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Alternative Methods for the Estimation of Carbon Emissions from Transportation Sector Based on Data Availability

by :

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Where we are ...

- **ITS** is a technological university,
- Located in Surabaya, East Java
- The second largest city in Indonesia
- With the total population of 3.2 M

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Areal View of ITS

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ITS with 17,000 student bodies

6 Faculties:

- Matematics and Science
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- Marine Technology
- Informatic Engineering
- Industrial Creative and Design

INTRODUCTION

The Primary Footprint

The Secondary Footprint

INTRODUCTION

Energy Consumption Reached 851 million BOE (Indonesian Environmental Status, 2008)

96%

The transportion sector contributes 23% of total global CO_2 emissions. Overal contribution of these emissions, 75% by road transport (Regmi & Hanaoka, 2011)

INTRODUCTION

How to handle this problem ?

Calculation Method of The IPCC, 2006.

One part of the handling CO_2 emission is by conducting the emissions inventory in each region, to support the mapping and the management of national emissions programs

INTRODUCTION

The general approach for the measurement of CO_2 of emissions, are generally divided into two approaches (McKinno) :

- **Measurement based on Inputs (INPUT-BASED)**
  - This approach is essentially a top-down measurement
- **Measurement based on Output (OUTPUT-BASED)**
  - This is a bottom-up approach.
  - It usually gives a more accurate better estimation results

REVIEW OF ESTIMATION METHODS

Models emissions from transportation activities are classified into three equation principles. The equations include:

1. The calculation based on the quantity of fuels, for example is the Mobile Combustion Models
2. The calculation based on the quantity and type of contributor, for example is Mobile 6 Models
3. The calculation based on the methodology by the IPCC

Alternative 1 Method:

The calculation of CO_2 emissions using the amount of fuel consumed multiplied by the emission factor of the fuel type

$$Fuel\ Energy\ unit = fuel\ type\ x\ energy\ content$$

$$CO_2\ emission = \sum [Fuel\ Energy\ unit\ x\ emission\ factor]$$

Alternative 2 Method :

The calculation of CO_2 based on the type of vehicles that are grouped according to the types of fuel, respectively

$$Vehicle\ fraction = \frac{Sum\ of\ Specific\ Vehicle}{Total\ of\ all\ type\ Vehicle}$$

$$ER_n = [emission\ factor\ x\ vehicle\ fraction]$$

$$e = [\sum_{n=1}^{N}(TG_n x O x ER_n)]$$

$$Specific\ fuel\ consumption\ = \frac{fuel\ comsumption\ (litre)}{amount\ of\ specific\ vehicle\ (unit)}$$

$$CO_2\ emission = \sum[e\ x\ Specific\ fuel\ consumption]$$

IPCC Method 3:

This method provides a three-TIER approach for different degree of accuracy in accordance with the specification of the data availability. The higher TIER gives better accuracy, but requires more complex of data and procedures

Tier 1 methodology

$$CO_2\ emission = \sum (\text{Fuel}_a \text{x EF}_a)$$

Tier 2 methodology

Equation in Tier 1 can applied for Tier 2, with emission factors must be calculated based on actual fuel carbon content.

Tier 3 methodology

- Tier 3 is more accurate than the Tier 1 and Tier 2
- But the calculation of CO_2 emissions by the IPCC Guidelines is recommended only using Tier 1 and Tier 2

(Eggleston, 2006)

RESULTS AND DISCUSSION

Inventory Data of Transportation Sector

- The main results of the inventory are:
  1. Data length of roads for each road class in the study area.
  2. Data of the road density and types of vehicles of each road class
- The inventory results of the length and the class roads in the study area (Surabaya city, East Java, Indonesia) are shown in Table 1.
- The calculation of potential CO_2 emissions was approximated by predicting emissions for each road class. It was based on the load or density for each road class in each study area, as it is presented in Table 2

RESULTS AND DISCUSSION

Table 1. The area and length of each segment of the road class in the study area (km)

Location	Number of Study Area	AP (km)	AS (km)	CP (km)	CS (km)	L (km)
Center zone	4	6.32	16.98	0	44.39	107.85
Northern zone	5	10.84	14.16	0.68	32.81	216.66
Eastern zone	7	4.49	48.10	9.38	132.05	520.99
Southern zone	8	9.54	15.35	17.10	84.26	631.65
Western zone	6	1.89	11.39	5.67	48.59	352.84
Total	**30**	**33.08**	**105.98**	**32.83**	**342.10**	**1829.99**

AP = primary arterial road; AS = secondary arterial road; CP = primary collector road; CS = secondary collector road; L = local road

RESULTS AND DISCUSSION

Table 2. Average vehicle density (vehicles/hour) for each class of road

No.	Vehicles Type	AP	AS	CP	CS	L
1.	Motorcycles	6795	4884	3313	4885	1200
2.	Passenger cars (premium)	1342	917	897	968	147
3.	Passenger cars (diesel)	727	265	241	323	52
4.	Bus/mini trucks	129	23	14	24	5
5.	Trucks	121	76	26	0	0
6.	Large buses	26	2	3	0	0
Total		**9141**	**6166**	**4495**	**6210**	**1404**

RESULTS AND DISCUSSION

Specific Emission Factors (SEF) and Emissions Calculation from Transportion Sector

- The results of the emissions average calculation for each road class as in Table 3. The data was subsequently used to determine the value of the two alternatives SEF based on the inventory data, *i.e.*:

1. SEF each vehicle type

$$SEF_{V.i}\left(\frac{kg\ CO_2}{vehicle.km}\right) = \frac{emission\ average_i\left(\frac{kg\ CO_2}{km.hr}\right)}{density\ average_i\left(\frac{vehicle}{hr}\right)}$$

2. SEF for each road class

$$SEFS_{R.i} = \sum_{1}^{n} emission\ average_{V.i}$$

- The results of the calculation for both SEF above, are summarized in Table 4

RESULTS AND DISCUSSION

Table 3. Number of average emissions for each road class

Vehicle Types	Average Emission ($kgCO_2$/km.hour)				
	AP	AS	CP	CS	L
Motorcyles	468.8559	337.0057	228.6292	337.0563	82.7768
Passenger cars (premium)	410.6287	280.6166	274.5141	296.2123	44.8343
Passenger cars (diesel)	241.4406	87.9038	79.9724	107.3278	17.2418
Bus/mini trucks	40.2163	7.1822	4.4753	7.3762	1.6001
Trucks	56.0618	34.9662	12.0284	0	0
Large buses	12.9210	0.8943	1.3894	0	0
Total	**1230.1243**	**748.5688**	**601.0088**	**747.9726**	**146.4530**

RESULTS AND DISCUSSION

Table 4. SEF alternative values based on its data availability

Based on Fuel type, IPCC 2006		Alternative 1			Alternative 2	
Fuel Types	**SEF ($kgCO_2/l$)**	**Vehicle Types**	**Specific Energy Consumption *(l/ vhcle.100km)***	**SEF ($kgCO_2$/ *vhcle.km)***	**Road Class**	**SEF (kg CO_2/ jam.km)**
Premium	2,597.86	Motorcycles	2.66	0.069	Primary Artery	1230
		Cars (Premium)	11.79	0.306	Secondary Artery	749
		Cars (Diesel)	11.36	0.332	Primary Collector	601
Diesel	2,924.90	Bus/mini trucks	10.64	0.311	Secondary Collector	748
		Trucks	15.82	0.463	Local	146
		Large buses	16.89	0.494		
IPCC		*BPPT in Jinca et al.(2009) and Yamin et al. (2009)*		*Calculation*		*Calculation*

RESULTS AND DISCUSSION

Verification of the carbon emissions estimation based on the IPCC and both alternative methods

- The emission calculations using 3 methods:
  1. IPCC,
  2. Alternative 1
  3. Alternative 2.

- The result of the calculation using the three methods are listed in Table 5, and the proximity of its value is shown in Figure 1.
- To sharpen the results of these two methods , the correlation values with the IPCC estimates was shown in Figure 2 and Figure 3.

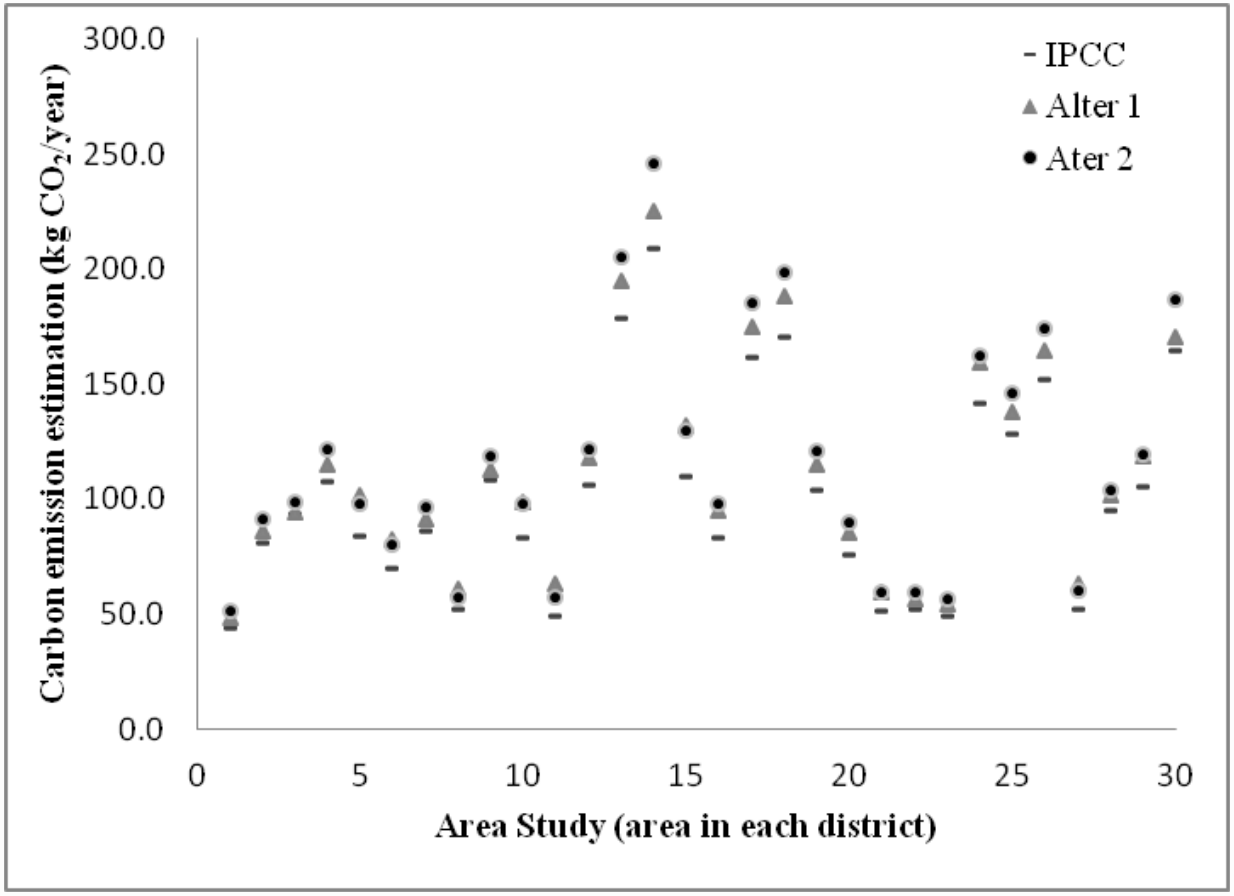
RESULTS AND DISCUSSION

Table 5. Carbon emissions estimation results by three alternative methods

Area	Emission Estimation ($kgCO_2$/ years)			Area	Emission Estimation ($kgCO_2$/ years)			Area	Emission Estimation ($kgCO_2$/ years)		
	IPCC	Alt. 1	Alt. 2		IPCC	Alt. 1	Alt.2		IPCC	Alt. 1	Alt. 2
1	44.2	48.7	51.4	11	49.4	63.2	57.0	21	51.4	59.6	59.6
2	80.7	86.3	91.4	12	105.8	118.0	121.4	22	51.8	56.5	59.4
3	93.3	94.5	99.0	13	178.8	195.0	205.0	23	49.3	53.9	56.8
4	107.6	114.9	121.4	14	208.5	224.8	245.8	24	141.3	159.5	162.3
5	84.0	101.6	97.8	15	109.6	131.8	129.5	25	127.9	137.9	146.0
6	69.9	82.3	80.5	16	83.4	95.2	97.6	26	151.7	164.2	173.7
7	85.9	91.6	96.5	17	161.4	174.9	185.0	27	51.9	63.3	59.9
8	52.0	60.9	57.1	18	170.3	188.0	198.7	28	95.1	101.6	104.1
9	108.1	112.8	118.7	19	103.8	114.9	120.8	29	105.5	118.5	119.0
10	83.3	98.7	97.7	20	75.4	85.1	89.5	30	164.5	170.6	186.3

RESULTS AND DISCUSSION

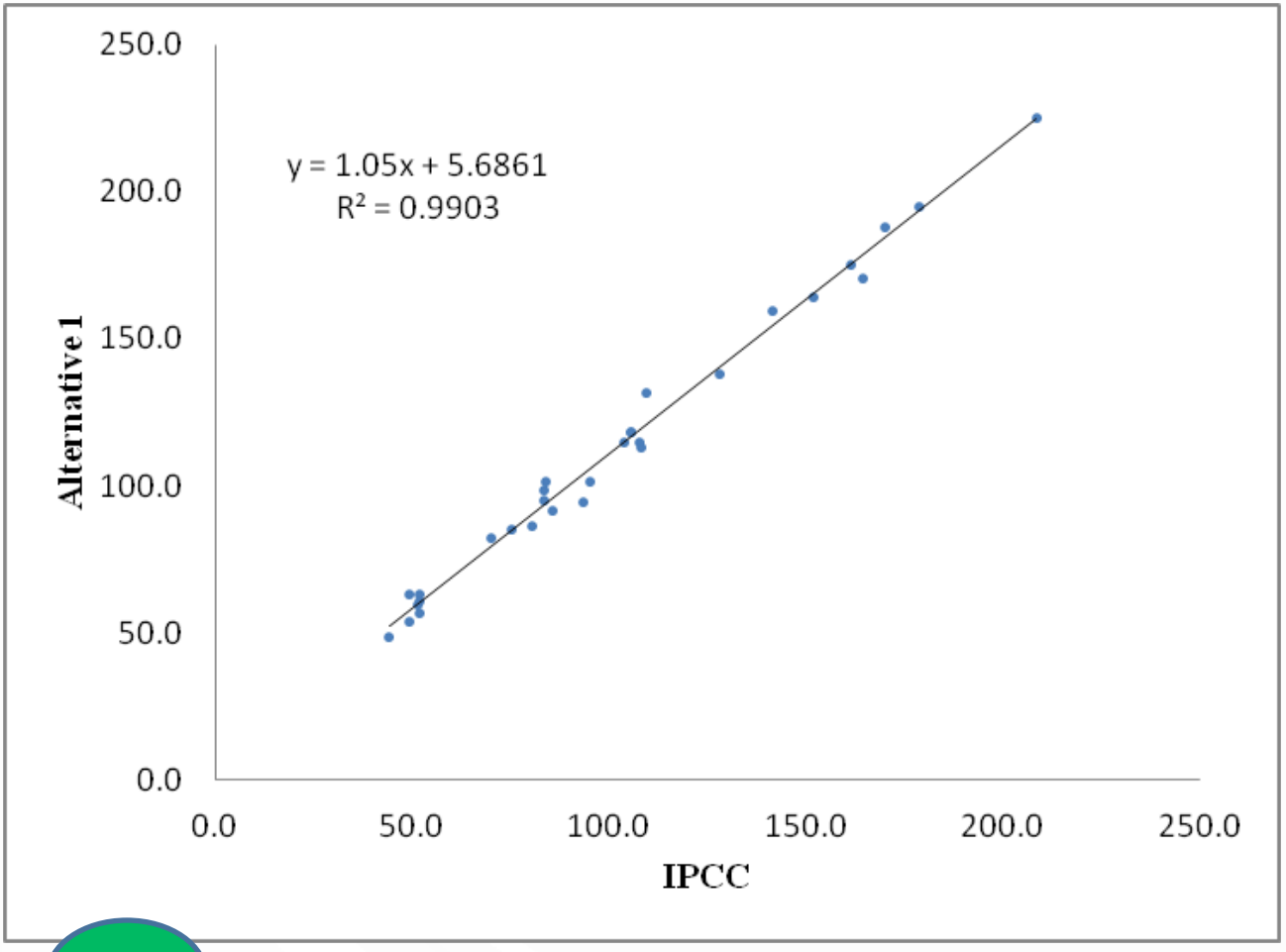
Figure 1. Value of Carbon Emissions from The Three Estimation Methods



In general, Figure 1 shows the values generated by the two alternative methods tend to result in **higher emission** values **from the IPCC**. However, these values are **consistent and fairly close to each other**

RESULTS AND DISCUSSION

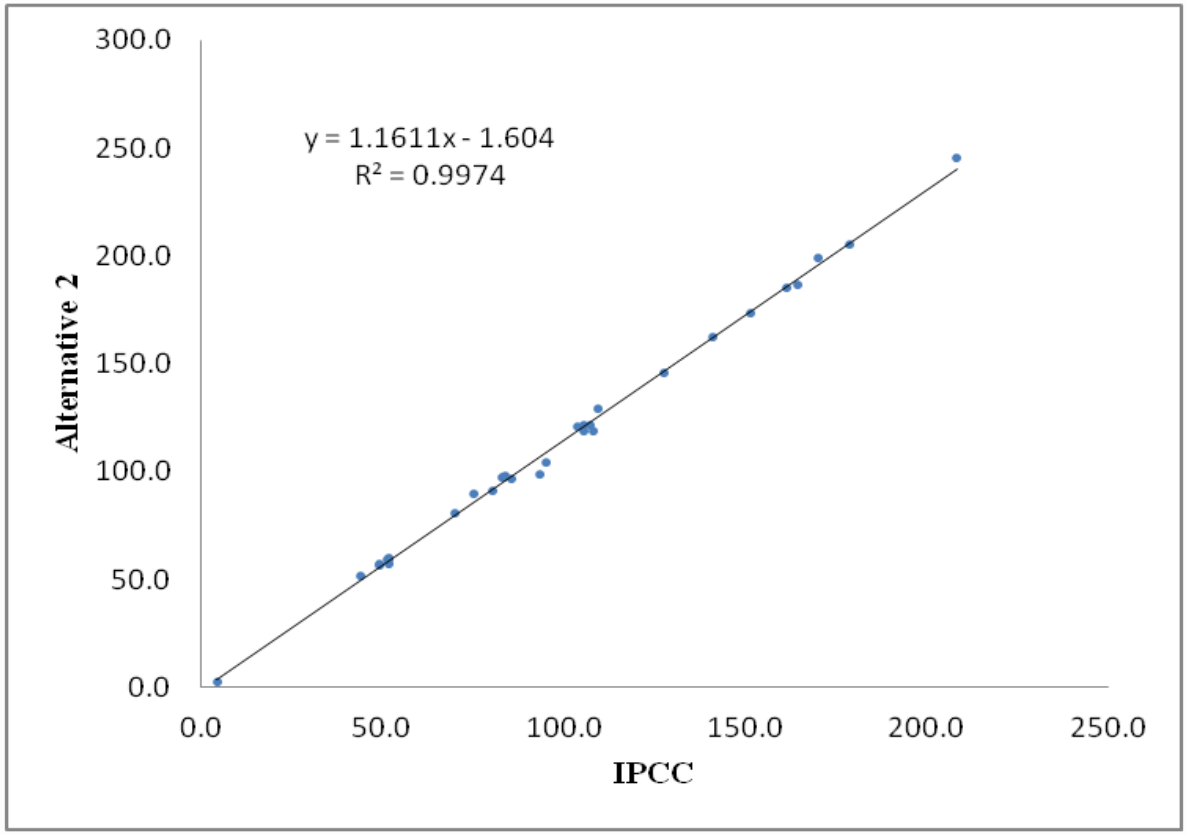
Figure 2. Correlation of Alternative 1 Emission Calculation Results to IPCC Estimate



It appears that both values are in the same tendency or **linear correlation**. Value of correlation (R^2) for alternative 1 and the IPCC is 0.990.

RESULTS AND DISCUSSION

Figure 3. Correlation of Alternative 2 Emission Calculation Results to IPCC Estimate



The calculation to standard error of the two alternative data correlation with the IPCC gives the following results:

- Alternative 1 provides the results of 112.3 ± 4.7 kg CO_2/year
- Alternative 1 provides the results of 116.3 ± 2.8 kg CO_2/year

If data is sufficient for all three methods, the priority calculation using the IPCC, then alternative 2 , and the latter using an alternative 1 .

CONCLUSIONS

- Two alternative methods of calculating carbon emissions for the transport sector can be applied in accordance with the availability of existing data in a region.
  - Alternative 1, the SEF in kg CO_2/vehicle.km, based on the type and number of vehicles in operation;
  - Alternative 2, the SEF in kg CO_2/hour.km, based on the length and class of road.

- Alternative 2 provides results that are closer to the IPCC by the correlation value 0.997 and standard error of 2.8 kg CO_2/year, compared to Alternative 1 (the correlation value of 0.990 and a standard error of 4.7 kg CO_2/year).

THANK YOU