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Article

Energy Saving and CO_2 Mitigation of Electric Vehicle (EV) Technology in Lao Transport Sector

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Abstract: The high increase in number of vehicles in Lao transport sector in the medium and long-term happens due to continuous growth in transport service demand, which in turn will increase energy consumption in the transport sector. Electric vehicle (EV) technologies can inhibit increment in energy demand growth and energy-related CO_2 emissions in the transport sector; however, cost remains a barrier for the technology diffusion. In this study, a stock vehicle turnover model of the passenger vehicles was developed to assess the potential of EV technology employment for energy saving and CO_2 mitigation in the case of Lao PDR. Three vehicle technologies of EV were chosen to develop countermeasure scenarios. They were the battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs). The Long-rang Energy Alternative Planning (LEAP) model was used to forecast sector-wise transport demand until 2050, considering the base year as 2010. Altogether three scenarios were developed namely, the business as usual (BAU) scenario that relies on conventional internal combustion engine vehicles (ICEVs), and two alternative scenarios, namely CM-R and CM-I scenarios, targeting the penetration of (i) BEVs, (ii) HEVs, and (iii) PHEVs. In addition to the analysis of emission mitigation and energy system impacts, co-benefits of CO_2 mitigation are also investigated in terms of emissions of local air pollutants under modelled scenarios. Results show that in the BAU scenario, energy consumption in the transport sector will increase from 548 ktoe in 2010 to 2,823 ktoe in 2050 while CO_2 emission will increase from 1,656 kt-CO_2 in 2010 to 8,511 kt-CO_2 in 2050. However, in countermeasure scenarios, the high penetration of EV technologies will result in reduction of CO_2 emissions when compared with the BAU scenario. In co-benefit analysis, reduction in emissions of other air pollutants was also observed.

Keywords: CO_2 mitigation, electric vehicle, LEAP, Lao transport sector.

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1. Introduction

1.1. The Importance of Transport Energy Saving in Laos

Transportation is the backbone of the economy of a nation, which provides access to service for the masses of country and it plays a vital role in determining the trend and pace of economic growth. Transport sector in many countries has significant impacts on energy consumption and energy-related CO_2 emissions, along with exhibits of the energy security condition in those countries [1, 2]. Energy consumption reduction and GHG mitigation are vital subjects due to the scarcity of fossil fuel supply to fulfill growing energy demand and dramatic increase in oil prices as well as environmental concerns. In Laos, these types of problems are becoming more outstanding. As a country with imported oil dependency, hence the problem of Laos's transport energy saving has attracted the attention from the ministry of energy and mines.

At present, Laos's transport is in the period of large-scale construction and development which can be seen as succinctly from the total new length of road network. It has increased by 108% in during the past fifteen years, from 20,000 km in 1997 to 43,600 km in 2012 [3]. Meanwhile, the number of vehicles registered has increased by 532% from 200,756 in 2000 to 1,288,700 in 2012. Transport sector in Laos is the major contributor for energy import and for the trade deficit in years while oil imported has increased every year. Fig. 1 shows the energy consumption from history record and future energy demand in Laos [4]. Therefore, the attendant is of increasing energy consumption and greenhouse gas emissions. Laos has adopted the National Energy Saving Plan (NESP) Towards 2030 [5] as national agenda to reduce domestic energy consumption by 10% when compared to the business as usual (BAU) scenario in 2030.

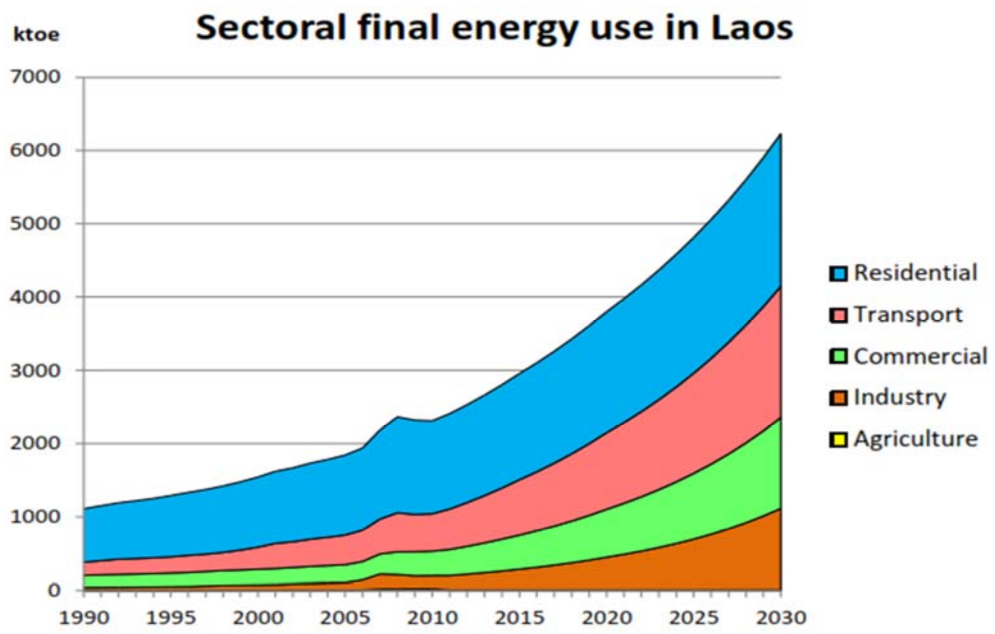

Fig. 1. Statistical record and projection of Lao final energy consumption in the BAU [4].

In Laos, transport sector is the second largest energy consuming sector and the major contributor for petroleum imported, which the imported petroleum volume has been accounted for 646 million litters in 2010. According to NESP, transport sector has largest potential on reducing energy consumption due to Laos has a very primitive transportation system where they are only diesel and gasoline which are mostly dominated by relatively low fuel conversion efficiency. Hence, this study was adopted the electric vehicle technology approach to identify the energy-saving and potential CO_2 mitigation in the transport sector in Laos.

1.2. Electric Vehicle (EV) Technology

Currently, electric vehicle is considered as one of the high efficiency energy technologies which has multiple advantages when compared to the internal combustion engine vehicles (ICEVs) [6] such as it has largest potential on reducing energy consumption and producing less life-cycle CO_2 emissions. Moreover, it operates with less noise and produces zero-tail emissions. When considered from the specific power aspect of the battery technology, EV car is classified into four modes, namely fully battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and fuel-cell electric vehicle (FCEVs) [7].

Due to multiple advantages especially, the advantages on energy conversion efficiency and environment hence, EV cars have been considered as the technology solution for road transportation [7] and have been widely promoted and utilized in both developed and developing countries for decades in order to reduce the dependency on imported oil and mitigate GHG emissions [8-10]. According to IEA blue map scenarios [11], the technology development and current market situation shown that the HEVs have already contributed some portion of passenger light-duty vehicles (passenger LDVs) since 2008 e.g., USA, Japan. While the new model of PHEVs and BEVs are introduced at low production volume due to the cost remains a barrier for the technology diffusion. However, the number of models of PHEVs and BEVs being released into the market will be rapid increased after 2020 as shown in Fig. 3.

For Laos, even though it is not clear on the policy for EVs yet but Lao government plans to be "Battery of Southeast Asia" where there are abundant renewable energy (RE) resources (biomass, hydropower, solar and wind). The most important RE resource is hydropower, where its power potential was estimated around 26,000 MW while the small-scale hydropower (below 15 MW) potential is around 2,000 MW [5]. Thus, hydro potential can be utilized to promote EV technology in Laos's transport system, which GHG emissions rate at 0 g/km when EV is charged with electricity from renewable energy.

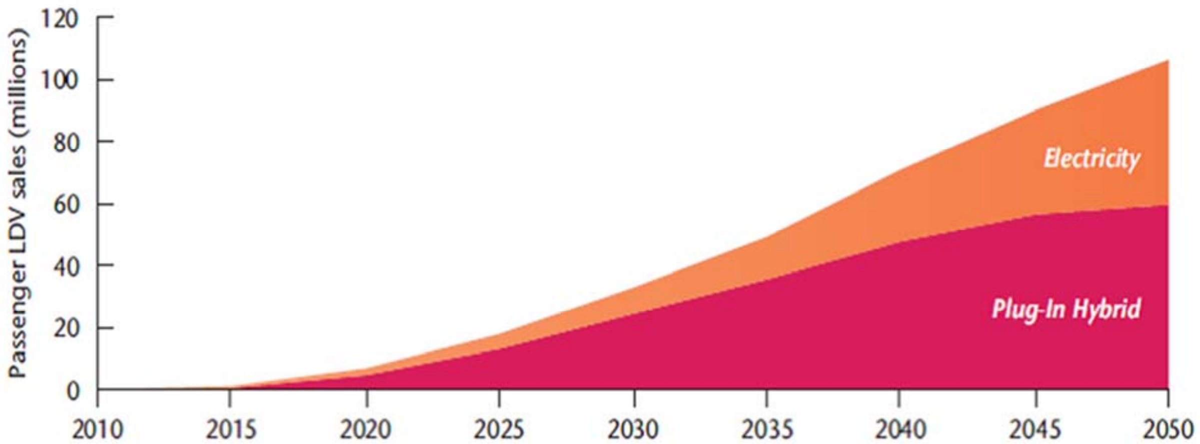

Fig. 2. Annual global BPEVs and PHEVs sales by region in the blue-map scenario [11].

1.3. The Purpose of Study

Although the electric vehicle technologies provide many advantages as mentioned above but in fact, EVs still face many issue that government have to be concern, e.g. electricity requirement, charging station, charging standard, battery management, etc [7]. Therefore, the purpose of this study is to analyse benefits and trade-off for EV technology penetration in Lao road transportation in order to investigate the energy reduction and CO_2 mitigation potential. The Long-rang Energy Alternative Planning (LEAP) model was used to forecast sector-wise transport demand until 2050, considering the base year as 2010. Altogether three scenarios were developed namely, the business as usual (BAU) scenario that relies on conventional internal combustion engine vehicles (ICEVs), and two alternative scenarios, namely realistic countermeasure (CM-R) scenario and idealistic countermeasure (CM-I) scenario, targeting different penetrations of (i) BEVs, (ii) HEVs, and (iii) PHEVs.

2. Methodology

The goal of this study is to investigate the energy savings and CO_2 mitigation by using electric technologies. The estimation of transport energy demand was performed by using a computer simulation model, which is widely used for energy system planning in developing countries, namely LEAP model. As data in the transport sector was searched the energy performance and average kilometre travelled were obtained from [12]. The engineering data such as number of registered vehicles was obtained from [13]. Fig. 1 shows the framework of the study.

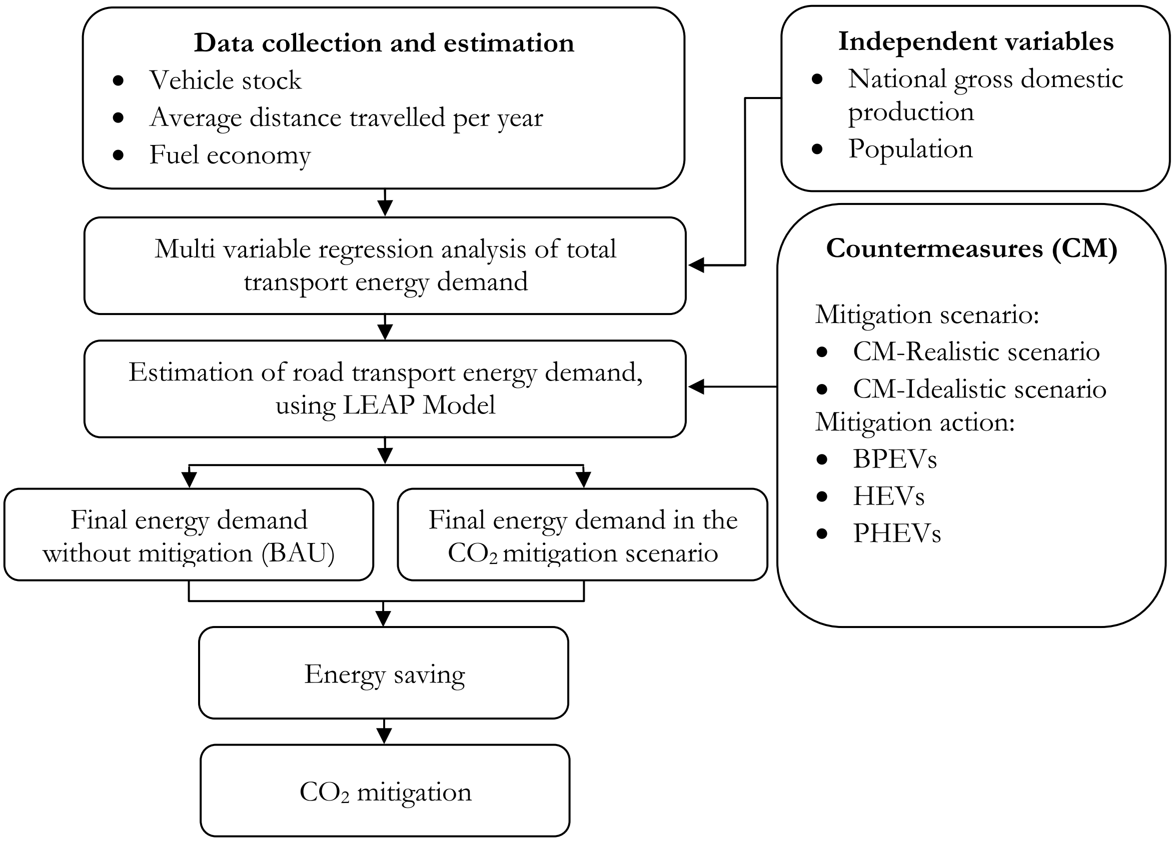

Fig. 3. The flowchart of methodology.

2.1. About LEAP

The Long-rang Energy Alternative Planning (LEAP) is a computer simulation program developed by Stockholm Environment Institute, available and used in more than 150 countries. LEAP simulate costs and emissions from energy consumption, production, and resource extraction for long-term planning by assessing the effects: physical, economic, and environmental impacts of alternative energy programs, technologies, investments, and actions [14, 15].

In recent times, LEAP has been applied to national energy and GHG analysis, e.g. Saisirirat, P. used LEAP to estimate energy consumption of EV technology penetration in Thailand [7] and Dias, M.V.X used LEAP to forecast electricity demand and CO_2 emission of electric car in Soa Paulo, Brazi [16].

2.2. Transport Model

2.2.1. Business as Usual (BAU) Scenario

The BAU scenario acts as a reference case that helps to estimate and analyze the exact future amount of energy consumption under various policies. The bottom-up model is a method that is used to create energy and demand projection in several works, e.g. [2], [7], [14], [15]. This method was selected for this study since it can explicitly integrate energy consumption in details for each vehicle type. The model was constructed and simulated by the LEAP model to produce demand projection in the long-term planning horizon of 2010-2050. To meet the goal, the significant factors for energy demand (ED) is necessary, namely the number of vehicles (NV), vehicle kilometre of travel (VKT), and fuel consumption (FC). Therefore, the energy consumption can be given by the equation bellow:

$$ED_{i,j} = NV_{i,j} \times VKT_j \times FC_{i,j} \quad (1)$$

where i is fuel type and j is vehicle type. In LEAP modelling, Laos's transport energy demand was modelled into two categories: passenger vehicles and freight vehicles. Passenger vehicles include motor tricycle, sedan, mini-bus; and bus while pick up and truck is belonging to the freight vehicle category. Fuel consumption and travelling distances of each vehicle type are gather from government offices, which are available in [12] and [17]. However, some factors of the distance travelled of vehicle types are need to be calibrated in order to match the actual final energy consumption from the government report (see Table 1).

Table 1. Assumptions of travelling distance and fuel consumption of vehicle type [12].

Vehicle type	Fuel economy and travelling distance by vehicle type	
	Driving distance (km)	**fuel efficiency (l/km)**
Motorcycle	5,500	30.00
Motortricycle	15,000	10.08
Sedan	9,100	10.50[17]
Pick-up	9,100	10.00
Mini Bus	33,000	8.64[17]
Jeep (SUV)	9,100	11.97[17]
Truck	32,000	3.50
Bus	41,000	4.00

Due to limitation of LEAP modelling, the future number of vehicle types was estimated individually by linear regression function, which the computation depends on independent variables; the population and gross demotic product (GDP) of Laos (see Table 2).

Table 2. Number of vehicles by vehicle types in Laos.

Vehicle Type	Number of vehicles in Laos				
	2010	**2020**	**2030**	**2040**	**2050**
Motorcycle	804,077	1,634,849	2,469,530	3,103,093	3,469,855
Motor tricycle	8,542	11,452	15,704	21,224	28,965
Sedan	21,638	64,703	1119,533	198,876	319,586
Pick-up	109,362	254,589	418,747	590,211	782,356
Mini Bus	24,727	24,638	45,161	74,817	119,893
Jeep (SUV)	12,155	30,066	53,602	87,435	138,673
Truck	25,452	24,644	36,574	52,797	76,399
Bus	2,825	4,384	5,696	7,070	8,616
Total	1,008,778	2,049,325	3,164,546	4,135,523	4,944,340

2.2.2. Scenario Analysis

In regard to technology penetration, International Energy Agency (IEA) mentions in the report [11] that the PHEV and BPEV are predicted to penetrate in transport since 2010 and they will be commercially competitive in 2015 especially, in OECD countries. For non OECD, Marcos Vinicius Xavier Dias examed the impact on electricity demand and emissions of EVs in Sao Paulo in Brazi by scenario simulation with EVs penetrations at 10% , 30% and 100% during 2015-2035 [16]. S.Selvakkumaran analyzed the low carbon society in Thailand transport sector by adding maximum EVs sharing in road transportation at rates of 0%, 5%, 10%, 20% in the examed years of 2010, 2020, 2030 and 2050, respectively [18].

In this study, besides the BAU scenario, two countermeasure scenarios are considered to study the impact of different mitigation actions in order to develop the new demand scenarios and CO_2 mitigation for Laos's road transportation, namely CM-R and CM-I. The CM-R is the realistic countermeasure scenario, which the mitigation action gives practical with lower level of CO_2 mitigation. The CM-I is the idealistic countermeasure which gives practical with highest level of CO_2 mitigation. In LEAP modeling, three mitigation actions are selected under CO_2 CMs. They are hybrid electric vehicles (HEVs), pug in hybrid electric vehicles (PHEVs) and battery electric vehicle (BEVs). For technology diffusion in the study, the CM-R scenario assumes switching to electric technology will start from 2020 and end in 2050 with maximum of EVs penetration at 15% for HEVs and 5% for PHEVs and BEVs. While the CM-I scenario assumes switching with higher level of EVs implement at 25% for HEVs and 15% for PHEVs and BEVs in 2050.

3. Results and Discussion

3.1. Energy consumption

Following the patterns of social-economic development in Laos's transport sector that reviewed in the section 2.2, the energy consumption in selected years is presented in Fig. 4. It can be seen that the total energy consumption (TEC) trends in each scenario have gradually been increased until 2050. The projection shows that energy consumption in the transport sector of Laos in the BAU scenario will increase from 548 ktoe in 2010 to 2,823 ktoe in 2050 with a total growth rate of 415%. The significant increasing is dominated by the freight transport where pick up and truck accounted for 48%. For the passenger, it is dominated by the motorcycle and minibus, and will be accounted for 37% of total energy consumption in 2050.

In Fig. 4, the BAU scenario shows the highest energy consumption amongst all scenarios because of a series of implementation of countermeasures for energy savings and emission reduction. Following the low level of mitigation countermeasure scenarios, the energy consumption would be reduced by 2.6% in the CM-R scenario when compared to the BAU scenario. The contribution of more intensive countermeasures results in the highest energy savings in the CM-I scenario with reduction of 5.3% of total energy consumption when compared with the BAU in 2050. The significant reduction in the energy consumption in the Lao transport sector in both scenarios exhibits the highest energy saving due to a direct resulted from HEVs and BEVs (see Fig. 4).

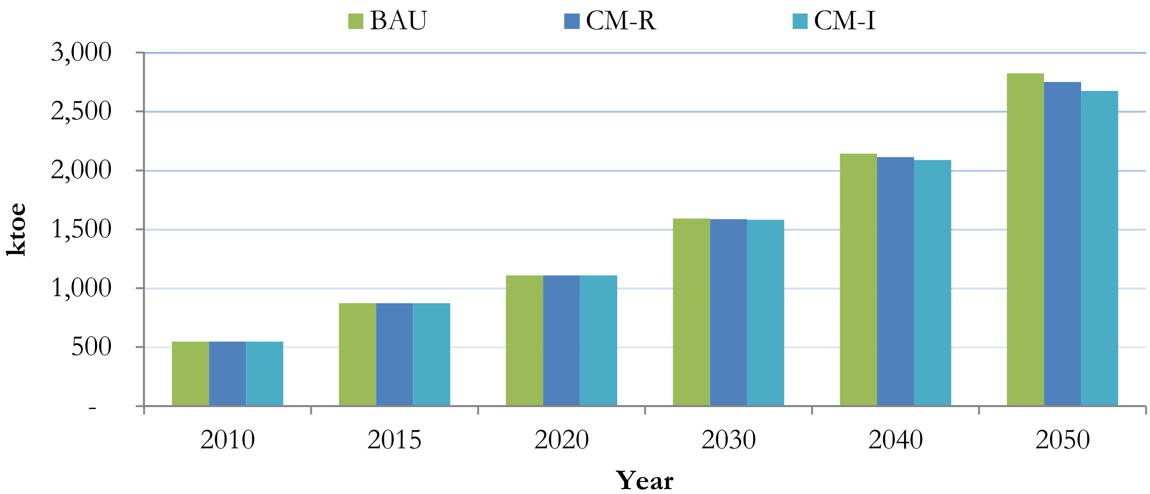

Fig. 4. Comparative energy consumption in the BAU, CM-R and CM-I scenarios.

Figs. 5 and 6 show comparative energy reduction in each mitigation action in the transport sector. Even though the implementation in realistic and idealistic scenarios of three mitigations shows small reduction in comparison to energy reduction in the transport sector, it should be said that both scenarios don't negatively impact on fossil fuel reduction. Also, there is higher energy saving in the CM-I scenario when compared to CM-R scenario, hence implying higher implement of countermeasures is beneficial to Laos's transport sector. In the case of CM-I and CM-R scenarios, the HEVs action reduces highest on fossil fuel in all mitigation actions because of the hybrid electric technology diffusion in transportation that is already available on both of passenger and freight transport [19]. HEVs can drop the energy consumption approximately 46 ktoe in the CM-R scenario and 67 ktoe in the CM-R scenario. In the case of PHEVs, it shows lower energy saving than other mitigation actions, which were accounted for 12 ktoe and 30 ktoe for the CM-R and CM-I scenarios respectively (see Figs. 5 and 6).

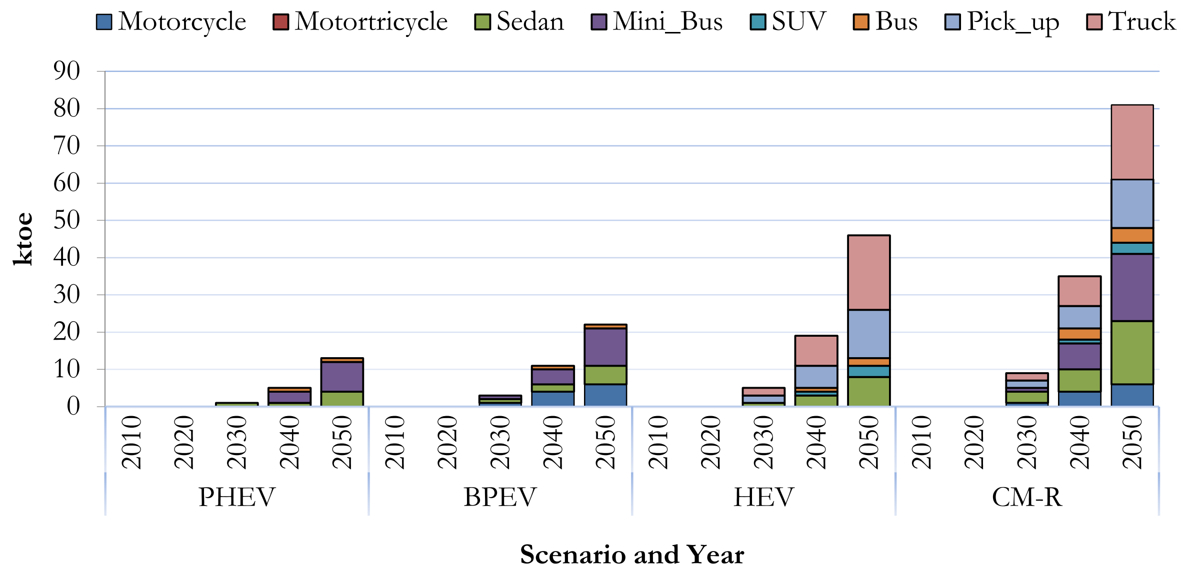

Fig. 5. Reduction in fossil fuel by mitigation actions in the realistic scenario.

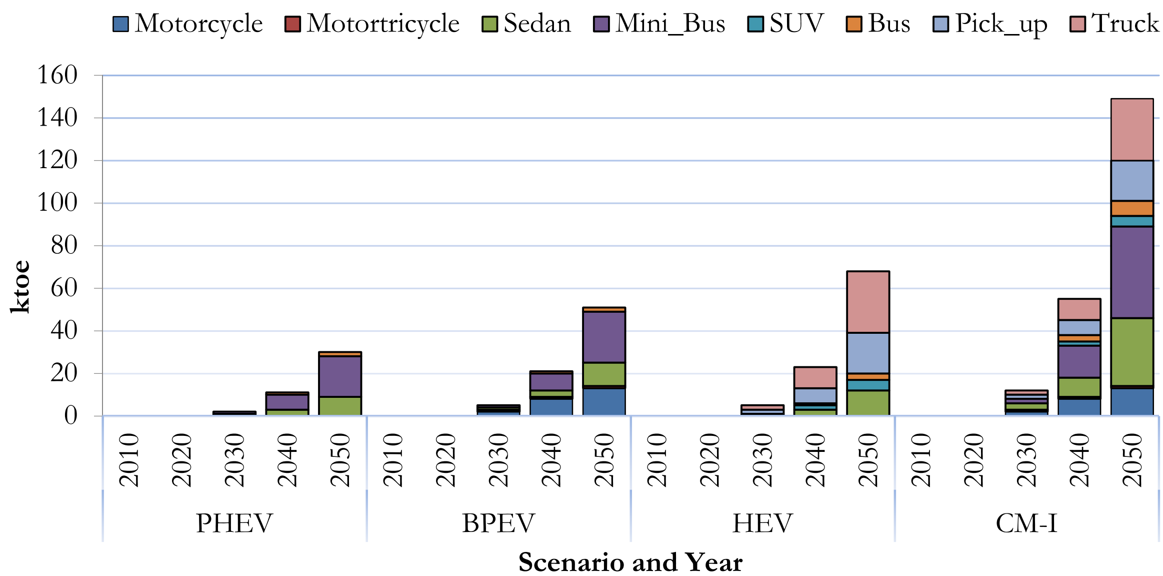

Fig. 6. Reduction in fossil fuel by mitigation actions in the idealistic scenario.

3.2. CO_2 Emissions

In Fig. 3, total CO_2 emission in the road transport in the BAU scenario will increase from 1,789 kt-CO_2 in 2010 to 8,993 kt-CO_2 in 2050 due to increasing energy demand and fossil fuel consumption. On the other hand, Results show potential reduction of CO_2 emissions in the CMs scenarios when compared with the baseline scenario due to implementation of mitigation actions. The cumulative mitigation of CO_2 emissions from 2010 to 2050 in the CM-R scenario when compared to the BAU is approximately 3% and the CM-I scenario shows the highest CO_2 mitigation in comparison with the BAU where as in the target year CO_2 reduction is approximately 6%, which is a direct effect of CMs which has been introduced in the countermeasure. (see Fig. 2) Figure 3 shows comparison of CO_2 emissions in CM-I and CM-R scenarios.

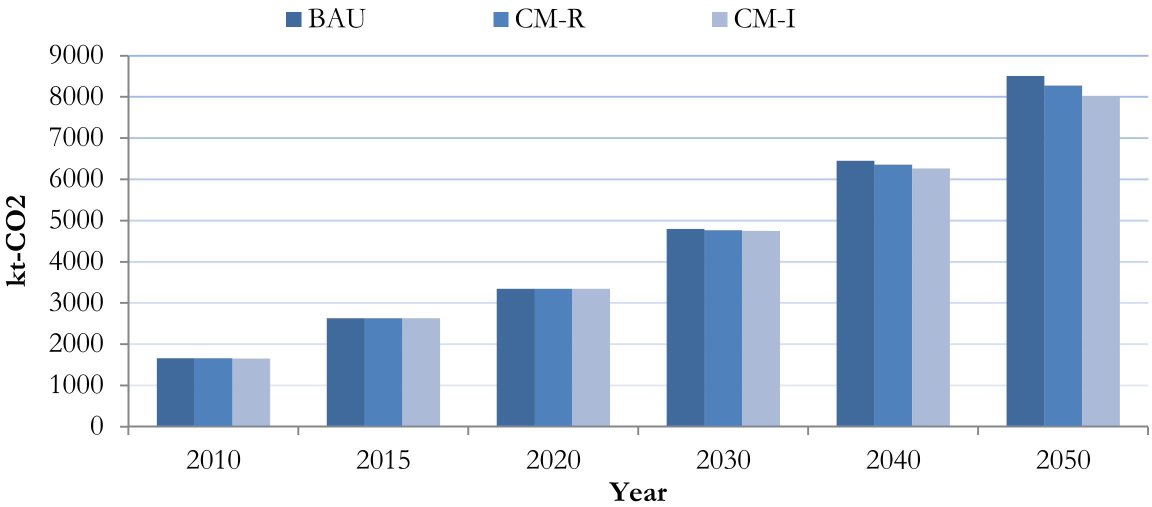

Fig. 7. Comparison of CO_2 emissions in the BAU, CM-R and CM-I scenarios.

Table 4 lists the cumulative reduction in air pollution for Lao road transport sector. The air pollutions in this study are CO, NO_x, NO_2 and SO_2. These have been selected because they are the primary air pollutants associated with transport and the primary elements to health risks. In this study, the analysis shows that all CMs scenarios drastically mitigate air pollutant emissions, when compared to the BAU case. The cumulative mitigation of CO in CM-I scenario can reduce highest carbon monoxide when compared to the BAU scenario with approximately 23.42 ktoe and other pollutant elements are also observed as presented in Table 4.

Table 3. Cumulative mitigation of air pollution in mitigation scenarios.

Scenarios	Cumulative mitigation (tons)			
	CO	NO_x	NO_2	SO_2
MC-R	11,410	2,700	2.20	490
MC-I	23,420	5,140	4.21	900

4. Conclusion

This study aims to present an overview of scenario analyses of energy consumption in the transport sector, energy savings and mitigation of CO_2 emissions is possible by the effectiveness of policy package in Lao transport sector under three scenarios: the BAU, the CM-R and the CM-I. These scenarios are modelled using LEAP. Results show reduction in energy consumption and CO_2 emissions. In the BAU scenario, the energy consumption in Lao transport will increase from 548 ktoe in 2010 to 2823 ktoe in 2050, and accounted for 5.2 folds increase. In the CM-I scenario, energy consumption in hybrid electric vehicle, plug-in hybrid EVs and full battery EVs in 2050 will be reduced by 73 ktoe resulting in CO_2 mitigation of 238 kt-CO_2. In the CM-R scenario, energy consumption in fuel switching, advanced technology and modal shift in 2050 will be reduced by 149 ktoe resulting in CO_2 mitigation of 503 kt-CO_2.

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