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Estimation of National Level Fuel Consumption and Emissions in Road Freight Transport

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1. Introduction

Road freight transport is growing with the rapid growth of economic activities resulting in an increase of GHG emission and carbon-based fuels consumption. The sector has been responsible for 35% of the world's transport energy use and diesel vehicles are the major fuel consumer in Asia [1]. Work towards more sustainable freight transportation should begin with a quantification of Vehicle Emissions (VE) and Fuel Consumption (FC) from the sector. Existing research on the Sri Lankan freight transport sector indicates a research gap in quantifying VE and FC at national level. The absence of a proper methodology to calculate VE and FC due to issues in calculation of diesel vehicle emissions has created this research gap.

Based on a recently developed diesel emission calculation equation and previously developed petrol emission calculation method, this study attempts to achieve the following research aims:

A. Development of a methodology to estimate VE and FC by road freight transport sector in Sri Lanka.

B. Estimation of VE and FC of road freight transport sector in Sri Lanka.

2. Methodology

2.1. Research Approach

Methods to estimate VE and FC at national level can take a top-down or a bottom-up approach. These bottom up approaches based on grass-roots level data closely reflects VE and FC data but the challenges to collecting nationwide data at grass-roots level keeps researches from adopting such. Adopting a method similar to those adopted by previous researchers [2], the proposed method attempts to calculate total vehicle emission from freight transport by considering prime movers, motor lorries and dual purpose vehicles that vehicle categories are the most-used vehicles on road as well as top ranking vehicle type based on number of vehicle registered in the past five years. This research thus proposes a bottom-up approach by combining vehicle fuel consumption data taken from a nationwide survey and individual vehicle emission rates taken at annual vehicle emission tests. Vehicle emission test data were gathered from Vehicle Emission Testing (VET) program of the Department of Motor Traffic (DMT) as vehicle emission checking is a cost of conduct. Fuel consumption data were collected from the survey. In addition, vehicle registration data were collected from DMT.

2.2. Determination of sampling size and sampling procedure

To obtain individual vehicle consumption data, national level data collection was conducted using stratified random sampling. Stratification was done using three types of strata namely by province, vehicle and fuel. Minimum sample sizes were calculated using a method followed for national level sampling based on the method used previously [3]. Accordingly, data collection was done for a total sample of 1,153 which was above the minimum sample size required at 95% level of confidence with a 3% of margin of error.

2.3. Calculation of petrol vehicle emissions

The VET emission data shows individual vehicle emissions by volume as a percentage. First, percentage emissions were converted to a per litre emission factors using equations 1 and 2 below. The total annual vehicle emissions from that vehicle category can be calculated according to equations 3 and 4. Carbon dioxide (CO_2), Carbon Monoxide (CO) and Hydro carbons (HC) were the basic emissions monitored in this study as they are the most critical.

Mi = Vmix *Qi *Ci - (1) [4]

Emission factor=Mass emission of pollutant/distance travelled in km /1liter –-(2)

*Total emission per vehicle = Emission factor * Total travel distance – (3)*

*Total emission of vehicles = Total emission per vehicle * Number of vehicles - (4)*

Mi = Mass emission of the pollutant i (CO, CO_2, HC) in g/l.

Vmix = Volume of diluted exhaust gas expressed in m^3 per 1liter and corrected to normal conditions 293K and 101.33 kPa.

Qi = Density of the pollutant i in kg/m^3 at normal temperature and pressure (293 K and 101.33 kPa).

Ci = Concentration of pollutant i in diluted exhaust gas expressed in ppm or (v/v) % and corrected by the amount of the pollutant i contained in the dilution air.

When using the above equation, the following assumptions were considered.

- Complete combustion takes place inside the engine.
- Air emission volume of 1L of petrol (m3 /l) = 9.03
- Air emission volume of 1L of diesel (m3 /l) = 15.81
- Combustion happen in normal temperature and pressure (293 K and 101.33 kPa).
- Density of HC = 0.5768 kg/ m3.
- Density of CO2 = 1.842kg/ m3.
- Density of CO = 1.165kg/ m3
- Densities of the emissions does not significantly vary with the temperature

2.4. Development of methodology for diesel vehicle emissions

The emission data for diesel vehicles is available in the form of the opacity factor named the "K factor". First K factor was converted to volume percentage using equations 5 and 6 based on a recently developed conversion equation [5]. This conversion enabled the calculation of emissions from diesel vehicles based on individual vehicle emissions. CO, $CO_2$are the pollutants that can be quantified through the calculation procedure.

$$CO_2 = 2.0110\ K\ (ppm\ v/v) \text{ - } (5)$$

$$CO = 0.1162\ K\ (ppm\ v/v) \text{ - } (6)$$

Feeding these outcomes, total annual emission from each vehicle type was estimated using equations 1, 2, 3 and 4.

2.5. Calculation of fuel consumption of vehicles

Fuel consumption was calculated by combining survey data and odometer reading from DMT by using equations 7 and 8.

*Fuel consumption / vehicle = fuel efficiency (km/l)*distance travelled (km)– (7) Total fuel consumption=No of vehicle * fuel consumption per vehicle (l) – (8)*

Fuel consumption data and emission data were analysed according to Province and vehicle type using equations in the methodology developed.

3. Results

Province-wise VE and FC is given in Table 1 while Table 2 gives the same results categorized by vehicle type. According to the results, the total fuel consumption was found to be 1,105,580,645.29 diesel litres and 112,727,989.5 petrol litres. Accordingly, road freight transportation is heavily dependent on diesel. In terms of geographical distribution, the Western Province is the main contributor of emissions and fuel consumption, while the Southern Province remains in second place. Uva Province shows the lowest values of both VE and FC. These show a closer correlation to economic development.

Table 1: Emissions and fuel consumption in goods transport by province

Province	HC		CO		CO_2		Petrol Consumption		Diesel Consumption	
	kg	%	Kg	%	Kg	%	Liters	%	Liters	%
Southern	44760	21	2,594,514	19	45,332,884	19	23,299,173	21	171,647,950	16
Northern	3,833	2	467,646	3	1,798,034	1	1,196,156	1	135,429,773	12
Central	32,915	15	2,230,551	17	29,045,806	12	14,040,266	12	126,221,574	11
Uva	6,640	3	560,985	4	12,193,337	5	4,532,935	4	34,246,366	3
North West	11,600	5	1,035,259	8	18,316,997	8	7,041,949	6	167,644,884	15
North Central	9,191	4	1,092,594	8	5,392,169	2	3,413,489	3	77,642,005	7
Sabaragamuwa	6,693	3	723,005	5	11,180,654	5	4,179,702	4	43,458,636	4
Western	93,584	44	4,421,431	33	111,247,913	46	52,040,791	46	325,699,111	29
Eastern	4,225	2	290,465	2	7,721,448	3	2,983,529	3	23,590,345	2
Total	213,441	100	47,066,700	100	1,212,662,455	100	112,727,990	100	1,105,580,644	100

Table 2: Emission and fuel consumption according to vehicle types

Vehicle type	HC(kg)		CO (kg)		CO_2(kg)		Petrol Consumption		Diesel Consumption	
	Kg	%	Kg	%	Kg	%	Liters	%	Liters	%
Motor Lorry(P)	9,326	44	6,377,603	47.5	64,328,682	26	31,676,271	28		
Dual Purpose(P)	12,017	56	7,035,482	52.4	177,803,507	73	81,051,718	72		
Motor Lorry(D)			2,481	0.02	53,294	0.02			540,832,415	49
Dual Purpose(D)			875	0.01	42,558	0.01			446,266,639	40
Prime Mover(D)			10	0.00	1,201	0.00			118,481,591	11

According to the results analysed, petrol vehicles contribute more emissions as shown in CO_2 levels. Among the petrol vehicles, petrol dual purpose vehicles show the highest contribution of CO_2, followed by petrol lorries. The main reason is that diesel engines are more efficient than petrol engines, with the result that CO2, CO and HC generation is very low. The prime movers show the lowest contribution to fuel consumption and emissions.

4. Conclusions

This research was intended to quantify the emissions and fuel consumption in Sri Lankan freight transport sector by proposing a suitable calculation method and by conducting corresponding calculations based on national level data collection. Road based freight transport vehicles consume more diesel than petrol. Further diesel dual purpose vehicles and motor lorries contribute to more emissions while consuming the majority of diesel. Prime movers contribute least to emissions and fuel consumption.

These outcomes are intended to be used for scenario based nationwide emission and energy consumption modelling exercise. These outcomes will also be helpful at policy decision level. For example, this will inform that dual purpose and motor lorries should be a prime focus in transport emission reduction programs.

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