Carbon emissions from Indian Railways

An estimation for transportation of goods during 2010-2011.

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Abstract

Indian railways is a critical infrastructure in the transportation of goods across India. It plays a vital role in the geographically balanced economic growth. By transporting a large volume of goods in comparison to air or road modality, it offers a better solution in cutting emissions. In this present paper a study is conducted based on data published by various governmental bodies; to quantify emissions from the transportation of goods by Indian railways. A comparison is attempted between the electric and diesel electric options for railways at the end, which will set out recomendations for a national policy for a healthier environment. The market share of Indian Railways is consistently falling over the years, it is losing to road transport. In the context it is worth mentioning that from the various studies published internationally, there is a close competition between railways and water transport in respect of environmental performance. Road transport is third choice in relation to Water transport & Railways wrt environmental performance. Major part of Railways goods is based on six major industries viz Electricity, Coal, Steel, Crude Petroleum, Petroleum Refinery products & Cement. A study by KPMG [1] found that the market share of transportation in India is 62% by Road, 29% by Railways,5% by Coastal, 4% by pipelines & < 1% by Airways. These statistics show that emissions from transportation can be reduced drastically by transportation modal shift to coastal waterways and railways combination.

At **School of Maritime Design & Research**, *we are working at assessing emissions from vessels operating in rivers, port and coastal transportation. The project is an attempt at estimation of emissions from coastal waterways transportation.*

1 Data[2] - Some of the facts and figures of Indian Railways

- Tonnes in millions originating (Freight) - 926427[3]

*Document typeset in LaTeX with GNU Emacs-Auctex on Fedora-Linux

[1] 'KPMG international' is a swiss entity. The data is sourced from their publication name: logistics in India, publication number: 173083, publication date: November 2010

[2] Data as at the end of the fiscal year 2010-11, published by Ministry of Railways.

[3] Including tonnes of railway's own freight.

- Tonne Kilometer[4] (in million) - 626472.611

Description	**Freight train** (Total ('000s))		**Wagon**	
	Diesel	Electric	(Total ('000s))	(% loaded)
Train kms	134720	233770	17749397	66.5
Traffic kms	579685		177523148	

Table 1: Freight train & wagon km, as on 31^{st} March 2011

Description	**Broad Gauge**			**Meter Gauge**			**Total** (incl. Narrow Gauge)		
	Steam	Diesel	Electric	Steam	Diesel	Electric	Steam	Diesel	Electric
Locomotives	0	4688	4033	30	310	0	43	5137	4033
Horse Power	NA	12287465	18825535	NA	391300	0	NA	12764785	18825535

Table 2: Rolling Stock - Locomotives, as on 31^{st} March 2011

Description	**Broad Gauge**	**Meter Gauge**	**Total**
Total			(incl. NG)
Goods Stock	212701	3651	216508
Capacity (Tonnes)	12037394	119732	12160033

Table 3: Rolling stock - Freight cars & Wagons, as on 31^{st} March 2011

Description	**Broad Gauge**	**Meter Gauge**	**Narrow Gauge**
Loaded wagons per train	32	12	0
Total wagons per train	48	23	0
Freight weight per train	1702	488	0
Gross Load per train	3063	902	0

Table 4: Average utilization of wagons in train, as on 31^{st} March 2011

[4]A unit of freight carriage equal to transportation of one metric ton of freight one kilometer [`www.merriam-webster.com`].

Activity	**Diesel**	**Electricity**	**Lube oil**
	(kL)	('000 kWh)	Liters
Passenger	1246796	5632345	NA
Goods	968025	4580992	NA
Mixed	356	0	NA
Departmental	28855	21526	NA
Miscellaneous services	15171	285957	NA
Rail car propulsion	2088	0	NA
Shunting & siding	262055	228874	NA
Total	2523346	10749694	8817482

Table 5: Total quantity consumed - Fuels, Lubes and Electricity, Year 2010 - 11

Description	**BG**	**MG**	**Total**
			(incl.NG)
Diesel oil (liters)	2.16	7.65	2.17
Electricity (kWh)	6.79	0	6.79

Table 6: Fuel consumption per 1000 gross tonne km - goods and proportion, Year 2010-11

Activity	**Diesel**	**Electricity**
	(kL)	('000 kWh)
Goods	4.82	15.8
Mixed	1.29	0
Shunting & Sliding	2.77	8.33

Table 7: Consumption per engine kilometer, Year 2010-11

Year	**Total route**	**Route electrified**	**% Electrified route**
	(kilometers)	(kilometers)	(All gauges combined)
Broad Gauge	55190	19610	35.53
Meter Gauge	6810	0	0
Narrow Gauge	2460	0	0
Total	64460	19610	30.42

Table 8: Electrification, as on 31^{st} March 2011

Description	Passenger part	Goods part	Other	Totals
Gross tonne-kms	589222330000	1130960700000		
Net freight-tonnes		625725767000		
Train kms	549935000	368484000		
Mixed train kms	276000	1000		
Departmental train kms	698000	5245000		
Shunting-engine-kms	18687000	9248000		
Shunting-train engine-kms	3299000	5959000		
Traffic-engine-kms	586559000	579685000	8500000	
Train hours	13591200	14353000	13500	
Shunting hours				5691300
Other engine hours				15382300
Departmental engine hours				646200
Total engine hours				49677500

Table 9: Train & Engine kilometers,time. Year 2010-11

Description	Through goods	Van & shunting
Train kms	363057000	5428000
Train engine hours	14039900	313100
Wagon kms (total)	17523148000	226249000
Net-tonne kms	618456678000	7269089000
Gross-tonne (excl.)	1056631133000	10650211000
Gross-tonne (incl.)	1113313064000	12346716000

Table 10: Goods trains performance, Year 2010-11

Description	Passenger part		Goods part	
	BG	MG	BG	MG
Shunting engine kms per 100 train kms	4.01	5.43	11.3	52.9
Light engine kms per 100 train kms	0.01	0.71	10.5	6.73
Light assist not reqd. kms per 100 train kms	0.56	0.82	15.6	6.73

Table 11: Shunting & light running average figures, Year 2010-11

Description	in Tonnes
Net freight weigth	488
Gross weight	902

Table 12: Average load per train freight, Year 2010-11

Data	**Diesel**			**Electric**			**Units**
	BG	MG	Total	BG	MG	Total	
Train kms	133.41	1.31	134.72	233.77	0	233.77	million
Engine kms	232.57	2.67	236.10	343.42	0	343.42	million
Shunting & other engine kms	50.15	1.69	52.7	12.3	0	12.3	million
Light assist, sliding & departmental kms	778.62	0.92	779.55	104.48	0	104.48	million
Net tonne kms per goods loco day use	302245	30552	332797	453960	0	453960	–
Net tonne kms per goods engine				20840	2407	23247	–
Percentage of train kms			37.1			62.7	–
Gross tonne km - goods & mixed			403752970			727207730	–

Table 13: Statistics - Freight, Year 2010-11

2 Emissions from electricity consumption - Freight

CO_2 Emission estimates from IEA[5] tables

IEA tables give CO_2 emissions by an emission factor (**EF**) as $[CO_2]_{g/kWh} = 912$ (for year 2010).
Electrical power consumed by Indian railways for an year can be calculated as,

$$\text{kWh per 1000 gross-tonne km} \times \text{gross tonne km (goods and mixed) electric part} \times 10^{-3} \tag{1}$$

$$\implies \text{Total electricity consumed for year 2010-11} = 6.79 \times 727207730 \times 10^{-3} \tag{2}$$

$$= 4937740.487\ kWh \tag{3}$$

CO_2 emissions in 'grams' from electric locomotives for Freight operations in the year 2010-11 is calculated as,

$$[CO_2]_{g/kWh} \times \text{Total electricity consumed in kWh} \tag{4}$$

$$\therefore CO_2 \text{ emissions in year 2010-11 is} = 4503.219 \text{ Tonnes} \tag{5}$$

3 CO_2 Emissions from HSD consumption - Freight

3.1 Application of IPCC Tier I method with range of possible emission scenarios

CO_2 emissions from the use of diesel fuels can be calculated with appropriate units as,

$$CO_2 \text{ emissions} = \text{HSD Consumption} \times [CO_2]_{\text{emission factor diesel}} \tag{6}$$

The $[CO_2]_{\text{emission factor diesel}}$ is calculated using the following data.

1. Carbon Oxidation Factor (during combustion) = 0.99
2. Molecular Weight Ratio = $\frac{44}{12}$

Assuming that the Indian railways used High Speed Diesel (HSD) conforming to BSIV during the year 2010-11, some of its data can be used for calculating amount of fuel consumed. Some of the data for BSIV HSD specification normally quoted[6] is:

Item no.	Parameter	Specification	Typical analysis value
1	Density @ 15^0C (kg/m^3)	$820 \sim 845$	825
2	Total sulfur content (mg/kg) Max	50	40
3	Water content (mg/kg) Max	200	150
4	Ash percent by mass, Max	0.01	< 0.01
5	Carbon residue (Ramsbottom) on 10% residue, percent by mass, Max	0.3	0.1

Table 14: BS IV (IS 1460:2005) specification for diesel fuels

CO_2 emissions are usually a function of the carbon content alone of the diesel oil. Diesel oil is a complex mixture of hydrocarbons having carbon numbers in the range of $C_9 \sim C_{20}$. Fuel suppliers do not usually quote the carbon content values and calorific values.

[5] CO_2 emissions from fuel combustion by IEA 2012 edition; © OECD/IEA, 2012. International Energy Association, 9 rue de la Fédération 75739, Paris Cedex 15, France.

[6] The data is published by ONGC-MRPL for BS IV (IS: 1460-2005)

3.2 HSD Consumption

HSD Consumption by diesel locomotives in appropriate units for goods part can be calculated as,

$$\text{HSD Consumption per 1000 gross tonne kms} \times \text{gross tonne kms (goods part)} \tag{7}$$

$$HSD_{cons} = 2.17 \times 403752970 \times 10^{-3}\text{Liters} \tag{8}$$

$$\therefore HSD_{cons} = 876143.95\text{Liters} \tag{9}$$

$$\approx 715459.15\text{kg @ } 25^0\text{C for HSD of density 825 kg/m}^3\text{ @ } 15^0\text{C} \tag{10}$$

3.3 Net Calorific Value

Net calorific value (**NCV**) for HSD in India is in the range of 10100 $\sim$ 10300 kcal/kg.[7]

Description	**Indian values**	**IPCC values**
NCV	10100 $\sim$ 10300 kcal/kg $\approx$ 42.26 $\sim$ 43.1 TJ/kilo-Tonne	43.33 TJ/kilo-Tonne

Table 15: Comparison of Net Calorific Values of HSD

3.4 Carbon content

Data of crude oil imports[8] for India during the year 2010-11 and its corresponding carbon content from IPCC 1996 tables are plotted in Fig. 1.

The density of the plot points shows that the average carbon content of the imported crude is about 85% by weight. Also from IPCC tables of 'Other Asia' we get the carbon content of fuels is 84.8% by weight. The total crude oil produced in India during 2010-11 is about 37.71 million metric tonnes, while cruide oil imported is 163.59 million metric tonnes. This implies that the Indian liquid fuels constitute roughly 18.7% of Indian crude and 81.3% of imported crude components.

3.5 Emission factor of HSD

The emission factor of HSD fuel consumed by Indian railways during 2010-11 can now be calculated in the following steps.

$$1\text{kg of HSD} = 0.85\text{kg of carbon} = 0.85 \times \frac{44}{12} \times 0.99\text{kg of } CO_2 \tag{11}$$

$$\therefore [CO_2]_{\text{emission factor diesel}} = 71572.72 \sim 72977.77 \text{ kg/TJ (for HSD shown in Table 15.)} \tag{12}$$

3.6 CO_2 emissions from diesel consumption in freight operations

CO_2 emission in Tonnes, from combined diesel locomotives for freight operations during the year 2010-11 is,

$$[CO_2]_{\text{emission}} = 715459.454 \times 43.1 \times 10^{-6} \times 71589.327 \tag{13}$$

$$= 2207.5 \text{ Tonnes} \tag{14}$$

[7]Data released by Central Electricity Authority (Govt. of India), New Delhi

[8]The data is reported by Nidhi Verma on 6^{th} August, 2012 for Reuters - "India's country-wise crude oil imports since 2001/02"

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This is a TeXmacs interface for GNUplot.

GNUplot] set xlabel "%Carbon Content (by weight)"
         set ylabel "% of Total Crude imported by India"
         plot "indiancrude.dat" u 13:($11*100/3285) w p
```

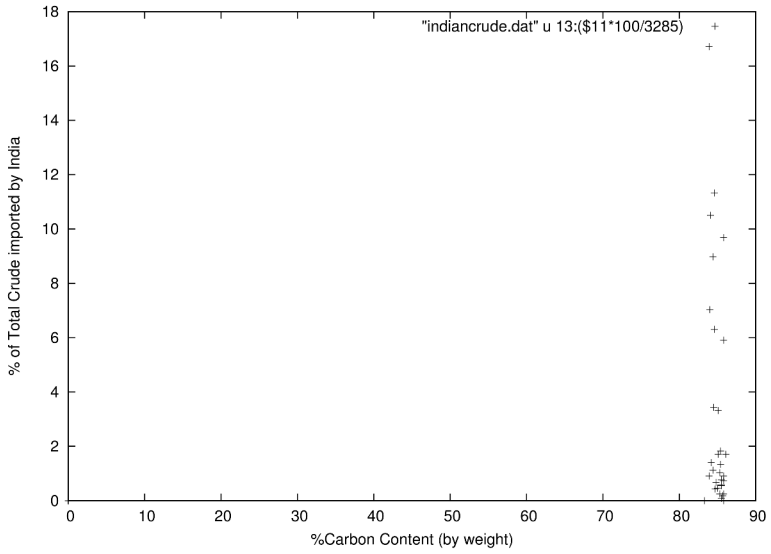

Figure 1: Scatter plot of crude oil imports in India for the year 2010-11

Parameter	**Interpreted values**	**IPCC values**
Carbon content (%wt)	0.85	0.848
NCV for HSD (TJ/kilo-tonne)	42.26 $\sim$ 43.1	43.33
CO_2 emission factor diesel (kg/TJ)	73012.305 $\sim$ 71589.327	72600 $\sim$ 74800

Table 16: Comparison of CO_2 emission factors for HSD

3.7 Estimation of CO_2 emissions from lubricant consumption (empirical)

CO_2 emissions from the consumption of engine lubricant in the diesel engines can be calculated in the following steps:

1. Consumption of lubricant = 0.5% of fuel consumption.
2. Oxidation of the carbon in lubricant can be assigned the value 0.2 (**ODU**), oxidized during use.
3. Lubricant oil is assumed to have a carbon content of 0.85% by weight.
4. CO_2 emission factor for lubricant = 14750 $\sim$ 14462.5 kg/TJ
5. Quantity of lubricant assumed to have burned = 3577.3 kg.
6. CO_2 emission from the lubricant consumption is $\therefore$ 2230 kg.

The total CO_2 emissions from goods diesel locomotives = **2209.73** Tonnes for the year 2010-11.

4 Summary & extrapolation of results

- **If the total goods were carried by diesel locomotives, the CO_2 emissions would be =** 2209.73/0.371 = 5956.15 **Tonnes.**
- **If the total goods were carried by electric locomotives, the CO_2 emissions would be =** 4503.22/0.627 = 7182.17 **Tonnes.**

Indian railways has better CO_2 emission performance with diesel locomotives. The total power supplied to the national grid and the power generation sources are considered in this evaluation. The power generated during the year 2010-11 from various sources can be found in the energy statistics published by the Ministry of Statistics and Programme Implementation, Govt. of India.

The following are the summary[9] of the CO_2 emissions evaluated for Indian railways freight movement during 2010-11:

1. CO_2 emissions per Net-Tonne-km for **diesel locomotive** = 0.00951 grams.
2. CO_2 emissions per Net-Tonne-km for **electric locomotive** = 0.01146 grams.
3. CO_2 emissions per Net-Tonne-km for **mixed** goods train = 0.01072 grams.

CO_2 emissions from Indian railways according to commodity wise transportation can be shown as in Table 17

Commodity	**Tonnage**	**NTKms**	**CO_2 emissions**
	Thousands		Tonnes
Coal	420372	268296130	2876.1
Iron ore	118460	46357091	496.9
Cement	99080	56952218	610.5
Mineral oils	39293	26084909	279.6
Food grains	43445	51996346	557.4
Fertilizers	48224	40713787	436.5
Iron & Steel	32819	32233958	345.5
Containers	37593	40990059	439.4
Raw materials	13300	9827744	105.4
Other commodities	69146	52271007	560.3
Total	921732	625723249	6707.7

Table 17: Commodity wise originating Tonnage & NTKms and their carbon emissions, Year 2010-11

[9]The data includes for shunting, siding and other parts of freight operations.