Environmental Carbon Footprint Assessment of a LHB Railway Coach

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Abstract. Indian railways play an important role on the overall development of country. As with increasing population, the numbers of trains are added for services, so does railways coaches. Consequently, the impact on environment is also increasing. This study closely examines the carbon footprint associated with railway coaches used by the Indian Railways. The system boundary is limited to manufacture of coaches itself. The railway coach of Linke Hofmann Busch (LHB) bogie is considered. The calculations are carried out on the basis of weight distribution of various materials used for manufacturing of coaches and it mainly focused on global warming potential (GWP) calculation. The total GWP for an LHB coach is likely to be 62.94 tonnes CO₂ equivalent. Steel is main contributor with approximately 47 tonnes of CO₂ equivalent, followed by plastic and stainless steel with approximately 9.8 tonnes and 3.6 tonnes, respectively.

Keywords: Carbon footprint, Global warming potential (GWP), LHB coaches, Indian Railways

1. Introduction

Indian railway is the third largest railway in world by its network size of 67,415kms as of March 2019 [1] provide a network map. It comes under ministry of railway hence making it a government entity. The total locomotives running under Indian railways till March 2019 are 12,147 and total wagons are 2,89,185. With continuous increase in population of our country along with the development of infrastructure, it is evident that in future railway network will grow with rapid pace so, number of wagons and locomotive also will increase. The Linke Hofmann Busch (LHB) coaches are preferred over conventional coaches [2] due to certain basic advantages as follows:

• Higher passenger capacity and cooling capacity.
• Higher speed potential and light weight
• The improved suspension mechanism of LHB coaches ensures additional comfort for the travelers
• The cooling system of the LHB coaches is operated by a microchip that provides a favored comfort to travelers during summer and winter seasons.
• Each coach carries a maximum noise level of 60 decibels and hence quieter while ordinary coaches can produce 100 decibels
LHB coaches are Indian railway passenger coaches built by LHB, Germany which is renamed as Alstom LHB GmbH, Alstom in 1998. Such coaches are not rolled over or flipped in situation of a collision due to its anti-telescopic feature. These coaches are generally manufactured by Rail Coach Factory (RCF) at Kapurthala in India. These LHB coaches have been used by Indian railways on broad gauge (1676) network since 2000. Initially, 24 air-conditioned coaches to be used in the Shatabdi Express trains were imported from Germany, after which the Rail Coach Factory started manufacturing after technology transfer. There is an advanced pneumatic disc brake system in every coach of LHB, to slow down the higher speed proficiently. The modular interiors of LHB coach incorporate the broader windows and light system into roof and luggage racks. There are some major advantages of using LHB coaches over ICF coaches [3], which are:

- Higher conveying limit
- Lesser weight with 72 passenger’s accommodation.
- Low corrosion, Low Maintenance, Better comfort for travelers [2].
- LHB Coaches have aesthetically superior interiors with FRP panels for side wall and rooftop.

These can be taken out effectively for support, wear resistant, also resist water seepage.

In order to provide safe and comfort environment, IR announced that all ICF coaches would be replaced by LHB coaches. On 19 January 2018, the last ICF Coach was flagged off making way for the LHB Coaches launched by Indian Railways.

Manufacturing, operation and maintenance of such a huge number of locomotive and wagons produces huge impact on environment. This pollution produced from railway network has different kind of impact on environment like human toxicity, acidification, global warming eutrophication etc.

LCA is the real investigation of the whole life cycle of an object regarding sustainability. All aspects of the life cycle of an object is – extraction of materials from the environment, the production of the item, the utilization stage and what befalls the item after it is not, at this point utilized – can affect the climate from various perspectives. With LCA, you can assess the natural effects of your item or administration from the absolute first to the absolute last or from cradle to grave. We can help to settle on decisions through life cycle strategy. Considering all the important effects on the economy, atmosphere and culture, everybody has a duty and a role to play in the whole chain of the life cycle of an entity i.e., from cradle to grave. LCA gives a complete picture of the item, cycle or administration for example while a little change may seem to bring ecological advantages, it might really make more fossil fuel byproducts downstream, refuting its general advantage. A cradle-to-gate permits the maker to assess any adjustment in the production timeline.

In this study we intend to study environmental impact by performing of Life cycle analysis for LHB coaches.

2. Life Cycle Analysis of LHB coaches

2.1 Goal and Scope definition

In this study an AC - Linke Hofmann Busch (LHB) coaches is considered. LHB coaches are Indian Railway’s passenger coaches produced by LHB, Germany and mainly manufactured by Rail Coach Factory of Kapurthala in India. The railway Bogie considered as Fabric Italina de Automobil Torino (FIAT) bogie of Linke Hofmann Busch (LHB) [4].

The objectives of the study are:

- To determine detrimental life cycle stages for LHB coaches based on global warming potential. Basically, global warming potential is termed as the heat absorbed by greenhouse gases present in the atmosphere.
- The impact on eco-systems attributable to railway coaches can be calculated as broadly as possible.

The functional unit of the study is taken as per coach of a LHB AC coaches.
2.2 Life cycle inventory assessment

The coaches are designed to run at speed of up to 160 km/h and can exceed 200 km/h. Though, they have been checked for up to 180 km/h. LHB coaches are 23.54 m in length and 3.24 m in width. The weight of AC chair car is around 39.5 tonnes. These coaches are made of stainless steel and the interior parts are made of aluminium which make them lighter. LHB assembly can be divided into two categories: (a) Coach body and (b) Bogie.

LHB coach is designed in such a way that it represents as light weight construction made from low corrosive stainless steel. The large vehicle size made it possible to create vehicle with more travel space, high traveler limit and more extensive sounds and entryways and so forth per meter length, weight of the coach is around 10% lesser then the ordinary coach, this implies lower haulage costs as well as less wear of the coaches and track. As indicated by the providing food idea of Indian Railways, every vehicle is outfitted with a pantry for putting away and serving cold and hot suppers which are served to the travelers at their seats. The modular construction and the coordinating of the lighting into the inside roof and the gear racks are trademark highlights for these coaches. Along with roomy windows and wonderful shades of the room, future oriented equipment features have been acknowledged in the coaches meeting the expanding necessities of the travelers. Some characteristic dimensions of LHB coaches are given in table 1 [3].

### Table 1. Characteristic dimension of LHB coaches

| Characteristics                                  | Dimensions                  |
|--------------------------------------------------|-----------------------------|
| Gauge length                                     | 1676mm                      |
| Length over body                                 | 23540mm                     |
| Length over CBC                                  | 24000mm                     |
| Wheel base                                        | 2560mm                      |
| Maximum width over body                          | 3240mm                      |
| Maximum distance between inner wheel             | 12345mm                     |
| Window opening                                    | 1180mm×760mm                |
| Distance between centre pivot                    | 14900mm                     |
| Height of compartment floor from rail level under are condition | 1303mm                     |
| Maximum height from rail level                   | 102mm                       |
| Maximum height of centre CBC above rail level for empty vehicle | 1105mm                     |
| Maximum height of centre CBC above rail level for loaded vehicle | 1030mm                     |
| Wheels diameter                                  | 915mm                       |
| Maximum axle load permissible                    | 16.25 tonnes                |
| Higher speed potential                           | 160kmph                     |
| Ride index of coach                              | 2.5 at 160kmph              |
Car body shell is built with inter locking strategy and made up of economical weight steel development. Sheet floor and rooftop sheeting are made of austenitic hardened steel. Rooftop structure, side wall and end wall are made of ferrite stainless steel. IRSM-41 CORTEN steel is used for casing and different parts.

Insulation of coach is done from inside. Glass wool and resonaflex is used for heat and sound insulation. Table 2 represents insulation material used for the coach.

**Table 2. Insulation materials used [3]**

| Insulation | Insulation material                              | Density   |
|------------|-------------------------------------------------|-----------|
| Heat       | Glass wool (above window bottom line)           | 18.75 kg/m³ |
|            | slag wool                                       | 47 kg/m³  |
| Sound      | Resonaflex (below window bottom line)           | 28 kg/m³  |

Body doors are generally made up of steel of sandwich construction. Compartment doors are sliding doors of 65 kg weight and made of single leaf, stainless steel sandwich construction. Door leaf has an aluminum extrusion frame and a sandwich construction and 2 mm thick HPL sheet is used to both sides and filling of phenolic resin foam is used. Lavatory doors are double leaf, hinged folding doors, weight of the assembly is 26kg. There are two vertical sliding doors of a moving mechanism with manual opening. Weight of the modular assembly is 94kg. The size of modular unit is 2300mm \((l)\times70\text{mm (w)}\times2080\text{mm (h)}\). The door leaf is a foam filled sandwich construction of stainless-steel frame with sheet 1mm thick on both the sides. Table 3 represents number of doors.

**Table 3. Number of doors [3]**

| Characteristics                | Dimensions |
|--------------------------------|------------|
| Body side doors                | 4          |
| Compartment doors              | 2          |
| Lavatory doors                 | 3          |
| Vertical sliding doors         | 2          |
| Pantry door                    | 1          |
| Roller shutter for pantry areas| 2          |

The sealed device consists of 8.4 mm externally coated glass and 4 mm internally tempered glass with 6 mm air hole with krypton/argon gas filler. Table 4 represents parameters for windows.

**Table 4. Window Parameters [3]**

| Parameter         | Value          |
|-------------------|----------------|
| Shell Opening     | 1480×880       |
| Clear Opening     | 1400×800       |
| Outer Glass       | 8.4mm          |
| Inside Glass      | 4mm            |
| Gap               | 6mm            |
| Total Thickness   | 18.4mm         |
| K Value           | 1.6W/m²K       |
| Transparency      | >39%           |
| Reflection        | >40%           |
| Energy Transmission| <21%         |

The floor surface has 16 mm composite board produced using cork panels glued to makore wood of 690 kg/m³ density. There are 2 AC units in one coach with intake and exhaust duct system. The fresh
air enters with speed of 160 km/h and discharge of 21m$^3$/h for one person. The refrigerating unit weights around 630kg and the refrigerant used is R22. Bio-digester tanks are made up of stainless steel. No human excreta is tossed on tracks from a bio-toilet fitted in trains. In these bio-toilets, fitted under the lavatories, human waste is gathered and processed by anaerobic microorganisms that convert it mainly into bio-gases (mainly carbon dioxide and methane) and water.

In this study, the impact category considered is global warming potential as it is one of major impact on environment and gives us better and clear idea about impact. There are large numbers of materials used in manufacturing of an LHB coach. Some materials like steel, stain less steel have high contribution in a coach, while others like seat covers, refrigerant etc. are negligible as compare to weight of coach. So, we have considered only those materials which possess significant contribution in manufacturing of coach by weight and of which we had concrete information about their weight distribution in coach.

In fig 2, the pie chart represents the distribution of materials used in LHB coaches by its weight, some materials whose weight was very less compared to whole coaches were neglected.

![Weight Distribution](image)

**Figure 2.** Weight distribution of materials used in LHB coaches

Steel used for body of coaches is around 23413 kg, maximum for the coaches. While plastic, used for seats comes next with overall weight of 1638 kg. While other major contributing materials were glass and slag wool for insulation, makore woods for flooring, stainless steel, glass. It is evident that steel, glass wool, stainless steel, plastic and makore woods contributes to major of the weight of coach. Slag wool, glass wool and aluminum are significant enough to consider their contribution. Table 5 represents weight distribution of LHB coach.

**Table 5.** Weight distribution of LHB coach

| Materials       | Weight (kg) |
|-----------------|-------------|
| Steel           | 23,413      |
| Slag wool       | 43          |
| Glass wool      | 139         |
| Resonaflex      | 138         |
| Makore woods    | 850         |
| Stainless steel | 1,250       |
| Plastic         | 1,638       |
| Aluminum        | 15          |
| Glass           | 426         |
| Water           | 1,910       |
3. Life Cycle Impact assessment and Interpretation

The chart shown in figure 3 represents the global warming potential per kg of material used and collected from eco-invent data base except steel, aluminium and slag wool. The characterization factor for steel, aluminium and slag wool are collected from references [6,7,8] respectively. Aluminum has the highest global warming potential of around 23 kg CO$_2$ equivalent per kg of aluminum. While glass and plastics are the next two with 8 kg CO$_2$ equivalent per kg and 6 kg CO$_2$ equivalent per kg respectively. The lowest emission is for makore woods.

![Figure 3. Global warming potential per kg of materials](image)

In fig 4, the chart represents the total global warming potential of materials used in making a single LHB coach. The total global warming potential of a LHB coach comes out to be 62.94 tonnes of equivalent CO$_2$ per LBH coach. This chart gives us an idea about how much impact every material is having on global warming potential. It represents the total global warming potential along with weight distribution for a LHB coach. From the chart it’s clear although the maximum GWP is of steel but plastic and glass wool have maximum GWP in comparison to their weight.

![Figure 4. Total Global warming potential](image)
4. Conclusions
In this study, the weight distribution of materials was used and their respective global warming potential was calculated. The study concludes that the total global warming potential of an LBH coach is approximately 62.94 tonnes of CO$_2$ equivalent per LBH coach. The major contributors are steel, plastic, stainless steel, glass wool and glass. The materials used like steel, plastic, glass wool act as hotspot for global warming potential. However, the main causes of concern are the use of plastic and glass wool, as they have relatively high equivalent CO$_2$ per kg of material as compared to other materials. As the overall global warming potential of these coach materials is quite high, there is a need to find alternative materials in order to reduce CO$_2$ equivalent footprint of the coach.

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