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METHODS OF ESTIMATING ENERGY DEMAND AND CO_2 EMISSIONS FOR INTER-REGIONAL ROAD TRANSPORT

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ABSTRACT: Carbon dioxide (CO_2) from the transport sector is by far considered as the major contributor of Greenhouse Gas (GHG) emission into the atmosphere. Many transport engineers and planners nowadays have shifted focus on the development of new approaches or tools that provide fast and reliable means of assessing different transportation strategies to achieve low-carbon transportation system. In this study, a new mathematical Origin-Destination (O-D) approach of estimating energy demand and CO_2 emissions is presented using inter-regional passenger and freight flow data. The lengths of three major road segments were used as independent variables to model fuel consumption for buses and trucks. The estimated energy demand under business as usual (BAU) scenario was compared to five different low-carbon policy scenarios. Study shows that the energy demand from inter-regional public buses and freight road transport under BAU scenario substantially increased from 6,358.86ktoe in 2015 to 36,410.43ktoe in 2050. These findings equate to 19.71 and 112.93 Megatons of CO_2 emissions in 2015 and 2050, respectively. Results also show that shifting to low-carbon alternative fuel such as Compressed Natural Gas (CNG) for buses and trucks provide the highest reduction in the overall inter-regional CO_2 emissions as compared other policy measures. Simultaneous implementation of the three selected policy measures would substantially reduce the CO_2 emissions by almost two-third (74.24%) in 2050.

Keywords: Energy Demand, CO_2 Emission, Origin-Destination, Passenger Trips, Vehicle-Kilometer Travel

1. INTRODUCTION

Given the increasing scientific understanding of the threat of global climate change and the decline of oil production to meet the demand, many countries are now finding ways to make energy consumption efficient and reduce greenhouse gas (GHG) emissions. One major considerations pertaining to transportation planning and development is the overall reduction of energy consumption and emissions produced from the transport sector during its operation.

Carbon dioxide (CO_2) from the transport sector is by far considered as the major contributor of GHG emission into the atmosphere accounting to 38% of the total fuel consumed in 2000 [1].

International Energy Agency (IEA) estimates that the global transport sector is responsible for 23% of all energy-related CO_2 emissions since majority (94%) of the transport sector is still oil-based. Although nearly half (47%) of the total transport energy consumption is in light vehicles, mostly passenger cars, but trucks and buses account for a significant share of 27% worldwide [2].

In the Philippines, land-based transport is the most dominant mode of transport representing 98% and 58% of passenger and cargo travel, respectively. However, for land-based inter-regional travel, 95.88% of public mode of transport use buses and 95.06% of freight transport use trucks. From 2000-2012, the country's total number of registered motor vehicles has doubled from around 3.7 million to 7.5 million. The total number continues to rise as registration of new motor vehicles increased by an annual average of 6% from 2004 to 2013 [3].

Since the early 2000, the Philippine Department of Energy (DOE) has been implementing a long-term Alternative Fuels Program to provide cheaper and more environment-friendly alternatives from the conventional fossil fuels, and to reduce the country's dependency on imported oil. Its main goal is to tap the country's domestic produce as viable sources of energy [4]. The Philippine Government created several policy measures to efficiently utilize its energy supply and resources from the transport sector. Administrative Order No. 126 Series of 2005 was issued directing all sectors in the government to enhance the implementation of its energy conservation program launched in August of 2004. The primary objective is to make energy conservation a way of life for every Filipino.

The government also launched the Natural Gas Vehicle Program for Public Transport (NGVPPT) designed to promote the utilization of compressed natural gas (CNG) in the transport sector in consonance with the goal of ensuring fuel supply diversification and supply security and help improve urban air quality through the reduction of harmful vehicular emissions [5].

To be able to assess effectively the impact of different plans and programs of the government in its effort to fight against global warming, appropriate methods or techniques of estimating energy demand and emissions must be readily available to the public. The Philippine government currently used the top-down method in estimating energy demand as mandated by Memorandum Circular No. 93-03-05 Series of 1993. However, the top-down approach is considered not reliable in capturing the impact of different transport policy measures particularly geared towards the reduction of energy demand and vehicle emissions from road transport at the regional level.

While, a limited number of studies in the Philippines with emphasis on national energy demand and CO_2 emissions from the transport sector [6],[7], attempt to develop a new technique of estimating energy demand and CO_2 emissions using inter-regional passenger and freight flow O-D data is considered very valuable to provide efficient methods of evaluating low-carbon measures[8],[9],[10].

In order to address this gap, availability of practical approach in estimating inter-regional energy demand and CO_2 emission must be sought to provide fast and reliable result in the assessment of strategies to realize low-carbon transport in the country.

2. OBJECTIVES OF THE STUDY

The general objective of this study is to develop a fuel consumption model for buses and trucks and present a new approach of estimating and forecasting energy demand and CO_2 emissions for the Philippine inter-regional road transport using available origin-destination data. The study will also develop a fuel efficiency model for buses and trucks in relation to road segment classifications such as urban road, rural highway, and expressway, to be used in estimating energy demand.

The study also assessed the potential implications of selected policies in the overall reduction of CO_2 emissions from the Philippine road transport sector.

3. STUDY METHODOLOGY

The general approach of this study was to estimate inter-regional energy demand and CO_2 emissions Origin-Destination data. Parameters used for the analysis were average vehicle kilometer traveled per vehicle trip, annual passenger trips, occupancy factor, load factor, and the distribution of vehicle and fuel types.

In developing a generalized fuel consumption models for buses and trucks, data from the result of the fuel consumption validation surveys were used. A regression analysis was then carried out using lengths of road segments and average speed as independent variables and total fuel consumption per trip as dependent variables.

The study considered only buses and trucks in modeling and estimating energy demand and CO_2 emissions as these two modes of transport dominated the share of all land-based public and freight inter-regional travel with an average of 95.88% and 95.06%, respectively.

Adjusted traffic growth rates by region found in Volume 1 of the DPWH Manual was used to forecast passenger and commodity trips to future scenario [11]. The method of estimating energy demand and CO_2 follows the ASIF approach and the IPCC guidelines as shown in Fig.1 [12].

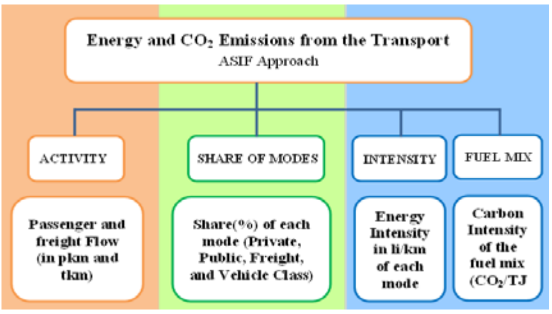

Fig.1 The ASIF approach

4. MODEL DEVELOPMENT OF FUEL CONSUMPTION FOR BUSES AND TRUCKS

4.1 Fuel Consumption Model for Large Bus

In developing the model, the average speed was not included as one of the independent variables in estimating energy demand since it shows a very high correlation with the other independent variable, that is the type of road segments as depicted in Fig.2.

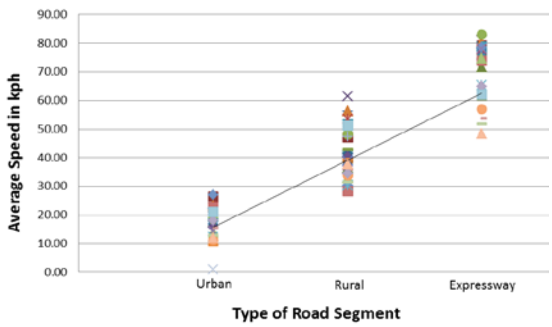

Fig.2 Average speed vs. type of road segment

Eighteen data samples from the fuel validation surveys were used to model fuel consumption for large buses using regression analysis. The first model considers the different lengths of road segment, that is, urban road (*UR*), rural road (*RR*), expressway (*E*) and fuel consumption as dependent variable. The result of the regression analysis for large bus yield high r-square of 0.98 and t-statistics greater than 2.0 as shown in Table 6.1. To evaluate if the first model can still be improved, the length of urban and rural road segments were combined. The result of the regression analysis for the second model shows a reduction of r-square and t-statistics of the two independent variables as shown in Table 1, thus, it was rejected and the first model was accepted as the final model to be used in estimating fuel consumption for large buses.

Table 1 First fuel consumption model for large buses, *n*=18

Variables	*Coeff*	*t-Stat*	*P-value*	R^2
Intercept	5.1652	1.1118	0.2850	0.98
UR	0.8405	6.6546	0.0000	
RR	0.3344	28.3843	0.0000	
E	0.1492	2.3458	0.0342	

Table 2 Second fuel consumption model for large buses

Variables	*Coeff*	*t-Stat*	*P-value*	R^2
Intercept	12.6244	2.0807	0.0550	0.967
UR+RR	0.3318	19.8234	0.0000	
E	0.1987	2.2372	0.0409	

To check whether the actual or observed sample frequencies are consistent from expected or predicted frequencies derived from the proposed model (i.e., the observed fuel consumption data is close to the predicted value), a chi-square test was performed. Since the sum of the chi-square of the predicted values of fuel consumption is 13.982 and is less than the critical value of 27.587 at 0.05 level of significance and 17 degree of freedom, it is safe to conclude that the model can predict actual fuel consumption for inter-regional travel.

Therefore, the proposed model for estimating fuel consumption for large buses is shown in Eq. (1).

$$FCM_{LB} = 5.165 + 0.841UR + 0.334RR + 0.149E \quad (1)$$

Where:

FC_{LB} : estimated fuel consumption for large bus per trip in liters
UR : length of urban road segment, km
RR : length of rural road segment, km
E : length of expressway segment, km

The development of the fuel consumption model for small buses, small trucks with two axles and large trucks with 3 or more axles was also performed using the same criteria above and the summary of the resulting models are shown in Eq. (2) to Eq. (4).

4.2 Fuel Consumption Model for Small Bus

$$\boldsymbol{FCM_{SB} = -3.658 + 0.221(UR + RR) + 0.468E} \quad (2)$$

R^2=0.93, *n=12*, Sum of Chi-Square of 3.039<Critical value of 19.675 at 0.05 level of significance and 11 degree of freedom.

4.3 Fuel Consumption Model for Large Trucks

$$FCM_{LT} = 3.375 + 0.403(UR + RR) + 0.450E \quad (3)$$

R^2=0.95, *n=20*, Sum of Chi-Square of 13.761< critical value of 31.144 at 0.05 level of significance and 19 degree of freedom.

4.4 Fuel Consumption Model for Small Trucks

$$FCM_{ST} = 7.482 + 0.185(UR + RR) + 0.106E \quad (4)$$

R^2=0.97, *n=28*, Sum of Chi-Square of 31.028<Critical value of 43.194 at 0.05 level of significance and 27 degree of freedom.

5. PROPOSED FORMULA OF ESTIMATING ENERGY DEMAND AND CO2 EMISSION

In estimating inter-regional energy demand and CO_2 emission from the road transport sector, the study followed the ASIF theory in a more elaborate approach. The modified formulas in estimating energy demand from the public and freight transport sectors are shown in Eq. (5) and Eq. (6), where E_m *(PT)* is the estimated total inter-regional energy consumption for public transport (buses) in ktoe, while E_m *(Freight)* is for freight transport (trucks) also in ktoe.

$$E_m(PT) = \frac{P_m}{\hat{O}_m} x\,(D_m)(FCM_{i,j})(A_{i,m})(Bi_{i,m,j})(C_j) \quad (5)$$

$$E_m(Freight) = \frac{W_m}{\hat{Z}_m} x\,(D_m)(FCM_{i,j})(A_{i,m})(B_{i,m,j})(C_j) \quad (6)$$

P_m is the constructed O-D table of annual passenger trips under vehicle category *m;* $\hat{\boldsymbol{O}}_m$ is the constructed O-D table of average occupancy of all vehicles; $\hat{\boldsymbol{D}}_m$ is the constructed O-D table of average annual distance travelled in km; $A_{i,m}$ is the modal share for each vehicle type *i* and category *m;* W_m is the constructed O-D table of annual gross tonnage of all commodity; $\widehat{\boldsymbol{Z}}_m$ is constructed O-D table of average carrying tonnage per freight trip; $B_{i,m,j}$ is the fuel composition factor; C_j is the energy conversion factor; $FCM_{i,j}$ is the formulated fuel consumption model; *m is the* vehicle category (i.e., public & freight transport); *i* is vehicle type (small bus, large bus, small truck, & large truck); and *j* is the fuel type.

In general, P_m and W_m are the expanded annual passenger trips and commodity flows for public and freight transport, respectively as a result of expanding 10-hour sample data to 24-hour population data.

Having estimated the energy demand for each category *m* and fuel type *j,* it is now possible to estimate the total energy demand as the sum of all categories as shown in Eq. (7).

$$E_{TJ}(Total) = \sum_j E_m(PT)_j + \sum_j E_m(Freight)_j \qquad (7)$$

Likewise, the total CO_2 emissions for each fuel type j, in tones can also be computed by applying the corresponding emission factor where EF_j is the emission factor of fuel type *j* as shown in Eq. (8).

$$CO2_{Tons}(Total) = \sum_j E_m(PT)_j(EF)_j + \sum_j E_m(Freight)_j(EF)_j \quad (8)$$

6. RESULTS AND ANALYSIS

Integrating fuel consumption models into Eq. (5) and Eq. (6), the inter-regional energy demand and CO_2 emissions for buses and trucks can now be estimated. Results of the estimation shows that energy demand from inter-regional public buses and freight road transport under BAU scenario substantially increased from 6,358.86ktoe in 2015 to 36,410.43ktoe in 2050. Consequently, the estimated CO_2 emissions from inter-regional public buses and freight road transport under BAU scenario is 19.72 Megatons in 2015 and 112.93 Megatons in 2050.

Results of the study shows that inter-regional travel from NCR to CAR registered the highest energy demand for buses followed by Region V to NCR as shown in Fig.3.

The highest inter-regional energy demand for freight trucks is from NCR to Region IV, followed by region I to NCR as indicated in Fig.4. It should be noted that Region IV has the highest number of population and registered vehicles according to the Philippine census in 201.

Likewise, the computed 2015 inter-regional CO_2 emissions for buses and trucks from the seven regions in Luzon are shown in Fig.5 and Fig.6. Results show that inter-regional travel from NCR to CAR generates the highest CO_2 emissions for buses followed by Region V to NCR as shown in Fig.5, while inter-regional travel from Region II to NCR generates the highest CO_2 emissions for freight trucks followed by Region II to Region III as shown in Fig.6.

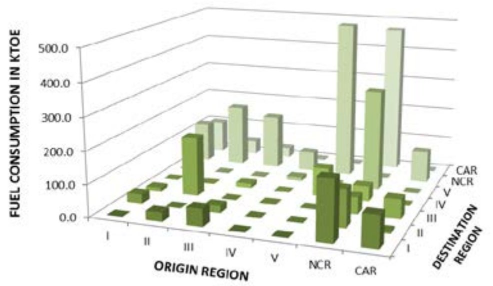

Fig.3 Computed inter-regional energy demand for buses in 2015

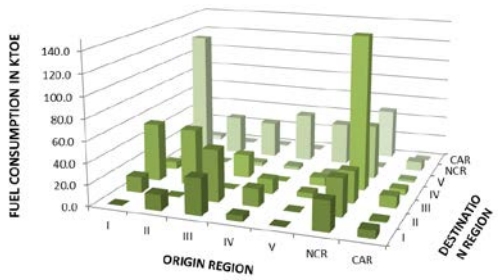

Fig.4 Computed inter-regional energy demand for for freight trucks in 2015

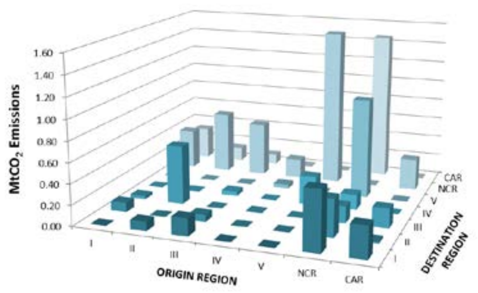

Fig.5 Computed inter-regional CO_2 emissions for buses in 2015

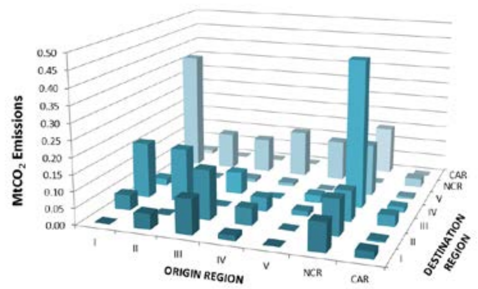

Fig.6 Computed inter-regional CO_2 emissions for freight trucks in 2015

7. IMPLICATIONS OF DIFFERENT POLICY SCENARIOS

There were five selected policy scenarios simulated and compared to the BAU scenario. It should be noted that the selection of the different policy measures was aligned with the existing government's strategies to realize low-carbon transport in the Philippines particularly on its long term target threshold of 0.33 $MtCO_2$ per capita per year as recommended in the study of long-term transport action plan for ASEAN [13]. These are the promotion of alternative fuel program (S1), promote better logistic management for freight transport (S2), revitalize the Philippine National Railway (S3), Implementation of High Standard Highway-HSH (S4), and the combination of the above scenarios (S5).

Under the promotion of alternative fuel program (S2), the goal is to have a gradual shift from conventional fuel to CNG for trucks and buses by 25% and 35% by 2030 and 2050, respectively.

The revitalized Philippine National Railway (S3) is projected to attract road-based public and freight transport to switch to railway in 2030 by 25% and 20%, respectively. Then continue to increase by 35% and 30% in 2050, respectively.

The study also assumed that through systematic and efficient logistic management, frequency of travel can be reduced by at least 1 in every 5-6 trips, thus resulting in at least 20% reduction in annual vehicle kilometer travel (VKT) in 2030 and 35% in 2050.

Comparisons of individual scenario show that promotion to alternative fuel program provides a more significant reduction in CO_2 emissions from the BAU scenario followed by the revitalization of national railway system and better logistics management, respectively (Fig.7). The least impact in reducing CO_2 emissions can be seen from the construction of more expressways under the HSH policy scenario simply because at a very high speed the vehicle fuel economy tend to decrease, thus increasing the CO_2 emissions. Results also show that simultaneous implementations of all the selected scenarios substantially reduce the BAU CO_2 emissions in 2050 by half (74.24%). It should be noted that the total estimates presented here does not include CO_2 emissions from other inter-regional mode of road transport such as private cars, SUVs, taxis, and jeepneys since there impact are considered very low with less that 5% of the total inter-regional passenger trips combined. The study shows that the target of 0.33tCO2 per capita per year seem achievable as shown in Fig.7 provided that the government must be aggressive and serious in the implementing various low-carbon policy measures including the provisions of facilities and incentives to public an freight transport operators to use alternative fuel.

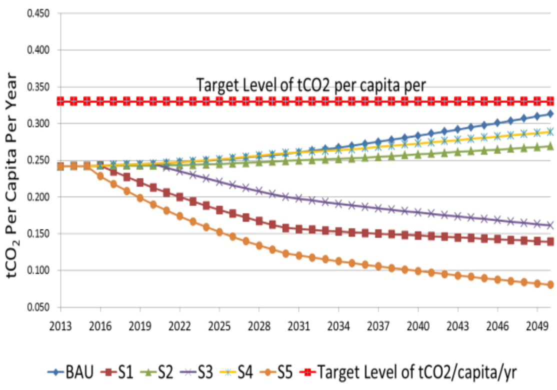

Fig.7 Comparison of the level of inter-regional CO_2 emissions from selected scenarios

8. SUMMARY AND CONCLUSION

The study presents a new technique and methodology of estimating energy demand and CO_2 emissions for public and freight transport using inter-regional passenger and freight flow data.

A fuel consumption model for buses and trucks was developed using regressions analysis and was used to estimate the CO_2 emissions from the different policy measures being selected. The estimated CO_2 emissions from the selected policy scenarios was compared with the reference "BAU" scenario. The study shows that the shift to better fuel such as CNG for buses and trucks provide a very substantial reduction in the estimated inter-regional CO_2 emission in Luzon compared with the other selected scenarios.

It should be noted that the computed total CO_2 emissions from inter-regional travel under the BAU is considered significant as far as the overall emission reduction is concerned, but by aggressive government interventions to encourage public to shift from convention fuel to a more eco-friendly alternative fuel will likely provide more significant changes. Likewise, improvement on vehicle technology including transmission, aerodynamics, tires and auxiliaries, as well as heat recovery must also be practiced to effectively reduce the overall CO_2 emissions of vehicle in the country.

From a policy perspective, it is recommended that the government should be aggressive in the implementation infrastructure development and the promotion of alternative fuels and the use of clean fuel especially for heavy vehicles.

Findings of this study will further strengthen the government's existing policies to promote the utilization of compressed natural gas (CNG) in the transport sector under the Natural Gas Vehicle Program for Public Transport (NGVPPT).

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