.7
Percentage reduction (%)	2.68	7.25	11.94	16.18	20.54	25.02

the current account balance in Malaysia that has been occurring over the past few years. The government of Malaysia as mentioned previously has already been providing financial incentives to switch to NGV. These incentives could be further increased as benefits from the scheme seem to be considerably huge for the country.

Biodiesel vehicles achieve second highest mitigation of road transport energy consumption, and the percentage decrease in energy consumption in the last year 2040 is about 5.03 % compared to BAU. A comparable alternate scenario concerning only the application of biodiesel for road vehicles has not been found in other studies that have used LEAP. Henceforth, a comparison could not be made with the results obtained from the BIO scenario in this study. Biodiesel as a fuel source for the transport sector has to compete with the subsidized petroleum products in Malaysia, and therefore, strong government support would be required to ensure the survival of the biodiesel industry. Financial incentives need to be provided to the producers of biodiesel to keep investing and building appropriate infrastructure and furthermore to maintain local demand for biodiesel. Malaysian government needs to advocate strong enforcement to continue with the mandatory implementation of biodiesel blend in private diesel-powered transportation.

The lowest mitigation of road transport energy consumption occurs in the HEV scenario. In a study by Saisirirat et al. (2013) in Thailand, a scenario of electric vehicle penetration is considered where in the end year energy consumption falls by 4.51 %. In this study in the end year 2040, energy consumption declines by 3.91 % in HEV relative to BAU. Although the mitigation of road transport energy consumption is lowest in this scenario among the other fuel policy scenarios, electric vehicle technology could still be a viable policy option as it is a much cleaner fuel source and also contributes towards reducing oil dependence. Electricity as a fuel source for not only private transport but also public transport such as buses and urban rails should be considered. However, high penetration of electric vehicles among the general people would require large amount of subsidies from the government. Malaysia currently provides several tax exemptions for HEV. More amounts of subsidies would be essential if Malaysia wants to promote the usage of HEV.

In summary, results of the various mitigation potential of alternate fuel policy scenarios in this study denote that all these policy scenarios may contribute substantially towards reducing the dependence on traditional petroleum products while attaining energy security for the transport sector in Malaysia. It should be noted that the forecast values from this study do bear some uncertainty due to the assumptions considered among the variables. For example, as has been mentioned in Sect. 3.2, vehicle occupancy rate has been taken from a study conducted in another developing nation due to data constraints. Similarly, annual vehicle mileage has been considered the same for all modes of vehicles and is also assumed to remain the same for future years. This might not be the case in reality as different vehicle modes tend to have different travel distances and these distances are likely to change as the vehicles age. However, these forecast values still provide a good projection of road transport energy consumption in Malaysia under different fuel policy scenarios, which the policy makers can analyse and compare.

4.2 Forecast of emissions

This section provides the forecast of CO_2, CO, NOx and NMVOC emissions from 2012 till 2040 for all four policy scenarios.

4.2.1 Carbon dioxide (non-biogenic) (CO_2) emissions

The trend of CO_2 emissions for all the scenarios from 2012 to 2040 is shown in Fig. 7. CO_2 emission in the base year 2012 was 73,140 thousand metric tonnes CO_2 equivalent (CO_2e). Total emissions are poised to increase to 271,659 thousand metric tonnes CO_2e in 2040.

In the BIO, HEV and NGV scenarios, the estimated amount of emissions in 2040 is 256,899, 261,984 and 203,725 thousand metric tonnes of CO_2e, respectively. The average annual increase rate of CO_2 emissions in BAU, BIO, HEV and NGV is 4.8, 4.6, 4.7 and 3.7 %, respectively. The highest mitigation of CO_2e in comparison with BAU scenario is achieved in NGV followed by BIO and HEV consecutively. The percentage decrease in CO_2e emissions in the alternate scenarios relative to BAU is shown in Table 3.

4.2.2 Carbon monoxide (CO) emissions

Figure 8 depicts the pattern of CO emissions from 2012 to 2040. It starts off with 7121 thousand metric tonnes in 2012 for all scenarios. In the BAU, the amount increases to 29,540 thousand metric tonnes in 2040 with a CAGR of 5.2 %. Emissions for the alternate scenarios in 2040 are projected at 29,271, 27,043 and 22,068 thousand metric tonnes for BIO, HEV and NGV, sequentially. Emissions in BIO, HEV and NGV have a CAGR of about 5.18, 4.9 and 4.1 %, respectively. NGV is most successful in reducing CO emissions with respect to BAU trailed by HEV and then BIO. Table 4 provides the mitigation potential of alternative scenarios to reduce CO emissions.

4.2.3 Nitrogen oxides (NOx) emissions

The trend for NOx emissions from 2012 to 2040 is shown in Fig. 9. NOx emissions in the base year 2012 are 670 thousand metric tonnes. Emissions in the BAU, BIO, HEV and NGV are poised to rise to 2422, 2405, 2230 and 1818 thousand metric tonnes, respectively,

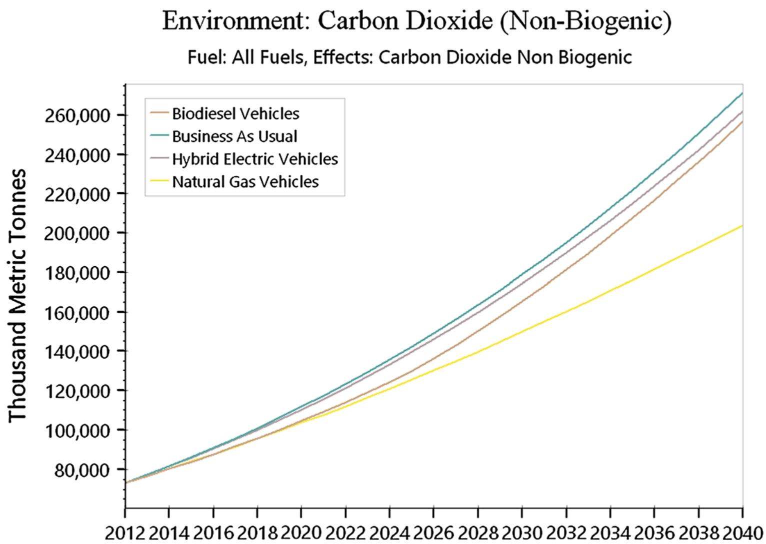

Fig. 7 Carbon dioxide (non-biogenic) emissions in each scenario

Table 3 Reduction of CO_2e emissions in alternative scenarios compared to BAU (unit: thousand metric tonnes)

	2015	2020	2025	2030	2035	2040
Business as usual	86,255.9	111,775.2	142,449.3	178,934.4	221,832.9	271,659.2
Biodiesel vehicles	83,832.8	104,587.1	129,779.3	165,441.7	207,653.7	256,899.2
Reduction	2423.1	7188.1	12,669.9	13,492.7	14,179.2	14,760.0
Percentage reduction (%)	2.81	6.43	8.89	7.54	6.39	5.43
Hybrid electric vehicles	85,856.9	110,443.6	139,773.2	174,551.6	215,161.1	261,984.3
Reduction	399.0	1331.6	2676.1	4382.8	6671.8	9674.9
Percentage reduction (%)	0.46	1.19	1.88	2.45	3.01	3.56
Natural gas vehicles	83,943.2	103,682.9	125,457.7	149,996.6	176,283.9	203,724.7
Reduction	2312.7	8092.3	16,991.6	28,937.8	45,549.0	67,934.5
Percentage reduction (%)	2.68	7.24	11.93	16.17	20.53	25.01

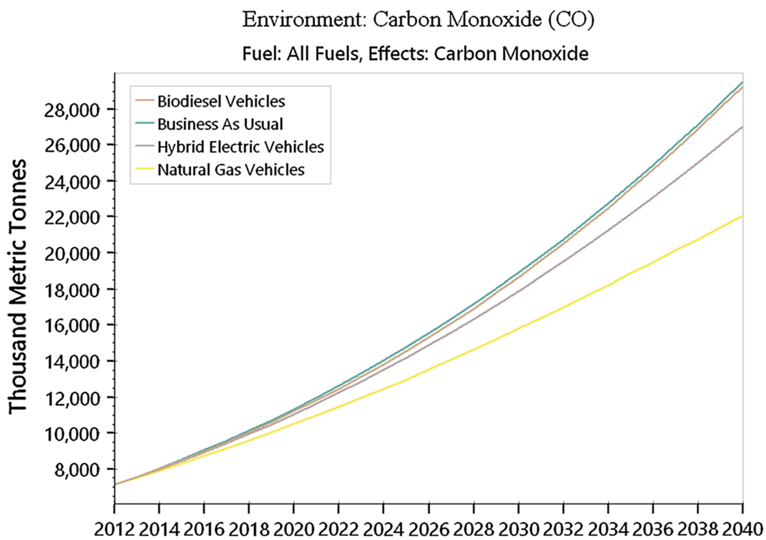

Fig. 8 Carbon monoxide emissions in each scenario

in 2040. The CAGR from 2012 to 2040 for BAU, BIO, HEV and NGV is 4.7, 4.67, 4.4 and 3.6 %, consecutively. The option that is most effective in reducing NOx emissions compared to BAU is again NGV. It is followed by HEV and last BIO. The percentage reduction in NOx emissions relative to BAU is detailed in Table 5 below.

4.2.4 Non-methane volatile organic compounds (NMVOC) emissions

Figure 10 illustrates the growth pattern of NMVOC emissions for each scenario from 2012 to 2040. Emissions for the base year 2012 for NMVOC are 1338 thousand metric tonnes under each scenario. The CAGR for the BAU is 5.2 % amounting to 5542 thousand metric

Table 4 Reduction of CO emissions in alternative scenarios compared to BAU (unit: thousand metric tonnes)

	2015	2020	2025	2030	2035	2040
Business as usual	8533.3	11,338.0	14,771.9	18,907.9	23,812.0	29,539.7
Biodiesel vehicles	8489.3	11,207.5	14,541.8	18,662.8	23,554.3	29,271.3
Reduction	44.0	130.5	230.1	245.1	257.7	268.4
Percentage reduction (%)	0.52	1.15	1.56	1.30	1.08	0.91
Hybrid electric vehicles	8454.6	11,056.9	14,170.7	17,868.8	22,155.5	27,043.2
Reduction	78.7	281.1	601.1	1039.2	1656.5	2496.4
Percentage reduction (%)	0.92	2.48	4.07	5.50	6.96	8.45
Natural gas vehicles	8300.5	10,503.5	12,982.1	15,808.5	18,862.3	22,067.9
Reduction	232.8	834.5	1789.8	3099.5	4949.7	7471.8
Percentage reduction (%)	2.73	7.36	12.12	16.39	20.79	25.29

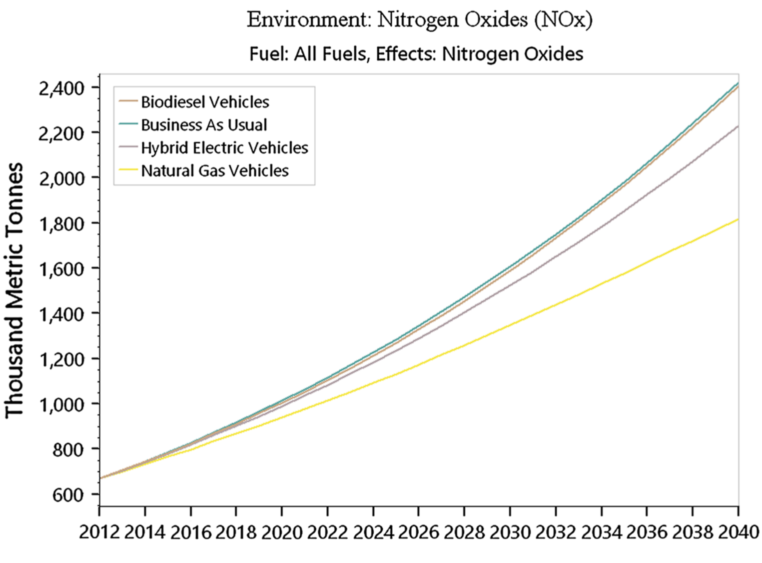

Fig. 9 Nitrogen oxides emissions in each scenario

tonnes in 2040. Emissions for the BIO, HEV and NGV show a CAGR of about 5.17, 4.9 and 4.1 %, respectively. Emissions for all these scenarios are expected to rise to 5487, 5084 and 4141 thousand metric tonnes in 2040, correspondingly. Similar to all other policy scenarios, NMVOC emissions attained the highest reduction in the NGV relative to BAU. The descending sequence of emission reduction potential of alternative policies is NGV, HEV and BIO. This mitigation potential is presented in Table 6.

In summary, NGV result in the highest reduction in emissions for all four pollutants. The reduction for every pollutant compared to the BAU reaches above 25 % in this scenario. In the context of CO_2 emissions reduction, biodiesel vehicles fall in second place, while HEV obtain the last position. It is probably unusual for HEV to have the lowest

Table 5 Reduction of NOx emissions in alternative scenarios compared to BAU (unit: thousand metric tonnes)

	2015	2020	2025	2030	2035	2040
Business as usual	786.7	1013.7	1285.1	1606.9	1984.4	2422.3
Biodiesel vehicles	783.7	1004.6	1269.3	1590.3	1967.3	2404.7
Reduction	3.1	9.1	15.8	16.6	17.2	17.6
Percentage reduction (%)	0.39	0.89	1.23	1.03	0.87	0.73
Hybrid electric vehicles	780.0	990.2	1236.3	1524.2	1854.9	2229.9
Reduction	6.8	23.4	48.9	82.7	129.5	192.3
Percentage reduction (%)	0.86	2.31	3.80	5.15	6.53	7.94
Natural gas vehicles	765.7	940.5	1132.4	1347.8	1578.1	1818.2
Reduction	21.0	73.1	152.8	259.1	406.3	604.1
Percentage reduction (%)	2.67	7.21	11.89	16.12	20.47	24.94

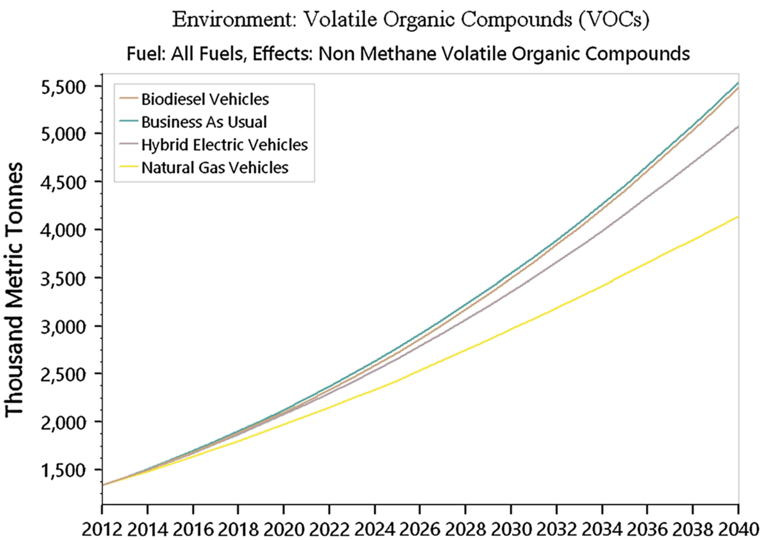

Fig. 10 Non-methane volatile organic compound emissions in each scenario

mitigation of CO_2 emission and have total emission much higher than NGV. A possible reason for these emission results could be because the scenario of NGV assumes a far higher penetration than the penetration share assumed in HEV scenario. Also HEV are not completely electric but rather use both petrol and electricity to power the engine. On the other hand, HEV give the second highest mitigation and biodiesel vehicles the lowest mitigation for CO, NOx and NMVOC emissions. Referring to NOx emission, it is generally observed that emission increases with the use of biodiesel (Hoekman and Robbins 2012). However, similar to the results found in this study, there are a few studies such as Nagaraju et al. (2008), Lapuerta et al. (2005) and Dorado et al. (2003) where biodiesel is found to decrease NOx emission compared to diesel. So in the end, although comparatively

Table 6 Reduction of NMVOC emissions in alternative scenarios compared to BAU (unit: thousand metric tonnes)

	2015	2020	2025	2030	2035	2040
Business as usual	1602.5	2128.7	2772.8	3548.5	4468.2	5542.3
Biodiesel vehicles	1593.4	2101.7	2725.2	3497.8	4414.9	5486.7
Reduction	9.1	27.0	47.6	50.7	53.3	55.5
Percentage reduction (%)	0.57	1.27	1.72	1.43	1.19	1.00
Hybrid electric vehicles	1588.1	2077.0	2662.3	3357.7	4164.1	5084.1
Reduction	14.5	51.7	110.5	190.9	304.1	458.2
Percentage reduction (%)	0.90	2.43	3.98	5.38	6.81	8.27
Natural gas vehicles	1558.8	1972.1	2436.9	2966.9	3539.5	4140.5
Reduction	43.7	156.7	335.9	581.6	928.7	1401.8
Percentage reduction (%)	2.73	7.36	12.11	16.39	20.79	25.29

lower, the two scenarios of HEV and biodiesel vehicles do reduce emissions relative to the BAU and are therefore useful to control air quality and mitigate climate change. The Prime Minister of Malaysia has voluntarily set a target to reduce the GHG emission intensity of GDP by up to 40 % of 2005 levels by 2020 subject to technology transfer and financial support during COP 15 in Copenhagen (Ministry of Natural Resources and Environment Malaysia 2011). These alternate fuel policies for the road transport can be beneficial policy options for the Malaysian government to consider if the aim of reducing the GHG emission intensity of GDP is to be achieved.

5 Conclusion

The transportation sector consumes the highest energy among all economic sectors of Malaysia. Consequently, it is also one of the leading emitters of GHG pollutants in the country, thus creating a significant impact on pollution and climate change. This sector would therefore have to be a key player to achieve substantial reductions in GHG emission intensity of GDP for Malaysia. This study estimated and forecasted energy consumption and emission of pollutants (CO_2, CO, NOx, NMVOC) from the road transport sector of Malaysia from 2012 till 2040 using the LEAP model under four fuel policy scenarios. The purpose of this study is to evaluate the potential of alternative fuel policies to reduce energy consumption and emissions. Results indicate that with the continuation of current trends and absence of new policy measures, total road sector energy consumption from 2012 to 2040 will increase by about 3.7 times. However, implementing alternative fuel policies can reduce energy consumption to some extent. The greatest reduction in energy consumption is possible through increasing the usage of NGV with a reduction of 25 % in 2040 relative to the BAU scenario. This is followed by BIO and then HEV. The rank order of alternate fuel policies from the highest to lowest mitigation potential of CO_2 emissions is also NGV, BIO and HEV. This rank order for CO, NOx and NMVOC emissions is NGV, HEV and BIO. The findings from this study signify that rising energy consumption and emission from the road transport in Malaysia can be limited if alternative fuel policy measures are imposed. The outcome from this study can be useful for policymakers for strategizing and implementing alternative fuel policies for the road transport sector in order to reduce consumption of traditional petroleum products, thereby attaining energy security. Additionally, results from this study would help device fuel policies for the purpose of reducing emission which can contribute towards achieving pollution control and climate change mitigation. It is important to note that this study utilizes a technical-engineering approach where the focus was on the effect of alternative policies on energy consumption and pollutant emissions. There has been no attempt to consider the cost efficiency or benefit–cost analysis of alternative policies.

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