Analysis of CO₂ emissions reduction in the Malaysian transportation sector: An optimisation approach

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HIGHLIGHTS

- An optimisation model for CO₂ emissions reduction in Malaysia’s road transport is formulated.
- Sensible policy options to achieve the CO₂ emissions reduction target are provided.
- Increase in fuel price has induced shift towards fuel efficient vehicles.
- The CO₂ emissions can be reduced up to 5.7 MtCO₂ with combination of mitigation policies.

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ABSTRACT

The demand for transport services is expected to rise, causing the CO₂ emissions level to increase as well. In Malaysia, the transportation sector accounts for 28% of total CO₂ emissions, of which 85% comes from road transport. By 2020, Malaysia is targeting a reduction in CO₂ emissions intensity by up to 40% and in this effort the role of road transport is paramount. This paper attempts to investigate effective policy options that can assist Malaysia in reducing the CO₂ emissions level. An Optimisation model is developed to estimate the potential CO₂ emissions mitigation strategies for road transport by minimising the CO₂ emissions under the constraint of fuel cost and demand travel. Several mitigation strategies have been applied to analyse the effect of CO₂ emissions reduction potential. The results demonstrate that removal of fuel price subsidies can result in reductions of up to 652 ktonnes of fuel consumption and CO₂ emissions can be decreased by 6.55%, which would enable Malaysia to hit its target by 2020. CO₂ emissions can be reduced significantly, up to 20%, by employing a combination of mitigation policies in Malaysia. This suggests that appropriate mitigation policies can assist the country in its quest to achieve the CO₂ emissions reduction target.

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1. Introduction

Climate change emanating from CO₂ emissions has emerged as the most challenging environmental problem in recent decades. Global CO₂ emissions have increased rapidly over the years as a result of increasing energy consumption boosted by rapid economic growth in many countries. This has led to significant changes in temperature and precipitation patterns and has had serious environmental consequences, such as increased frequency of floods, storms and droughts and a rise in sea level and global temperatures (IPCC, 2007; Stern, 2009; Safaai et al., 2010). Intrinsically, a considerable reduction in CO₂ emissions is needed to avoid disastrous consequences. Hence, a move towards a lower carbon economy is highly desirable. Worldwide, the annual CO₂ emissions must be reduced by an estimated 50–80% by 2050 to alleviate the destructive climate change impacts (IPCC, 2007).

As the increase in CO₂ emissions has become an important global issue, many countries, including Malaysia, have played active roles in the effort to reduce such emissions by supporting national mitigation actions and intergovernmental mechanisms, particularly the United Nations Framework Convention on Climate Change (UNFCCC), a non-binding agreement aimed at reducing CO₂ emissions. In 2009, at the 15th Conference of Parties (COP15) in Copenhagen, Malaysia stated a voluntary target of reducing its CO₂ emissions intensity by 40% (based on its 2005 levels) by 2020. The move towards high-income and developed nation status by 2020 (EPU, 2010) is a challenge for Malaysia. This is because, as the country progresses, the demand for energy will increase in
tandem, which will directly result in an increase in CO₂ emissions. Fig. 1 shows that the gross domestic product (GDP) and CO₂ emissions annual growth rate stand at 5.2% and 6%, respectively. This suggests that the CO₂ emissions in Malaysia increase in line with GDP growth.

The transport sector is an important segment of the economy and its rapid development has contributed significantly to the socioeconomic development of the country. In fact, conflicts are ever increasing between the goals of fulfilling society’s mobility needs and improving the quality of the environment (Rawshan et al., 2015). The global transportation sector is responsible for 23% of global CO₂ emissions and its rate of increase is faster than any other energy-related sector (IEA, 2012). A recent study proved that transportation will be the highest potential contributor to environmental problems in the near future (Unger et al., 2010). It is thus essential for transport to become a top priority so as to achieve the targets for CO₂ emissions reduction.

One study also suggests a positive relationship between income, GDP and demand for transportation (Dargay and Gately, 1999). This is particularly true in Malaysia as increasing GDP and income has made private motor vehicles more affordable, leading to an increased demand for transport services (Kasipillai and Chan, 2008).

Consequently, due to the aforementioned concerns on growing fuel consumption in road transportation and CO₂ emissions, a study is needed to investigate effective policy options in the context of Malaysia. In recent years, a few studies have been carried out in this regard (Ong et al., 2011, 2012; Almselati et al., 2011; Indati et al., 2013; Hosseini et al., 2013; Indati and Bekhet, 2014; Shahid et al., 2014). However, these studies are still in their infancy and empirical results regarding meeting the CO₂ emissions reduction target in the road transportation sector in Malaysia is rather limited. Driven by the desire to investigate the optimal level of CO₂ emissions that can be reduced from Malaysia’s road transportation, the intended contribution of the study is to estimate the potential CO₂ emissions reduction when moving from business-as-usual scenario to a low-carbon scenario by using optimisation approach. Various policy options are presented so that the potential CO₂ emissions reduction target can be compared and effective road transport strategies can be determined.

The rest of this paper is structured as follows: Section 2 sets out the current status of Malaysian transport sector, including its impact on the CO₂ emissions as well as highlighting the need to achieve CO₂ emissions reduction target. Section 3 discusses the past empirical analyses of CO₂ emissions reduction using various models in various sectors. Section 4 describes the data sources and the methodologies for model development. The empirical findings are discussed in Section 5. Finally, Section 6 presents the conclusions and policy implications drawn from the results of the study.

2. Malaysian transport sector

The number of motor vehicles in Malaysia increased by 7.4% per annum from about 5 million in 1990 to 23.7 million in 2013 (MOT, 2013). The insufficient public transportation infrastructure has also aided the ever increasing motor vehicle population. In 2013, motor cars and motorcycles together accounted for about 92% of the vehicles in the country. On the other hand, public transportation modes in Malaysia have only an 8% share of the total registered vehicles. The share of public transport in cities has declined continuously from 34% in 1985 to 20% in 1997 and is now close to 10–12% (Ong et al., 2012). Such undeveloped public transportation and high mobility caused a rapid increase in private vehicles (IEA, 2012). Moreover, an increasing population and urbanisation also contributed to the rapid increase in vehicle numbers. In fact, as shown in Fig. 2, growth in the number of vehicles in the country has been much faster than growth in the population; while the total population increased by 2.5% per annum for the 1990–2013 period, the number of vehicles in the country increased by 8.6% per annum in the same period. As more than 80% of vehicles still run on petroleum fuels, this growth in the vehicle population has
resulted in a significant increase in fuel demand and CO₂ emissions.

The transportation sector relies primarily on petroleum fuels. Presently, this sector consumes about 36% of the total energy, largely in road transportation modes (Kamarudin et al., 2009; Lim and Lee, 2012). The heavy reliance of the transport sector on petroleum products, especially petrol and diesel, is a worrying trend for the future in terms of energy security and CO₂ emissions contribution (Silitonga et al., 2012; Mo'fleh et al., 2010). As indicated in Fig. 3, the CO₂ emissions in Malaysia’s energy sector have increased over the years. In 2012, 196 million tonnes (Mtonnes) of CO₂ emissions were emitted from the energy sector (IEA, 2014b). Electricity generation, transport, manufacturing and other (residential, commercial and agriculture) are the major sectors contributing to CO₂ emissions in the country. Electricity generation, transport, manufacturing and other sectors contributed 46%, 22%, 19% and 13% of the total CO₂ emissions, respectively.

Fig. 4 shows the share of CO₂ emissions by transportation mode in the transportation sector. Road transportation accounts for the largest share with 85.2% of total CO₂ emissions, followed by aviation, maritime and rail. Fig. 5 shows the contribution of different road vehicles in CO₂ emissions and demonstrates that private vehicles (motorcars and motorcycles) represent the largest share of CO₂ emitters, with about 70% of the total road transportation sector (Ong et al., 2011). Thus, one can deduce that in the light of unprecedented growth in the prevalence of private cars and the projected increase for transport services, the road transport sector will be a pivotal sector in any strategy of CO₂ emissions reduction.

Achieving higher GDP and at the same time reducing CO₂ emissions is a daunting task. With a growing economy that may require emissions to rise, an absolute limit on CO₂ emissions release is needed. Table 1 shows the estimated CO₂ emissions reduction target as planned by the government. The NRE (2011) reported that the total CO₂ emissions must be limited to about 335 Mtonnes. However, based on an expected growth in GDP of 5% per annum (2000–2020), CO₂ emissions are projected to reach 375 Mtonnes. The plan is, therefore, to reduce about 40 Mtonnes of CO₂ emissions from all economic sectors by 2020. For the transportation sector, CO₂ emissions should be reduced by 8.27 Mtonnes, from 77.61 Mtonnes (2.9% per annum) to 69.33 Mtonnes, to meet the 40% CO₂ emissions intensity reduction target.

One can deduce that Malaysia will not be able to meet its target of CO₂ intensity reduction. However, the target is still achievable with reductions in growth in total CO₂ emissions from the energy-consuming sectors. Several studies have examined mitigation options for CO₂ emissions reduction (Beuno, 2012; Leighty et al., 2012; Ashina et al., 2012; Baños et al., 2011; Ou et al., 2010; Zanni and Bristow, 2010; Mo'fleh et al., 2010; Erdmenger et al., 2009; Kannan and Strachan (2009); Timilsina and Shrestha, 2009). They have suggested the need for radical mitigation measures, such as using alternative technologies, reducing mobility, eliminating fuel subsidies and increasing energy efficiency, to achieve substantial CO₂ emissions reductions in the transportation sector.

3. Literature review

Many studies in various countries have analysed the CO₂ emissions and implementing mitigation policies and sustainable energy planning for emissions reduction. To reduce CO₂ emissions, different types of energy models have been used to quantify the benefits and cost by employing certain policy measures based on the economic situation in a particular country. Consequently, various related methodologies and applications related to CO₂ emissions reduction planning are reviewed. Perspectives on the effective measures of different methods are discussed, demonstrating numerous CO₂ emissions reduction options in different energy fields. Indeed, the choice of solution varies depending on the methods and the researcher's solicitation.

Several researchers have used an econometric model for energy planning analysis. For instance, Marrero (2010) found that the
impact of CO2 emissions reduction depends on the choice of fuel mix, and significant use of renewable energy provides great reductions in emissions. Pongthanaisawan and Sorapiatana (2013) developed an econometric model to estimate the energy demand and CO2 emissions in the transport sector. The study concluded that fuel switching options and energy efficiency improvement options are effective in reducing CO2 emissions. Using a similar model, Klier and Linn (2013) statistically found that fuel price is an effective instrument for reducing the CO2 emissions level in several European countries. Correspondingly, Sultan (2010) found a strong relationship between income per capita and fuel price, while Bozkurt and Akan (2014), Bekhet and Ivy (2014), Ivy and Bekhet (2014), Wang et al. (2011), Azlina and Mustapha (2012), Bekhet and Yusop (2009), Ang (2008) and Ediger and Akar (2007) found a long-term relationship between energy consumption and CO2 emissions. Rawshan et al. (2015) studied the impact of GDP, fuel consumption and population growth on the CO2 emissions in Malaysia and suggested that low-carbon technologies reduce growth in CO2 emissions.

A number of Optimisation models has also been developed to facilitate sustainable energy planning. Lou et al. (1995), for instance, used linear programming analysis for the optimal arrangement of pollution control equipment in various pollution sources. Jhebaraj et al. (2008), Muslu (2004) and Limabu and Rrome (2002) used a linear programming model to investigate effective fuel cost and environmental impacts for the energy sector. Bai and Wei (1996) and Wang et al. (2008) formulated a linear programming model to investigate the cost-effectiveness of possible CO2 mitigation options for the electricity sector and steel industry sector, respectively.

In addition, Hashim et al. (2005) developed a mixed integer linear programming model and studied the effects of fuel switching and fuel balancing options on power generation. Three modes (economic, environmental and integrated) were applied to the Ontario electricity generation plant. Their results suggested that fuel switching has a major effect on overall CO2 emissions reductions and that integrated modes offer the best option to reduce CO2 emissions. Muis et al. (2010) also formulated a mixed integer linear programming model to meet electricity demand within CO2 constraints at minimal cost. Hongbo et al. (2010) developed a multi-objective optimisation to analyse the optimal operation strategy for a distributed energy resource system to find a solution that is both cost-effective and less polluting. As a case study, Tan et al. (2013) used mixed integer linear programming analysis for the optimal planning of waste to energy that minimises electricity generation costs and CO2 emissions for Iskandar Malaysia.

Other research has investigated energy planning in the transportation sector. Pan et al. (2013), for instance, used mixed integer programming with an objective of minimising the CO2 emissions in the freight transport sector. This study concluded that a significant CO2 emissions reduction could be achieved by merging supply chains in the road and rail sectors. Johanssons (2009) and Gao and Stasko (2009) used a linear programming model to evaluate the cost-effectiveness of fuel and technology choices that can meet a given limitation on fuel resources and CO2 emissions in the transport sector. Kamarudin et al. (2009) also developed a linear programming model to determine the minimum cost and optimum hydrogen delivery network in Peninsular Malaysia.

In terms of other modelling approaches, Hickman et al. (2010) developed the Transport and Carbon Simulation Model (TC-SIM) to explore effective policy options to reduce CO2 emissions in the transport sector in London. They emphasised that low-carbon vehicle technologies remain the most important policy measures and suggested that behavioural change, supported with an effective policy package, would be an important means for CO2 emissions reduction. On the other hand, Ong et al. (2011) employed the Computer Programme to Calculate Emissions from Road Transport (COPERT 4) model to examine public transportation as a means of mitigation of greenhouse gas emissions in the road transport sector. The study suggested that promotion of natural gas vehicles and fleet renewal will contribute towards emission reduction in Malaysia. Yang et al. (2015), Ichinohe and Endo (2010), Ichinohe and Endo (2006) and Gielen and Changhong (2001) applied the Market Allocation (MARKAL/TIMES) model to analyse the CO2 emissions reduction effect and cost competitiveness of energy technology. Mattila and Antikainen (2011) used a backcasting model and found that fuel efficiency, vehicle technology improvement and alternative fuel use can substantially reduce CO2 emissions in freight transportation. Pasagolu et al. (2012) developed a technical economic model based on the descriptive approach to analyse the CO2 emissions reduction from the road sector in Europe. They found that a combination of alternative fuels, deployment of efficient vehicles and technological improvement could decrease CO2 emissions by up to 57% from 2010 levels.

One can see from these studies that the econometric model and Optimisation modelling for CO2 emissions reduction in energy planning have been widely used in various fields. The Optimisation model appears to be an interesting approach motivated by its effectiveness in evaluating mitigation options for optimal CO2 emissions reduction (Ziolkowska, 2014; Kim et al., 2014; Baños et al., 2011). Builds on the desire of the country for CO2 emissions reduction target, this paper aims to develop a least CO2 emission model to investigate the CO2 emissions reduction potential of deploying a range of mitigation measures in the road transport sector. When considered in conjunction with the least emissions model, this allow a simple sector-specific assessment of CO2 emissions reduction of each vehicle technology and measures in the sector rather than according to least cost. Whilst the least cost provide cost minimisation and the corresponding CO2 emissions reduction, this least emissions by contrast, allows the investigation of the policy changes impact on the optimal CO2 emissions reduction of changing particular assumptions (such as fuel prices,
technical fuel efficiency and technological changes) in the road transport sector. This type of analysis could serve as a useful tool to help policy makers decide which mitigation strategies are most important to reduce road transport CO₂ emissions.

4. Data source and methodology

4.1. Data sources

In this study, the analysis of optimal CO₂ emissions reduction is scoped on only the road transport sector in Malaysia. The vehicle type covers only passenger vehicles, such as motorcars, taxis, hire and drive cars, buses and motorcycles. The conventional drivetrain types are based on three different fuels: petrol, diesel and natural gas. The composition of the road transport sector in the study is depicted in Table 2.

The latest total fuel consumption from transport sector data for the year 2012 was used due to the lack of fuel statistics by transport sub-sectors. The estimated total fuel consumption from passenger vehicles in the road transport sector in 2012 was 9350 ktoe and the CO₂ emissions was 28.29 Mtonnes (Indati and Bekhet, 2014). This information is used as the reference case and the details of the data are shown in Table 3.

Several factors affect the CO₂ emissions level in the road transport sector. In this study, travel demand (Bueno, 2012), fuel efficiency (IEA, 2012; Aizura et al., 2011; Pieczyk and McKinnon, 2010), fuel price (Klier and Linn, 2013) and fuel consumption (Wang et al., 2011) are considered the significant factors affecting the CO₂ emissions level. Consequently, the data with regard to these factors have been collected and estimated from various official data sources and studies, as presented in Table 4.

4.2. Methodology

In principle, CO₂ emissions depend on energy used from different vehicle technologies and the specific CO₂ emissions coefficient of different fuels used. The intended contribution of the study is generally to estimate the potential CO₂ emissions reduction when moving from business-as-usual scenario to a low-carbon scenario by using optimisation approach. In the proposed sector-specific model, the optimisation model minimise CO₂ emissions and maximise efficiency of fuels consumption and vehicle technologies. The model provide least emission optimised technology mix to reduce CO₂ emissions while satisfying the constraints involved in the road transport. The schematic representation of the model is shown in Fig. 6.

4.3. Objective function

For the current paper, the approach elaborated in Hashim et al. (2005) and Bai and Wei (1996) is used. This is due to similarity that builds on the objective function of the optimal level of CO₂ emissions reduction as illustrated in Fig. 6. The model has been modified to represent the energy used in the road transportation structure which includes breadth of different drivetrain options and vehicle types, as shown in Table 2. The total CO₂ emissions is a function of emissions associated with various energy uses of vehicle technologies in the road sector (which is based on three different drivetrain types: d=diesel, p=petrol and n=natural gas). Accordingly, the objective function of the CO₂ emissions reduction model is formulated as in Eq. (1).

\[
\text{Minimise } CO_2 = \sum_{i=1}^{3} \sum_{j=1}^{6} e_i f_{ij} + \sum_{i=4}^{6} \sum_{j=1}^{8} e_{ij} f_{ij} + \sum_{i=7}^{8} \sum_{j=1}^{8} e_{ij} f_{ij}
\]  

\[
(1)
\]

CO₂ is the total CO₂ emissions from the road transport sector where \(e_i\) is the coefficient of CO₂ emissions per unit of energy consumed by each drivetrain type \(i\) (which depends on the fuel used) and \(f_{ij}\) is the energy consumption for vehicle type \(i\) and drivetrain type \(j\).

4.3.1. Constraints

The total CO₂ emissions are minimised subject to a set of constraints that describes various factors and their interactions for reduction of CO₂ emissions. Useful constraints are developed with respect to demand satisfaction for transport mobility and fuel cost, which both reflect the economic factors, and lower/upper bound constraints, which reflect the technical factors (Liu et al., 2013; Hashim et al., 2005). The objective function given in Eq. (1) is subjected to four constraints as follows:

4.3.1.1. Travel demand satisfaction constraint. The model is optimised for satisfying travel demand in the road transport sector. Therefore, it is necessary to set travel demand as the total energy demand requirement by vehicle technologies in the road transport sector. The total travel demand is associated with different types of technologies, fuel efficiency and occupancy level (Bueno, 2012). The total travel demand, \(T\), was calculated by multiplying the vehicle number \((V_{ij})\) by fuel efficiency \((Y_{ij})\) and by occupancy level \((O_{ij})\). This is represented in Eq. (2).

\[
T = \sum_{i=1}^{5} \sum_{j=1}^{3} V_{ij} \times Y_{ij} \times O_{ij}
\]  

\[
(2)
\]

where \(i\) is the vehicle type and \(j\) is the drivetrain type (which depends on the fuel used) in the model. The exogenous total travel demand \((T)\) [Eq. (2)] must be satisfied and hence the sum of the distance travel, \(d_{ij}\), must be greater than or equal to the total demand in the road transport sector, \(T\), as shown in Eq. (3):

\[
\sum_{i=1}^{5} \sum_{j=1}^{3} d_{ij} \geq T
\]  

\[
(3)
\]
Table 4
Variables, description and sources.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel efficiency (y)</td>
<td>Average fuel efficiency by vehicle technology.</td>
<td>km/liters</td>
<td></td>
</tr>
<tr>
<td>Fuel consumption (f)</td>
<td>Fuel consumption by type of fuel.</td>
<td>ktoe (kilotonne of oil equivalent)</td>
<td></td>
</tr>
</tbody>
</table>

Note: The data and assumptions used in the model are summarised in Appendix A.

At present, an upper bound is set for each competing vehicle technology based on fuel demand shares in the market. This constraint is formulated to prevent efficient vehicle technology from exceeding a particular demand share in the road transport sector (Kim et al., 2014). A lower bound for diesel vehicles and natural gas vehicles is set in the model. This constraint is formulated to ensure minimum availability of certain vehicle technology in the road transport sector (Kim et al., 2014).

\[ \text{Min} f_{ij} \leq f_{ij} \leq \text{Max} f_{ij} \quad \forall \ ij \]  

where, \( i \) is the vehicle type and \( j \) is the drivetrain type (which depends on the fuel used) in the model. In Eq. (6), the energy consumption, \( f_{ij} \), must not exceed the upper bound, Max, which represents the maximum level of consumption of \( f_{ij} \) that can be operated in the sector. Also, the energy consumption, \( f_{ij} \), must be greater than some minimum, Min; otherwise, the vehicle technology will not be chosen. The lower bound, Min, represents the minimum level of consumption of \( f_{ij} \) that will be operated in the sector.

4.3.1.4. Non-negativity constraint. This constraint ensures that \( f_{ij} \), the energy consumption from all vehicle types, \( i \) and drivetrain \( j \) are greater than zero; hence, the amount of fuel consumed from all vehicle technologies is defined as positive/non-negative variables.

\[ f_{ij} \geq 0 \quad \forall \ ij \]  

5. Results and discussion

The results from the CO2 emissions reduction model are shown in Table 5. In the analysis, with present market price level, the optimal CO2 emissions reduction can be achieved by switching the vehicle technologies to less emitting and more efficient technologies in meeting the transport demand. Table 5 shows that the share of CO2 emissions from petrol vehicles (cars and motorcycles) remains the same at 92.8%. However, petrol cars have lost share to motorcycles. The share of CO2 emissions from motorcycles has increased by 15.6% while the share of cars has declined by 16.4%. These results follow from the assumptions made regarding the relative distance travel per vehicle for motorcycles, which is higher than for passenger cars (Yan and Crookes, 2009). On the other hand, for diesel and natural gas vehicles, the optimal share among competing technologies produced almost the same amount of CO2 emissions, as in the reference case. The diesel and natural gas vehicle technology contributed about 5.2% and 2.7% of total CO2 emissions, respectively. Notwithstanding that the fuel price of diesel and natural gas vehicles is much lower than for petrol vehicles, the vehicle technology mix remains the same due to fuel availability and market constraints imposed on these vehicles in the model (Kim et al., 2014). Overall, 6.55% of CO2 emissions are reduced.
6. Sensitivity analysis

In practice, CO₂ emissions reductions can also be achieved through the substitution of low-carbon alternative fuel vehicles, most notably through biofuel blending, improving fuel efficiency through increased CO₂ intensity of fuels (increased kilometre travel per unit of fuel use) as well as technology and travel demand improvements. To investigate the implications of these options on the CO₂ emissions reduction level, a scenario and sensitivity analysis was conducted and is summarised in Table 7.

The impact of post optimality analysis on the CO₂ emissions level is discussed below.

6.1. Alternative fuel use

The results of undertaking sensitivity analysis on the alternative fuel use (see Table 7) are shown in Fig. 7, which illustrates the influence of B5 in diesel vehicle types and E10 in petrol vehicle types on the CO₂ emissions level. As expected, one can observe that a switch to low-carbon fuels can decrease the CO₂ emissions level (Yee et al., 2011; Lim and Lee, 2012). The results show that a reduction of CO₂ emissions by 6.7% to 26.4 Mtonnes can be achieved by using B5. Moreover, if E10 is used, the CO₂ emissions reduction would increase further by 15.1% to 24.03 Mtonnes. The introduction of E10 significantly reduced the amount of CO₂ emissions due to the higher share of petrol vehicles (93%) in the country. Furthermore, if both B5 and E10 are used, the CO₂ emissions reduction would slightly increase by 15.3% to 23.96 Mtonnes.

6.2. Fuel efficiency improvement

The results of the fuel efficiency improvement (Table 7) are shown in Fig. 8. The low level of fuel efficiency improvement for petrol vehicle (3.33%) and diesel (3.33%) vehicle technologies could reduce the CO₂ emissions level in the road transport sector by 7.2% while meeting the travel demand. The high level of fuel efficiency improvement in petrol (5.21%) and diesel (4.11%) vehicle technologies could reduce the CO₂ emissions level by 7.9% without affecting the travel demand. The benefit of improving fuel efficiency, which lowers the per kilometre fuel for travel, lies in the fact that it would tend to boost the travel demand (Yan and Crookes, 2009). However, due to the constraints on satisfying the travel demand and fuel supply in the model, improvement of fuel efficiency yields a reduction in total fuel consumption, which results in an increase in CO₂ emissions reduction.

Furthermore, because of zero tailpipe emissions from electric vehicles (EVs), the analysis shows that the CO₂ emissions level in the road transport sector would decrease by 6.31% while meeting the travel demand. A reduction in CO₂ emissions is clear with the introduction of EVs. This reduction from EVs would be higher if more EVs were used in the market.

6.3. Travel demand improvement

Fig. 9 shows the result of the travel demand improvement scenario (Table 7). One can see that increasing the public share by 10% results in a changed pattern of energy usage whereby the replacement of petrol cars with public transport (taxis and buses) will occur in the vehicle mix while meeting the mobility needs.
The effect of CO2 emissions level by increasing share of public transporta-
Fig. 9. The effect of CO2 emissions level by increasing share of public transportation. Source: optimal solution obtained from modelling results by authors.

These results follow from the assumptions that petrol cars consume more fuel than taxis and buses with the same passenger-km or distance travel (Ong et al., 2011; Yan and Crookes, 2009). This response created savings in energy consumption and reductions in CO2 emissions of 10.8% and 9.5%, respectively.

6.4. Fuel pricing

Fuel price is an important measure to reduce CO2 emissions. Fig. 10 shows the results of this scenario (see Table 7). The results show that a fuel price increase at market price can reduce CO2 emissions by 6.55%. Also, the results reveal that if the current fuel price is reduced to a subsidies price (a reduction of diesel price by 20% and petrol price by 36.4% from the fuel price used in the current model), the travel demand and CO2 emissions level will increase by 1.3% and 0.5%, respectively, from their current levels. Undoubtedly, a decrease in fuel price will tend to increase the travel demand (Herring, 2006), which increases the CO2 emissions level.

The fuel pricing policy demonstrates that it is an effective instrument in reducing the CO2 emissions level in the country. The changes in fuel price would reflect the change in travel behaviour whereby people would opt for more efficient vehicle technology to

Fig. 10. The effect of CO2 emissions level with fuel price subsidy. Source: optimal solution obtained from modelling results by authors.

Table 7
Scenario and sensitivity analyses used in the model.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Sensitivity</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alternative fuel use</td>
<td>Included B5 (blend of 5% palm biodiesel and 95% petroleum diesel) in diesel vehicle types and E10 (blend of 10% bioethanol and 90% petrol) in petrol vehicle types.</td>
<td>Reference case assumes no biofuel usage in the road transport sector. As the government is promoting the use of biofuels, B5 and E10 are employed in the model to achieve reduction in CO2 emissions. To explore the impact of fuel efficiency improvement, the global target of fuel efficiency improvement in terms of engine and vehicle technology is assumed in the analysis (IEA, 2012; Stilloonga et al., 2012; Takao, 2009). Malaysia is targeting a quantity of 100,000 EV cars and 2000 EV buses in the transport fuel mix of the country by 2020 (PEMANDU, 2013). Thus, this case assumes a share of EV of all vehicle types on an annual basis. As Malaysia is targeting improving the public transportation system, this case is to explore the impact of increasing the share of public transportation on the CO2 emissions level. Explore the impact of using subsidised price on the CO2 emissions level. Assume that several policies are implemented together to explore the impact to achieve higher reductions in CO2 emissions while satisfying the demand for travel.</td>
</tr>
<tr>
<td>2. Fuel efficiency improvement</td>
<td>Increased fuel efficiency of petrol and diesel vehicles. For this, a low level of fuel efficiency for diesel vehicles (3.33%) and petrol vehicles (3.33%) and a high level of fuel efficiency for diesel vehicles (4.11%) and petrol vehicles (5.21%) are set up. Included share of electric vehicles (EV) for buses and cars from 0% to 0.06% in the year (consists of 12,500 cars and 250 buses in the total market).</td>
<td></td>
</tr>
<tr>
<td>3. Improving travel demand</td>
<td>Increased share of public vehicles (buses and taxis) make up 10% of all vehicle types in the year, whereas the reference case in this study has only 6.7%.</td>
<td></td>
</tr>
<tr>
<td>4. Fuel pricing</td>
<td>Decreased the fuel price by 20% for diesel vehicles and 36.4% for petrol vehicles.</td>
<td></td>
</tr>
</tbody>
</table>
| 5. Policy mix options             | **Moderate policy mix options (policy Option A).**  
- Included B5 in diesel vehicle types.  
- Included share of EV for buses and cars from 0% to 0.06% in the year.  
- Increased share of public vehicles (buses and taxis) to make up 10% of all vehicle types in the year.  
- Increased fuel efficiency of petrol and diesel vehicle types by 3.33% in the year.  

**High policy mix options (policy Option B).**  
- Included B5 in diesel vehicle types and E10 in petrol vehicle types.  
- Included share of EV for buses and cars from 0% to 0.06% in the year.  
- Increased share of public vehicles, such that buses and taxis make up 10% of all vehicle types in the year.  
- Increased fuel efficiency of petrol vehicle types by 5.21% and fuel efficiency of diesel vehicles by 4.11% in the year. | |

Fig. 7. The effect of CO2 emissions level by different strategies of alternative fuel use. Source: optimal solution obtained from modelling results by authors.

Fig. 8. The effect of CO2 emissions level by different strategies of fuel efficiency improvement. Source: optimal solution obtained from modelling results by authors.

Fig. 10. The effect of CO2 emissions level with fuel price subsidy. Source: optimal solution obtained from modelling results by authors.
reduce fuel consumption in distance travel (Klier and Linn, 2013; Piecyk and McKinnon, 2010).

6.5. Policy mix options

Table 8 shows the results of a policy mix options scenario for Policy Options A and Policy Options B (see Table 7).

The CO2 emissions can be reduced further by 12.1% from 28.29 Mtonnes in the reference case to 24.86 Mtonnes (Table 8, Policy Options A). The model suggests that increasing public transportation leads to switching of petrol vehicles from passenger cars to public vehicles (buses and taxies) to meet the target CO2 emissions reduction. Structural change in vehicle technologies within petrol vehicles can also be seen, as the motorcycle share would be higher than the motorcar share. In this policy, the share of diesel vehicles increased from 5% to 7% while natural gas vehicles decreased from 93% to 89% from the reference case. The shift in vehicle technologies results in a large reduction in CO2 emissions. Moreover, penetration of EVs in the vehicle technologies mix to meet the transport demand would reduce emissions.

With high policy options (Table 8, Policy Options B), the CO2 emissions can be reduced further by 20.0% from 28.29 Mtonnes in the reference case to 22.63 Mtonnes. The vehicle technology share is similar to Option A, albeit with a larger CO2 emission reduction. This is because the improvement in fuel efficiency of vehicle technology and the use of E10 reduced fuel consumption by petrol vehicle technologies, which resulted in significant reductions in the CO2 emissions level in the road transport sector. The inclusion of E10 and the increase in fuel efficiency at high levels will reduce the CO2 emission further as compared to Policy Options A, albeit with a marginal reduction in total fuel consumption. The policies of Options A and Options B reveal that a reduction of 1% in CO2 emissions is equivalent to a reduction in fuel consumption of about 11.13 ktoe and 11.14 ktoe, respectively.

In general, the impact of different mitigation options on CO2 emissions reduction is shown in Fig. 11. The analysis shows that each of the mitigations options is able to meet, and in fact exceed, the CO2 emissions reduction target (27.5 Mtonnes). On an individual case, the smallest CO2 emissions reduction (save 1.0 Mtonnes from 27.5 Mtonnes) can be obtained with 0.06% of EVs from total vehicles in the market. A 10% shift from passenger vehicles to public transportation appears to be the most effective solution for CO2 emissions reduction (Ong et al., 2011). However, the results indicate that large emissions reductions can be achieved by implementing a mix of mitigation options.

Furthermore, the results of the current paper are consistent with the theory that fuel consumption is significantly related to CO2 emissions (Wang et al., 2011). Hence, efficient fuel use is a key strategy for achieving CO2 emissions savings. This is because fuel efficiency improvement will increase the travel demand but decrease the energy use required for travel and thus reduce the CO2 emissions level (Shahid et al., 2014; Ichinohe and Endo, 2006;...
Aizura et al., 2009). The results are also consistent with previous empirical findings that significant CO₂ emissions can be avoided by increasing the public vehicle share (Rawshan et al., 2015) and utilising biofuels (Marrero, 2010; Hosseini et al., 2013; Pongthananaisawan and Sorapipatana, 2013).

7. Conclusions and policy implications

Using an optimisation approach has demonstrated that the CO₂ emissions could be reduced by 6.55% in the Malaysian road transport sector. This reduction exceeds the annual CO₂ emissions needed for the sector to achieve a 40% reduction of CO₂ emissions intensity by 2020. A range of sensitivity analysis is used to test the potential emissions reduction. The assessment in the present study shows that more CO₂ emissions can be avoided while meeting the transport demand requirement through specific mitigation measures. It is apparent from the study that using the fuel price at market price level would change travel behaviour towards efficient vehicles. Also, there is potentially much to be gained in terms of reduced CO₂ emissions and reduce fuel consumption from the increasing penetration of a range of low-carbon options (improving fuel efficiency, increasing alternative fuel use and increasing public transportation) on the CO₂ emissions level. These options are likely to bring significant savings in fuel consumption and reductions in the CO₂ emissions level. Also, the study reveals that by combining these options, the CO₂ emissions in Malaysia can be reduced further up to 12.1% in the moderate Policy Options A and 20% in the high Policy Options B. Thus, it is clear that appropriate mitigation options would make a significant contribution to reducing the CO₂ emissions beyond the expected target.

This study may shed light on what would be the best mitigation options to fulfill the CO₂ emissions intensity reduction target while meeting the transport demand. Based on scenarios analysis (Section 5), the policy measures of this study are as follows:

First, the Malaysian government should intensify fuel efficiency improvement strategies in the country. In terms of the transport fuel mix, the diversification of fuel use with biofuels is an effective measure to reduce emissions. The national biofuel policy has encouraged the use of B5 in the road transport sector, resulting in a significant reduction of CO₂ emissions which will enable Malaysia to meet the target and reduce CO₂ emissions even more than expected. Moreover, if the government adopts the use of E10 in the road transport sector, the CO₂ emissions reduction will be higher as most passenger vehicles run on petrol (93%). In terms of engine and vehicle technology, the fuel economy standard on vehicles can also reduce CO₂ emissions as this standard can assist the country and encourage car manufacturers to produce efficient vehicles (Silitonga et al., 2012; Mahlia et al., 2002). The experiences of other areas (Japan, the United States, Europe and Singapore) which have implemented fuel economy policies signal that this measure reduces fuel use and CO₂ emissions. However, to establish the fuel economy standard on vehicles, a regulatory authority must be institutionalised and capacity must be built to implement this policy in Malaysia. The current fuel economy initiatives around the world and in the Association of Southeast Asian Nations (ASEAN) countries to achieve vehicle efficiency and reduce CO₂ emissions provide a good platform for promoting competitiveness and inducing a market transformation among car manufacturers in Malaysia to produce efficient vehicles.

Second, the government should promote the use of public transportation as such use results in the largest emissions reduction. Poor public transport increases people’s dependence on private vehicles. However, a dramatic change from private vehicles to public transport cannot be expected as appropriate measures must be put in place to shift passengers from private vehicles to public transportation. In this regard, the government’s current initiative towards improvement of the public transport infrastructure is commendable. The current government initiative to integrate land use and transportation planning in urban areas and to expand and improve the public transportation infrastructure with, for example, light rail transit (LRT), buses and mass rapid transit (MRT) would certainly improve the move towards public transportation and contribute to the reduction of CO₂ emissions.

Third, switching away from a conventional fuel technology by using more fuel efficient technology such as EVs can reduce fuel consumption and the emissions level in Malaysia. This is apparent from the findings that even a marginal share of electric vehicles in the market can contribute a significant reduction of CO₂ emissions which is almost equivalent with B5 implementation. The government should intensify the promotion of EVs and provide necessary fiscal incentives to enlarge the share and accelerate the use of these vehicles. Even though EVs reduce tailpipe emissions, a wider use of renewable energy resources (e.g. solar and biomass) to replace fossil fuels in power generation would increase the advantages in terms of total CO₂ emissions reduction in the country (Sang and Bekhet, 2015, 2014).

Fourth, the government’s removal of the fuel price subsidy has shown signs of reducing the CO₂ emissions level. However, as the global oil price is declining, the increase in fuel price would still offer marginal improvements and, due to the increasing affordability of both purchasing and using private modes of transportation, the impact of efficient vehicles and public transport services might not be significant. Thus, additional demand management measures, such as congestion charges in city areas, should be implemented to reduce fuel consumption and emissions.

Fifth, effective mitigation measures in an appropriate combination are therefore of utmost important in ensuring that CO₂ emissions are reduced as desired. However, the path towards effective implementation of these mitigation options demands great support and commitment from policy makers, relevant stakeholders and political leaders, as well as changes in individuals’ behaviour.

The present study focused on issues relating only to the least emissions in the road transport sector. The model is developed to assist decision makers in identifying the optimal CO₂ emissions reduction level under different CO₂ mitigation options. However, future work can improve the modelling framework in terms of economic evaluation to also include the least cost CO₂ emissions reduction. This is because there is a cost associated with CO₂ emissions reduction and such cost minimisation may influence emissions reductions. Thus, the integration of CO₂ emissions and cost minimisation is necessary to achieve compromise decisions that consider both economic and environmental objectives. In addition, other modes of transportation (i.e. rail, maritime and air) should be included to improve representation of the transportation infrastructure in Malaysia.

Acknowledgement

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A. Appendix A

A.1. Data and assumptions for CO2 emission reduction model

<table>
<thead>
<tr>
<th>Transport vehicle and fuel</th>
<th>Number of vehicle (V)</th>
<th>Fuel consumption average distance (ktoe) (km)</th>
<th>Occupancy/load factor (O/L)</th>
<th>Distance travelled (BPKM)</th>
<th>Average fuel efficiency (y) (km/litre)</th>
<th>Efficiency distance travelled (BPKM per ktoe)</th>
<th>Retail fuel price (RM/litre)</th>
<th>Market fuel price (RM/litre)</th>
<th>CO2 emission (Mt/ktoe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcar ICE/Petrol</td>
<td>10,147,584</td>
<td>6716.05 20,499b</td>
<td>1.8</td>
<td>379.0</td>
<td>13.26f</td>
<td>0.0302</td>
<td>1.9</td>
<td>2.56</td>
<td>0.003056</td>
</tr>
<tr>
<td>Motorcar ICE/Diesel</td>
<td>207,093</td>
<td>72.049bb</td>
<td>1.8</td>
<td>7.7</td>
<td>17.24e</td>
<td>0.0345</td>
<td>1.8</td>
<td>2.16</td>
<td>0.003131</td>
</tr>
<tr>
<td>Motorcar EV</td>
<td>2000</td>
<td>99.47 20,499bb</td>
<td>1.8</td>
<td>7.7</td>
<td>17.24e</td>
<td>0.0345</td>
<td>1.8</td>
<td>2.16</td>
<td>0.002975</td>
</tr>
<tr>
<td>Motorcycle ICE/Petrol</td>
<td>10,147,584</td>
<td>6716.05 20,499bb</td>
<td>1.8</td>
<td>379.0</td>
<td>13.26f</td>
<td>0.0302</td>
<td>1.9</td>
<td>2.56</td>
<td>0.002751</td>
</tr>
<tr>
<td>Bus ICE/Diesel</td>
<td>71,329</td>
<td>284.01 60,000d</td>
<td>28</td>
<td>102.0</td>
<td>3.13f</td>
<td>0.0972</td>
<td>1.8</td>
<td>2.88</td>
<td>0.003131</td>
</tr>
<tr>
<td>Bus ICE/Natural Gas</td>
<td>2206</td>
<td>82.92 60,000d</td>
<td>28</td>
<td>3.16</td>
<td>1.96f</td>
<td>0.1064</td>
<td>0.68</td>
<td>0.68</td>
<td>0.002432</td>
</tr>
<tr>
<td>Gas EV</td>
<td>250</td>
<td>3.4 60,000d</td>
<td>28</td>
<td>0.42</td>
<td>3.528</td>
<td>0.1248</td>
<td>0.317f</td>
<td>0.317f</td>
<td>0</td>
</tr>
<tr>
<td>Taxi ICE/Diesel</td>
<td>50,241</td>
<td>57.5 60,000d</td>
<td>1.8</td>
<td>4.84</td>
<td>17.24e</td>
<td>0.0345</td>
<td>1.8</td>
<td>2.88</td>
<td>0.003131</td>
</tr>
<tr>
<td>Taxi ICE/Natural Gas</td>
<td>42,798</td>
<td>209.08 60,000d</td>
<td>1.8</td>
<td>4.12</td>
<td>15.92e</td>
<td>0.0523</td>
<td>0.68</td>
<td>0.68</td>
<td>0.002432</td>
</tr>
<tr>
<td>Hire and Drive ICE/Petrol</td>
<td>19,296</td>
<td>2.45 20,499bb</td>
<td>1.8</td>
<td>1.98</td>
<td>13.26f</td>
<td>0.0377</td>
<td>1.9</td>
<td>3.3</td>
<td>0.003056</td>
</tr>
</tbody>
</table>

ICE: Internal Combustion Engine.
Sources a: Fuel Consumption is estimated and adapted from EC (2012) and MOT (2013).
d: Masjuki et al. (2004)
e: Aizura et al. (2012) for petrol. Diesel and gas is assumed to be 30% and 20% efficient than petrol (IEA, 2012).
g: MDTCA (2012).
h: Data is estimated based on Means of Platts Singapore (MOPS) price for 2012 from EC (2014). Data based on crude Oil Price at US65/bbl.
i: The figures are adapted from IPCC (2006). Refer to Appendix B.
j: MGTC (2014). Data is in RM/kwh.

B. Appendix B

B.1. Calculation of CO2 emission coefficient

The CO2 emission coefficient, \( e \), consumed by drivetrain are calculated as follows:

\[
e_j = EF_j \times CF_j
\]

where \( EF \) is the emission factor by type \( j \) (which depends on the fuel used), \( CF \) is the conversion factor \((1 \text{ to } = 41.868 \text{ GJ})\). The CO2 emissions factor is converted accordingly as shown in Table B1. The values of \( EF \) is converted to unit Mt/ktoe for the modelling purpose.

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Emission factor (Kg/TJ)</th>
<th>Emission Coefficient (Mt/ktoe)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>73.0</td>
<td>0.003056</td>
<td>Upper range given in source.</td>
</tr>
<tr>
<td>Diesel</td>
<td>74.1</td>
<td>0.003131</td>
<td>Upper range given in source.</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>58.1</td>
<td>0.002432</td>
<td>Upper range given in source.</td>
</tr>
<tr>
<td>Biodiesel (B5)</td>
<td>71.1</td>
<td>0.002975</td>
<td>Assumption based on EIA (2005).</td>
</tr>
<tr>
<td>Bioethanol (E10)</td>
<td>65.7</td>
<td>0.002751</td>
<td>Assumption based on EIA (2003).</td>
</tr>
<tr>
<td>Electricity</td>
<td>0</td>
<td>0</td>
<td>Assumption based on tailpipe emissions.</td>
</tr>
</tbody>
</table>


