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Analysis of CO_2 emissions reduction in the Malaysian transportation sector: An optimisation approach

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H I G H L I G H T S

- An optimisation model for CO_2 emissions reduction in Malaysia's road transport is formulated.
- Sensible policy options to achieve the CO_2 emissions reduction target are provided.
- Increase in fuel price has induced shift towards fuel efficient vehicles.
- The CO_2 emissions can be reduced up to 5.7 $MtCO_2$ with combination of mitigation policies.

A R T I C L E I N F O

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A B S T R A C T

The demand for transport services is expected to rise, causing the CO_2 emissions level to increase as well. In Malaysia, the transportation sector accounts for 28% of total CO_2 emissions, of which 85% comes from road transport. By 2020, Malaysia is targeting a reduction in CO_2 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 CO_2 emissions level. An Optimisation model is developed to estimate the potential CO_2 emissions mitigation strategies for road transport by minimising the CO_2 emissions under the constraint of fuel cost and demand travel. Several mitigation strategies have been applied to analyse the effect of CO_2 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 CO_2 emissions can be decreased by 6.55%, which would enable Malaysia to hit its target by 2020. CO_2 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 CO_2 emissions reduction target.

1. Introduction

Climate change emanating from CO_2 emissions has emerged as the most challenging environmental problem in recent decades. Global CO_2 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 CO_2 emissions is needed to avoid disastrous consequences. Hence, a move towards a lower carbon economy is highly desirable. Worldwide, the annual CO_2 emissions must be reduced by an estimated 50–80% by 2050 to alleviate the destructive climate change impacts (IPCC, 2007).

As the increase in CO_2 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 CO_2 emissions. In 2009, at the 15th Conference of Parties (COP15) in Copenhagen, Malaysia stated a voluntary target of reducing its CO_2 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

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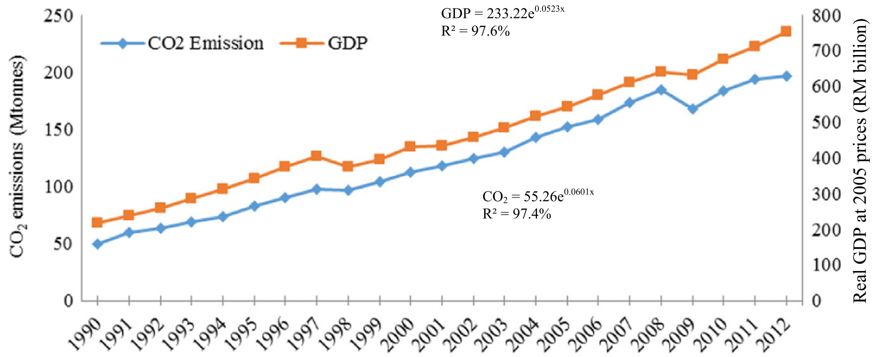

Fig. 1. CO_2 emissions and GDP trends in Malaysia (1990–2012). Source: DOSM (2012) and IEA (2014a).

tandem, which will directly result in an increase in CO_2 emissions. Fig. 1 shows that the gross domestic product (GDP) and CO_2 emissions annual growth rate stand at 5.2% and 6%, respectively. This suggests that the CO_2 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 fulfiling 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 CO_2 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 CO_2 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 CO_2 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 CO_2 emissions reduction target in the road transportation sector in Malaysia is rather limited. Driven by the desire to investigate the optimal level of CO_2 emissions that can be reduced from Malaysia's road transportation, the intended contribution of the study is to estimate the potential CO_2 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 CO_2 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 CO_2 emissions as well as highlighting the need to achieve CO_2 emissions reduction target. Section 3 discusses the past empirical analyses of CO_2 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

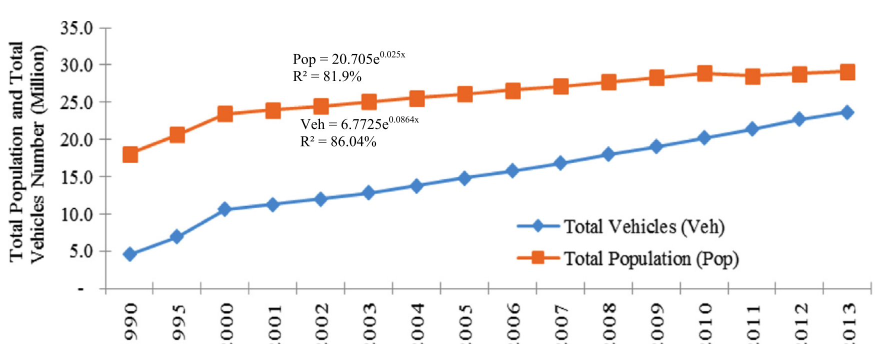

Fig. 2. Trends in vehicle numbers and population growth in Malaysia (1990–2013). Source: DOSM (2013) and MOT (2013).

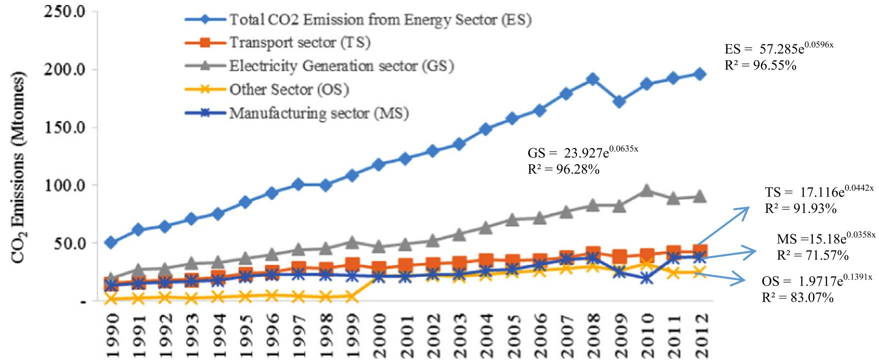

Fig. 3. Trends of CO_2 emissions from energy sub-sectors in Malaysia (1990–2012). Source: IEA (2014b).

resulted in a significant increase in fuel demand and CO_2 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 CO_2 emissions contribution (Silitonga et al., 2012; Mofleh et al., 2010). As indicated in Fig. 3, the CO_2 emissions in Malaysia's energy sector have increased over the years. In 2012, 196 million tonnes (Mtonnes) of CO_2 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 CO_2 emissions in the country. Electricity generation, transport, manufacturing and other sectors contributed 46%, 22%, 19% and 13% of the total CO_2 emissions, respectively.

Fig. 4 shows the share of CO_2 emissions by transportation mode in the transportation sector. Road transportation accounts for the largest share with 85.2% of total CO_2 emissions, followed by aviation, maritime and rail. Fig. 5 shows the contribution of different road vehicles in CO_2 emissions and demonstrates that private vehicles (motorcars and motorcycles) represent the largest share of CO_2 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 CO_2 emissions reduction.

Achieving higher GDP and at the same time reducing CO_2 emissions is a daunting task. With a growing economy that may require emissions to rise, an absolute limit on CO_2 emissions release is needed. Table 1 shows the estimated CO_2 emissions reduction target as planned by the government. The NRE (2011) reported that the total CO_2 emissions must be limited to about

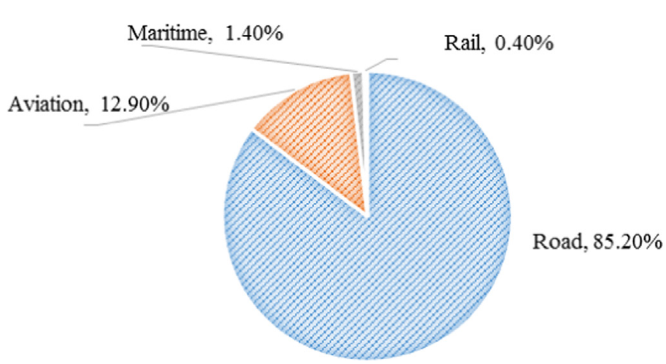

Fig. 4. CO_2 emissions shares by type of mode in Malaysia. Source: CO_2 emissions adapted from MOT (2013), EC (2012) and IPCC (2006).

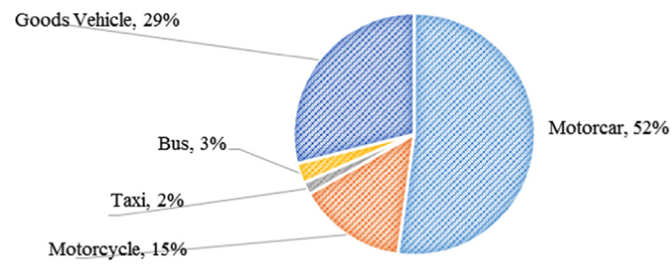

Fig. 5. CO_2 emissions share by vehicle type of the road transport sector in Malaysia. Source: CO_2 emissions adapted from MOT (2013), EC (2012) and IPCC (2006).

335 Mtonnes. However, based on an expected growth in GDP of 5% per annum (2000–2020), CO_2 emissions are projected to reach 375 Mtonnes. The plan is, therefore, to reduce about 40 Mtonnes of CO_2 emissions from all economic sectors by 2020. For the transportation sector, CO_2 emissions should be reduced by 8.27 Mtonnes, from 77.61 Mtonnes (2.9% per annum) to 69.33 Mtonnes, to meet the 40% CO_2 emissions intensity reduction target.

One can deduce that Malaysia will not be able to meet its target of CO_2 intensity reduction. However, the target is still achievable with reductions in growth in total CO_2 emissions from the energy-consuming sectors. Several studies have examined mitigation options for CO_2 emissions reduction (Beuno, 2012; Leighty et al., 2012; Ashina et al., 2012; Baños et al., 2011; Ou et al., 2010; Zanni and Bristow, 2010; Mofleh 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 CO_2 emissions reductions in the transportation sector.

3. Literature review

Many studies in various countries have analysed the CO_2 emissions and implementing mitigation policies and sustainable energy planning for emissions reduction. To reduce CO_2 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 CO_2 emissions reduction planning are reviewed. Perspectives on the effective measures of different methods are discussed, demonstrating numerous CO_2 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

Table 1
CO_2 emissions reduction target for Malaysia.

Scenario	Unit	2005	2020 (Projection)
Total CO_2 emissions (business as usual)	Mtonnes	279.30	375.00
CO_2 emissions in energy sector (business as usual)	Mtonnes	204.30	274.4
CO_2 emissions in transport sector (business as usual)	Mtonnes	45.30	77.61
GDP	RM billion	449.3	906.6
Total CO_2 emissions intensity	Mtonnes/RM billion	0.62	0.41
40% Emissions intensity reduction by 2020 (total CO_2 emissions)	Mtonnes	–	335.00
40% Emissions intensity reduction by 2020 (transport sector)	Mtonnes	–	69.33
CO_2 emissions intensity with 40% reduction by 2020	Mtonnes/RM billion	0.62	0.37

Source: Data adapted from NRE (2011) on pg. 27, 29, 32 and 47.

impact of CO_2 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 CO_2 emissions in the transport sector. The study concluded that fuel switching options and energy efficiency improvement options are effective in reducing CO_2 emissions. Using a similar model, Klier and Linn (2013) statistically found that fuel price is an effective instrument for reducing the CO_2 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 CO_2 emissions. Rawshan et al. (2015) studied the impact of GDP, fuel consumption and population growth on the CO_2 emissions in Malaysia and suggested that low-carbon technologies reduce growth in CO_2 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. Jebaraj et al. (2008), Muslu (2004) and Linaresa and Romeo (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 CO_2 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 CO_2 emissions reductions and that integrated modes offer the best option to reduce CO_2 emissions. Muis et al. (2010) also formulated a mixed integer linear programming model to meet electricity demand within CO_2 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 CO_2 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 CO_2 emissions in the freight transport sector. This study concluded that a significant CO_2 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 CO_2 emissions in the transport sector. Kamarudin et al. (2009) also a developed 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 CO_2 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 CO_2 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 CO_2 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 CO_2 emissions in freight transportation. Pasaoglu et al. (2012) developed a technical economic model based on the descriptive approach to analyse the CO_2 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 CO_2 emissions by up to 57% from 2010 levels.

One can see from these studies that the econometric model and Optimisation modelling for CO_2 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 CO_2 emissions reduction (Ziolkowska, 2014; Kim et al., 2014; Baños et al., 2011). Builds on the desire of the country for CO_2 emissions reduction target, this paper aims to develop a least CO_2 emission model to investigate the CO_2 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 CO_2 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 CO_2 emissions reduction, this least emissions by contrast, allows the investigation of the policy changes impact on the optimal CO_2 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 to decide which mitigation strategies are most important to reduce road transport CO_2 emissions.

4. Data source and methodology

4.1. Data sources

In this study, the analysis of optimal CO_2 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 CO_2 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 CO_2 emissions level in the road transport sector. In this study, travel demand (Bueno, 2012), fuel efficiency (IEA, 2012; Aizura et al., 2011; Piecyk and McKinnon, 2010), fuel price (Klier and Linn, 2013) and fuel consumption (Wang et al., 2011) are considered the significant factors affecting the CO_2 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, CO_2 emissions depend on energy used from different vehicle technologies and the specific CO_2 emissions coefficient of different fuels used. The intended contribution of the study is generally to estimate the potential CO_2 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 CO_2 emissions and maximise efficiency of fuels consumption and vehicle technologies. The model provide least emission optimised technology mix to reduce CO_2 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 CO_2 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

Table 2
Representation of passenger vehicle in road transport sector.

Drivetrain type	Vehicle type				
	Motorcar	Taxi	Hire and Drive	Bus	Motorcycle
Diesel	√	√	–	√	–
Petrol	√	–	√	–	√
Natural gas	–	√	–	√	–

Table 3
CO_2 emissions in passenger vehicles of the road transport sector for 2012.

Vehicle type	Fuel type	Energy use (ktoe)[a]	CO_2 emissions factor (Mtonnes/ktoe)[b]	CO_2 emissions (Mtonnes)
Car	Diesel	99.47	0.003131	0.31
Taxi	Diesel	57.5	0.003131	0.18
Bus	Diesel	284.01	0.003131	0.88
Hire and drive car	Petrol	2.45	0.003056	0.01
Car	Petrol	6716.05	0.003056	20.47
Motorcycle	Petrol	1898.5	0.003056	5.79
Bus	Natural Gas	82.92	0.002432	0.19
Taxi	Natural Gas	209.08	0.002432	0.47

[a] Energy use by fuel type and vehicle type is proportionate based on the number of vehicles from MOT (2013). Calculation is available from the authors.
[b] CO_2 emissions are calculated based on IPCC (2006). For more details see Appendix B.

and vehicle types, as shown in Table 2. The total CO_2 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 CO_2 emissions reduction model is formulated as in Eq. (1).

$$\text{Minimise } CO_2 = \sum_{i=1}^{3}\sum_{j=1}^{3} e_{dj}\cdot f_{dij} + \sum_{i=4}^{6}\sum_{j=4}^{6} e_{pj}\cdot f_{pij} + \sum_{i=7}^{8}\sum_{j=7}^{8} e_{nj}\cdot f_{nij} \tag{1}$$

CO_2 is the total CO_2 emissions from the road transport sector where e_j is the coefficient of CO_2 emissions per unit of energy consumed by each drivetrain type j (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 CO_2 emissions are minimised subject to a set of constraints that describes various factors and their interactions for reduction of CO_2 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 (Beuno, 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).

$$T = \sum_{i=1}^{5}\sum_{j=1}^{3} Vij \times Yij \times Oij \tag{2}$$

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):

Table 4
Variables, description and sources.

Variable	Description	Unit	Source
Travel demand (d)	Distance travel in transport sector by vehicle technology.	Billion passenger km (Bpkm)	MOT (2013), Masjuki et al. (2004) and Indati and Bekhet (2014).
Fuel efficiency (y)	Average fuel efficiency by vehicle technology.	km/liters	Masjuki et al. (2004), IEA (2012), Aizura et al. (2010) and IANGV (2000).
Fuel price (p)	Market price of fuel by type of fuel.	RM/liter	MDTCA (2013) and EC (2014).
Fuel consumption (f)	Fuel consumption by type of fuel.	ktoe	EC (2012).
CO_2 emission factor (e)	Emission factor for CO_2 emission.	kg/TJ	IPCC (2006).

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

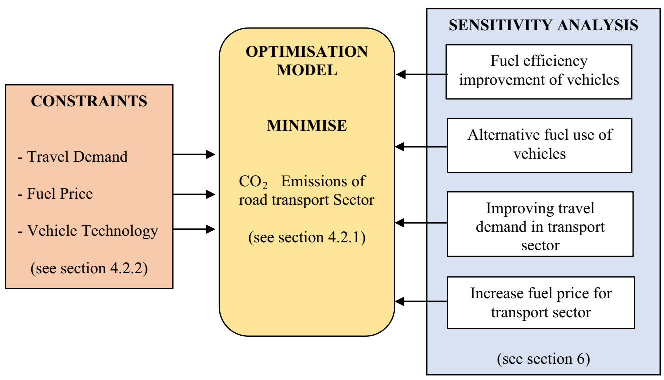

Fig. 6. Schematic representation of CO_2 emissions reduction model.

$$\sum_{i=1}^{5}\sum_{j=1}^{3} d_{ij}\cdot f_{ij} \geq T \tag{3}$$

4.3.1.2. Fuel price constraint. The fuel price constraint is established to set limitations for the total fuel cost under the given fuel price. This constraint ensures that with the given fuel price, the quantity of fuel demanded by vehicle technology balances the fuel availability. Thus, the model is optimised to satisfy the total fuel cost in the road transport sector. The total fuel costs (TC_j) is the fuel costs for drivetrain j (which depends on the fuel used) in the road transport sector. The fuel costs are calculated by multiplying the amount of fuel supply availability (S_j) by the fuel price (p_j) as in Eq. (4).

$$TC_j = \sum_{j=1}^{3} S_j \times P_j \tag{4}$$

The fuel price is denoted as p_j, and f_{ij}, the energy use by vehicle type i and drivetrain j, must be less than or equal to the exogenous total fuel cost (TC_j), as shown in Eqs. (5a)–(5c).

$$\sum_{i=1}^{3}\sum_{j=1}^{3} p_{dj}\cdot f_{dij} \leq TC_j \quad \forall j \in \text{ Diesel vehicles} \tag{5a}$$

$$\sum_{i=4}^{6}\sum_{j=4}^{6} p_{pj}\cdot f_{pij} \leq TC_j \quad \forall j \in \text{ Petrol vehicles} \tag{5b}$$

$$\sum_{i=7}^{8}\sum_{j=7}^{8} p_{nj}\cdot f_{nij} \leq TC_j \quad \forall j \in \text{ Natural gas vehicles} \tag{5c}$$

4.3.1.3. Upper and lower bound on vehicle technology constraint. To express the constraint for dissemination of fuel consumption by vehicle technology, an upper and lower bound is set as in Eq. (6). 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).

$$Minf_{ij} \leq f_{ij} \leq Maxf_{ij} \quad \forall\, ij \tag{6}$$

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.

$$f_{ij} \geq 0 \quad \forall\, ij \tag{7}$$

5. Results and discussion

The results from the CO_2 emissions reduction model are shown in Table 5. In the analysis, with present market price level, the optimal CO_2 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 CO_2 emissions from petrol vehicles (cars and motorcycles) remains the same at 92.8%. However, petrol cars have lost share to motorcycles. The share of CO_2 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 CO_2 emissions, as in the reference case. The diesel and natural gas vehicle technology contributed about 5.2% and 2.7% of total CO_2 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 CO_2 emissions

Table 5
Optimal CO_2 emissions coefficient of the CO_2 emissions reduction model.

Vehicle category	Fuel type	Reference case[1]				Optimal CO_2 emissions[2]			
		Energy use		CO_2 emissions		Energy use		CO_2 emissions	
		(ktoe)	(%)	(Mtonnes)	(%)	(ktoe)	(%)	(Mtonnes)	(%)
Car	Diesel	99.47	1.1	0.31	1.1	99.47	1.1	0.31	1.2
Taxi	Diesel	57.5	0.6	0.18	0.6	57.5	0.7	0.18	0.7
Bus	Diesel	284.01	3.0	0.88	3.1	284.01	3.3	0.89	3.4
Hire and Drive	Petrol	2.45	0.0	0.01	0.0	2.45	0.0	0.01	0.0
Car	Petrol	6716.05	71.8	20.47	72.4	4842.71	55.7	14.80	56.0
Motorcycle	Petrol	1898.5	20.3	5.79	20.5	3120.6	35.9	9.54	36.1
Bus	Natural Gas	82.92	0.9	0.19	0.7	83.0	1.0	0.20	0.8
Taxi	Natural Gas	209.08	2.2	0.47	1.7	209.0	2.4	0.51	1.9
Total		9350.5	100	28.29	100	8698.31	100	26.44	100
CO_2 emissions reduction rate (%)						−7.0%		−6.55%	

Source: (1) Reference case is for the year 2012 and adapted based on data from MOT (2013), MDTCA (2012) and EC (2012).
(2) Optimal solution obtained from modelling results by authors.

Table 6
Optimal resources distribution of the CO_2 emissions reduction model.

	Reference case[1]	Optimal CO_2 emissions level[2]	Percentage change (%)
Total CO_2 emissions (Mtonnes)	28.3	26.44	−6.55
Demand travel (Bpkm)	714.0	714.1	0
Petrol price (RM/liter)	1.9	2.56	36.4
Diesel price (RM/liter)	1.8	2.16	20
Natural gas price (RM/liter)	0.64	0.64	0
Total fuel consumption (ktoe)	9350.5	8698.31	−7.0

Source: (1) Reference case is for the year 2012 and adapted based on data from MOT (2013), MDTCA (2012) and EC (2012).
(2) Optimal solution obtained from modelling results by authors.

reduction can be achieved from the Optimisation model.

The effect of the CO_2 emissions reduction model on fuel consumption, fuel price and demand travel is shown in Table 6. In meeting the demand travel, a fuel price increase of 36.4% and 20% in petrol and diesel, respectively, can reduce fuel consumption by 7%. This would enable a reduction of CO_2 emissions by 6.55% from the reference case. The increase in fuel price would reflect a change in travel behaviour (Klier and Linn, 2013). In effect, this rise would encourage car users to shift from cars to motorcycles to reduce fuel consumption in distance travel.

To reach the CO_2 emissions intensity target by 2020, the CO_2 emissions from the road transport sector must be reduced by 2.9% per annum. From the optimal result (Tables 5 and 6), one can empirically deduce that the CO_2 emissions reduction target can be largely achieved by using fuel price at the market price level.

6. Sensitivity analysis

In practice, CO_2 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 CO_2 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 CO_2 emissions reduction level, a scenario and sensitivity analysis was conducted and is summarised in Table 7.

The impact of post optimality analysis on the CO_2 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 CO_2 emissions level. As expected, one can observe that a switch to low-carbon fuels can decrease the CO_2 emissions level (Tye et al., 2011; Lim and Lee, 2012). The results show that a reduction of CO_2 emissions by 6.7% to 26.4 Mtonnes can be achieved by using B5. Moreover, if E10 is used, the CO_2 emissions reduction would increase further by 15.1% to 24.03 Mtonnes. The introduction of E10 significantly reduced the amount of CO_2 emissions due to the higher share of petrol vehicles (93%) in the country. Furthermore, if both B5 and E10 are used, the CO_2 emissions reduction would slightly increase by 15.3% to 23.96 Mtonnes.

6.2. Fuel efficiency improvement

The results of 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 CO_2 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 CO_2 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 CO_2 emissions reduction.

Furthermore, because of zero tailpipe emissions from electric vehicles (EVs), the analysis shows that the CO_2 emissions level in the road transport sector would decrease by 6.31% while meeting the travel demand. A reduction in CO_2 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.

Table 7
Scenario and sensitivity analyses used in the model.

Scenario	Sensitivity	Rationale
1.Alternative fuel use	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 vehicles types.	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 CO_2 emissions.
2. Fuel efficiency improvement	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.	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; Silitonga et al., 2012; Takao, 2009).
	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).	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.
3. Improving travel demand	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%.	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 CO_2 emissions level.
4. Fuel pricing	Decreased the fuel price by 20% for diesel vehicles and 36.4% for petrol vehicles.	Explore the impact of using subsidised price on the CO_2 emissions level.
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 vehicles 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.	Assume that several policies are implemented together to explore the impact to achieve higher reductions in CO_2 emissions while satisfying the demand for travel.

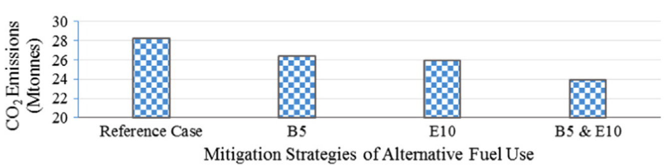

Fig. 7. The effect of CO_2 emissions level by different strategies of alternative fuel use. Source: optimal solution obtained from modelling results by authors.

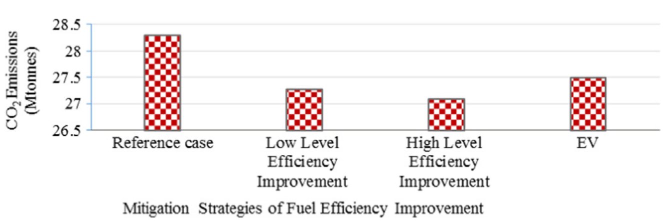

Fig. 8. The effect of CO_2 emissions level by different strategies of fuel efficiency improvement. Source: optimal solution obtained from modelling results by authors.

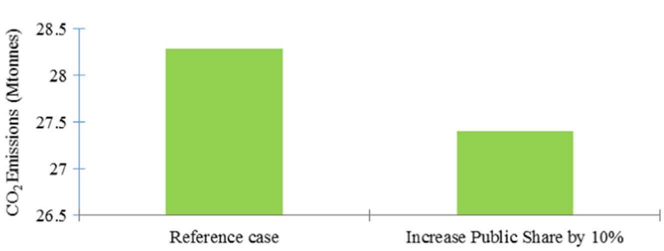

Fig. 9. The effect of CO_2 emissions level by increasing share of public transportation. Source: optimal solution obtained from modelling results by authors.

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 CO_2 emissions of 10.8% and 9.5%, respectively.

6.4. Fuel pricing

Fuel price is an important measure to reduce CO_2 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 CO_2 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 CO_2 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 CO_2 emissions level.

The fuel pricing policy demonstrates that it is an effective instrument in reducing the CO_2 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

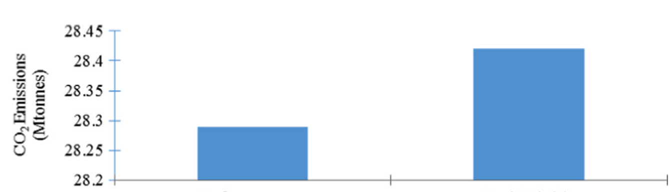

Fig. 10. The effect of CO_2 emissions level with fuel price subsidy. Source: optimal solution obtained from modelling results by authors.

Table 8
CO_2 emissions reduction level by using policy mix options.

Vehicle category	Fuel type	Reference case		Optimal CO_2 emissions policy options A		Optimal CO_2 emissions policy options B	
		Energy use (ktoe)	CO_2 emissions (Mtonnes)	Energy use (ktoe)	CO_2 emissions (Mtonnes)	Energy use (ktoe)	CO_2 emissions (Mtonnes)
Car	Diesel	99.47	0.31	99.0	0.30	99.0	0.30
Taxi	Diesel	57.5	0.18	57.0	0.17	57.0	0.17
Bus	Diesel	284.01	0.88	424.2	1.26	398.5	1.19
Hire and Drive	Petrol	2.45	0.01	2.0	0.01	2.0	0.005
Car	Petrol	6716.05	20.47	4149.0	12.68	4174.4	11.48
Motorcycle	Petrol	1898.5	5.79	3120.6	9.54	3120.6	8.58
Bus	Natural gas	82.92	0.19	106.0	0.26	106.0	0.26
Taxi	Natural gas	209.08	0.47	268.0	0.65	268.0	0.65
Car	Electricity	0	0	7.0	0.00	7.0	0.00
Bus	Electricity	0	0	3.4	0.00	3.4	0.00
Total		9350	28.29	8236.21	24.86	8235.96	22.63
CO_2 emissions reduction rate (%)				11.91%	−12.1%	11.91%	−20.0%

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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 emissions level in the road transport sector. The inclusion of E10 and the increase in fuel efficiency at high levels will reduce the CO_2 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 CO_2 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 CO_2 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 CO_2 emissions reduction target (27.5 Mtonnes). On an individual case, the smallest CO_2 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 CO_2 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 CO_2 emissions (Wang et al., 2011). Hence, efficient fuel use is a key strategy for achieving CO_2 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 CO_2 emissions level (Shahid et al., 2014; Ichinohe and Endo, 2006;

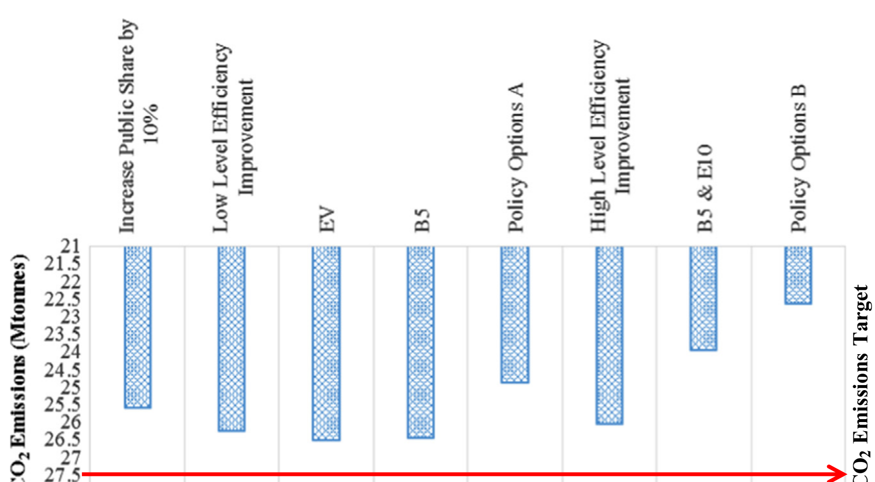

Fig. 11. The effect of CO_2 emissions level with different mitigation options. Source: optimal solution obtained from modelling results by authors.

Aizura et al., 2009). The results are also consistent with previous empirical findings that significant CO_2 emissions can be avoided by increasing the public vehicle share (Rawshan et al., 2015) and utilising biofuels (Marrero, 2010; Hosseini et al., 2013; Pongthanaisawan and Sorapiatana, 2013).

7. Conclusions and policy implications

Using an optimisation approach has demonstrated that the CO_2 emissions could be reduced by 6.55% in the Malaysian road transport sector. This reduction exceeds the annual CO_2 emissions needed for the sector to achieve a 40% reduction of CO_2 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 CO_2 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 CO_2 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 CO_2 emissions level. These options are likely to bring significant savings in fuel consumption and reductions in the CO_2 emissions level. Also, the study reveals that by combining these options, the CO_2 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 CO_2 emissions beyond the expected target.

This study may shed light on what would be the best mitigation options to fulfil the CO_2 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 CO_2 emissions which will enable Malaysia to meet the target and reduce CO_2 emissions even more than expected. Moreover, if the government adopts the use of E10 in the road transport sector, the CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 emissions reduction level under different CO_2 mitigation options. However, future work can improve the modelling framework in terms of economic evaluation to also include the least cost CO_2 emissions reduction. This is because there is a cost associated with CO_2 emissions reduction and such cost minimisation may influence emissions reductions. Thus, the integration of CO_2 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.

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A. Appendix A

A.1. Data and assumptions for CO_2 emission reduction model

Transport vehicle	Technology and fuel	Number of vehicle (V)	Fuel consumption (ktoe)[a]	Average distance (km)	Occupancy/load factor(O)[d]	Distance travelled (BPKM)	Average fuel efficiency (y) (km/litre)	Efficiency distance travelled (BPKM per ktoe)	Retail fuel price (RM/litre)[g]	Market fuel price (RM/litre)[h]	CO_2 emission (Mt/ktoe)[i]
Motorcar	ICE/Petrol	10,147,584	6716.05	20,499[b]	1.8	379.0	13.26[e]	0.0302	1.9	2.56	0.003056
	ICE/Diesel	207,093	99.47	20,499[b]	1.8	7.7	17.24[e]	0.0345	1.8	2.16	0.003131
	EV	2000	7	20,499[b]	1.8	0.07	30.11	0.0684	0.317[j]	0.317[j]	0
	B5	207,093	99.47	20,499[b]	1.8	7.7	17.24[e]	0.0345	1.8	2.16	0.002975
	E10	10,147,584	6716.05	20,499[b]	1.8	379.0	13.26[e]	0.0302	1.9	2.56	0.002751
Motorcycle	ICE/Petrol	10,589,818	1.898.5	15,879[c]	1.2	202.1	43.41[d]	0.0659	1.9	3.3	0.003056
Bus	ICE/Diesel	71,329	284.01	60,000[d]	28	102.0	3.13[f]	0.0972	1.8	2.88	0.003131
	ICE/Natural Gas	2206	82.92	60,000[d]	28	3.16	1.96[f]	0.1064	0.68	0.68	0.002432
	EV	250	3.4	60,000[d]	28	0.42	3.528	0.1248	0.317[j]	0.317[j]	0
Taxi	ICE/Diesel	50,241	57.5	60,000[d]	1.8	4.84	17.24[e]	0.0345	1.8	2.88	0.003131
	ICE/Natural gas	42,798	209.08	60,000[d]	1.8	4.12	15.92[e]	0.0523	0.68	0.68	0.002432
Hire and Drive	ICE/Petrol	19,296	2.45	20,499[b]	1.8	1.98	13.26[e]	0.0377	1.9	3.3	0.003056

ICE: Internal Combustion Engine.
Sources a: Fuel Consumption is estimated and adapted from EC (2012) and MOT (2013).
b–c: MIROS (2010).
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).
f: IANGV (2000).
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 is adapted from IPCC (2006). Refer to Appendix B.
j: MGTC (2014). Data is in RM/kwh.

B. Appendix B

B.1. Calculation of CO_2 emission coefficient

The CO_2 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 toe=41.868 GJ). The CO_2 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 B.1
CO_2 emission coefficient assumptions.

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

Source: IPCC (2006).

References

Aizura, A.B., Mahlia, T.M.I., Masjuki, H.H., 2010. Potential fuel savings and emission reduction from fuel economy standards implementation for motor vehicle. Clean Technol. Environ. Policy 12 (3), 255–263.
Almselati, A.S., Rahmat, R.A., Jaafar, O., 2011. An overview of urban transport in Malaysia. Soc. Sci. 6 (1), 24–33.
Ang, J., 2008. The long-run relationship between economic development, pollutant emissions and energy consumption: evidence from Malaysia. J. Policy Model. 30, 271–278.
Ashina, S., Fujino, J., Masui, T., Ehara, T., Hibino, G.A., 2012. A roadmap towards a low-carbon society in japan using backcasting methodology: feasible pathways for achieving an 80% reduction in CO_2 emissions by 2050. Energy Policy 41, 584–598.
Azlina, A.A., Mustapha, N.N.H., 2012. Energy, economic growth and pollutant emissions nexus: the case of Malaysia. Soc. Behav. Sci. 65, 1–7.
Baños, R., Manzano-Agugliarob, F., Montoyab, F.G., Gil, C., Alcaydeb, A., Gómez, J., 2011. Optimization methods applied to renewable and sustainable energy: a review. Renew. Sustain. Energy Rev. 15, 1753–1766.
Bai, H., Wei, J., 1996. The CO_2 mitigation options for the electric sector. Energy Policy 24, 221–228.
Bekhet, H.A., Yusop, N.Y.M., 2009. Assessing the relationship between oil prices, energy consumption and macroeconomic performance in Malaysia: co-integration and vector error correction model (VECM) approach. J. Econ. Stud. 2 (3), 152–173.
Bekhet, H.A., Ivy, Y.L.L., 2014. Highlighting energy policies and strategies for the residential sector in Malaysia. Int. J. Energy Econ. Policy 4 (3), 448–456.
Beuno, G., 2012. Analysis of scenario for the reduction of energy consumption and GHG emission in transport in Basque country. Renew. Sustain. Energy Rev. 16, 1988–1998.
Dargay, J., Gately, D., 1999. Income's effect on car and vehicle ownership, worldwide: 1960–2015. Transp. Res. A Policy Pract. 33 (2), 101–138.
Department of Statistics Malaysia (DOSM), 2012. Gross Domestic Product. Retrieved from: 〈http://www.statistics.gov.my/portal〉 (accessed on December 2013).
Department of Statistics Malaysia (DOSM), 2013. Population in Malaysia. Retrieved from: 〈http://www.statistics.gov.my/portal〉 (accessed on December 2014).
Economic Planning Unit (EPU) Malaysia, 2010. The Tenth Malaysia Plan 2011–2015. EPU, Putrajaya.
Ediger, V.S., Akar, S., 2007. ARIMA forecasting of primary energy demand by fuel in Turkey. Energy Policy 35, 1701–1708.
Energy Commission (EC), 2012. National Energy Balance 2012. Ministry of Energy, Green Technology and Water, Malaysia.
Energy Commission (EC), 2014. Malaysia Energy Statistics Handbook. Energy Commission, Malaysia.
Energy Information Administration (EIA), 2005. Carbon Dioxide Emission Factor, DOE/EIA-0638. Available from: 〈http://www.eia.gov/survey/form/eia_1605/excel/Fuel_Emission_factor.xls〉.
Erdmenger, C., Lehmann, H., Muschen, K., Tambke, J., Mayr, S., Kuhnhenn, K., 2009. A climate protection strategy for Germany – 40% reduction of CO_2 emissions by 2020 compared to 1990. Energy Policy 37, 158–165.
Gao, H.O., Stasko, T.H., 2009. Diversification in the driveway: mean-variance optimization for greenhouse gas emissions reduction from the next generation of vehicles. Energy Policy 37, 5019–5027.
Gielen, D., Changhong, C., 2001. The CO_2 emission reduction benefits of chinese energy policies and environmental policies: a case study for Shanghai, period 1995–2020. Ecol. Econ. 39, 257–270.
Hashim, H., Douglas, P., Elkamel, A., Croiset, E., 2005. Optimization model for energy planning with CO_2 emission considerations. Ind. Eng. Chem. Res. 44, 879–890.
Herring, H., 2006. Energy efficiency—a critical view. Energy 31, 10–20.
Hickman, R., Ashiru, O., Banister, D., 2010. Transport and climate change: simulating the options for carbon reduction in London. Transp. Policy 17, 110–123.
Hongbo, R., Zhou, W., Nakagamib, K., Gaoc, W., Wuc, Q., 2010. Multi-objective optimization for the operation of distributed energy system considering economic and environmental aspects. Energy 34, 1396–1400.
Hosseini, S.E., Wahid, M.A., Aghili, N., 2013. The scenario of greenhouse gases reduction in Malaysia. Renew. Sustain. Energy Rev. 28, 400–409.
Ichinohe, M., Endo, E., 2006. Analysis of the vehicle mix in the passenger-car sector in japan for CO_2 emission reduction by a MARKAL model. Appl. Energy. 83, 1047–1061.
Indati, M.S., Bekhet, H.A., 2014. Highlighting of the factors and policies affecting CO_2 emission level in Malaysian transportation sector. Int. J. Environ. Earth Sci. Eng. 8 (1), 10–18.
Indati, M.S., Ghate, A.T., Leong, Y.P., 2013. Towards greater environment: energy efficient pathways for the transportation sector in Malaysia. Earth Environ. Sci. 16, 658–667.
Intergovernmental Panel on Climate Change (IPCC), 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Japan.
Intergovernmental Panel on Climate Change (IPCC), 2007. The IPCC Fourth Assessment Report on Climate Change. IPCC, Geneva.
International Association for Natural Gas Vehicles (IANGV), 2000. Retrieved from: 〈http://ntl.bts.gov/lib/11000/11400/11453/iangv_bus_report.pdf〉 (accessed on March 2014).
International Energy Statistics (IEA), 2012. Technology Roadmap: Fuel Economy of Road Vehicles. IEA, Paris.
International Energy Agency (IEA), 2014a. Key World Energy Statistics. IEA, Paris.
International Energy Agency (IEA), 2014b. CO_2 Emission from Fuel Combustion. IEA, Paris.
Ivy, Y.L.L., Bekhet, H.A., 2014. Modelling residential electricity consumption function in Malaysia: time series approach. Int. J. Electr. Electron. Sci. Eng. 8 (3), 1–7.
Jebaraj, S., Iniyan, S., Suganthi, L., Goic, R., 2008. An optimal electricity allocation model for effective utilization of energy sources in India with focus on biofuels. Manag. Environ. Qual. 19 (4), 480–486..
Johanssons, B., 2009. Will restrictions on CO_2 emissions require reductions in transport demand? Energy Policy 36, 3286–3299.
Kamarudin, S.K., Daud, W.R.W., Yaakub, Z., Misron, Z., Anuar, W., Yusuf, N.N., 2009. Synthesis and optimization of future hydrogen energy infrastructure planning in peninsular Malaysia. Int. J. Hydrog. Energy 34 (5), 2077–2088.
Kannan, R., Strachan, N., 2009. Modelling the UK residential energy sector under long-term decarbonisation scenarios: comparison between energy systems and sectoral modeling approaches. Appl. Energy 86, 416–428.
Kasipillai, J., Chan, P., 2008. Travel management: lessons for Malaysia. J. Public Transp. 11 (3), 41–56.
Kim, H., Paik, C., Chung, Y., Kim, Y.J., 2014. Mathematical properties and constraints representation for bottom-up approaches to the evaluation of GHG mitigation policies. Transp. Res. Part D 32, 48–56.
Klier, T., Linn, J., 2013. Fuel prices and new vehicle fuel economy—comparing the United States and Western Europe. J. Environ. Econ. Manag. 66 (2), 280–300.
Klier, T., Linn, J., 2013. Fuel prices and new vehicle fuel economy—comparing the United States and Western Europe. J. Environ. Econ. Manag. 66 (2), 280–300.
Leighty, W., Ogden, J.M., Yang, C., 2012. Modeling transitions in the California light-duty vehicles sector to achieve deep reductions in transportation greenhouse gas emissions. Energy Policy 44, 52–67.
Lim, S., Lee, K.T., 2012. Implementation of biofuels in Malaysian transportation sector towards sustainable development: a case study of international cooperation between Malaysia and Japan. Renew. Sustain. Energy Rev. 16 (4), 1790–1800.
Linaresa, P., Romeo, C., 2002. Aggregation of preferences in an environmental economics context: a goal-programming approach. Int. J. Manag. Sci. 30, 89–95.
Liu, J., Lin, Q.G., Huang, G.H., Wu, Q., Li, H.P., 2013. Energy systems planning and GHG-emission control under uncertainty in the province of Liaoning China – a dynamic inexact energy systems optimization model. Int. J. Electr. Power Energy Syst. 53, 142–158.
Lou, J.C., Chung, K.F., Chen, K.S., 1995. An optimization study of total emission controls for particulate pollutants. J. Environ. Manag. 43, 17–28.
Mahlia, T.M.I., Masjuki, H.H., Choudhury, I.A., 2002. Theory of energy efficiency standards and labels. Energy Convers. Manag. 43, 743–761.
Malaysia Green Technology Corporation (MGTC), 2014. Malaysia's Catalyst for Green Technology 2014: The Flagship Approach. Accessible from: 〈http://www.greentechmalaysia.my/file/download/YIM%20-Teh%20Tarik%20Session%20Slides%2017%20March%202014.pdf〉.
Malaysia Institute of Road Safety Research (MIROS), 2010. Vehicle Kilometer Travelled. Accessible from: 〈http://miros.gov.my/web/guest/events〉.
Marrero, G.A., 2010. Greenhouse gas emissions, growth and the energy mix in Europe. Energy Econ. 32, 1356–1363.
Masjuki, H.H., Karim, M.R., Mahlia, T.M.I., 2004. Energy Use in the Transportation Sector of Malaysia. Economic Planning Unit of the Prime Minister's Department, Putrajaya.
Mattila, T., Antikainen, R., 2011. Backcasting sustainable freight transport systems for Europe in 2050. Energy Policy 39, 1241–1248.
Ministry of Domestic Trade and Consumer Affairs Malaysia (MDTCA), 2012. Petroleum Information 2012–2012. Accessible from: 〈http://www.kpdnkk.gov.my/en/maklumat-petroleum-2012〉 (accessed on May 2014).
Ministry of Natural Resources and Environment Malaysia (NRE), 2011. Second National Communication to the UNFCCC. NRE, Malaysia.
Ministry of Transport Malaysia (MOT), 2013. Transport Statistics Malaysia. Retrieved from 〈http://www.mot.gov.my〉 (accessed on December 2014).
Mofleh, A., Taib, S., Salah, W.A., 2010. Malaysian energy demand and emissions from the transportation sector. Transport 25 (4), 448–453.
Muis, Z.A., Hashim, H., Manan, Z.A., Taha, F.M., Douglas, P.L., 2010. Optimal planning of renewable energy-integrated electricity generation schemes with CO_2 reduction target. Renew. Energy 35, 2562–2570.
Muslu, M., 2004. Economic dispatch with environmental considerations: tradeoff curves and emission reduction rates. Electr. Power Syst. Res. 71, 153–158.
Ong, H.C., Mahlia, T.M.I., Masjuki, H.H., 2011. A review on emission and mitigation strategies for road transport in Malaysia. Renew. Sustain. Energy Rev. 15, 3516–3522.
Ong, H.C., Mahlia, T.M.I., Masjuki, H.H., 2012. A review on energy pattern and policy for transportation sector in Malaysia. Renew. Sustain. Energy Rev. 6 (1), 532–542.
Ou, X., Zhang, X., Chang, S., 2010. Scenario analysis on alternative fuel/vehicle for China's future road transport: life-cycle energy demand and GHG emissions. Energy Policy 38 (8), 3943–3956.
Pan, S., Ballot, E., Fontane, F., 2013. The reduction of greenhouse gas emission from freight transport by pooling supply chains. Int. J. Prod. Econ. 143, 86–94.
Pasaoglu, G., Honselaar, M., Thiel, C., 2012. Potential vehicle fleet CO_2 reductions and cost implications for various vehicle technology deployment scenarios in Europe. Energy Policy 40, 404–421.
Performance Management & Delivery Unit (PEMANDU), 2013. Electrical and Electronics National Key Economic Areas. Prime Minister's Department, Malaysia. Accessible from: 〈http://etp.pemandu.gov.my/upload/NKEA_Factsheet_Elec

trical_Electronics.pdf〉.
Piecyk, M.I., McKinnon, A.C., 2010. Forecasting the Carbon footprint of road freight transport in 2020. Int. J. Prod. Econ. 128, 31–42.
Pongthanaisawan, J., Sorapiatana, C., 2013. Greenhouse gas emission from thailand's transport sector: trends and mitigation options. Appl. Energy 101, 288–298.
Rawshan, A.B., Sohag, K., Sharifah, S.A., Mokhtar, J., 2015. CO_2 emissions, energy consumption, economic and population growth in Malaysia. Renew. Sustain. Energy Rev. 41, 594–601.
Safaai, M.N., Noor, Z.Z., Hashim, H., Ujang, Z., Talib, J., 2010. Projection of CO_2 emissions in Malaysia. Environ. Prog. Sustain. Energy 30 (4), 658–665.
Sang, Y.-N., Bekhet, H.A., 2015. Modelling electric vehicle usage intentions: an empirical study in Malaysia. J. Clean. Prod. 92, 75–83.
Sang, Y.-N., Bekhet, H.A., 2014. Determining key predictors influencing intension to use electric vehicles in Malaysia. In: Proceedings of the International Conference and Utility Exhibition 2014 on Green Energy for Sustainable Development, Thailand, 19th–21st March, 2014.
Shahid, S., Minhans, A., Othman, C.P., 2014. Assessment of greenhouse gas emission reduction measures in transportation sector in Malaysia. J. Teknol. 70 (4), 1–8.
Silitonga, A.S., Atabani, A.E., Mahlia, T.M.I., 2012. Review on fuel economy standard and label for vehicle in selected ASEAN countries. Renew. Sustain. Energy Rev. 16, 1683–1695.
Stern, N., 2009. A Blueprint for a Safer Planet. Random House, London.
Sultan, R., 2010. Short-run and long-run elasticity of gasoline and demand in Mauritius: an ARDL bound test approach. J. Emerg. Trends Econ. Manag. Sci. 1 (2), 90–95.
Takao, O., 2009. The Global Fuel Economy Initiative: Background and Purpose. Accessible from: 〈http://www.Unece.org/trans/doc/2009/wp29/WP29-147-16e.pdf〉.
Tan, S.T., Hashim, H., Ho, W.S., Lee, C.T., W.S., 2013. Optimal planning of waste-to-energy through mixed integer linear programming. Int. J. Environ. Ecol. Geol. Geophys. Eng. 7 (6), 183–190.
Timilsina, G.R., Shrestha, A., 2009. Transport sector CO_2 emissions growth in Asia: underlying factors and policy options. Energy Policy 37 (11), 4523–4539.
Tye, Y.Y., Lee, K., Abdullah, W.N., Leh, C.P., 2011. Second-generation bioethanol as a sustainable energy source in Malaysia transportation: status, potential and future prospects. Renew. Sustain. Energy Rev. 15, 4521–4536.
Unger, N., Bond, T.C., Wang, J.S., Koch, D.M., Menon, S., Shindell, D.T., 2010. Attribution of climate forcing to economic sectors. Proc. Natl. Acad. Sci. USA 107 (8), 3382–3387.
Wang, C., Larsson, M., Ryman, C., Grip, C.-E., Wikstro, J.-O., Johnsson, A., Engdahl, J., 2008. A model on CO_2 emission reduction in integrated steelmaking by optimization methods. Int. J. Energy Res. 32, 1092–1106.
Wang, S.S., Zhuo, D.Q., Zhuo, P., Wang, Q.W., 2011. CO_2 emission, energy consumption and economic growth in China: a panel data analysis. Energy Policy 39, 4870–4875.
Yan, X., Crookes, R.J., 2009. Reduction potentials of energy demand and GHG emission in China's road transport sector. Energy Policy 37 (2), 658–668.
Zanni, A.M., Bristow, A.L., 2010. Emissions of CO_2 from road freight transport in London: trends and policies for long run reductions. Energy Policy 38, 1774–1786.
Ziolkowska, J.R., 2014. Optimizing biofuels production in an uncertain decision environment: conventional vs. advanced technologies. Appl. Energy 114, 366–376.