Final Report

# Green House Gas Emission Reduction Analysis for Dedicated Freight Corridor

Dedicated Freight Corridor Corporation of India Ltd

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Contents

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List of abbreviations

| | |
|---|---|
| BM | Build Margin |
| CAGR | Compounded Annual Growth Rate |
| CBTC | Communication Based Train Control |
| CDM | Clean Development Mechanism |
| DFC | Dedicated Freight Corridor |
| DFCCIL | Dedicated Freight Corridor Corporation of India Ltd |
| EF | Emission Factor |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| IL&FS | Infrastructure Leasing & Financial Services Ltd |
| IPCC | Intergovernmental Panel on Climate Change |
| IR | Indian Railways |
| JICA | Japan International Cooperation Agency |
| OHE | Overhead Equipment |
| OM | Operating Margin |
| POL | Petroleum Product |
| PV | Photovoltaic |
| RO-RO | Roll-on Roll-off |
| TEU | Twenty-foot equivalent unit |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WBCSD | World Business Council for Sustainable Development |

**DISCLAIMER**

Although reasonable care has been taken to ensure that the information sourced is relevant and correct, Ernst & Young Pvt. Ltd in particular, makes no representation or warranty, express or implied, as to the accuracy, timeliness or completeness of any such information.

Our responsibility in performing this study is solely to the management of Dedicated Freight Corridor Corporation of India Ltd (DFCCIL), and in accordance with the terms of reference agreed with DFCCIL. We do not therefore accept or assume any responsibility for any other purpose or to any other person or organization.

We made specific efforts to quantify GHG emissions only based on our information from discussions and data and information made available to us by DFCCIL and discussions with other railway experts. However, the outcome of the exercise may not be considered exhaustive and representing all possibilities, in view of uncertainties in the processes of implementation of the future Dedicated Freight Corridor, though we have taken reasonable care to cover different scenarios in the Report.

This Report is meant for internal use by the management of DFCCIL, and should not be used for any other purpose.

## 1. Highlights of the key study outcomes

The huge industrial growth rate of India has increased the demand of freight transportation in the country. It will be difficult for Indian Railways alone to cater to the projected freight transportation demand of India for the next 25-30 years even if it pursues ambitious capacity growth plan. Also global endeavor for a low carbon economic growth is emphasizing on low carbon infrastructure and energy efficient transport system. In view of these facts, Indian Railways has conceptualized the Eastern and Western Dedicated Freight Corridors (DFC) between the Indian metro cities. The implementation of the DFC is expected to generate two major impacts on the freight movement: shift of freight from road to the low carbon intensive mode rail transport and inherent improvement in energy efficiency of freight rail through adoption of improved technologies. The key purpose behind initiating this study was:

- To establish, through an objective and independent analysis, that DFC is a more climate-friendly way of freight transportation since it reduces GHG emissions w.r.t freight transportation by existing rail and road system
- To develop a long-term low carbon road-map which will enable DFC to adopt more energy efficient and carbon-friendly technologies, processes and practices

The study, for the sake of analysis, considers two reference scenarios *viz* the 'No-DFC scenario' and the 'DFC scenario' to analyze and compare the 30 year projection of GHG emissions between them. The **'DFC scenario'** refers to the scenario where Dedicated Freight Corridor is implemented in the Eastern and Western Region of India. Eastern Corridor stretches between Dankuni and Sirhind (1799 km) whereas the Western Corridor stretches between Dadri and Jasai (1483 km). **'No-DFC scenario'** represents the scenario where in absence of DFC implementation the freight would have been carried by the Indian Railway and road.

1. Cumulative GHG emissions for 30 years (in million ton $CO_2$) for each of the corridors under the DFC and No-DFC scenarios is presented in the table below :

| | Eastern Corridor | Western Corridor |
|---|---|---|
| Freight to be transported under DFC scenario | 1975 | 3241 |
| GHG emissions under No-DFC scenario | 114 | 465 |
| GHG emissions under DFC scenario | 48 | 77 |
| GAP of corridor wise GHG emissions between No-DFC scenario and the DFC scenario | 67 | 388 |

2. Coal and iron & steel are the two major commodities carried by the Eastern DFC which account for almost 65% of total freight GHG emissions in the corridor. Container and RO-RO are the two major commodities carried by the Western DFC, accounting for about 85% of total freight GHG emissions of this Corridor.
3. The study establishes that the transportation infrastructure under the 'No-DFC scenario' is inadequate to cater to the freight volume and category mix proposed to be carried by the DFC

route. Besides, being less carbon intensive, this is another driver for the implementation of the DFC.

4. GHG emissions solely contributed by the construction of the new route of DFC are about 0.64 million ton $CO_2$. This is a one-time emission and represents about 2.5% of the total GHG emissions.
5. DFC intends to follow a low carbon path adopting various technological options which can help DFC to operate in a more energy efficient fashion and at the same time explore options to offset its own GHG emissions by investing in low carbon assets such as solar power, wind power and afforestation. Some of the interventions which could reduce GHG emissions are communication based train control (CBTC), driver advice system, regenerative braking, aerodynamic profiling in rolling stock and on-board lubrication system. DFC project team is working closely with various experts and technology suppliers to assess feasibility of implementing these ideas for low carbon growth which would further decrease the carbon intensity of DFC's operation resulting in GHG emission of about 6.8 million ton $CO_2$ in the Eastern Corridor and 10.9 million ton $CO_2$ in the Western Corridor over a period of 30 years.
6. Some of the GHG abatement levers which also have potential to earn carbon revenue through Clean Development Mechanism (CDM) include Regenerative Braking, Adoption of green building features, CBTC, solar power generation etc.

## 2. Executive Summary

The economic growth of India has put a huge pressure on the rail freight transportation network, one of the most affordable modes of transport in the country. It will be difficult for Indian Railways, even under the ambitious growth plan, to achieve the required freight transportation capacity. On the other hand, global endeavor for a low carbon economy has put thrust on low carbon infrastructure and public transport systems like energy efficient railways to strategize their operations in the future years. Considering the huge freight traffic movement between the metros, Indian Railways is mulling to introduce Eastern and Western Dedicated Freight Corridors (DFC). The Special Purpose Vehicle named Dedicated Freight Corridor Corporation of India Limited (DFCCIL) is entrusted with the responsibility of implementation of the DFC. The implementation of the DFC is expected to generate two major impacts on the freight movement: shift of freight from road to the low carbon intensive mode rail transport and inherent improvement in energy efficiency of rail transport.

The scope of this study primarily consists of two key elements:

- Forecasting of the greenhouse gas (GHG) emission trend under the DFC scenario and the No-DFC scenario over a period of 30 years. The trend analysis has been performed in five year bands, with the reference year of each band coinciding with the terminal year of successive five year plans of the Government of India.
- Identification of possible interventions or levers of GHG abatement (over and above the measures proposed for the DFC) and their techno-economic assessment to suggest a low carbon path for DFC's operation.

**Some key terminologies:**

**DFC scenario:** Implementation and operation of dedicated freight railway and associated infrastructure in Eastern and Western India called the Eastern DFC and Western DFC respectively and catering to a total freight volume of 5216 billion tonne-km. While the Eastern DFC will mainly cater to coal, iron & steel and empties, the Western DFC will cater to container, fertilizer and POL. GHG emissions under DFC scenario will include $CO_2$ emissions due to:

- Electricity consumption in locomotives during freight movement through DFC with axle load 25 T.
- Fossil fuel and electricity usage in support infrastructure of DFC[1].

**No-DFC scenario[2]:** In this scenario, there will be no investment in creating dedicated rail freight transportation network like DFC. Instead freight will continue to be carried by freight trains operated by the Indian Railways and road based transport (i.e. commodity carriage and heavy duty trucks). This is also the most plausible alternative mode of transport in absence of DFC and is termed as No-DFC scenario. GHG emissions under No-DFC scenario will constitute of $CO_2$ emissions from:

[1] IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009

[2] This is the Baseline which is the scenario that reasonably represents the anthropogenic emissions by sources of GHG that would occur in the absence of the proposed DFC. Here Baseline to the DFC is the most plausible mode of transport catering to similar quantity of freight volume on the same route as that of DFC.

- Diesel and electricity consumptions in locomotives during freight movement through rail with axle load 22.9 T, catering to equivalent quantity of freight.
- Diesel and electricity consumptions in locomotives during unplanned halting[3] of freight trains due to congestion on rail routes.
- Diesel consumption in heavy duty trucks during freight movement through road where modal shift happens from rail to road due to inadequate freight carrying capacity of the railway
- Fossil fuel and electricity usage in the support infrastructure[4].

**Base Year:** 2016-17 is the Base Year for estimation of GHG inventory. This is also the expected year of the start of DFC's operations.

**Base Case:** This is the reference case taken for the GHG emission calculations. All scenarios such as high growth and low growth scenarios have computed with variations in the base case parameters.

**Forecasting period:** GHG forecasting and scenario modeling has been performed for 30 year period (i.e. 2016-17 to 2041-42)[5]. The initial year of each period is also termed as reference year.

**Annual emissions:** GHG emissions are estimated for each reference year of a 5 year period. The emissions are expected to remain constant in each year of the 5 year period. 'Annual GHG emissions' under any reference year denotes the annual emission for each year of that 5 year band.

**Approach and methodology**

The GHG emission estimation followed by development of monitoring and reporting framework has been performed following internationally accepted guidelines such as GHG Accounting Protocol of World Business Council of Sustainable Development/World Resources Institute and ISO 14064. The boundary for the study has been selected in accordance with the 'Control Approach' as per the guidelines of the GHG Accounting Protocol.

For the purpose of GHG emissions forecasting and scenario modeling all the freight projections have been taken from the IL&FS Report (which did the freight projection along Eastern and Western Corridor based on GDP, capacity expansion plans, industrial growth etc). The saturation capacity of each rail section (commodity wise) is estimated based on the year of attaining the saturation capacity provided by the JICA report. Based on the freight projections and saturation capacity/year, the shift to road is estimated for the No-DFC scenario.

For details on the methodology adopted for the study please refer to the Annexure 2.

**Key Outcomes of the Study:**

- In 2016-17, GHG emissions under 'No-DFC scenario' would have been 8.7 million ton $CO_2$ while those in case of DFC would be 2.59 million ton $CO_2$.
- According to the projection, in 2041-42, GHG emissions under 'No-DFC scenario' would have been 33.2 million ton $CO_2$ while those in case of DFC scenario would be 5.97 million ton $CO_2$.

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[3] The DFC track would be dedicated only for freight train movements and hence no unplanned halt due to passenger trains.

[4] No-DFC scenario support infrastructure primarily includes rail stations, workshops, wagon sheds, signaling system, staff quarters, administrative buildings, *etc* with facilities and features presently found in Indian Railways.

[5] This actually means 2016-17 to 2045-47. Here each 5 year period is denoted by its initial year or reference year for that 5 year period. Annual emissions have been estimated for each reference year. The annual emissions are expected to remain constant for each year in that 5 year period.

- The GAP of GHG emission between No-DFC scenario and DFC scenario increases from 6.11 million ton $CO_2$ in 2016-17 to 27.23 million ton $CO_2$ in 2041-42 i.e. almost by 4.5 times.
- Cumulative GHG emissions over the 30 year period in the No-DFC scenario would have been 582 million ton $CO_2$ while in the DFC scenario it would be 124.5 million ton $CO_2$. This demonstrates that in absence of DFC implementation approximately 4.5 times more GHG would be emitted in 30 year period for freight transportation in the Eastern and Western Corridor.
- In both No-DFC scenario and DFC scenario, the Eastern Corridor produces less GHG emissions than the Western since the latter caters to a higher volume of freight.
- In the Eastern DFC, coal transportation is the highest contributor of GHG emissions followed by transportation of iron & steel. However in the Western DFC, transportation of container and RO-RO are the major contributors of GHG emissions.

**Exhibit A1: Trend of projected annual GHG emissions due to freight transportation by DFC (in million ton $CO_2$)**

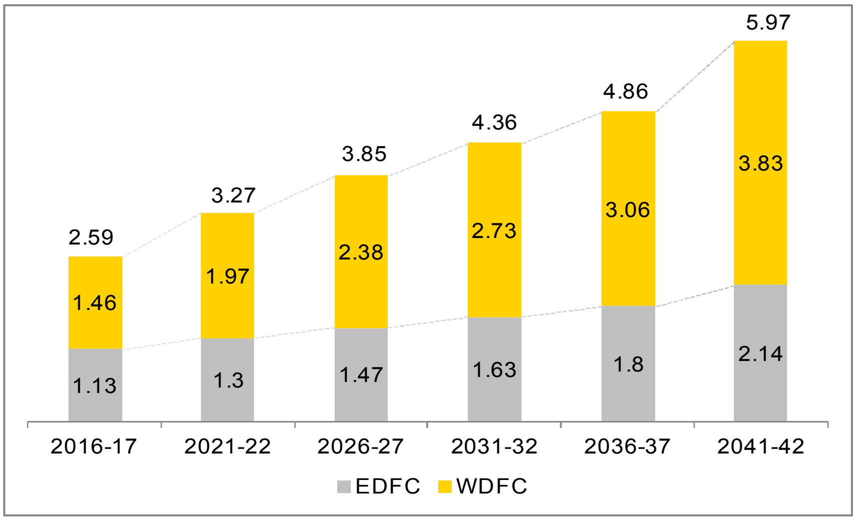


Exhibit A2: Trend of projected annual GHG emissions due to freight transportation in absence of DFC: Corridor-wise (in million ton $CO_2$)

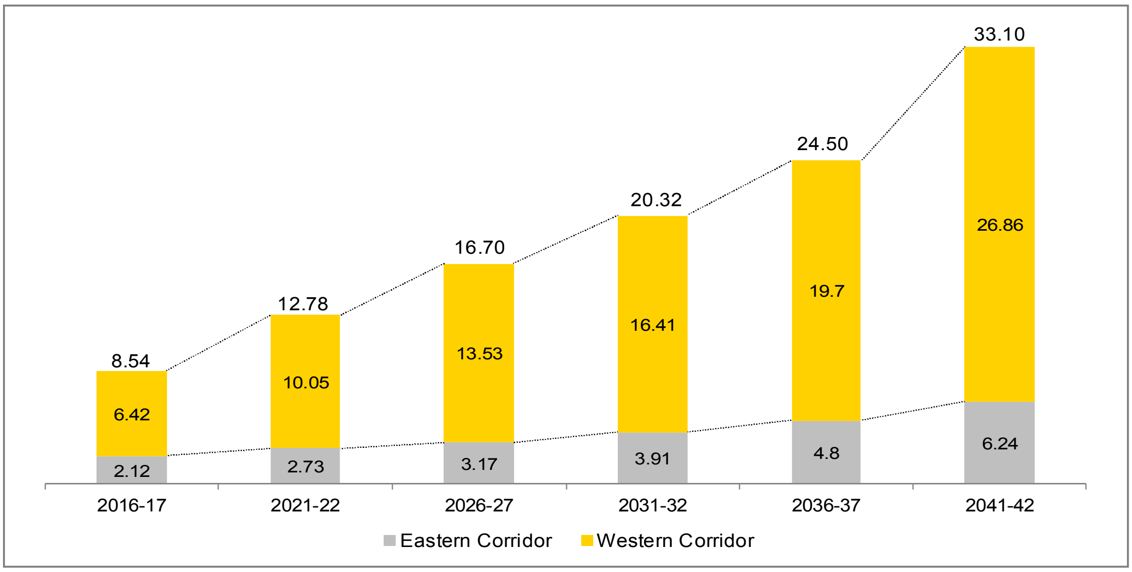
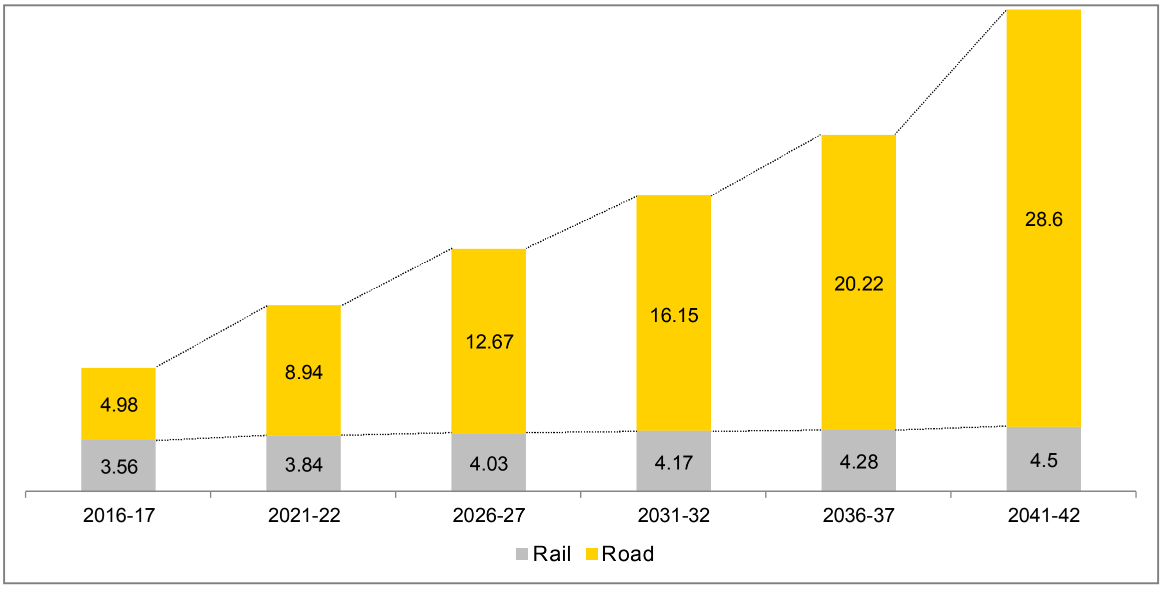



Exhibit A3: Rail-road share of total annual projected GHG emissions due to freight transportation in absence of DFC (in million ton $CO_2$)

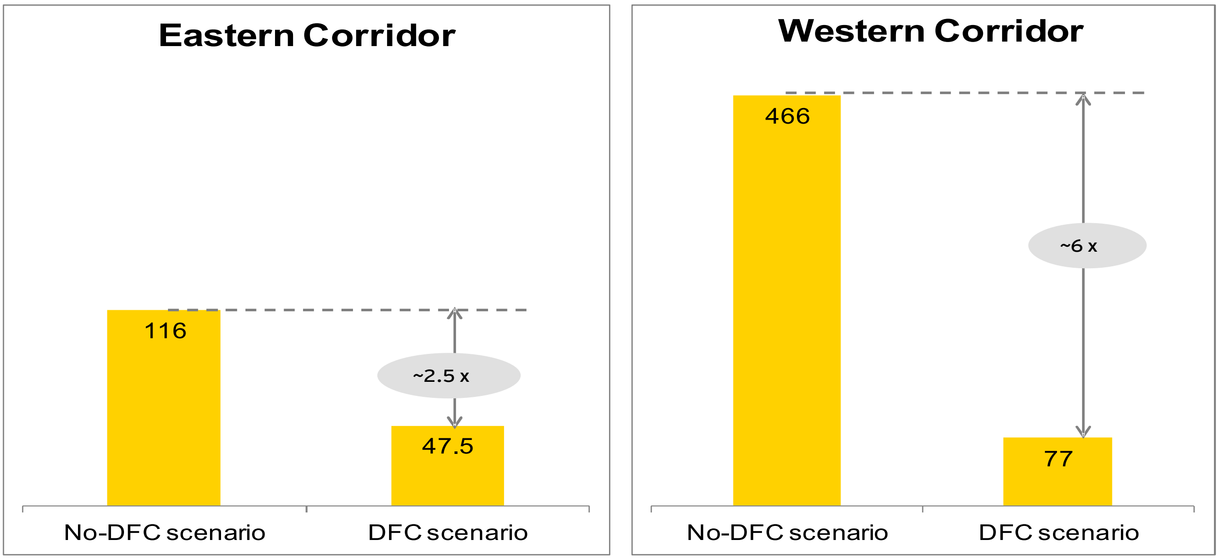



*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

From the above Exhibit it is evident that under 'No-DFC scenario' GHG emissions from rail becomes almost constant from 2026-27 onwards as the saturation sets in the railway sections and as a consequence, more and more freight shifts to road. This leads to increased GHG emissions from road based freight transport since road transport is more GHG-intensive than rail transport ($CO_2$ emission factor of heavy duty vehicles is greater than emission factor of rail).

On a cumulative basis (over 30 years), in the Eastern Corridor, the No-DFC scenario produces 2.5 times more GHG emissions than the DFC scenario while for the Western Corridor, the No-DFC scenario produces 6 times more GHG emissions than the DFC scenario.

**Exhibit A4: Cumulative GHG emissions over 30 years (2016-17 to 2041-42): No-DFC scenario vs. DFC scenario (in million ton $CO_2$)**

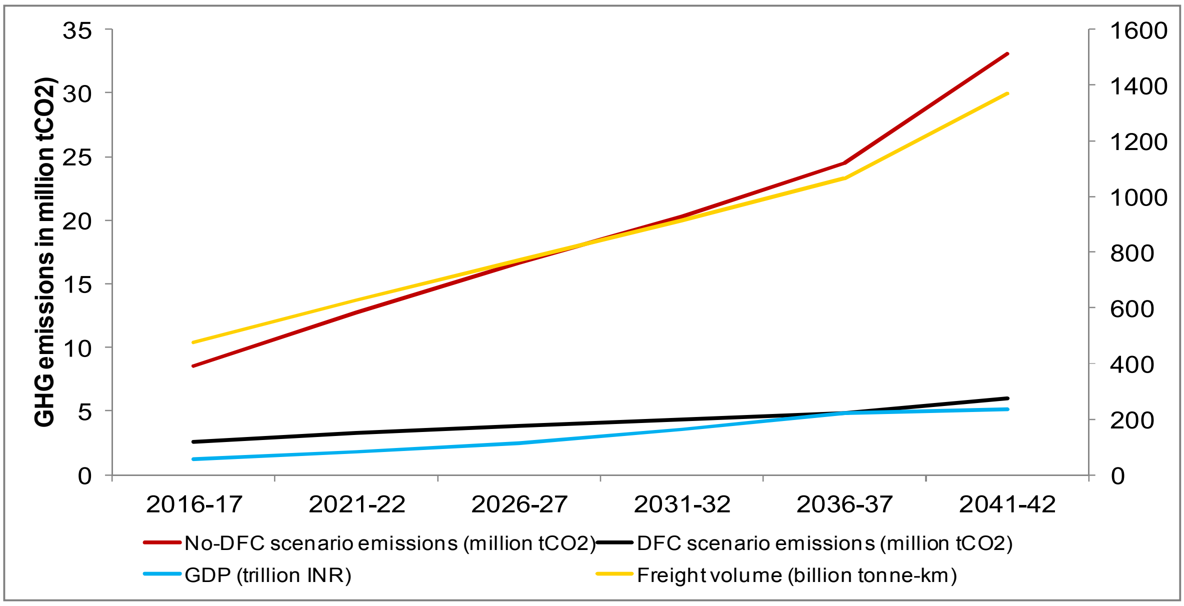



*Note: Cumulative denotes that the emissions are not on an annual basis (for each reference year) but a summation of emissions of all 30 years i.e. the summation of emissions for all 6 reference years multiplied by 5.*

GDP figures, freight volume and GHG emissions due to freight transportation in the DFC scenario as well as the No-DFC scenario increases almost linearly over the 30 year period. The growth of GHG emissions in the No-DFC scenario show a steeper slope in the second half of the 30 year period due to:

-almost all rail sections in both corridors get saturated and modal shift from rail to road takes place. Road being a more carbon intensive way of freight transport as compared to the railway system, GHG emissions increase due to road based transport.

**Exhibit A5: Variation of GHG emissions with GDP and freight volume**




All the important figures have been tabulated for the DFC and No-DFC scenarios in the following tables.

**Table A1: Important figures at a glance**

| Parameters | No-DFC scenario | | | | | | DFC scenario | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-27 | 2041-42 | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-27 | 2041-42 |
| Annual GDP (trillion INR) | 58 | 83 | 116 | 161 | 221 | 235 | 58 | 83 | 116 | 161 | 221 | 235 |
| Total annual freight transport (billion ton-km) | 563 | 718 | 852 | 975 | 1113 | 1391 | 474 | 628 | 769 | 913 | 1065 | 1367 |
| % of freight by road | 25.2 | 35.7 | 42.5 | 47.4 | 52.0 | 58.8 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| % of freight by rail | 74.8 | 64.3 | 57.5 | 52.6 | 48.0 | 41.2 | 100 | 100 | 100 | 100 | 100 | 100 |
| % of electric locos | 44 | 47 | 49 | 45 | 60 | 66 | 100 | 100 | 100 | 100 | 100 | 100 |
| % of diesel locos | 56 | 53 | 51 | 55 | 40 | 34 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Grid emission factor ($tCO_2/MWh$) | 0.683 | 0.653 | 0.624 | 0.597 | 0.571 | 0.546 | 0.683 | 0.653 | 0.624 | 0.597 | 0.571 | 0.546 |
| **Annual GHG emissions (in million ton $CO_2$)** | | | | | | | | | | | | |
| $CO_2$ emissions from congestion | 0.10 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| $CO_2$ emissions from freight transport | 8.54 | 12.78 | 16.70 | 20.32 | 24.50 | 33.10 | 2.59 | 3.27 | 3.85 | 4.36 | 4.86 | 5.97 |
| $CO_2$ emissions due to energy consumed in support infrastructure | 0.015 | 0.015 | 0.015 | 0.015 | 0.016 | 0.015 | 0.026 | 0.026 | 0.025 | 0.025 | 0.024 | 0.024 |
| $CO_2$ emissions due to energy consumed in construction for DFC[6] | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 0.642 | N.A. | N.A. | N.A. | N.A. | N.A. |
| **Total $CO_2$ emissions** | **8.655** | **12.885** | **16.795** | **20.405** | **24.576** | **33.165** | **3.258** | **3.296** | **3.875** | **4.385** | **4.884** | **5.994** |

*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

[6] This is a one-time emission and has been accounted for in the first year of DFC operation for sake of simplicity.

**Table A2: Important figures at a glance-Eastern Corridor**

| Parameters | No-DFC scenario | | | | | | DFC scenario | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-27 | 2041-42 | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-27 | 2041-42 |
| Total annual freight Transport (billion ton-km) | 213 | 252 | 276 | 311 | 350 | 408 | 206 | 250 | 293 | 341 | 395 | 490 |
| % of freight by road | 94 | 90 | 88 | 84 | 79 | 73 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| % of freight by rail | 6 | 10 | 12 | 16 | 21 | 27 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Annual GHG emissions (in million ton $CO_2$)** | | | | | | | | | | | | |
| $CO_2$ emissions from congestion | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| $CO_2$ emissions from freight transport | 2.12 | 2.73 | 3.17 | 3.91 | 4.80 | 6.24 | 1.13 | 1.30 | 1.47 | 1.63 | 1.80 | 2.14 |
| **Total $CO_2$ emissions** | **2.17** | **2.77** | **3.21** | **3.94** | **4.83** | **6.26** | **1.13** | **1.30** | **1.47** | **1.63** | **1.80** | **2.14** |

*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

**Table A3: Important figures at a glance-Western Corridor**

| Parameters | No-DFC scenario | | | | | | DFC scenario | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-27 | 2041-42 | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-27 | 2041-42 |
| Total annual freight Transport (billion ton-km) | 350 | 466 | 576 | 664 | 764 | 983 | 268 | 378 | 476 | 572 | 670 | 877 |
| % of freight by road | 63 | 50 | 43 | 38 | 34 | 28 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| % of freight by rail | 37 | 50 | 57 | 62 | 66 | 72 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Annual GHG emissions (in million ton $CO_2$)** | | | | | | | | | | | | |
| $CO_2$ emissions from congestion | 0.05 | 0.05 | 0.04 | 0.03 | 0.03 | 0.02 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| $CO_2$ emissions from freight transport | 6.42 | 10.05 | 13.53 | 16.41 | 19.70 | 26.85 | 1.46 | 1.97 | 2.38 | 2.73 | 3.06 | 3.83 |
| **Total $CO_2$ emissions** | **5.47** | **10.10** | **13.57** | **16.44** | **19.73** | **26.87** | **1.46** | **1.97** | **2.38** | **2.73** | **3.06** | **3.83** |

*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

Note: The No-DFC scenario considers freight transportation by existing Indian Railways structure (considering growth rate of IR based on historic trends). However due to saturation of certain sections of IR, commodities are required to be transported by road. In case of powerhouse coal, road transportation is not economically feasible. Therefore, for the purpose of this study it is assumed that no coal is transported by road. Other roadable commodities like salt and food grains are transported by road. There is a surplus capacity created due to the shift of these roadable commodities from rail to toad which is used to transport more coal. However even this rail capacity is not sufficient to carry the entire volume of coal to be transported to meet the projected demand of coal. Hence, quite logically some of the powerhouses slip to the next 5 year plan.

**Interventions for GHG abatement**

The above analysis establishes that DFC scenario is expected to be less GHG emitting than the No-DFC scenario. However there are specific technological interventions possible which if implemented could reduce GHG intensity of the designed system of DFC even further. DFC intends to follow a low carbon path adopting various technological options which can help DFC to operate in a more energy efficient fashion and at the same time explore options to offset its own GHG emissions by investing in low carbon assets such as solar power, wind power and afforestation. Some of the interventions which could reduce GHG emissions are communication based train control (CBTC), driver advice system, regenerative braking, aerodynamic profiling in rolling stock and on-board lubrication system. DFC project team is working closely with various experts and technology suppliers to assess feasibility of implementing these ideas for low carbon growth.

The following CDM interventions would be most attractive in terms of CDM revenue.

- Communication based train control (CBTC): Falls in the category of energy efficiency. Applicable CDM methodology could be AMS II.D
- Regenerative braking: Falls in the category of low GHG emitting vehicles. Applicable CDM methodology could be AMS III.C
- Adaptation of green building features: Falls in the category of energy efficiency. Applicable CDM methodology could be AMS II.E
- Utilization of Solar power (PV) or wind power as a power source for DFC support infrastructure (demand side): Falls in the category of renewable energy sources. Applicable CDM methodology could be AMS I.A or AMS I.D

**Exhibit A6: Evaluation of CDM potential of GHG abatement levers**

| Parameters description | | CDM potentiality evaluation | | | | | |
|---|---|---|---|---|---|---|---|
| | | Methodology applicability | Emission Reduction | Additionlity | Monitoring | Overall Comment | |
| Weightage | | 20% | 30% | 45% | 5% | Final score (out of 3) | 100% |
| GHG abatement levers | | | | | | | |
| Demand Side energy efficiency improvement measures | Utilization of steel in super structure | 1 | 3 | 1 | 1 | 1.6 | Low |
| | Utilization of aluminum in super structure | 1 | 3 | 1 | 1 | 1.6 | Low |
| | Double stack container (5 car articulated unit) | 1 | 3 | 1 | 1 | 1.6 | Low |
| | Double stack container (flat car 5 car unit) | 1 | 1 | 1 | 1 | 1 | Low |
| | On board rail and wheel lubrication | 3 | 2 | 2 | 1 | 2.15 | Moderate |
| | Aerodynamic profiling | 3 | 2 | 2 | 1 | 2.15 | Moderate |
| | Regenerative braking | 3 | 3 | 3 | 3 | 3 | High |
| | Bathtub moncoque design | 1 | 3 | 1 | 2 | 1.65 | Low |
| | Use of centre sill design | 1 | 1 | 1 | 2 | 1.05 | Low |
| | Communication based train control( +Electrinically controlled pneumatic brakes) | 1 | 2 | 3 | 1 | 2.2 | Moderate |
| | Adoptation of green building features | 3 | 1 | 3 | 3 | 2.4 | High |

**References**

The study broadly follows the following documents:

- WBCSD/WRI[7] Green House Gas Protocol Corporate Accounting and Reporting Standard for the approach/methodology of carbon accounting.
- Infrastructure Leasing & Financial Services Ltd (IL&FS)- Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC" – August 2009- data and information used for the analysis and for 30 years projection, parameters pertaining to features of the rolling stock and conversion multiplication factor from 22.9T to 25T axle load have been accumulated from here
- Japan International Cooperation Agency (JICA) Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"– October 2007, Rites Feasibility Study Report – January 2006- data and information used for estimating the modal shift from rail to road, the year of attaining capacity saturation for each rail section in No-DFC scenario has been sourced from this report.
- Rites Feasibility Study Report -parameters related to support infrastructure for DFC and standards of construction has been taken.
- Inputs from DFCCIL (tenders floated, business plan etc), railway domain experts, technical consultants and other information from publicly available sources have been used as required.

[7] World Business Council for Sustainable Development/World Resources Institute

## 3. Key terminologies

- DFC scenario: DFC scenario' refers to the scenario where Dedicated Freight Corridor is implemented in the Eastern and Western Region of India. Eastern Corridor stretches between Dankuni and Sirhind (1799 km) whereas the Western Corridor stretches between Dadri and Jasai (1483 km).
- No-DFC scenario: 'No-DFC scenario' represents the scenario where in absence of DFC implementation the freight would have been carried by the Indian Railway and road.
- Base case: This is the reference case taken for the GHG emission calculations. All scenarios such as high growth and low growth scenarios have computed with variations in the base case parameter values.
- Baseline: Refers to the No-DFC scenario
- High growth scenario: A scenario has been conceived when annual GDP will be 2% higher w.r.t. annual Base Case GDP , increase in share of electric locomotives will be 5% compared to the Base Case and No-DFC scenario rail freight capacity will witness 5% increase w.r.t. Base Case.
- Low growth scenario: This scenario conceives a lower economic growth where the annual GDP will be 2% lower w.r.t. annual Base Case GDP, increase in share of electric locomotives will be 2% compared to the Base Case and No-DFC scenario rail freight capacity will witness 2% increase w.r.t. Base Case .
- Low carbon scenario over base case: This scenario is conceptualized considering potential clean technologies and practices (in both energy demand side and supply side), that could be adopted by DFC in its proposed configuration in order to achieve a growth path with minimum GHG emissions. In this scenario we have also forecasted India's grid emission factor ($tCO_2$ / MWh) considering 10% increase in capacity share of renewable/ non-conventional energy to the grid, over and above the planned renewable/ non-conventional capacity addition.
- Support infrastructure: It includes all energy consumption sources required for the smooth working of the Indian railways or DFC except the operation of the trains. This includes DG sets, lights/fans/ACs at staff quarters and stations/wagon sheds, emergency lighting, signals etc.
- Construction activities: Activities related to construction of the DFC which includes earthwork, slope leveling, blanketing, ballasting, track laying, welding of rails, packing of tracks, piling, OHE and signaling works erection, construction of bridges and transportation of required materials.
- Carbon intensity: Ratio of GHG emissions and the freight quantity transported.
- Annual emissions: GHG emissions are estimated for each reference year of a 5 year period. The emissions are expected to remain constant in each year of the 5 year period. 'Annual GHG emissions' under any reference year denotes the annual emission for each year of that 5 year band.
- Total GHG emissions indicates that the emission figures are a summation of Eastern Corridor and Western Corridor
- Cumulative denotes that the emissions are not on an annual basis (for each reference year) but a summation of emissions of all 30 years i.e. the summation of emissions for all 6 reference years multiplied by 5.

## 4. Project background

The Indian Railways consumes about 1.1% of the total energy consumption in the country[8] and its contribution to the GDP is 1.2%[9]. In 2007-08, 40% freight was transported by Indian railways and the rest 60% by road. However rail emissions accounted for only 4% of the total GHG emissions due to freight transportation while road emissions accounted for the rest 96%. The economic growth of India would contribute to the rapid increase in demand for freight transport. The key player in the freight transport sector of India, Indian Railways, would not be able to achieve the required freight transportation capacity, even with all its ambitious growth plans. This is expected to drive the demand for higher GHG emitting road based transportation further. Besides being less carbon intensive, the railway is a more economic mode of freight transportation. Also, the global endeavor for a low carbon economy has put thrust on low carbon infrastructure and public transport systems like energy efficient railways to strategize their operations in the future years.

Indian Railways is proposing to develop Dedicated Freight Corridors (DFC), connecting four metros of Delhi, Mumbai, Kolkata and Chennai. Development of the DFCs is expected to cater to the growing freight demand and promote modal shifts of freight from road transport to the rail network. In addition to the efficiency improvement and other operational benefits, this shift is expected to offer a significant reduction of GHG emissions. Certain GHG abatement levers if implemented could also provide carbon revenues through Clean Development Mechanism (CDM) under the Kyoto Protocol.

This study proposes to estimate and forecast the GHG emissions under the DFC scenario and the No-DFC scenario (i.e. in absence of the DFC) for a period of 30 years. The study would focus on the Eastern DFC and the Western DFC. The Eastern DFC extends from Dankuni to Dhandhari Kalan for a distance of 1799 km and would transport 1975 billion ton-km of freight over the 30 year period. Major commodities on this corridor would include coal, iron and steel and empties. The Western DFC extends between JN Port to Dadri for a distance of 1483 km and would transport 3241 billion ton-km of freight over the 30 year period. Major commodities on this corridor would include container and RO-RO.

The objective of the study essentially comprises of:
i) Estimation and forecasting of the Baseline (No-DFC scenario) GHG Emission trends of freight transport operations on the planned DFC corridor. The same shall be projected for the 30 year period.
ii) Assessment of the GHG Emission Trends from various components of DFC, and support infrastructure such as train stations, wagon sheds, signal rooms, storage yards, other amenities / infrastructure for the operation of the DFC.
iii) Assessment of the GHG Emission Potential during Construction of DFC due to use of various construction equipments, movement of vehicles, setting up of sleeper yards, fabrication units, quarries, staff quarters and various other construction activities.

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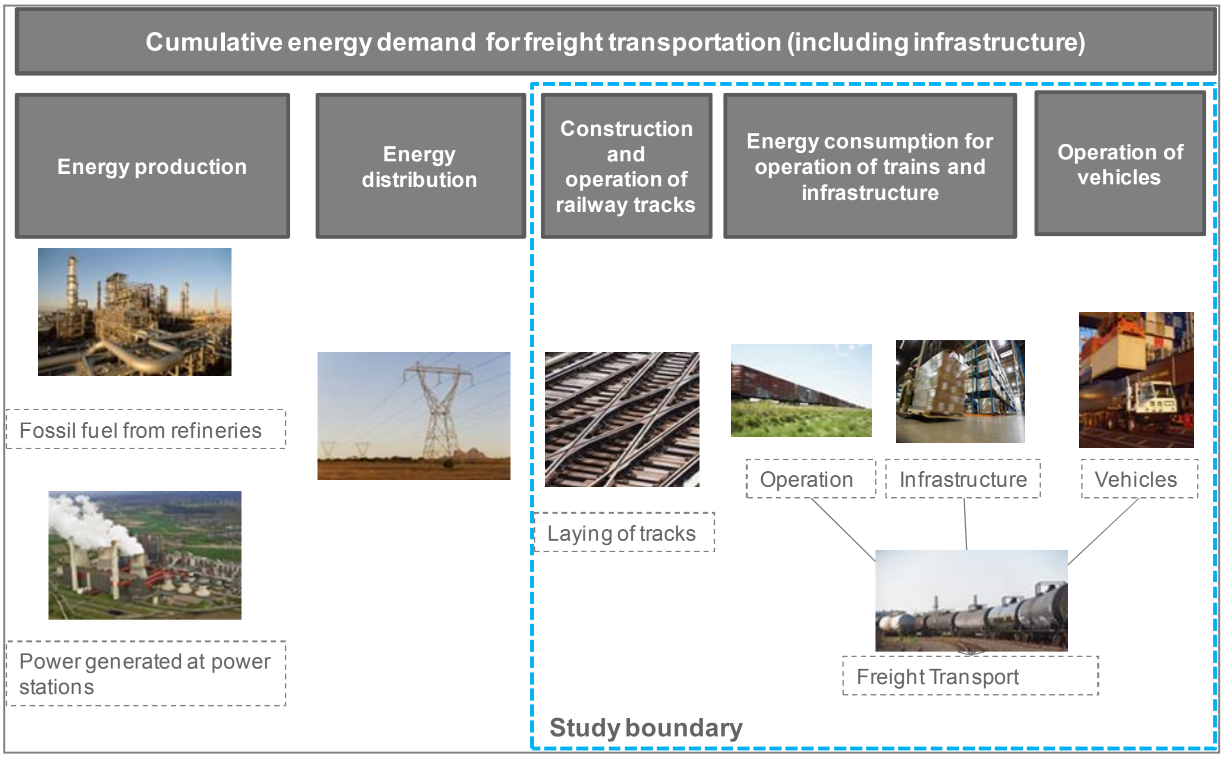
[8] http://www.uic.org/IMG/pdf/Powerpoint-bmlal-2.pdf

[9] http://www.rb.indianrailways.gov.in/indianrailways/VISION%202020_Eng_SUBMITTED%20TO%20PARLIAMENT.pdf

iv) Identification of specific GHG Emission Reduction Interventions in the design (through suitable design modifications, change of technical specifications, etc.), construction (through suitable construction practices, strategies, techniques, tools, etc.) and operation phase of the DFC.

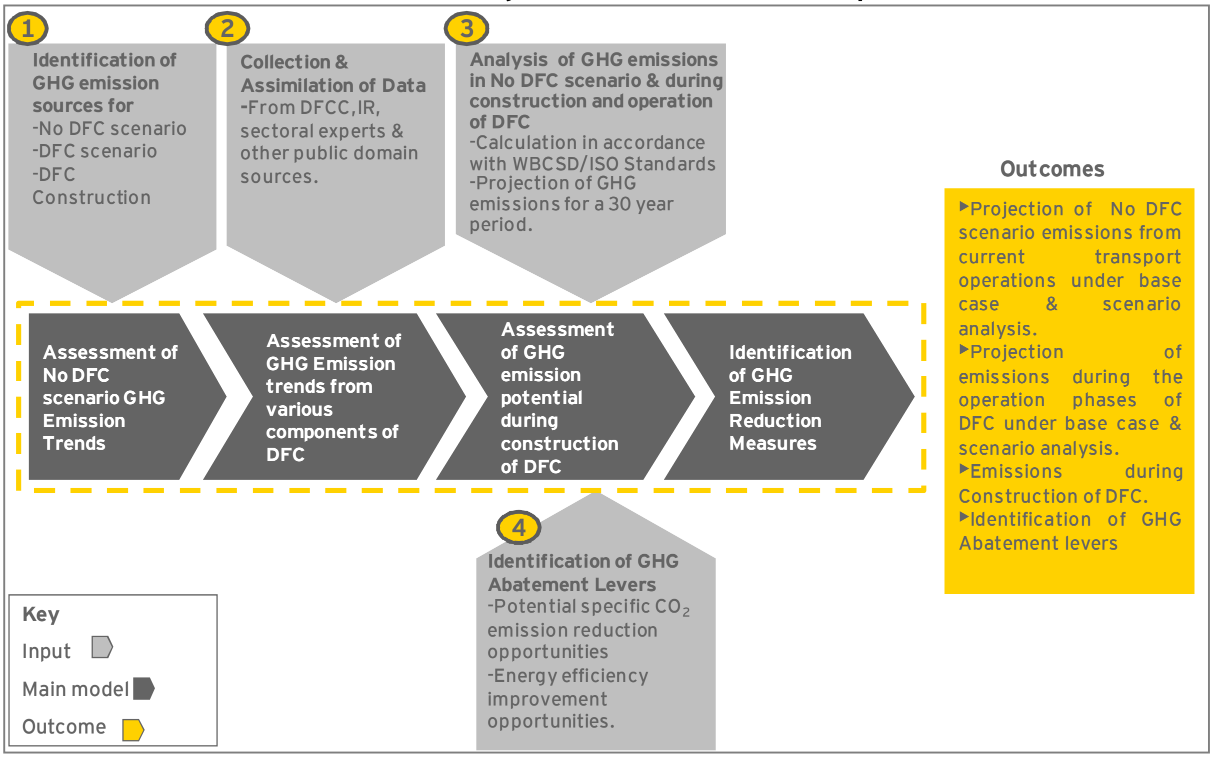
**Exhibit 1: Scheme of relevant processes for rail freight transportation**



## 5. Approach and Methodology

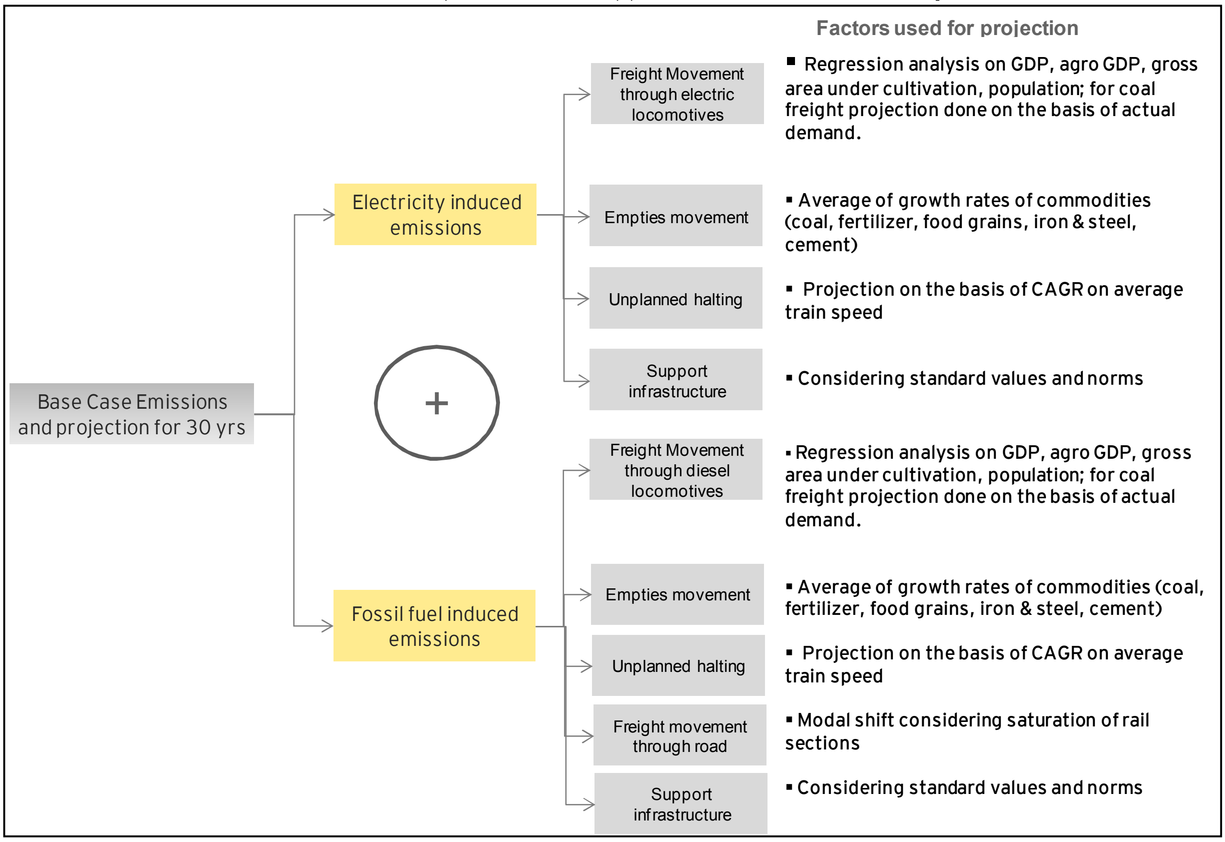
The approach and methodology followed for this study has been illustrated as below.

**Exhibit 2: High level overview of the study**



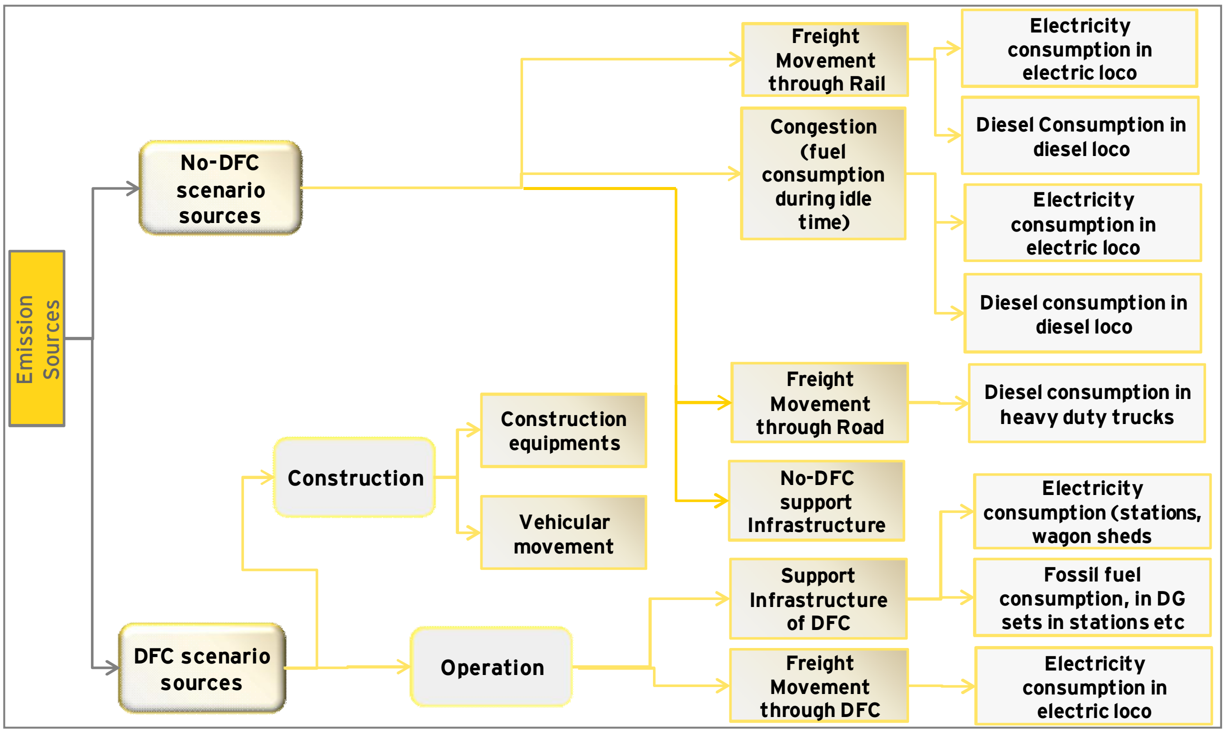

- The study period of 30 years has been split into six five year bands and annual GHG emissions have been estimated for each such band. The trend analysis has been done in six five year bands, with the reference year of each band coinciding with the terminal year of successive five year plans of Government of India.
- All the freight projections (no. of trips per day per section for each commodity) for the DFC scenario (axle load 25 T) have been provided by IL&FS Report (based on GDP, capacity expansion plans, industrial growth etc).
- The no. of trips have been converted to No-DFC scenario (axle load 22.9 T) using multiplication factors.
- The saturation capacity and year of attaining saturation capacity by each rail section under the No-DFC scenario has been provided by the JICA Report. All freight above saturation capacity is assumed to be transported by road (except coal, since coal is a non-roadable commodity).
- The total train load (wagon + locomotive) is determined and multiplied with each sectional distance commodity wise.
- The summation of train loads is multiplied with mix of diesel-electric trains and corresponding emission factors.

**Exhibit 3: Snapshot of the approach used for the study**




GHG emission sources for both the No-DFC and DFC scenarios have been identified and are illustrated in the following exhibit.

**Exhibit 4: GHG Emission Sources for No-DFC & DFC scenarios**




For setting the operational boundary for the GHG emission estimation study, guidelines of the GHG Protocol (of WBCSD/WRI) has been followed.

- The control approach has been followed while boundary setting.
- The operational boundary for the Eastern Corridor includes Eastern Railways, East Central Railways, Northern Railways, North Central Railways and National Highways.
- The operational boundary for the Western Corridor includes Western Railways, Central Railways, North Western Railways, North Central Railways and National Highways.

Both emission factor and calorific value for diesel have been taken from 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The grid emission factor has been projected based on data from Central Electricity Authority and Planning Commission, Govt of India.

This GHG emission quantification, monitoring and reporting has been performed following internationally accepted guidelines such as the GHG Accounting Protocol[10] and ISO 14064.

Please refer to Annexure-2 for further details.

[10] of World Business Council of Sustainable Development (WBCSD) and World Resources Institute (WRI)

## 6. Estimation and forecasting of major input parameters used for the analysis

### a) Projection of India's national grid emission factor

$CO_2$ emission factor of the national grid is an important factor to estimate GHG emissions from railways drawing power from the electricity grid. Central Electricity Authority (CEA) of Govt. of India publishes the emission factor (EF) of the national grid which is updated every year based on factors such as installed thermal/nuclear/renewable capacity and units of power generated from different sources. Since EF is dynamic it is forecasted for the coming 30 year period.

The projection of emission factor for national grid[11] over and above the base-year[12] has been done based on projected thermal/renewable capacity additions[13].

| Table 1: Emission factor of national grid ($tCO_2$/ MWh) | | | | | | |
|---|---|---|---|---|---|---|
| 2007-08 | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 |
| 0.81 | 0.68 | 0.65 | 0.62 | 0.60 | 0.57 | 0.55 |

### b) Factors used for estimation of diesel emissions

To estimate GHG emissions due to freight transportation by road, emission factor of diesel and net calorific value of diesel have been used. The same is tabulated as below.

| Table 2: IPCC factors for diesel | | |
|---|---|---|
| Parameter | Unit | Value |
| Emission factor | $tCO_2$/TJ | 74.1 |
| Net Calorific Value | TJ/ton | 0.043 |

### c) GDP figures considered for the study

The GDP figures used for the study (to calculate freight volume) are tabulated in the following table. Scenario analysis (i.e. the high growth scenario and low growth scenario) has been conceptualized by changing the GDP figures by +/-2% (this has been discussed in Chapter 8).

[11] http://www.planningcommission.nic.in/aboutus/committee/wrkgrp11/wg11_power.pdf
http://mnre.gov.in/pdf/11th-plan-proposal.pdf

[12] As per Combined Margin Emission Factor of CEA database version 5.0 for 2007-08

[13] Considered from (a) Planning Commission Working Group for Power Sector report – February 2007, (b) grid-interactive renewable energy capacity addition from MNRE XI[th] Plan Proposal – December 2006, (c) Solar power capacity addition forecasted by the National Solar Mission.

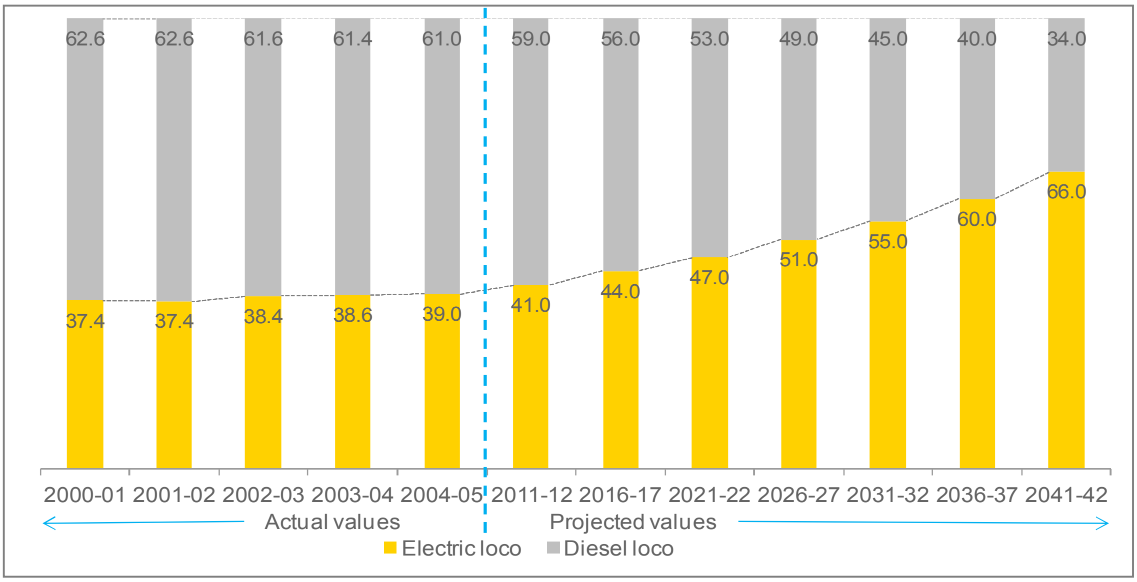
Table 3: Projection of GDP figures for India

| Year | Annual GDP (INR trillion) |
|---|---|
| 2016-17 | 58 |
| 2021-22 | 83 |
| 2026-27 | 116 |
| 2031-32 | 161 |
| 2036-37 | 221 |
| 2041-42 | 235 |

## d) Other important factors determining the GHG emission trends

The mix of electric-diesel locomotives is an important parameter which determines the trend of GHG emission values in the No-DFC scenario. The analysis shows that the share of electric locomotives increases at a CAGR of 1.4% over the 30 year study period.

**Exhibit 5: Mix of diesel-electric locomotives: No-DFC scenario (in %)**




The year of attaining saturation by the various rail sections is another important factor which has a major impact on the GHG emissions under the No-DFC scenario. This factor determines the volume of freight to be transported by road.

<table>
<tr><th colspan="5">Table 4: Expected year of reaching saturation capacity of rail sections in No-DFC scenario[14]</th></tr>
<tr><th colspan="3">Eastern DFC</th><th colspan="2">Western DFC</th></tr>
<tr><th>Sl. No.</th><th>Section</th><th>Expected year of capacity saturation</th><th>Section</th><th>Expected year of capacity saturation</th></tr>
<tr><td>1</td><td>Dankuni - Andal - Dankuni</td><td rowspan="3">Not expected within a period 30 years</td><td>Dadri-Rewari - Dadri</td><td rowspan="3">Not expected in the 30 years period</td></tr>
<tr><td>2</td><td>Andal - Gomoh - Andal</td><td>Delhi-Rewari - Delhi</td></tr>
<tr><td>3</td><td>Gomoh - Son Nagar - Gomoh</td><td>Hisar - Rewari - Hisar</td></tr>
<tr><td>4</td><td>Son Nagar - Mughal Sarai - Son Nagar</td><td>2030</td><td>Rewari - Phulera - Rewari</td><td rowspan="6">2010</td></tr>
<tr><td>5</td><td>Mughal Sarai - Allahabad - Mughal Sarai</td><td rowspan="2">2015</td><td>Phulera – Ajmer - Phulera</td></tr>
<tr><td>6</td><td>Allahabad - Kanpur - Allahabad</td><td>Ajmer – Marwar - Ajmer</td></tr>
<tr><td>7</td><td>Kanpur - Tundla - Kanpur</td><td rowspan="4">2020</td><td>Marwar - Palanpur - Marwar</td></tr>
<tr><td>8</td><td>Tundla - Aligarh - Tundla</td><td>Palanpur-Mahesana - Palanpur</td></tr>
<tr><td>9</td><td>Aligarh - Khurja - Aligarh</td><td>Mahesana-Sabarmati - Mahesana</td></tr>
<tr><td>10</td><td>Khurja - Dadri - Khurja</td><td>Sabarmati-Vadodara - Sabarmati</td><td rowspan="3">2015</td></tr>
<tr><td>11</td><td>Khurja - Kalanaur - Khurja</td><td>2010</td><td>Vadodara - Gothangam - Vadodara</td></tr>
<tr><td>12</td><td>Kalanaur - Sirhind - Kalanaur</td><td rowspan="2">2015</td><td>Gothangam-Vasai Rd - Gothangam</td></tr>
<tr><td>13</td><td>Sirhind - Dhandhari Kalan - Sirhind</td><td>Jasai - JN Port - Jasai</td><td>2025</td></tr>
</table>

[14] JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"– Volume 3, Task 2, October 2007

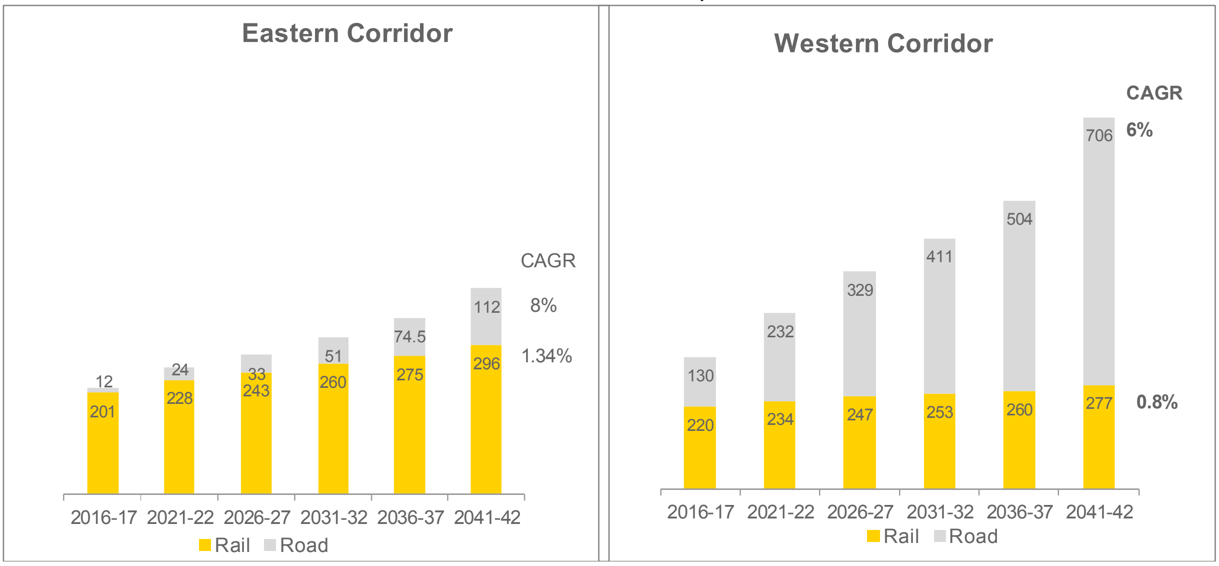
## e) Freight volume transported by the No-DFC scenario

In the No-DFC scenario freight is transported by both rail and road (once railway sections get saturated due to inadequate capacity of Indian Railways). The freight volume to be transported by the No-DFC scenario is greater in case of the Western Corridor. This is on account of the facts that:

-Western Corridor has greater proximity to active ports

-Huge volume of container traffic which would be transported by the Western Corridor

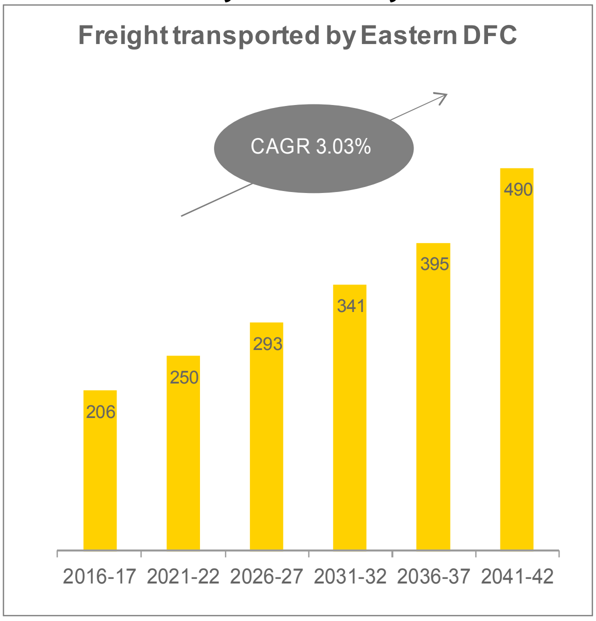
**Exhibit 6: Annual growth in freight volume to be transported by No-DFC scenario (mode wise) (in billion tonne-km)**

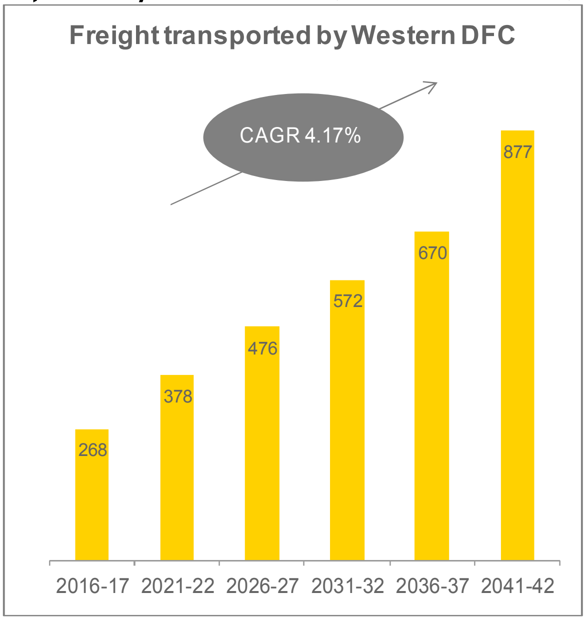


### f) Freight volume transported by the DFC scenario

The cumulative freight volume to be transported by the Eastern DFC is 1975 billion tonne-km while the Western DFC would transport 3241 billion tonne-km of freight over the period of 30 years.

**Exhibit 7: Annual growth in freight volume to be transported by DFC scenario (in billion tonne-km)**




Billion tonne-km for No-DFC case is greater than that in DFC case due to the different axle loads and corresponding multiplication factor for conversion. DFC case axle load is 25T while No-DFC case axle load is 22.9T

## 7. Analysis outcomes

### a) GHG Emissions under No-DFC scenario

The GHG emissions under No-DFC scenario can be attributed to three major activities:

i) GHG emissions under 'No-DFC scenario' for freight movement
ii) GHG emissions due to congestion along rail
iii) GHG emissions from support infrastructure
Each of the activities has been analyzed below.

#### *i) GHG emissions under 'No-DFC scenario' for freight movement*

The GHG emissions under the No-DFC scenario for rail transportation and road transportation have been tabulated in the following tables.

**Table 5: Annual GHG emissions under 'No-DFC scenario' from freight movement on rail (million tonnes of $CO_2$)**

| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 | Total cumulative emissions |
|---|---|---|---|---|---|---|---|
| GHG emissions in the Eastern Corridor in absence of DFC | 1.70 | 1.90 | 2.00 | 2.12 | 2.20 | 2.32 | 61.15 |
| GHG emissions in the Western Corridor in absence of DFC | 1.86 | 1.95 | 2.03 | 2.05 | 2.08 | 2.18 | 60.75 |

*Note: GHG emissions under any reference year denotes the annual emission for each year of that 5 year band. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

| Table 6: Annual GHG emissions under No-DFC scenario from freight movement on road (million tonnes of $CO_2$) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 | Total cumulative emissions |
| GHG emissions in the Eastern Corridor in absence of DFC | 0.43 | 0.84 | 1.17 | 1.79 | 2.60 | 3.92 | 53.7 |
| GHG emissions in the Western Corridor in absence of DFC | 4.56 | 8.11 | 11.49 | 14.37 | 17.62 | 24.68 | 404.1 |

*Note: GHG emissions under any reference year denotes the annual emission for each year of that 5 year band. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

- While the freight volume grows at a CAGR[15] of 8% and 1.3% for road and rail respectively, the corresponding GHG emissions growth figures are 8% and 1.08% for the Eastern Corridor.
- For the Western Corridor, the freight volume grows at a CAGR of 6% and 0.8% for road and rail respectively, the corresponding GHG emissions growth figures are 6% and 0.5%.
- This means that the GHG emissions from rail transport grow at a lower rate compared to growth of freight volume. This may be attributed to the following reasons:

-increasing share of electric locomotives
-decreasing grid emission factor

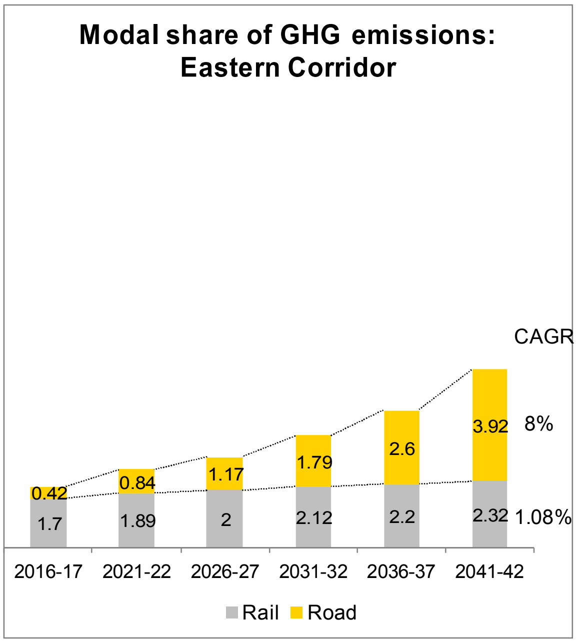
Below are the Exhibits depicting the share of annual GHG emissions due to rail freight movement and road freight movement.

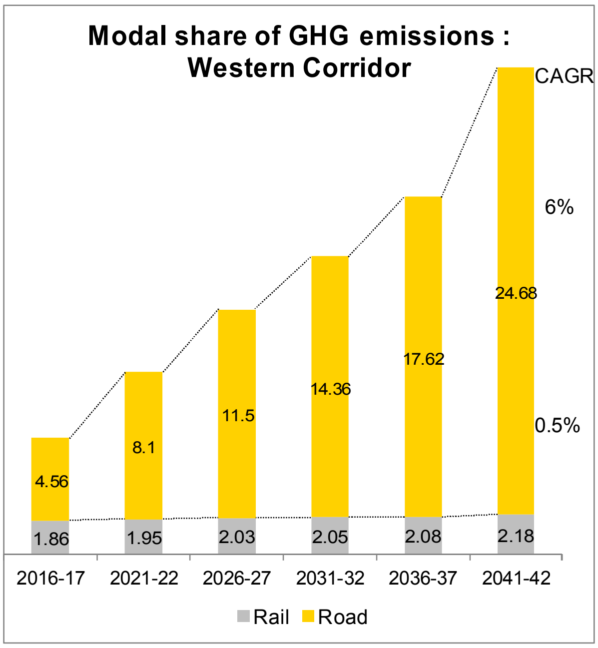
[15] Compound Annual Growth Rate in a given period is the rate at which a variable quantity would have grown if it grew at a steady rate during that period.

$$CAGR = \left(\frac{Ending\ value}{Begining\ value}\right)^{\frac{1}{n}} - 1$$

Where 'n' is the number of years considered.

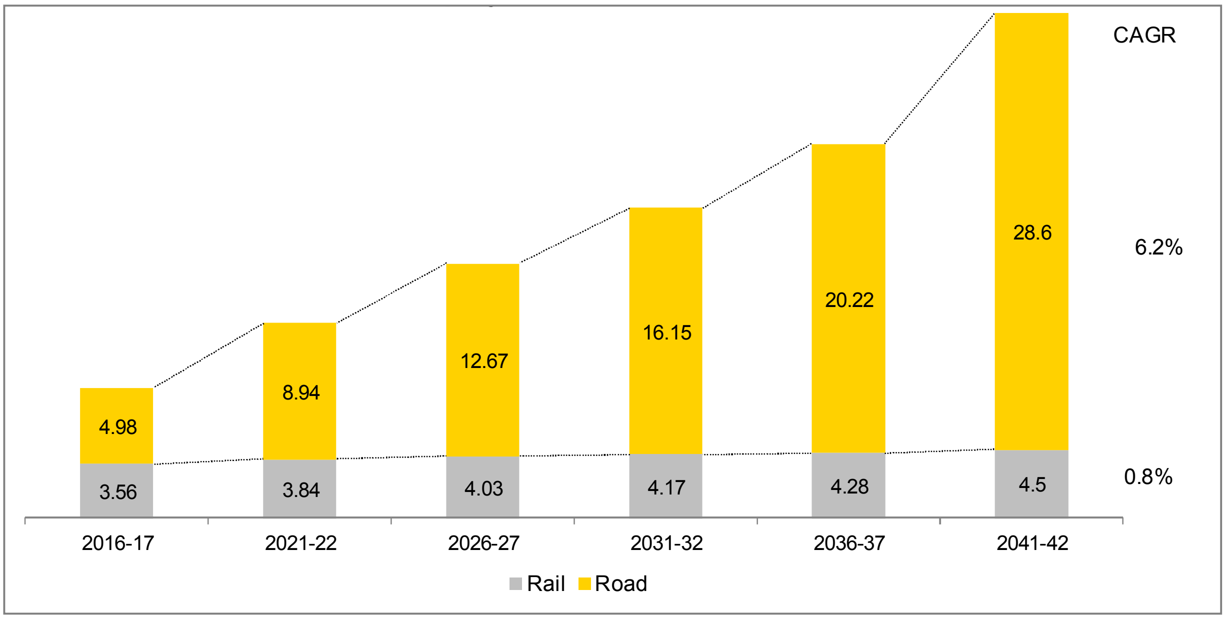
**Exhibit 8: Share of corridor-wise road vs. rail GHG emissions annually: No-DFC scenario (in million ton $CO_2$)**




Total annual GHG emissions under 'No-DFC scenario' from freight movement along rail and road over the 30 year period have increased at a CAGR of 0.8% and 6% respectively. The total annual GHG emissions (mode wise) over the 30 year period for the No-DFC scenario is illustrated below.

**Exhibit 9: Total annual GHG emissions under 'No-DFC scenario' from rail freight and road freight (in million ton $CO_2$)**



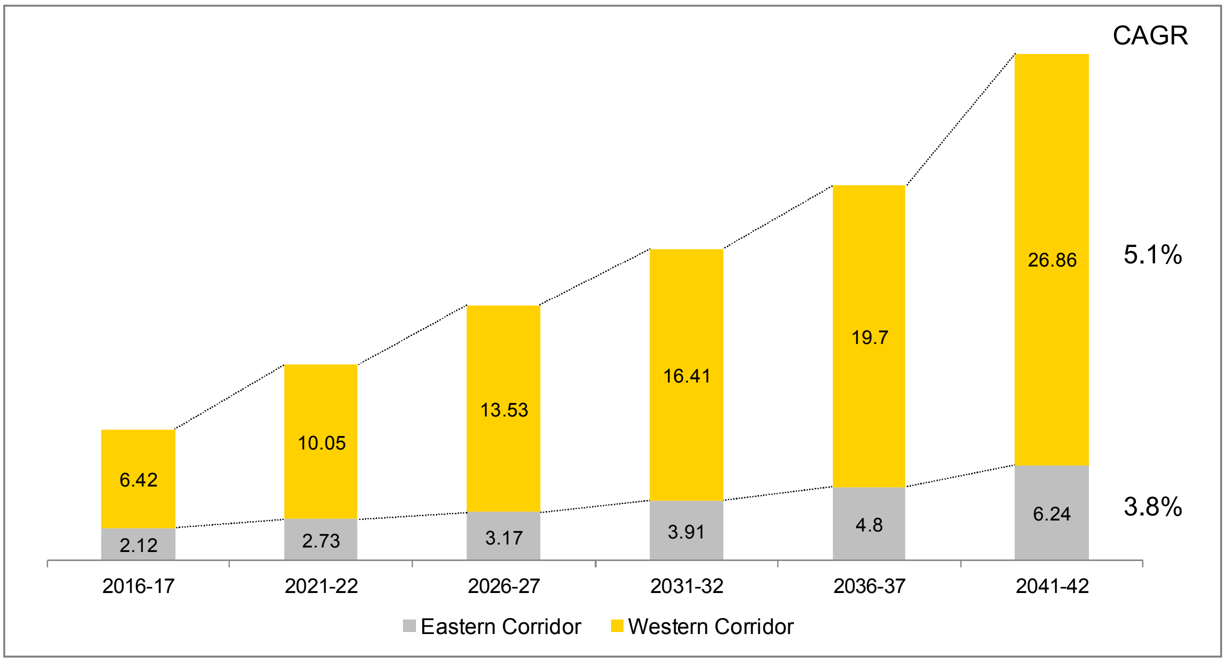

*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

- It is evident from the above diagram that over the period of 30 years the contribution from road freight movement towards GHG emissions will be much higher than rail freight movement. This may be attributed to the fact that:

-modal shift takes place once the rail routes achieve saturation
-road transportation results in more GHG emissions compared to rail transportation

The annual GHG emissions due to the Eastern Corridor and Western Corridor is as illustrated below.

**Exhibit 10: Corridor wise annual GHG emissions due to freight transportation and congestion under No-DFC scenario (in million ton $CO_2$)**




- As freight volume is projected to increase throughout the 30 years period, annual GHG emissions from rail and road freight movement in the same period will show an upward trend (but with a different rate).
- The growth rate of GHG emissions due to rail transport under No-DFC scenario will slow down because of:
  -rail to road modal shift which will increase with time as more number of rail sections reach saturation
  -emission factor of the national grid comes down due to increasing addition of renewable energy capacity to the grid
  -an increase in the share of electric locomotives in the diesel-electric locomotive mix

### *ii) GHG emissions due to congestion along rail corridors*

The annual GHG emissions under No-DFC scenario due to congestion is tabulated below.

| Table 7: Annual GHG emissions under 'No-DFC Scenario' due to congestion on rail (million tonnes of $CO_2$) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **2016-17** | **2021-22** | **2026-27** | **2031-32** | **2036-37** | **2041-42** | **Total cumulative emissions** |
| GHG emissions in the Eastern Corridor under 'No-DFC scenario' | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 1.05 |
| GHG emissions in the Western Corridor under 'No-DFC scenario' | 0.05 | 0.05 | 0.04 | 0.03 | 0.03 | 0.02 | 1.10 |

*Note: GHG emissions under any reference year denotes the annual emission for each year of that 5 year band. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

GHG emissions due to congestion show a linear decreasing trend with a growth rate of -1%. This is attributed to:

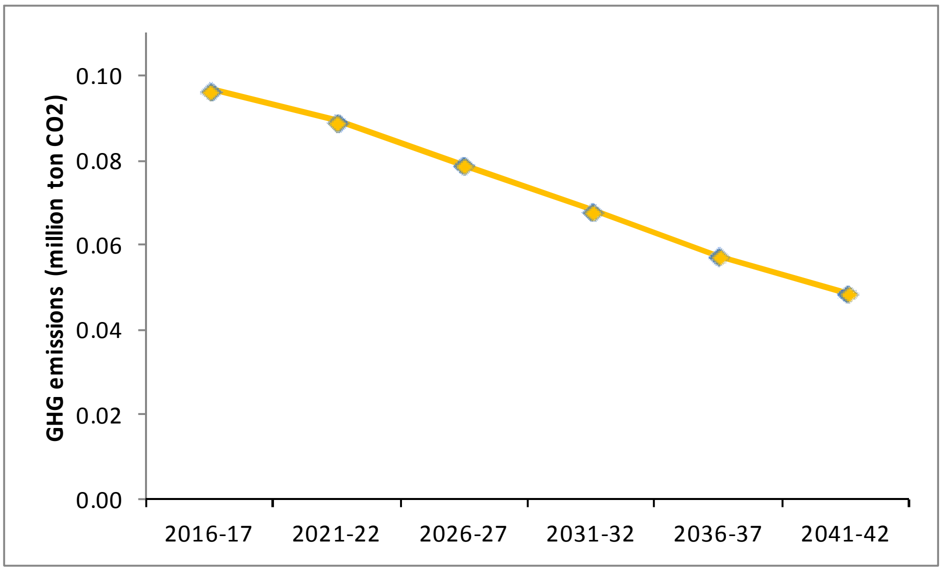
-an upward trend of average train speed (projected from historical Indian Railways data of average freight train speed), which implies reduced GHG emissions from congestion

-decreasing trend of emission factor of the national grid (CAGR of -1.2%)

-increasing share of electric locomotives which means that the impact of decrease in grid emission factor is even more profound on the congestion related GHG emissions value

The total annual GHG emission trend under No-DFC scenario due to congestion is as illustrated in the following exhibit.

**Exhibit 11: Total annual GHG emission trend under 'No-DFC scenario' due to congestion**




*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

**Commodity wise share of GHG emissions:** In the Eastern corridor, coal transportation is the highest contributor to GHG emissions followed by iron & steel transportation (together they account for about 51% emissions). In the Western corridor, container transportation is the major contributor to GHG emissions followed by transportation of empties (together they account for about 92% emissions).

**Exhibit 12: Commodity wise annual GHG emissions in Eastern Corridor under No-DFC scenario (in million ton $CO_2$)**

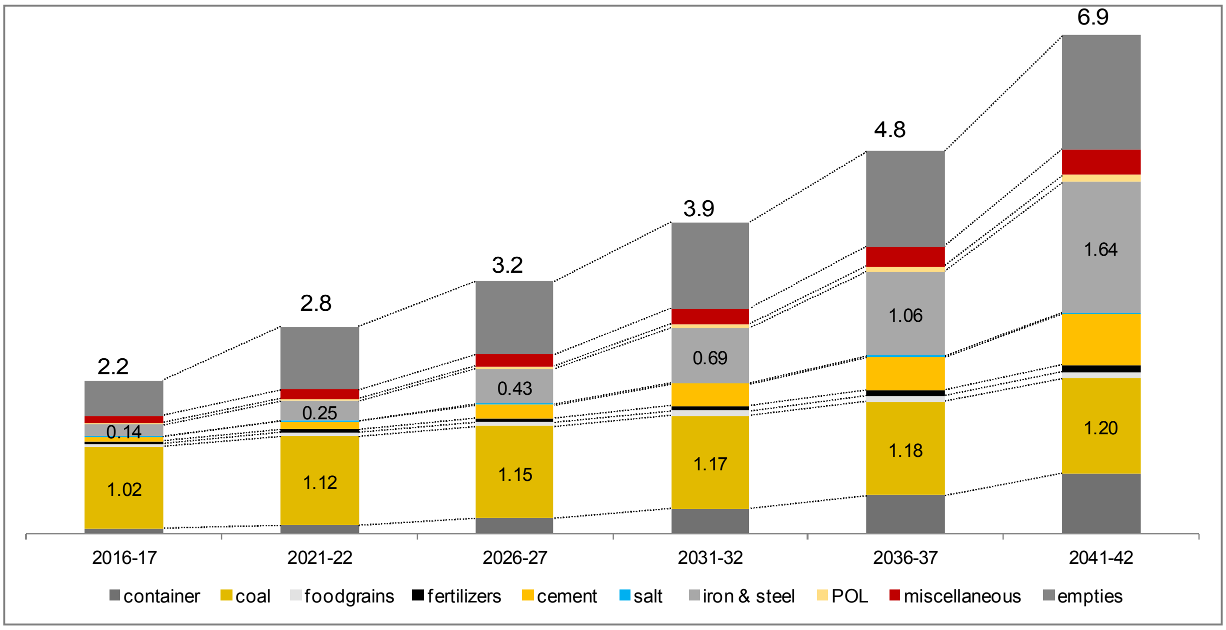
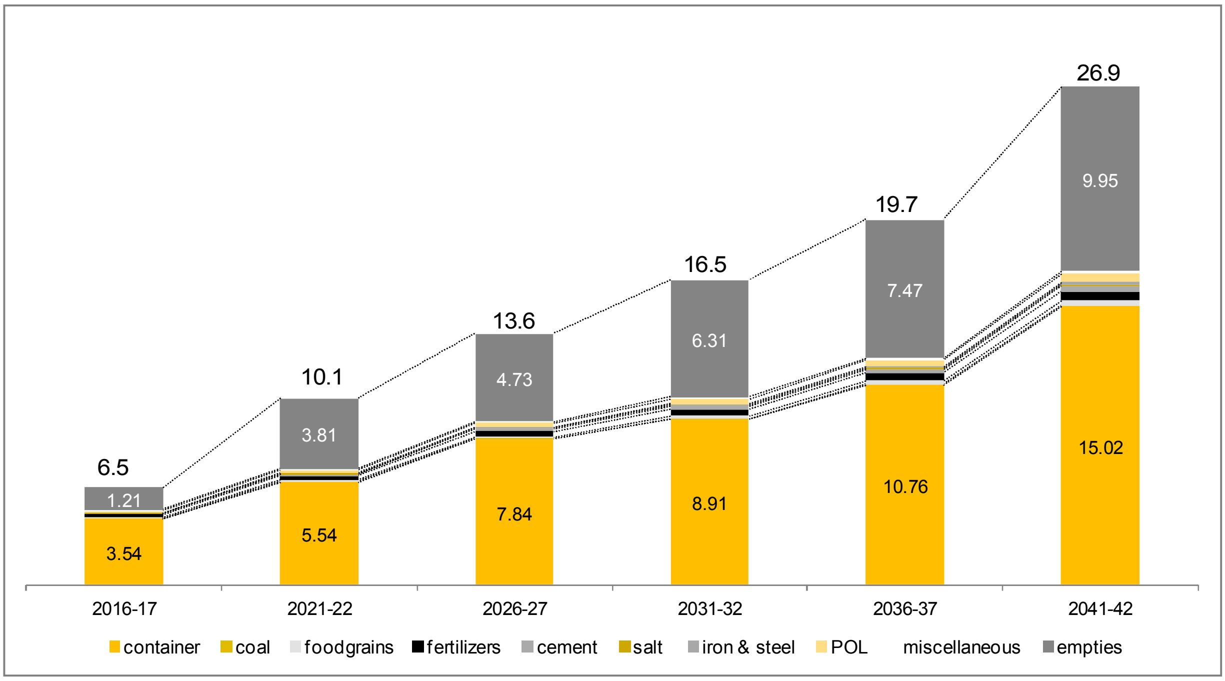


**Exhibit 13: Commodity wise annual GHG emissions in Western Corridor under No-DFC scenario (in million ton $CO_2$)**




### *iii) GHG emissions from support infrastructure*

The annual GHG emissions from support infrastructure under the No-DFC scenario is tabulated below.

| Table 8: Annual GHG emissions from support infrastructure under No-DFC scenario | | | | | | |
|---|---|---|---|---|---|---|
| 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 | Total cumulative emissions |
| Annual energy consumption in support infrastructure under No-DFC scenario (in TJ) | | | | | | |
| 131 | 131 | 138 | 138 | 145 | 145 | 4140 |
| Corresponding annual GHG emissions (million tonnes of CO2) | | | | | | |
| 0.0155 | 0.0152 | 0.0158 | 0.0155 | 0.0161 | 0.0159 | 0.47 |

*Note: GHG emissions/energy consumption figures under any reference year denotes the annual emission for each year of that 5 year band. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

The annual GHG emissions under No-DFC scenario from support infrastructure show very little variation as the percentage increase in electricity consumption (every 10 years) is being compensated by the corresponding decrease in projected emission factor of the national grid.

## b) GHG Emissions under DFC scenario

The GHG emissions under DFC scenario can be attributed to three major activities:

i) GHG emissions under 'DFC scenario' for freight movement
ii) GHG emissions from support infrastructure
iii) GHG emissions from construction activities
Each of the activities has been analyzed below.

### *i) GHG emissions from freight movement*

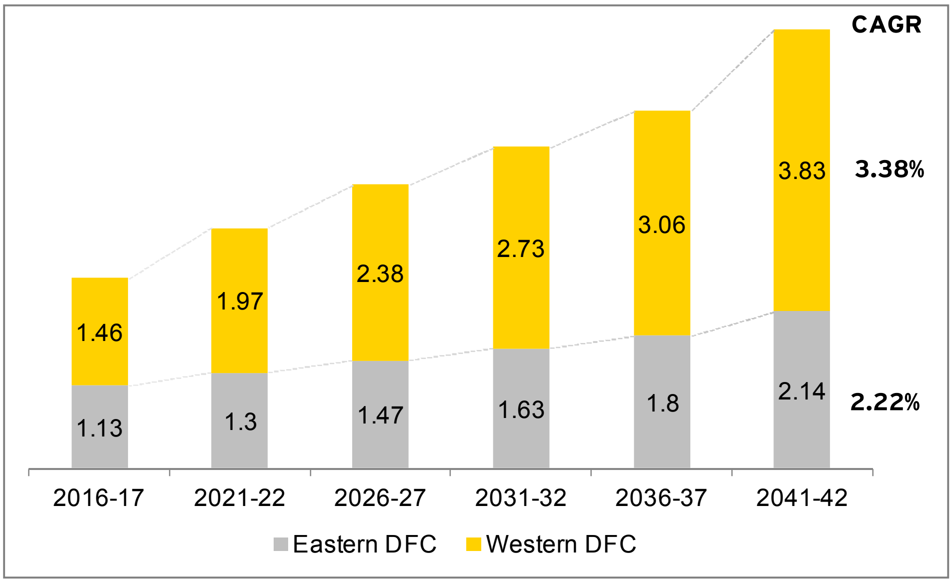
**Table 9: Annual GHG emissions from freight movement along DFC (million tonnes of $CO_2$)**

| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 | Total cumulative emissions |
|---|---|---|---|---|---|---|---|
| Eastern DFC | 1.13 | 1.30 | 1.47 | 1.63 | 1.80 | 2.14 | 47.5 |
| Western DFC | 1.46 | 1.97 | 2.38 | 2.73 | 3.06 | 3.83 | 77.0 |

*Note: GHG emissions under any reference year denotes the annual emission for each year of that 5 year band. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

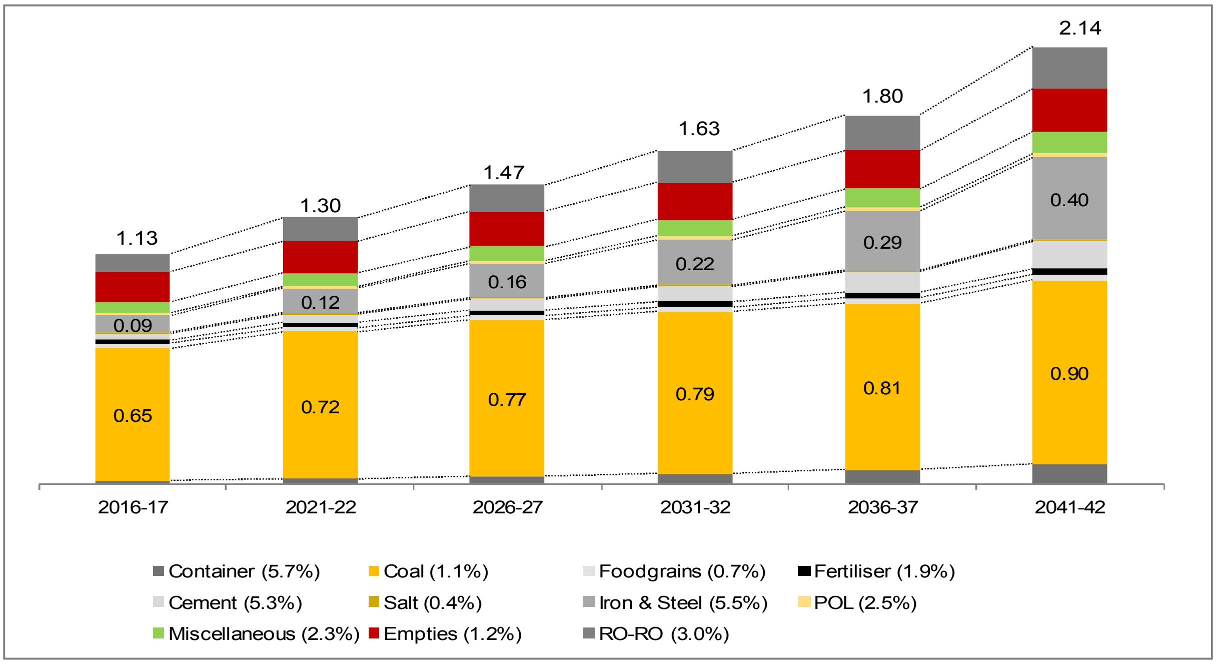
- While the freight volume grows at a CAGR of 3.0% and 4.1% for the Eastern DFC and Western DFC respectively, the corresponding GHG emissions growth figures are 2.2% and 3.3%.
- This means that the GHG emissions from rail transport grow at a lower rate compared to growth of freight volume. This may be attributed to the decreasing grid emission factor.

**Exhibit 14: Annual GHG emissions from freight movement along Eastern and Western DFC (in million ton $CO_2$)**



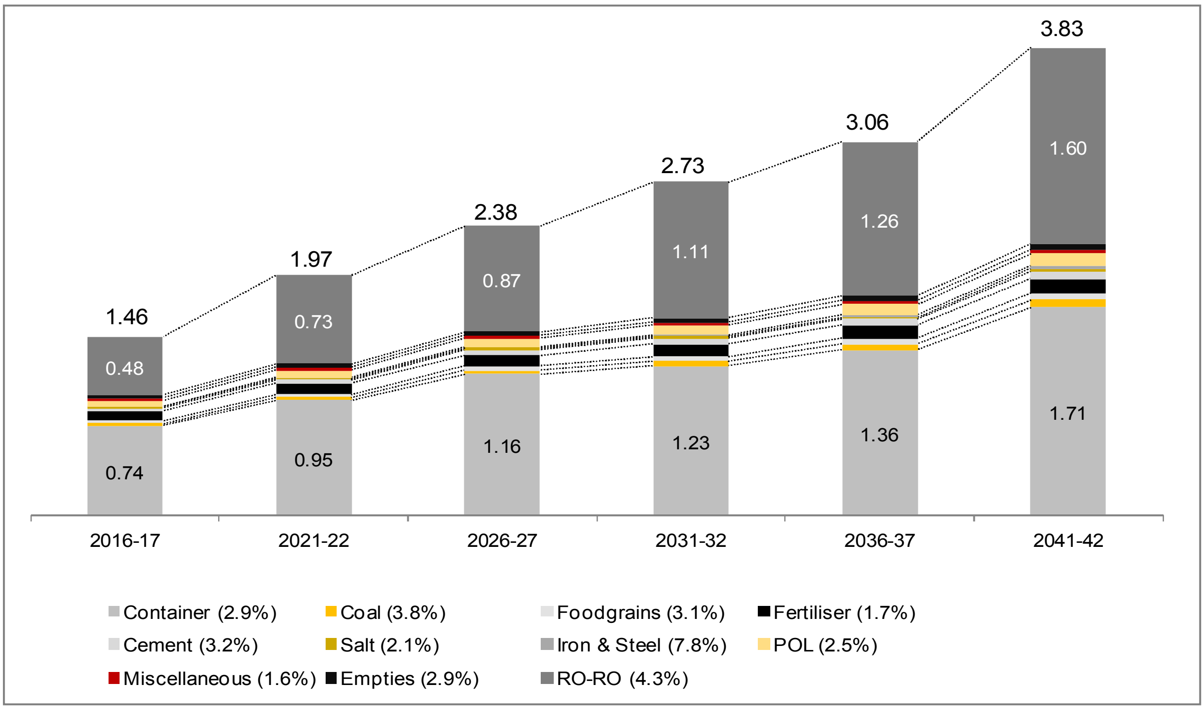
**Commodity wise share of GHG emissions:** In the Eastern DFC, coal transportation is the highest contributor to GHG emissions followed by empties, iron & steel transportation and RO-RO (together they account for about 75% emissions). In the Western DFC, container transportation is the major contributor to GHG emissions followed by transportation of RO-RO (together they account for about 87% emissions).

**Exhibit 15: Commodity wise annual GHG emissions in DFC scenario for Eastern DFC (in million ton $CO_2$)**




*Note: CAGR of GHG emissions for transportation of each commodity over 30 year period in brackets*

**Exhibit 16: Commodity wise annual GHG emissions in DFC scenario for Western DFC (in million ton $CO_2$)**




*Note: CAGR of GHG emissions for transportation of each commodity over 30 year period in brackets*

### *ii) GHG emissions from support infrastructure*

The annual GHG emissions from support infrastructure under the No-DFC scenario is tabulated below.

| Table 10: Annual GHG emissions from DFC support infrastructure | | | | | | |
|---|---|---|---|---|---|---|
| 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 | Total cumulative values |
| Energy consumption in support infrastructure under DFC scenario (in TJ) | | | | | | |
| 140 | 147 | 147 | 154 | 154 | 162 | 4520 |
| Corresponding annual GHG emissions (in million tonnes of $CO_2$) | | | | | | |
| 0.0262 | 0.0264 | 0.0253 | 0.0254 | 0.0243 | 0.0244 | 0.76 |

*Note: GHG emissions/energy consumption figures under any reference year denotes the annual emission for each year of that 5 year band. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

This includes all energy consumption sources required for the smooth working of the Indian railways or DFC except the operation of the trains. This includes DG sets, lights/fans/ACs at staff quarters and stations/wagon sheds, emergency lighting, signals etc. Even though the energy consumption in the support infrastructure shows an upward trend, the GHG emissions from support infrastructure follows no particular trend. This is primarily because the increase in energy consumption is balanced by the decreasing trend of emission factor of the national grid.

### *iii) GHG emissions from construction activities*

These are one time emissions which may be attributed to activities such as:

- Earthwork (vehicular movement)
- slope leveling (roller movement)
- blanketing (vehicular movement)
- ballasting (vehicular movement, crushing operations)
- track laying (vehicular movement)
- welding of rails (welding operations)
- packing of tracks (tamping machine operation)
- piling (operation of piling equipments)
- OHE and signaling works erection (vehicular movement)
- construction of bridges (vehicular movement, machinery operations)
- transportation of required materials (vehicular movement)

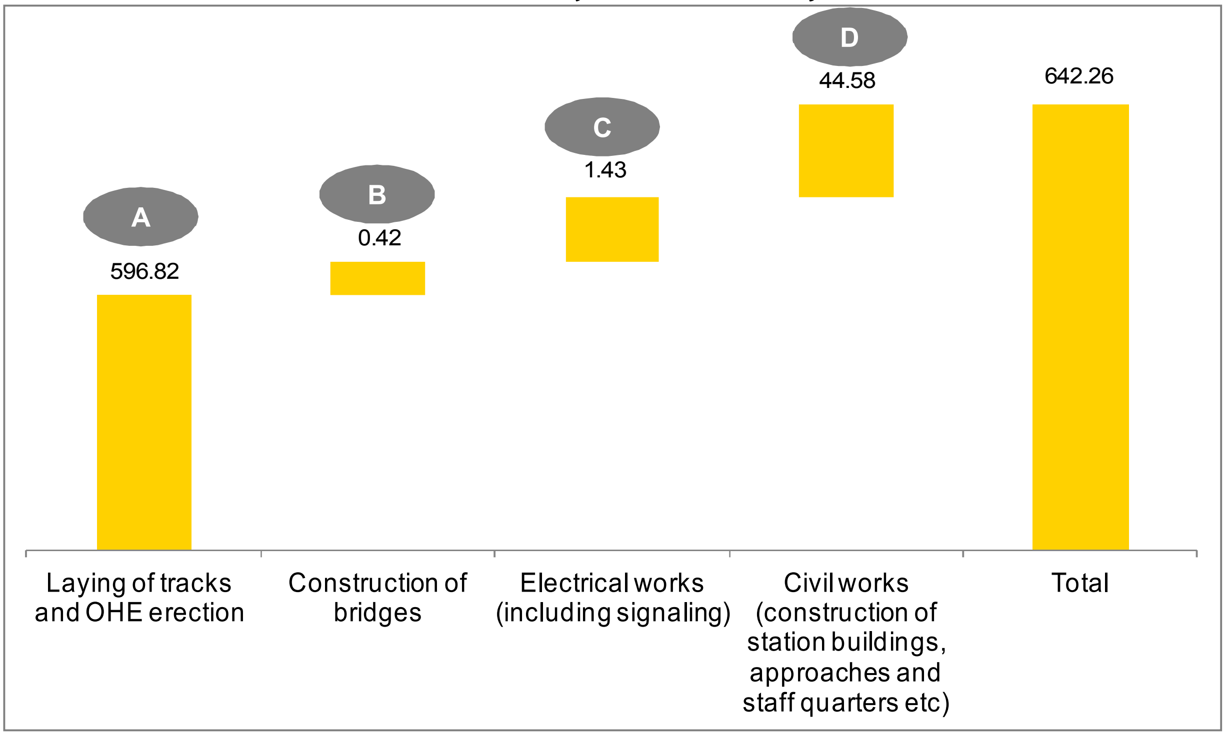
**Table 11: GHG emissions from construction of DFC**

| GHG emission head | Value (in million ton $CO_2$) |
|---|---|
| Construction of tracks (ballasting, earthwork, slope leveling, blanketing, piling, track laying) | 0.595 |
| Construction of bridge | 0.00042 |
| OHE erection | 0.0001 |
| Civil works and signaling installation | 0.046 |
| Testing of signal | 0.000 |
| GHG emissions from construction activities of DFC | 0.642 |

Laying of tracks and OHE erection is the most GHG emission intensive activity. The same is attributed to appreciable vehicular movement. Thus greater diesel consumption due to vehicular movement leads to high GHG emissions from this activity. Under laying of tracks, ballasting is the most GHG emission intensive activity.The same is attributed to appreciable vehicular movement for transport of ballast up to the construction site from the ballast formation site,the latter being located at remote locations from both the corridors. Moreover DFC requires 3000 $m^3$/km of ballast. Thus greater diesel consumption due to vehicular movement leads to high GHG emissions from Ballasting operation.

The major activities of the construction phase have been indicated in the next exhibit and breakup of emissions due to sub-activities is illustrated in the following exhibits.

**Exhibit 17: GHG emissions due to various major activities during construction (in '000 ton $CO_2$)**




Each of the above GHG emission heads have been further subdivided into activties and GHG emissions due to these sub-activties have been illustrated in the following exhibits.

**Exhibit 18: GHG emissions due to laying of tracks and OHE erection (in '000 ton $CO_2$)**

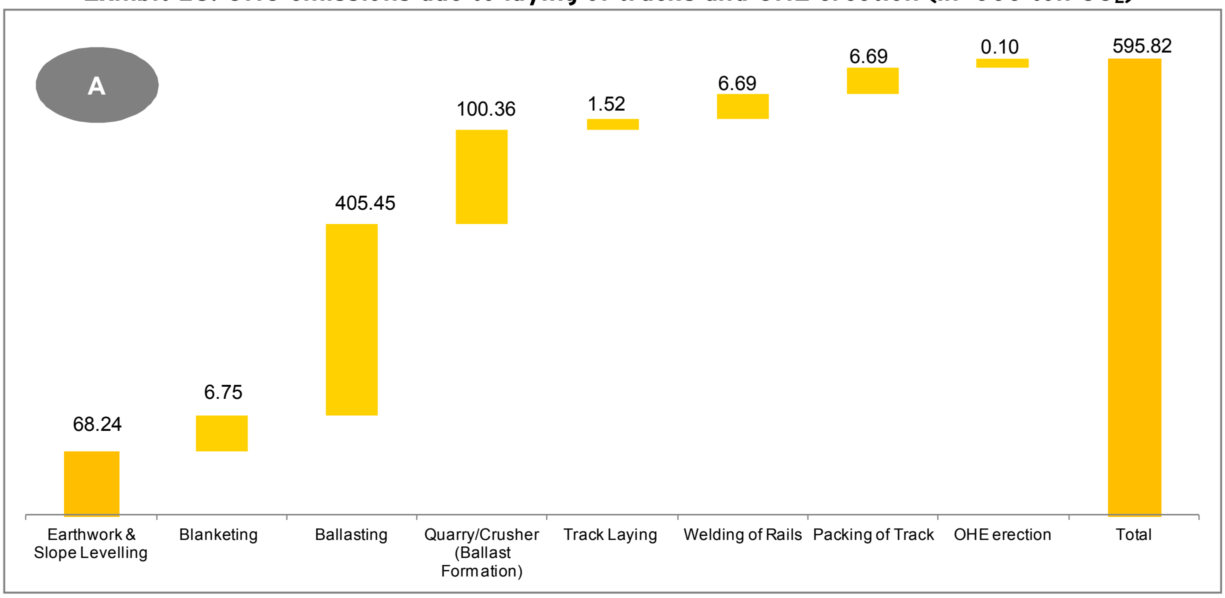


**Exhibit 19: GHG emissions due to construction of bridges (in ton $CO_2$)**

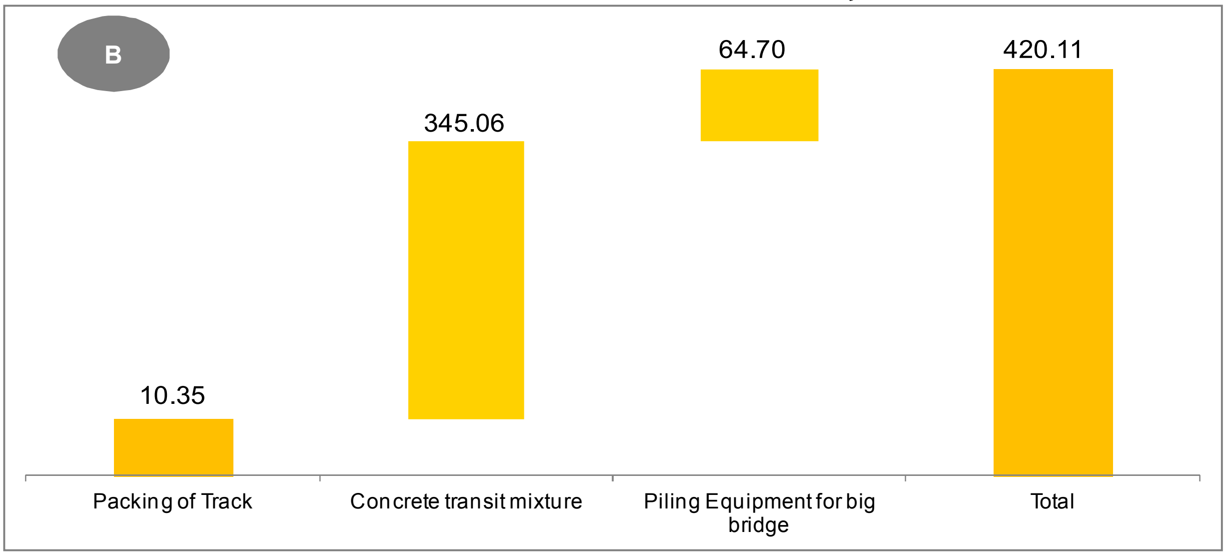



**Exhibit 20: GHG emissions due to electrical works (in '000 ton $CO_2$)**

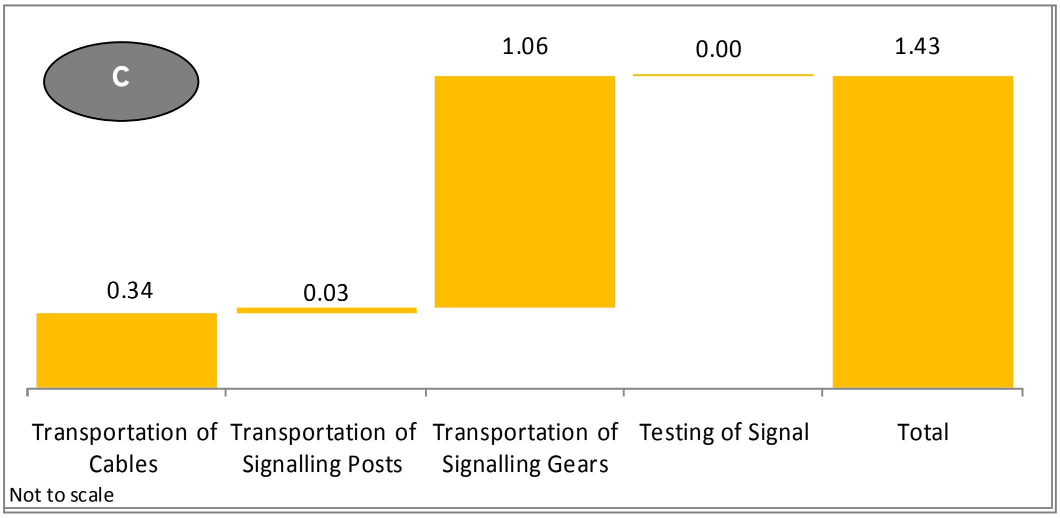
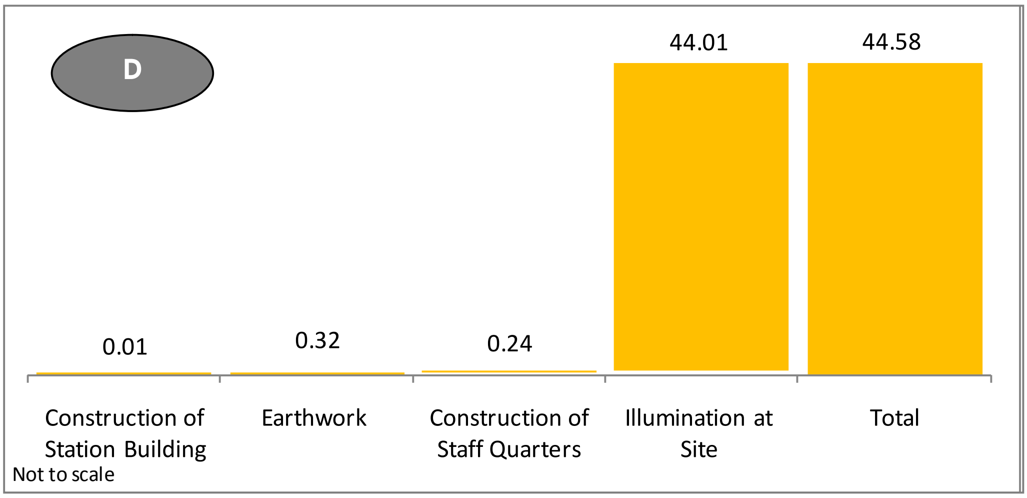


**Exhibit 21: GHG emissions due to civil works (in '000 ton $CO_2$)**



### c) Comparison between GHG emissions under the No-DFC and DFC scenarios

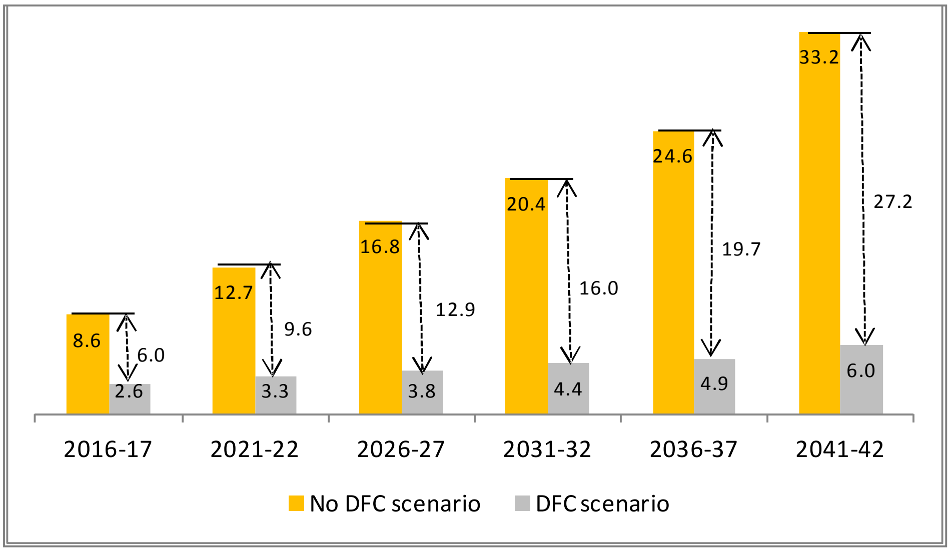
The comparison has been done for GHG emission under No-DFC scenario and DFC scenario for the following activities:

i) Freight transportation
ii) Support infrastructure
Both the comparisons have been elaborated as below.

#### *i) Comparison of GHG emissions for freight transportation*

The comparison between GHG emissions for freight transportation from No-DFC scenario and DFC scenario is illustrated in the following exhibit.

**Exhibit 22: Total annual GAP in GHG emissions between No-DFC and DFC scenario (in million ton $CO_2$)**




*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

Total annual GHG emissions from freight movement in No-DFC scenario and in DFC scenario will increase at a CAGR of 4.59% and 2.82% respectively.

The GAP between GHG emissions under No-DFC and DFC scenarios for each corridor have been illustrated below.

**Exhibit 23: Annual GAP in GHG emissions between No-DFC and DFC scenario-Eastern corridor (in million ton $CO_2$)**

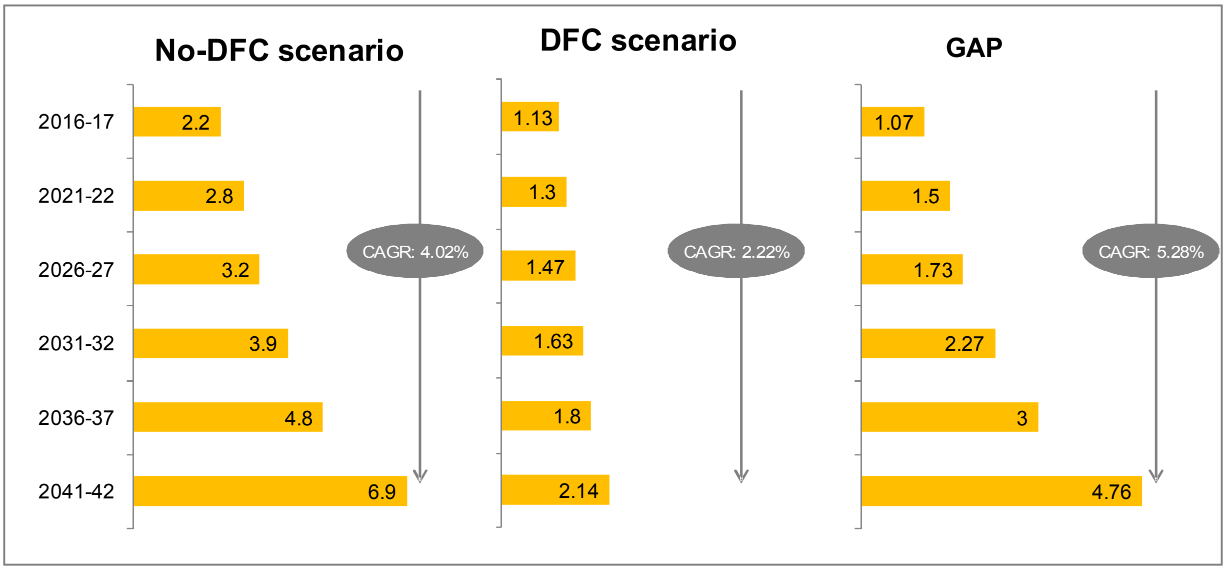
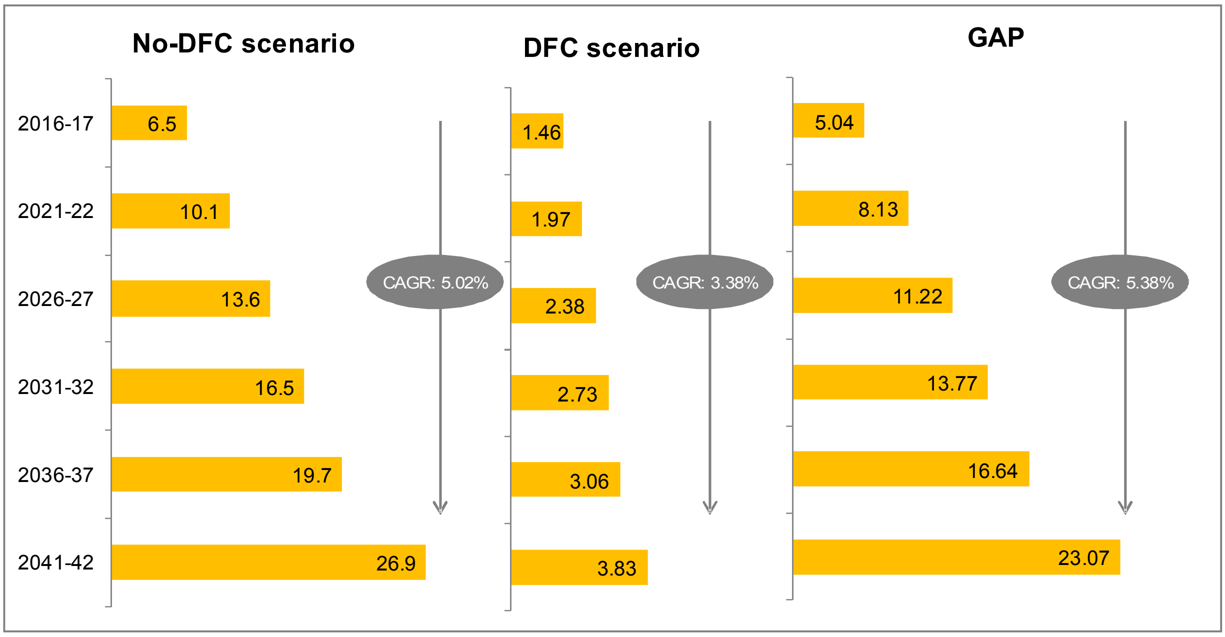



**Exhibit 24: Annual GAP in GHG emissions between No-DFC and DFC scenario-Western corridor (in million ton $CO_2$)**

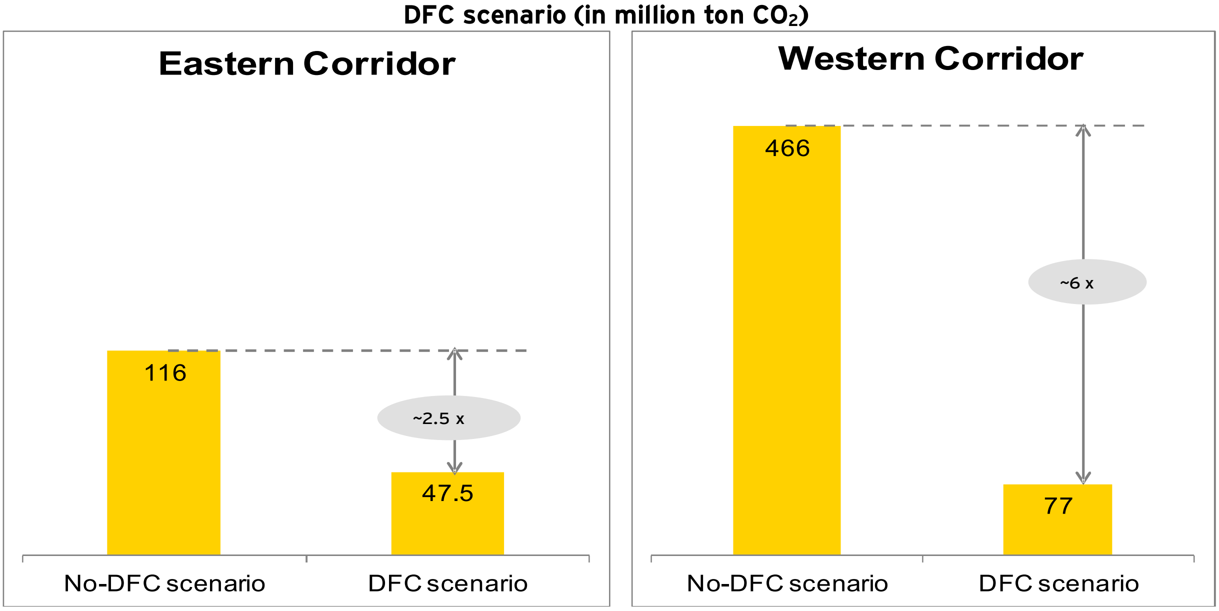



The previous exhibits indicate that from 2016-17 onwards, the GAP of GHG emissions is increasing, following are the reasons contributing to this increasing GHG emission GAP:

- Electric locomotives to be in operation in DFC are expected to be more energy efficient (in terms of specific electricity consumption) w.r.t. that of No-DFC scenario electric locomotives[16]. The decreasing grid emission factor ensures that the mix of electric-diesel locomotives becomes a predominant factor in reducing GHG emissions.

- Rail sections in No-DFC scenario are expected to reach saturation leading to rail to road modal shift for freight movement. As heavy duty vehicles (like trucks) are more GHG emission intensive than railway (transported freight volume remaining constant), with increase in road share in freight movement, annual GHG emissions under No-DFC scenario will shoot up. This is evident from the carbon intensity of road transport which stands at 35 gm $CO_2$/ tonne-km while the carbon intensity of rail transport under No-DFC scenario is 9 gm $CO_2$/tonne-km. The DFC is the most energy efficient mode as its carbon intensity stands at 5 gm $CO_2$/tonne-km.
- Energy consumption during unplanned halting due to rail congestion will also have its share in the total annual GHG emission under No-DFC scenario. The basic proposition of DFC will be congestion free rail movement through the freight corridors. Congestion-free train movement in DFC scenario will reduce energy consumption.
- Since the payload in case of DFC is higher (25 T) w.r.t. No-DFC scenario (22.9 T), the number of trains required to carry equal load will be less in the former. Thus, energy consumed to transport an equal amount of freight is less in case of the DFC scenario as compared to the No-DFC scenario.

**Exhibit 25: Cumulative GHG emissions over 30 years (2016-17 to 2041-42): No-DFC scenario vs. DFC scenario (in million ton $CO_2$)**



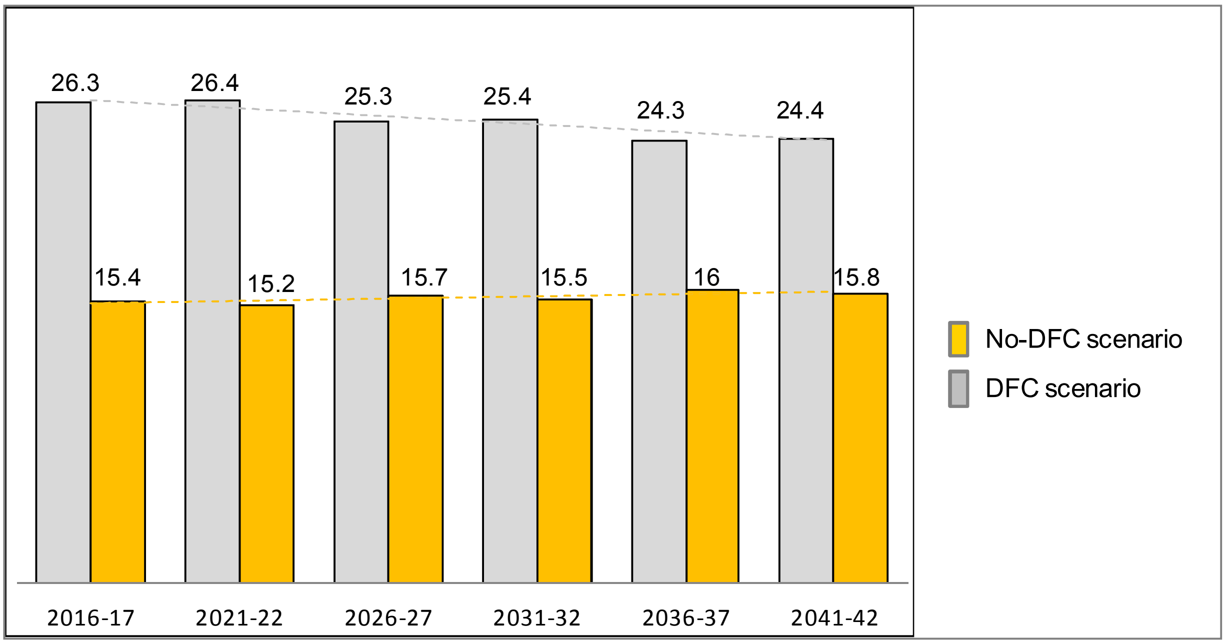

*Note: The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

[16] As per railway experts the DFCC has also indicated an energy efficiency improvement in loco in DFC as stated in the Request for Proposal (RFP No.: HQ/EL/PPF/1).

### ii) *Comparison of GHG emissions from support infrastructure*

The comparison between annual GHG emissions from support infrastructure under the No-DFC scenario and DFC scenario is illustrated below.

**Exhibit 26: Total annual GHG emissions from No-DFC and DFC support infrastructure (in '000 ton CO2)**




*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

The analysis reveals that throughout the forecasting period of 30 years, GHG emissions from the support infrastructure to be implemented under the DFC-scenario are greater than that of the No-DFC scenario. This is because of the presence of less dedicated support infrastructure in No-DFC scenario vs. greater freight handling facilities, *viz.*, logistics parks in the DFC scenario.

## 8. Scenario analysis

To make the study more robust, two scenarios have been analyzed to arrive at a holistic picture of GHG emissions due to freight transport operations in case of DFC and No-DFC scenarios. The critical parameters considered for the same has been identified on the basis of its impact on GHG emissions and level of uncertainty. From the assessment of GHG emissions over a period of 30 years, it has been observed that the fundamental variables affecting GHG emissions from freight movement along rail and road include:

**Exhibit 27: Uncertainty vs. Impact Matrix**

| Impact on Emissions | Level of Uncertainty: Low | Medium | High |
|---|---|---|---|
| High | ►Specific Energy Consumption<br>►Grid Emission Factor<br>►Mileage of Trucks<br>►Capacity of heavy truck<br>►Payload of each wagon | ►Rail Freight Capacity<br>►Electric – diesel loco share in freight transport | ►GDP (Container traffic, Cement, Iron & Steel, POL, Automobiles)<br>►Agro GDP (Food grains, Fertilizer) |
| Medium | | | |
| Low | ►No. of Wagons<br>►Tare weight of each wagon<br>►Weight of Locomotive<br>►Booked/Max speed of locomotive<br>►Average speed of locomotive | ►Population (Salt) | |

Among all the parameters identified above, scenario analysis has been done based on variations in only those parameters which lie in the high-high/high-medium/medium-high quadrants. The parameters considered to arrive at the scenario have been justified below.

- **GDP (Commodity Freight Volume)** – The freight traffic is largely forecasted on the basis of future demand-supply scenario and more basic parameters in the economic context like GDP. GDP is one of the basic economic variables considered for the future freight volume projections[17]. Thus in lieu of the same, the GHG emissions from transport operations in case of DFC and No-DFC scenario has been studied with reasonable variation in GDP.
- **Share of electric-diesel locomotives in freight transport** – In Base Case the No-DFC scenario rail freight is transported by diesel locomotives as well as electric locomotives. The Indian Railways has some ambitious plans for electrification of rail routes, thus share of electric locomotives in transporting No-DFC scenario freight is expected to increase over the period of 30 years which will impact the No-DFC scenario GHG emission volume. Hence, share of electric locomotives in No-DFC scenario freight transport will be a critical variable parameter in analyzing No-DFC scenario GHG emissions.

[17] IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009

- **Rail Freight Capacity** – An incremental rail freight capacity would have a major impact on No-DFC scenario GHG emissions. This has also accounted for any future capacity expansion plan of Indian Railways for the present infrastructure. However, the increase in rail freight capacity has not been considered in case of DFC, as traffic growth along both the corridors has been forecasted for the 30 year period, based on which DFC is being implemented. Thus capacity of DFC is subject to negligible variation and hence increase in freight carrying capacity has not been considered for Project.

The following two scenarios with variations of the above parameters have been analyzed:

- **Scenario 1-High Growth Scenario:** Here a scenario has been constructed when annual GDP will be 2% higher w.r.t. annual Base Case GDP, share of electric locomotives in No-DFC scenario freight transport will increase by 5% compared to Base Case and No-DFC scenario rail freight capacity will witness 5% increase w.r.t. Base Case. The 2% higher GDP has been considered from GDP growth rate projection of Reserve Bank of India (RBI) and also IL&FS – Final Traffic Report which predicted GDP to vary within a range of 3% for a 30 year period. The 5% increase in share of electric locomotives over and above the Base Case is adopted considering the ambitious plans of Indian Railways for electrification of railway routes in the near future. The 5% increase in No-DFC scenario rail freight capacity has been adopted from the growth in rail freight traffic over the period 1950 – 2000 as reported in "Vision 2020, Transport" Report of the Planning Commission, Government of India.
- **Scenario 2-Low Growth Scenario:** This scenario conceives a lower economic growth where the annual GDP will be 2% lower w.r.t. annual Base Case GDP, share of electric locomotives in No-DFC scenario freight transport will increase by 2% compared to the Base Case and No-DFC scenario rail freight capacity will witness 2% increase w.r.t. Base Case. The consideration of 2% lower GDP can be justified as stated for Scenario 1. 2% increase in share of electric locomotives for No-DFC scenario freight transport over and above the Base Case has been considered based on moderate increase in electrification of existing rail routes. 2% increase in freight movement on rail has been adopted from the growth in rail freight traffic over the period 1990-2000 as reported in "Vision 2020, Transport" Report of the Planning Commission, Government of India.

Increase in freight carrying capacity of railways for No-DFC scenario has been considered in the following way: 2% increase in freight train movement w.r.t. Base Case has been done considering an increase in number of trips per day for a No-DFC scenario section. 5% increase in freight train movement w.r.t. Base Case has been undertaken in the similar way.

It is worthwhile to mention that RO-RO traffic is hardly found in Indian Railway before implementation of DFC[18]. However the same has been considered for accounting GHG emissions from freight movement through road.

Change in GDP has been taken into account in the following way: IL&FS – Final Traffic Report demonstrates the relation between GDP and commodity traffic volume which includes container, cement, iron and steel and POL. On that basis relations between change in GDP and change in growth rate of a particular commodity freight volume have been derived. For other types of

[18] IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009

commodities average of the change in growth rates of the above mentioned commodities have been considered.

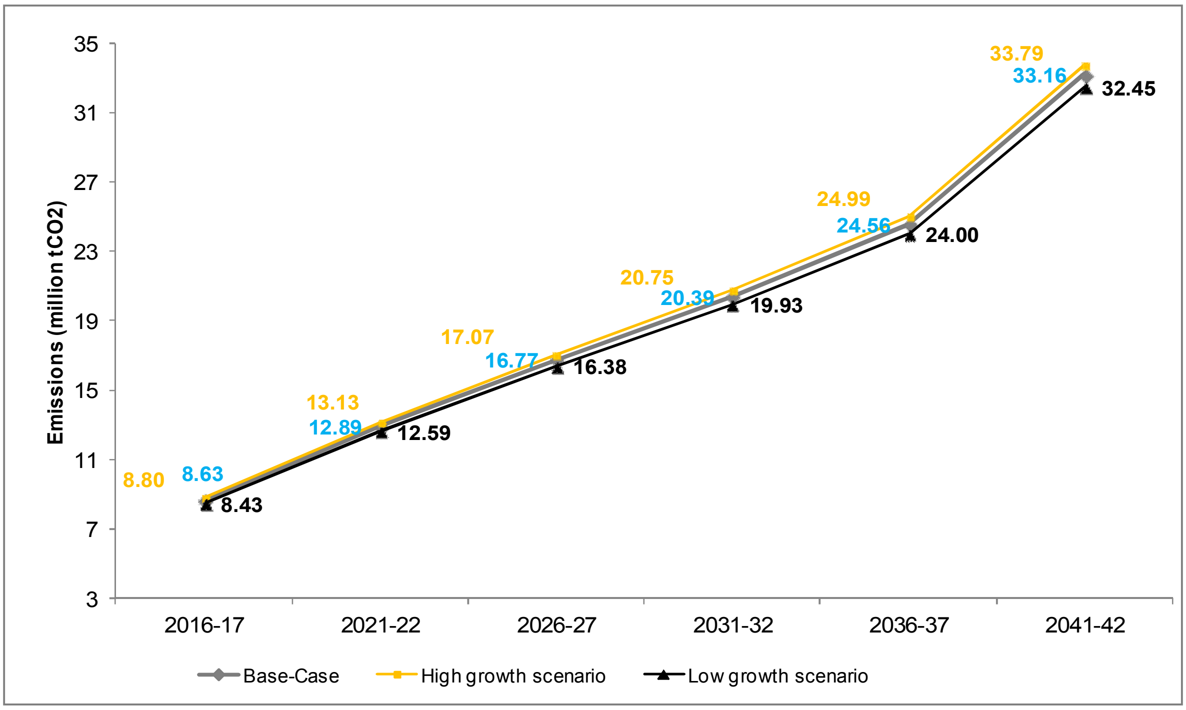
Increase in share of electric locomotives for No-DFC scenario freight transport has been considered in analyzing GHG emissions from freight movement as well as during congestion.

| Table 12: Annual GHG emissions - Scenario 1 (million tonnes of $CO_2$) | | | | | | |
|---|---|---|---|---|---|---|
| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 |
| No-DFC | 8.80 | 13.13 | 17.07 | 20.75 | 24.99 | 33.79 |
| DFC | 2.64 | 3.33 | 3.91 | 4.44 | 4.95 | 6.09 |

| Table 13: Annual GHG emissions - Scenario 2 (million tonnes of $CO_2$) | | | | | | |
|---|---|---|---|---|---|---|
| | 2016-17 | 2021-22 | 2026-27 | 2031-32 | 2036-37 | 2041-42 |
| No-DFC | 8.43 | 12.59 | 16.38 | 19.93 | 24.00 | 32.45 |
| DFC | 2.53 | 3.20 | 3.75 | 4.26 | 4.76 | 5.85 |

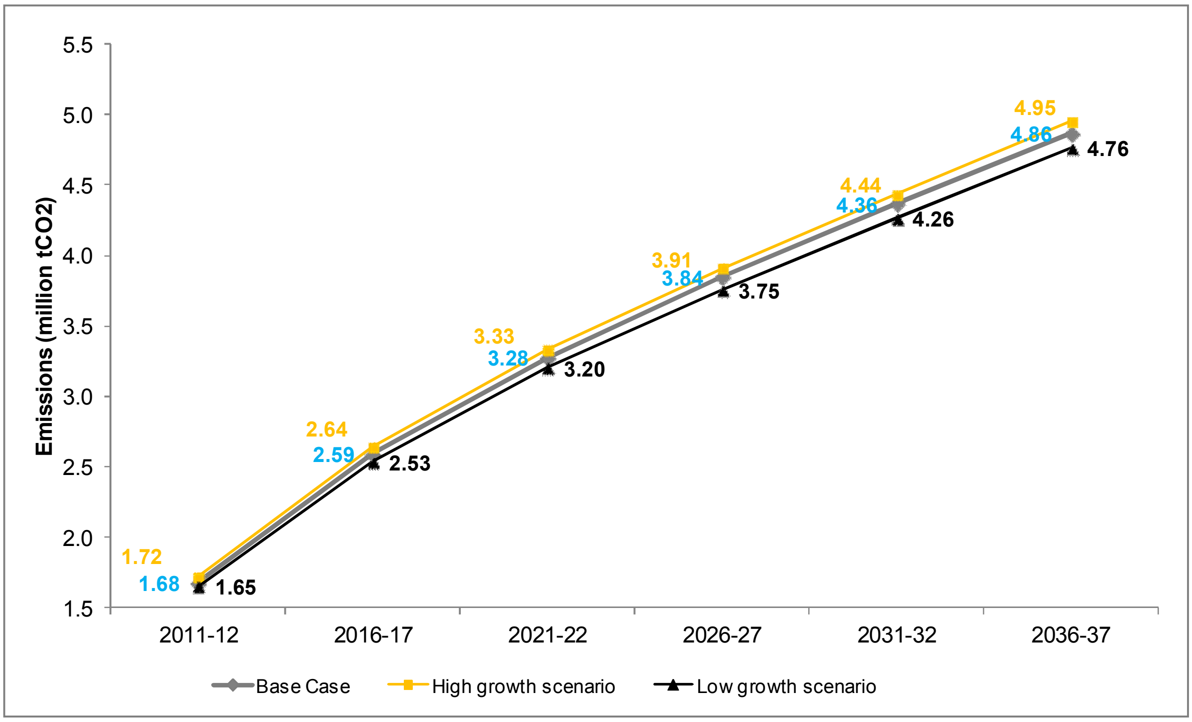
The scenario analysis for No-DFC scenario and DFC scenario is illustrated by the following exhibits.

**Exhibit 28: Scenario analysis for total annual GHG emissions under No-DFC scenario (in million ton $CO_2$)**




*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

**Exhibit 29: Scenario analysis for total annual GHG emissions under DFC scenario (in million ton $CO_2$)**




*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor*

One of the major findings of this study is: freight transport through DFC is expected to be much less GHG emission intensive as compared to the No-DFC scenario throughout the assessment period of 30 years in all the three cases - Base Case, High growth scenario and Low growth scenario.
Other scenarios that have been conceptualized and analyzed are described below.

**Scenario 3- Low Carbon Scenario over base case:** This scenario is conceptualized considering potential clean technologies and practices (in both energy demand side and supply side), that could be adopted by DFC in its proposed configuration in order to achieve a growth path with minimum GHG emissions. In this scenario we have also forecasted India's grid emission factor ($tCO_2$ / MWh) considering 10% increase in capacity share of renewable/ non-conventional energy to the grid, over and above the planned renewable/ non-conventional capacity addition.

The comparison between DFC scenario and low carbon scenario has been illustrated for each corridor by the following exhibits.

**Exhibit 30: Annual GHG emission gap between DFC scenario and low carbon scenario-Eastern corridor (in million ton $CO_2$)**

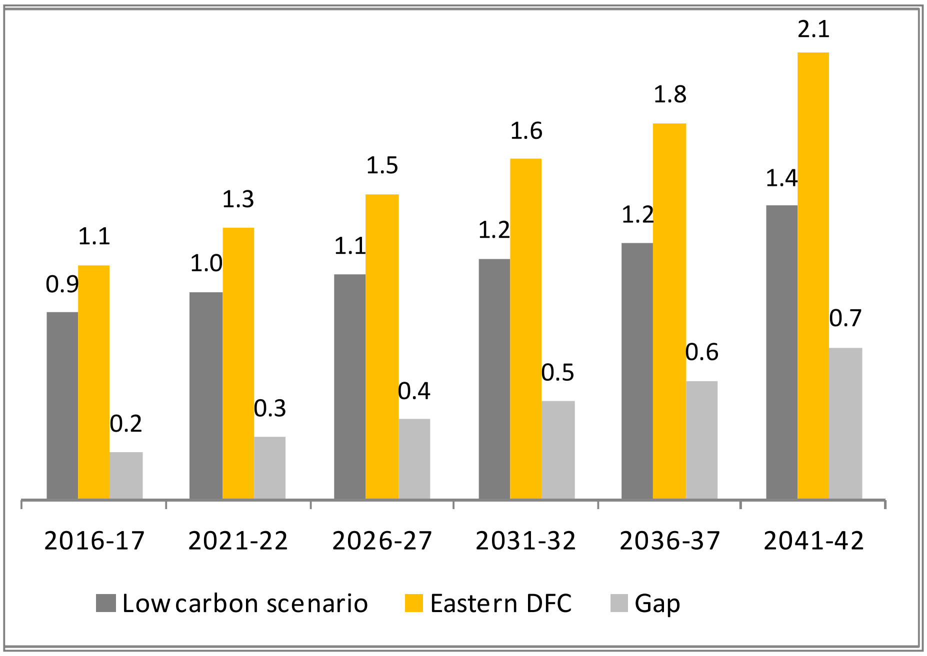
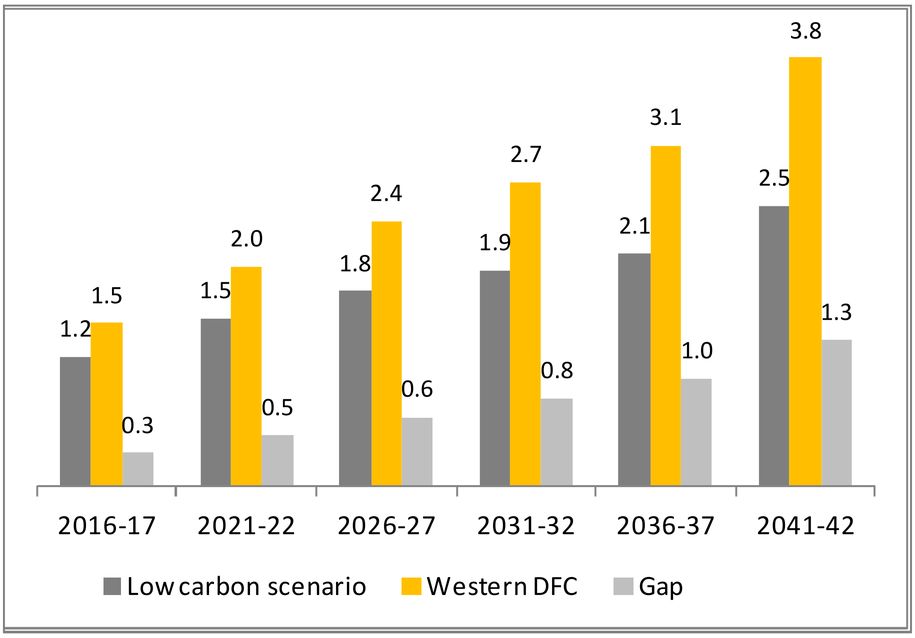
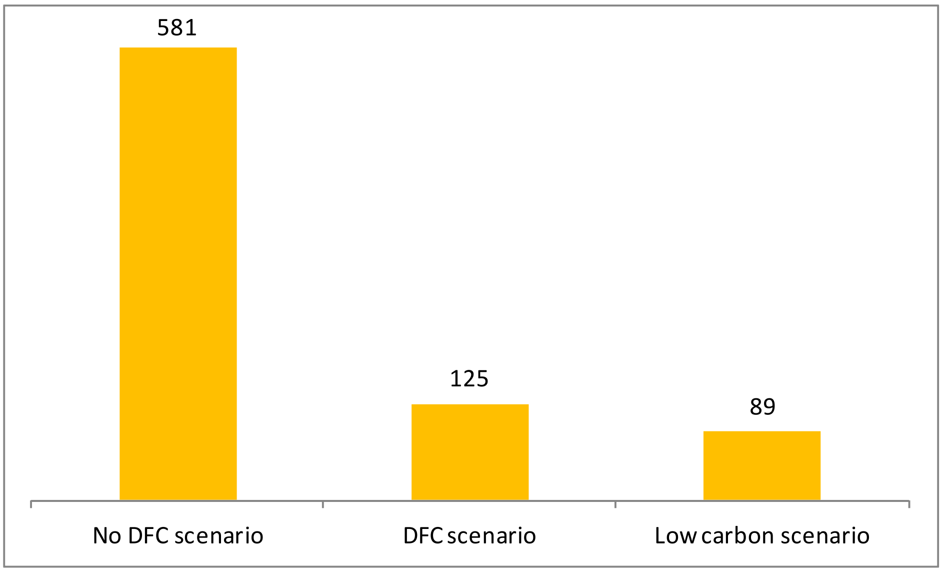



**Exhibit 31: Annual GHG emission gap between DFC scenario and low carbon scenario-Western corridor (in million ton $CO_2$)**




The comparison of cumulative GHG emissions under No-DFC scenario, DFC scenario and low carbon scenario have been compared in the following exhibit.

**Exhibit 32: Comparison of cumulative total GHG emissions in the low carbon, DFC and No-DFC scenarios over 30 year study period (in million ton $CO_2$)**




*Note: 'Total' indicates that the emission figures are a summation of Eastern Corridor and Western Corridor. The cumulative emissions have been calculated by multiplying the annual emissions of each reference year by 5 and summation of all these emission values.*

- The DFC scenario results in almost 78% reduction in GHG emissions over the No-DFC scenario.
- The low carbon scenario would further decarbonize the DFC scenario by 28% reduction in GHG emissions.

## 9. Analysis of the proposed GHG Abatement Levers

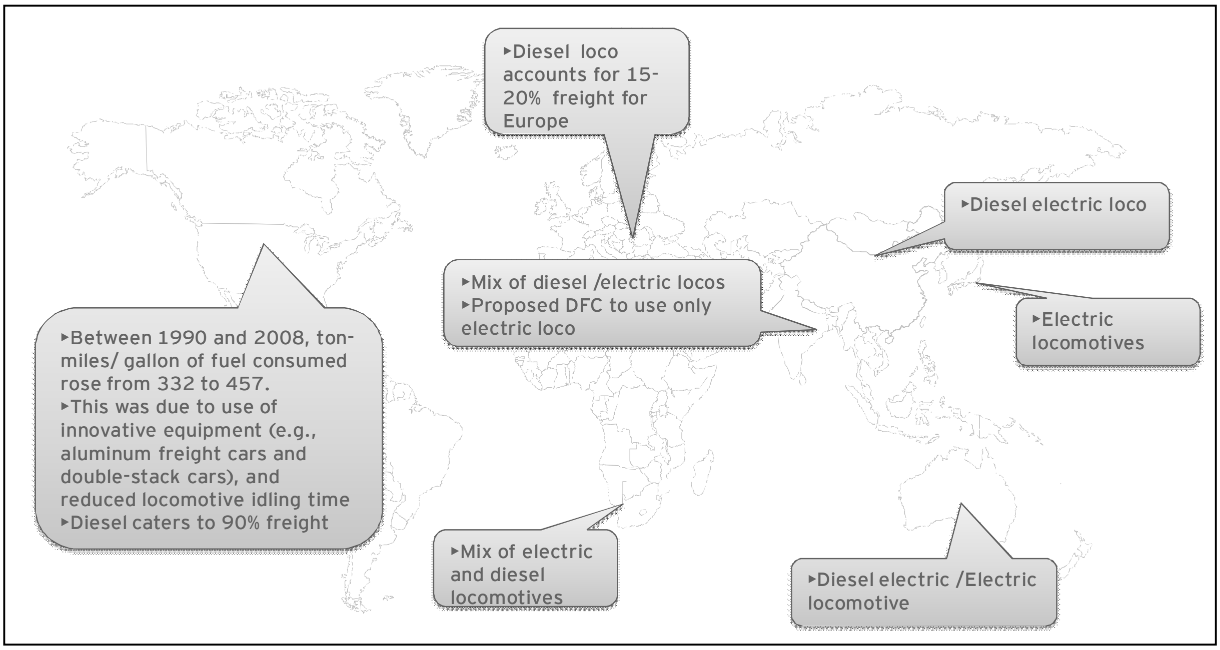
The history of railway technology can be traced back to the 19th century when the steam engines were invented. Later on in the 20th century, with the commercialization of the diesel and electric locomotives, railway underwent a major shift in technology. This was visible in improved fuel efficiency and locomotive power rating. The journey of the railway technology since the beginning of the 20th century and its future direction has been illustrated in the following exhibit.

**Exhibit 33: Chronology of development of rail technology**

| | 1900-1950 | 1950-2000 | 2000-2050 |
|---|---|---|---|
| Technological innovation | ▶ Commercial operation of steam engines | ▶ Use of diesel and electric locos on a large scale after World War II<br>▶ Diesel electric or diesel hydraulic traction<br>▶ Gas electric loco | ▶ IGBT technology<br>▶ Magnetic levitation<br>▶ Hybrid loco<br>▶ Fuel cell electric loco |
| Drivers | ▶ Haul train on tracks<br>▶ Ease and flexibility: Easy to replace one loco with another. In case of failure. Large locomotives can be substituted for small locomotives where grades are steeper / more power is needed. | ▶ More fuel efficient<br>▶ Less maintenance and lower O&M costs<br>▶ Higher speed | ▶ Climate change regulations (penalties and incentives )<br>▶ Increased fuel efficiency and productivity<br>▶ More sophisticated (like no overhead wires) and faster mode of transport |
| Challenges | ▶ Energy intensive<br>▶ Very pollutive<br>▶ Running of trains sometimes broke cast iron plates<br>▶ Intensive maintenance | ▶ Depleting fossil fuel reserves and increasing fuel prices put high pressure on railways<br>▶ Climate regulations required even cleaner modes of transport | ▶ Most of the technologies are very expensive and yet to be demonstrated on a commercial scale |

Globally both diesel and electric locomotives are used for freight transportation. Dedicated freight corridors are present in many countries in Europe and elsewhere which lead to less congestion and hence contribute to energy efficient freight transportation.

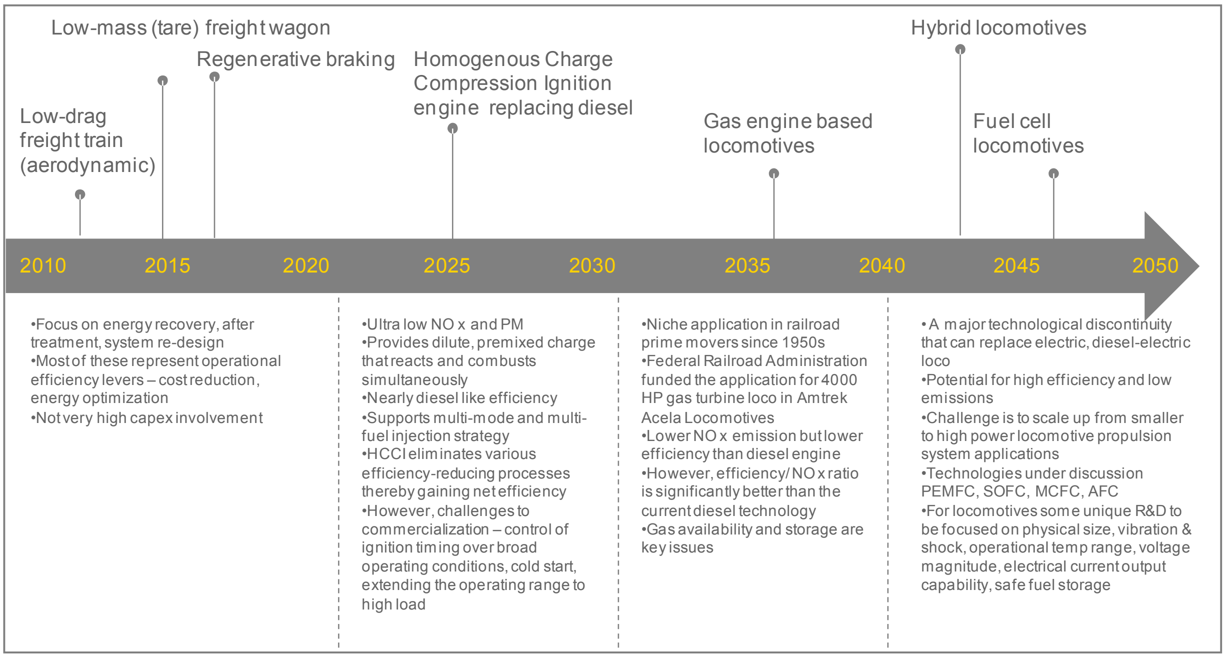
**Exhibit 34: Technology overview of railways globally**




Source: 1) Union of international railway – UIC, 2) EY internal research, 3) External railway experts

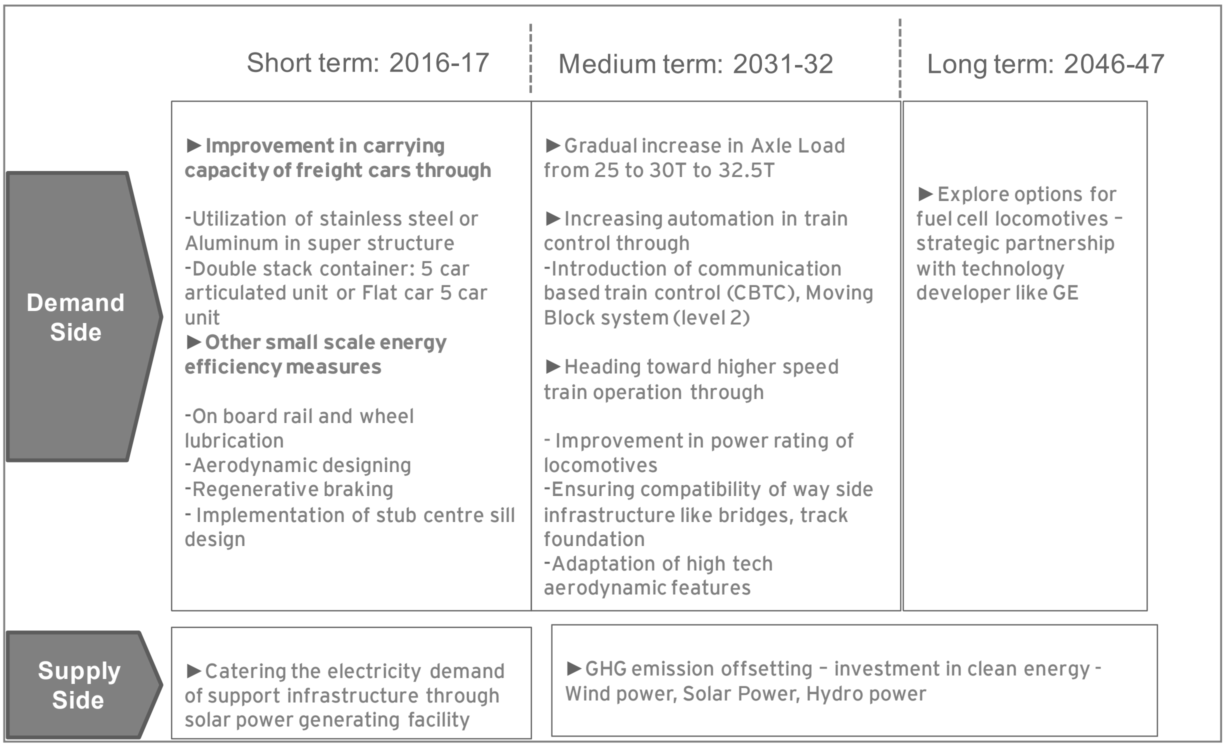
For the railway sector, a long term technology trajectory suggests that the locomotive engines would be moving towards low carbon intensive fuels like gas and hybrid locos. However fuel cell technology might be the ultimate answer to the problem of carbon emissions.

**Exhibit 35: Technology trajectory suggests hybrid locomotive will be the future in 2030-40**



In this section we have drawn a Macro level implementation roadmap for DFC aiming at decarbonizing it from GHG emission perspective. This road-map has been developed in view of the short/medium/long term strategies and the best railway practices across the world and their suitability in Indian context (i.e. proposed DFC configuration).

**Exhibit 36: Roadmap for implementation of GHG abatement opportunities**




Further to the above we have conducted a micro level assessment study for some of the GHG abatement levers which are extremely relevant for the DFC and could be implemented readily owning to their techno-commercial attractiveness. These GHG abatement levers have been identified under the following two categories:

1. Demand side GHG abatement levers which typically include energy efficiency improvement through retrofit, replacement or modification - please refer to Annexure 3 for details on each of the demand side levers
2. Supply side GHG abatement levers which may include energy efficiency improvement measure or fuel switch which predominantly involve changing energy mix – Please refer to Appendix 5 for details on the each of the supply side levers

While doing the micro-level assessment technological, economic and environmental potential of each of the levers has been assessed by means of a customized evaluation tool. In addition to the above key direct and indirect benefits along with impeding factors for dissemination has also been analyzed. The findings of this assessment study are intended to facilitate DFC in adapting effective and cognizant implementation schedule.

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## Exhibit 37: Synopsis of the GHG abatement levers

| | Category of Initiatives | Specific Actionable Initiatives | Financial Impact: NPV | Financial Impact: Incremental capital Investment | Financial Impact: Cost savings due to reduction in electricity consumption | Financial Impact: Comments | Technological impact: Emission Reduction | Technological impact: Technology penetration |
|---|---|---|---|---|---|---|---|---|
| GHG Abatement Levers | 1 Utilization of lighter metal in super structure | Utilization of stainless steel | ~ 646 million | Instead INR 28700/wagon cap-ex saving | INR 74 million/annum | 1. Demand supply gap of stain less steel could be an issue<br>2. Cash inflow: savings -reduction in power consumption -reduction in no of trips - material cost | 25000 $tCO_2$/ annum | |
| GHG Abatement Levers | 2 Utilization of lighter metal in super structure | Utilization of Aluminum | ~ 1144 million | Instead INR 48000 / wagon cap-ex saving | INR 183 million/annum | 1. Upstream energy consumption (production side) high,<br>2. Cash inflow-savings due to reduction in: -power consumption -no of trips - material cost | 62000 $tCO_2$/ annum | |

Nil Low Medium High

| | Category of Initiatives | Specific Actionable Initiatives | Financial Impact: NPV | Financial Impact: Incremental Capital Investment | Financial Impact: Cost savings due to reduction in electricity consumption | Financial Impact: Comments | Technological impact: Emission Reduction | Technological impact: Technology penetration |
|---|---|---|---|---|---|---|---|---|
| GHG Abatement Levers | 3 Rail and wheel lubrication | Implementation of on-board rail and wheel lubrication – using special lubricating vehicles | ~120 million IRR 60% | ~INR 50 million | ~INR 48 million | 1. This is especially effective in curves but can also be applied on tangent tracks.<br>2. While computing the NPV following has been considered as cash inflow -Saving due to reduction in electricity consumption | 16000 $tCO_2$/annum | |
| GHG Abatement Levers | 4 Double stack container | 5 car articulated unit | ~13million | No significant incremental investment with respect to the BAU design | ~INR 3.95 million | 1.Require axle load up to 35.7t.<br>2. Needs larger vertical clearances and lower operating speed due to higher centre of gravity<br>3. Cash inflow -Saving due to reduction in electricity consumption -Saving due to reduction in no of trips (due to reduction in tare weight | 1000 $tCO_2$/annum | |
| GHG Abatement Levers | 4 Double stack container | Flat car 5 car unit | ~44million | No significant incremental investment than BAU design | ~INR 13.32 million | | 5000 $tCO_2$/annum | |

Nil Low Medium High

| Category of Initiatives | Specific Actionable Initiatives | NPV | Incremental Capital Investment | Revenue generation | Comments | Emission Reduction | Technology penetration |
|---|---|---|---|---|---|---|---|
| | | Financial Impact | | | | Technical impact | |
| GHG Abatement Levers: 5 Aerodynamic designing | Incorporating few aerodynamic features | ~ 1 million IRR 12% | ~INR 100 million | ~INR 24 million | 1. Significant only in case of high speed trains 2. While computing the NPV following has been considered as cash inflow -Saving due to reduction in electricity consumption | ~8000 $tCO_2$/ annum | |
| 6 Regenerative Braking | Electric stock may recuperate energy during braking by using traction motors as generators. 50 Hz, 25 kV supply systems offer medium conditions for feeding back recovered energy | ~ 1939 million | ~INR 1000 million | ~INR 119 million | 1. Heavy weight of the fleet limits regeneration 2. While computing the NPV following has been considered as cash inflow -Saving due to reduction in electricity consumption | ~ 40000 $tCO_2$ /annum | |
| 7 Wagon designing | Bath tub and Monocoque design in Gondola cars | ~ 323 million | No significant incremental investment with respect to the BAU design | ~INR 97 million/ annum | 1. Applicable to 32t to 37t axle load 2. While computing the NPV following has been considered as cash inflow -Saving due to reduction in electricity consumption | ~ 30000 $tCO_2$ /annum | |

Nil Low Medium High

| Category of Initiatives | Specific Actionable Initiatives | NPV | Incremental Capital Investment | Revenue generation/ cost saving | Comments | Emission Reduction | Technology penetration |
|---|---|---|---|---|---|---|---|
| | | Financial Impact | | | | Technical impact | |
| GHG Abatement Levers: 8 Wagon designing | Implementation of stub centre sill design | ~ 1 million | No significant incremental investment with respect to the BAU design | ~ INR 0.348 million | 1. Application is only restricted to tank cars 2. While computing the NPV following has been considered as cash inflow -Saving due to reduction in electricity consumption | ~120 $tCO_2$/ annum | |
| 9 Signaling | Implementation of Communication based train control | Very low/ unattractive | Very high, please refer to Annex 5 of report | ~ very low | 1. Involves high investment, long implementation schedule (almost 20yrs) 2. While computing the NPV following has been considered as cash inflow -Saving due to reduction in electricity consumption | ~16354 $tCO_2$/ annum | |

Nil Low Medium High

*Source: 1) Union of international railway – UIC, 2) Infrastructure Leasing & Financial Services Ltd (IL&FS)- Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC" – August

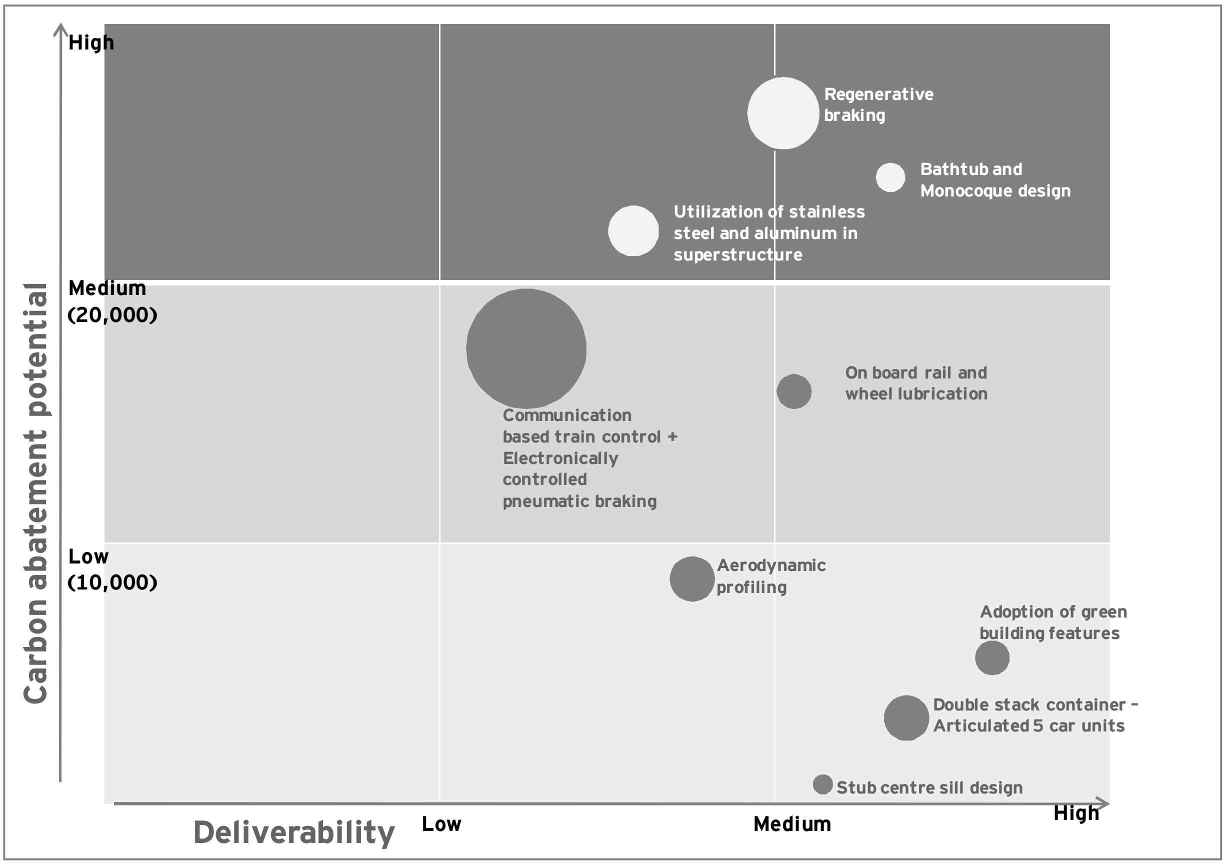
2009, 3) Inputs from DFCCIL (tenders floated, business plan etc), railway domain experts, technical consultants.

**For detail please refer to Annexure 3.

In addition to the techno-commercial assessment, as part of scope a CDM potential assessment matrix (evaluation parameters for the matrix are mentioned below) has also been presented here. Based on the outcome of our CDM potentiality assessment study we would like to focus further on the following GHG abatement lever considering their high CDM potentiality.

| Table 14: Top GHG abatement opportunities |
|---|
| ▶ Regenerative braking<br>▶ Adaptation of green building features<br>▶ Utilization of Solar power (PV) as a power source for DFC support infrastructure<br>▶ Utilization of wind power as a power source for DFC support infrastructure<br>▶ Communication based train control (CBTC) |

**Exhibit 38: Carbon abatement potential of the GHG abatement levers**




*Note: Size of the bubble indicates CAPEX for the project. Deliverability is assessed based on parameters such as financial returns, technology penetration, emission reduction potential, operating expenditure etc.*

**Table 15: CDM potential assessment Matrix**

| SI No | GHG abatement lever | Emission Reduction ( in ton of $CO_2$/annum)[19] | Methodology[20] | Additionality | Monitoring | Overall CDM potential[21] |
|---|---|---|---|---|---|---|
| Demand side GHG abatement levers | | | | | | |
| 1 | Wagon designing | | | | | |
| I | Utilization of stainless steel as super structure material instead of black steel | - 25000[22] | Not available | - Weak (financially attractive, and no such technological barrier) | -Low: Difficult to monitor energy savings that may be attributed to either of these measures | Low |
| II | Utilization of aluminum as super structure material instead of black steel | - 62000[23] | Not available | - Weak (financially attractive, and no such technological barrier) | -Low: Difficult to monitor energy savings that may be attributed to either of these measures | Low |
| III | Productivity improvement in double stack container | - 1,358[24]<br>- 4,576[25] | Not available | - Weak (financially attractive, and no such technological barrier) | - Low: Difficult to monitor energy savings that may be attributed to this | - Low |

[19] This is an indicative emission reduction rate – an incremental benefit over and above the proposed DFC configuration. Please refer to excel sheet for details.

[20] For large scale methodologies refer to the following link - http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html, For small scale methodologies refer to the following link - http://cdm.unfccc.int/methodologies/SSCmethodologies/approved.html

[21] Overall potentiality has been determined considering 35% weightage on emission reduction, 45% weightage on additionality and 20% weightage on monitoring

[22] This is the energy saving rate due to utilizing of stainless steel as super structure instead of black steel (a prevalent practice)

[23] This is the energy saving rate due to utilizing of aluminum as super structure instead of black steel (a prevalent practice)

[24] in case of Double stack 5 car articulated unit

[25] in case of Double stack on flat cars (5 car units))

| Sl No | GHG abatement lever | Emission Reduction ( in ton of $CO_2$/annum)[19] | Methodology[20] | Additionality | Monitoring | Overall CDM potential[21] |
|---|---|---|---|---|---|---|
| | | | | | measure | |
| IV | Others | | | | | |
| A | Bath tub and Monocoque design for Gondola cars | - 33,345[26] | - Not available | - Weak (financially attractive, and no such technological barrier) | - Low: Some parameters required to compute the energy savings may be difficult to monitor | - Low |
| B | Use of stub centre sill design | - 120[27] | - Not available | - Weak | - Low: Some parameters required to compute the energy savings may be difficult to monitor | - Low |
| 2 | Aerodynamic and friction | | | | | |
| I | Aerodynamic profiling | - 8,177 | - AMS IID | - Moderate (Financially unattractive - like low benefit due to low fleet speed) | - Moderate: Some parameters required to compute the energy savings may be difficult to monitor | - Moderate |
| II | On board rail and wheel lubrication | - 16,354 | - AMS IID | - Moderate (Moderate investment, low benefit expectation due to straight track) | - Low: Difficult to monitor energy savings that may be attributed to this measure | - Moderate |
| 3 | Signaling | | | | | |

[26] in case of coal transported by wagon having monocoque design
[27] In case of POL transportation through tank wagons

| SI No | GHG abatement lever | Emission Reduction ( in ton of $CO_2$/annum)[19] | Methodology[20] | Additionality | Monitoring | Overall CDM potential[21] |
|---|---|---|---|---|---|---|
| I | Communication based train control (CBTC) | - 16,354 | - AMS IID | - High (financially unattractive, high technological barrier, not a common practice ) | - High: Easy to monitor energy savings | - Moderate |
| II | Electronically controlled pneumatic brakes | | | | | |
| III | Regenerative Braking | - 40,886 | - AMS IIIC | - High (high initial investment, Low financial benefit due to less number of braking activity, financially unattractive) | - High: Easy to monitor energy savings | - High |
| 4 | Energy efficiency in support infrastructure | | | | | |
| I | Adopting green building features in DFCCIL owned buildings | - 8,448[28] | - AMS IIE/ AM0060/ AMS IIIAE | - High (Financially unattractive) | - High: Easy to monitor energy savings | - High |

[28] For 0.425 million sq.ft commercial building-operating time 24 x 7 hours

To monitor the improvement in carbon performance of the DFC with respect to the No-DFC scenario, the following monitoring framework could be followed. Since the DFC and No-DFC scenario would be carrying different amount of freight over different distances, hence an exact and absolute GHG emission reduction computation may not be possible. However the Key Performance Indicator identified here would give an indication of the possible reduction in GHG emission.

**Table 16: Monitoring framework**

| S. No. | Parameters to be monitored for DFC scenario | Parameters to be monitored for No-DFC scenario | Remarks |
|---|---|---|---|
| 1. | Electricity consumption ($E_D$) | a) Diesel consumption ($D_{ND}$)<br>b) Electricity consumption ($E_{ND}$) | This parameter has to be monitored to arrive at the specific energy consumption. |
| 2. | Electricity from renewable sources ($E_{D,R}$) | Electricity from renewable sources ($E_{ND,R}$) | Percentage of renewable energy in:<br>i) $DFC\ case = \frac{E_{D,R}}{E_D} \times 100$<br>ii) $no\ DFC\ case = \frac{\frac{E_{ND,R}}{860}}{D_{ND} \times NCV + \frac{E_{ND}}{860}} \times 100$<br>iii) The above two case results are compared and a higher figure for DFC scenario would indicate improvement in environmental performance as a result of implementation of DFC. |
| 3. | Freight transported from origin to destination (tonne-km) | Freight transported from origin to destination (tonne-km) | This parameter has to be monitored to arrive at the specific energy consumption. |
| **Key Performance Indicators** | | | |
| **S. No.** | **DFC scenario** | **No-DFC scenario** | **Environmental performance improvement computation steps** |
| 1. | Specific energy consumption (ratio of total energy consumed and tonne-km traversed) ($SEC_D$) | Specific energy consumption (ratio of total energy consumed in terms of diesel and electricity and tonne-km traversed) ($SEC_{ND}$) | i) $SEC_D = \frac{E_D}{tonne-km\ in\ DFC\ case}$<br>ii) $SEC_{ND} = \frac{E_{ND} + D_{ND} \times NCV \times 860}{tonne-km\ in\ no\ DFC\ case}$<br>iii) $Percentage\ improvement = \frac{SEC_{ND} - SEC_D}{SEC_{ND}} \times 100$<br>iv) The above figure would be a key performance indicator to show how much more less carbon intensive the DFC is as compared to the No-DFC scenario. |

## 10. Conclusion

The DFC is a welcome initiative by the Indian Railways, Govt of India. From a GHG inventory point of view, the DFC contributes to huge GHG emission reduction volumes. Annual GHG emission GAP between the No-DFC scenario and DFC scenario is 13.7 million ton $CO_2$ and 77.8 million ton $CO_2$ in the Eastern and Western Corridors respectively. On an average, the No-DFC scenario is about 4 times more carbon intensive[29] as compared to the DFC scenario.

In fact as per projections, the existing Indian Railways infrastructure would not be adequate to cater to the huge demand of non-roadable commodities like coal. Saturation of rail sections shifts the roadable commodities to carbon intensive modes of transport like diesel trucks or heavy duty vehicles which increases the GHG intensity of the No-DFC scenario. This is evident from the carbon intensity of road transport which stands at 35 gm $CO_2$/ tonne-km while the carbon intensity of rail transport under No-DFC scenario is 9 gm $CO_2$/tonne-km. The DFC is the most energy efficient mode as its carbon intensity stands at 5 gm $CO_2$/tonne-km.

Besides being less carbon intensive, the DFC would also supply coal to powerhouses, ensuring that they come up in the planned period. The DFC would provide a congestion free and more energy efficient mode of freight transport for the Indian economy.

The GHG performance of the DFC can be further improved under the low carbon scenario. Identified GHG abatement levers, which are high on deliverability[30] and have a high CDM potential can be implemented. Some of these levers include:

- Communication based train control (CBTC)
- Regenerative braking
- Adaptation of green building features
- Utilization of Solar power (PV) and wind power as power source for DFC support infrastructure

The CDM revenue earned from these GHG abatement levers would further improve their financial attractiveness. Focus should be put on them to take them through the UNFCCC route for CDM registration.

[29] Carbon intensity means the ratio of GHG emissions and the freight carried.

[30] Deliverability has been assessed w.r.t financial attractiveness, energy savings potential, degree of technology penetration/global practice etc and implementation barriers

# Annexure-1: Approach of the study and selection of Base Year

## a) Approach

The analysis of GHG emission trends for No-DFC as well as DFC scenarios have been done in accordance with the guidance of the international standards for accounting and reporting of GHG emissions. Broadly, the principles of accounting, collection of data, calculation and reporting have been incorporated from the *GHG Protocol Corporate Accounting and Reporting Standard,* (henceforth this Protocol has been referred to as WBCSD Protocol) developed by World Business Council for Sustainable Development (WBCSD)[31] and World Resources Institute (WRI), which is also in line with the guidance provided in the *ISO 14064*, developed by International Standards Organization (ISO).

However, there have been a few deviations from the international standards, due to unavailability of appropriate and authentic information. As explained below, this is mainly in case of delineation of the operational boundary while allocating GHG emissions from construction activities and support infrastructure.

- Since DFC would be sharing certain support infrastructure of Indian Railways, GHG emissions due to those infrastructures cannot be allocated under separate heads.
- It is not clear which of the construction activities would be outsourced to contractors/sub-contractors that are not directly under the control of DFCCIL. Hence the same could not be allocated under separate heads.

The WBCSD Protocol specifies two approaches to GHG accounting namely the equity share approach and control approach. Under the equity share approach, a company accounts for GHG emissions from operations according to its share of equity in the operation. Under the control approach, a company accounts for100 percent of the GHG emissions from operations over which it has control. It does not account for GHG emissions from operations in which it owns an interest but has no control. The control approach is followed for this exercise. The deviation from the WBCSD Protocol is due to the lack of information regarding the extent of control of DFCCIL on the support infrastructure and construction activities.

[31] Source:- http://www.ghgprotocol.org/files/ghg-protocol-revised.pdf

**Exhibit 39: Approach used for the study**

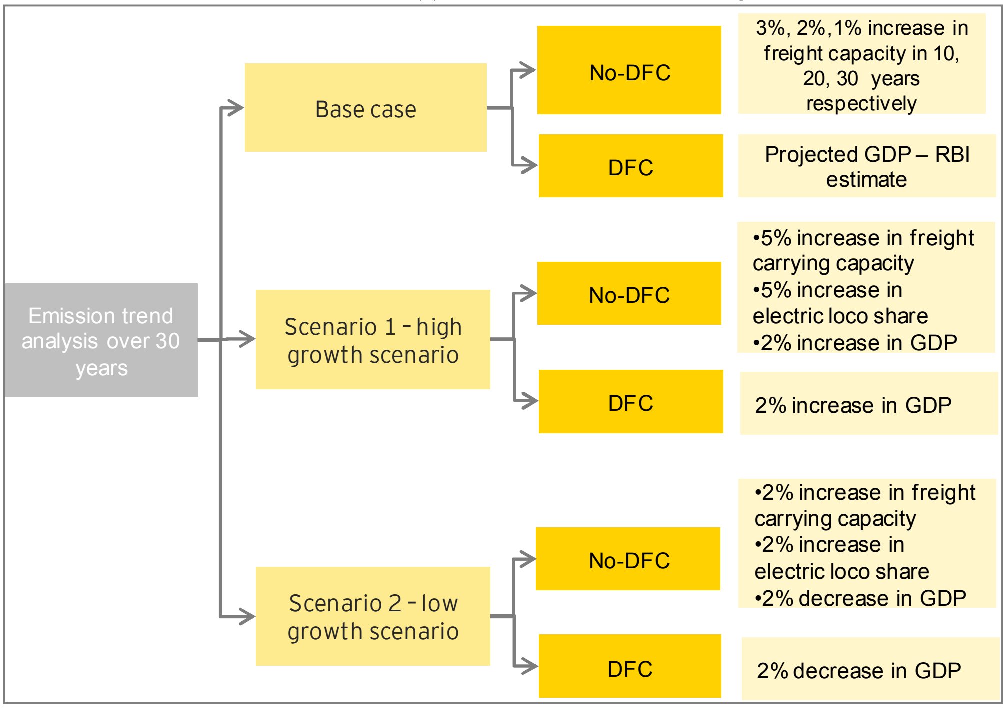



**Exhibit 40: List of Guidelines and Tools used for the study**[32]

| | |
|---|---|
| Determination of No-DFC scenario inventory | • World Business Council for Sustainable Development (WBCSD) GHG Protocol Corporate Accounting & Reporting Standard<br>• ISO 14064<br>• IPCC 2006 guidelines |
| Projection of No-DFC scenario inventory over next 30 years | • Statistical tools like linear regression, *etc.* |
| Determination of GHG inventory due to construction of DFC | • WBCSD GHG Protocol Corporate Accounting & Reporting Standard<br>• ISO 14064<br>• IPCC 2006 guidelines |
| Determination of GHG emissions due to operation of DFC and projection of the same | • WBCSD GHG Protocol Corporate Accounting & Reporting Standard<br>• ISO 14064<br>• Statistical tools like linear regression, *etc.* |
| Identification and analysis of GHG abatement levers | • EY Analysis<br>• Insights from railway experts<br>• Information available from public domain |
| Development of CDM methodology | • Guidelines from United Nations Framework Convention on Climate Change<br>• Other CDM tools, methodologies and guidance as necessary |

[32] Sources:-WBCSD GHG Protocol -http://www.ghgprotocol.org/files/ghg-protocol-revised.pdf
http://www.iso.org/iso/catalogue_detail?csnumber=38381
http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

**Selection of Base Year**

DFCCIL may need to track GHG emissions over time as a requirement of a variety of business goals, such as public reporting, establishing GHG targets, managing risks and opportunities and addressing the needs of investors[33] and other stakeholders. The preliminary use of the GHG inventory is towards arriving at futuristic abatement, mitigation and management strategies. A meaningful and consistent comparison of GHG emissions over time requires setting up a performance datum with which to compare current GHG emissions. This datum is the Base Year. The choice of Base Year and its validity is demonstrated as follows:

- **Data Availability**-The selection of an appropriate Base Year is attributed to the availability of verifiable GHG emissions data for that year. The Base Year may either be a single year data or a multi-year average or rolling average data.
- **GHG Target** -The GHG inventory Base Year can also be used as a basis for setting and tracking progress towards a GHG target in which case it is referred to as a target Base Year.

In accordance with the justification cited above, 2007-08 has been selected as the Base Year for estimation of GHG inventory for No-DFC scenario. GHG inventorization for DFC has been done starting from 2016-17 which is the expected year of commissioning of DFC.

## b) Identification and inclusion of GHG Emission sources within the operational boundary

- **Greenhouse Gas (GHG)** – Six anthropogenic greenhouse gases are identified as carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), Hydro fluorocarbons (HFCs), Per fluorocarbons (PFCs) and Sulphur hexafluoride ($SF_6$). Among these, $CO_2$ emissions have been accounted for in this assessment since $CO_2$ emissions from energy consumption in the different operations considered in the study constitute the bulk of the probable GHGs.
- **GHG sources**- Physical unit or process which releases a GHG into the atmosphere. Major GHG sources include freight train movement (where electricity and diesel consumption take place), heavy duty vehicles (diesel consumption) and support infrastructure (both electricity and fossil fuel consumption).

## c) Emissions factors

**Emission factor for computation of GHG emissions from electricity consumption -** The emission factor for electricity as mentioned in the emission factor calculation tool of WBCSD[34] is generic and may not apply to India's electricity supply – consumption scenario. So India specific data (primarily Central Electricity Authority database/ version 05) has been considered in the GHG emission computation. In order to calculate the GHG emissions corresponding to electricity

[33] Indian Railways is also contemplating to go for public-private partnership.
[34] World Business Council for Sustainable Development

consumption in electric locomotives during freight movement and in support infrastructure, the emission factor of grid has been considered. The value of emission factor of Indian grid for the Base Year, *i.e.*, 2007-08 has been sourced from the Central Electricity Authority (CEA) database, Version 05[35]. Values of the same for the next seven five-year periods starting from 2011-12 have been estimated/ projected every five years in the following way.

- Combined Margin Emission Factor has been calculated as weighted average of Build Margin (BM) and Operating Margin (OM) emissions factors as per "Tool to Calculate the Emission Factor for an Electricity System" (UNFCCC guidelines[36]).
- OM refers to the group of existing power plants whose current electricity generation would be affected by grid-connected future power generation projects. For the purpose of the study, the same has been determined using Simple OM method where the simple OM emission factor is calculated as the generation-weighted average $CO_2$ emissions per unit net electricity generation ($tCO_2/MWh$) of all generating power plants serving the system, not including low-cost/must-run power plants/units[37]. The same is calculated based on the net electricity generation of each power unit and a $CO_2$ emission factor of each power unit.

$$EF_{grid,OMsimple,y} = \frac{\sum_m EG_{m,y}.EF_{EL,m,y}}{\sum_m EG_{m,y}} \text{.......eqn. (1)}$$

where,

$EF_{grid,OMsimple,y}$ = Simple operating margin $CO_2$ emission factor in year y ($tCO_2/MWh$)

$EG_{m,y}$ = Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)

$EF_{EL,m,y}$ = $CO_2$ emission factor of power unit m in year y ($tCO_2/MWh$)

m = All power units serving the grid in year y except low-cost / must-run power units

y = relevant year as per the data vintage

- BM refers to group of prospective power plants[38] whose construction and future operation would be affected by any other grid-connected future power generation projects. The sample of power plant units considered for calculation of BM consists of the set of power capacity additions in the electricity system that comprise 20% of the system generation (in MWh) and that have been built most recently. The BM emissions factor is the generation-weighted average emission factor ($tCO_2/MWh$) of all power units m during the most recent year y for which power generation data is available.

$$EF_{grid,BM,y} = \frac{\sum_m EG_{m,y}.EF_{EL,m,y}}{\sum_m EG_{m,y}} \text{ .......eqn. (2)}$$

where,

$EF_{grid,BM,y}$ = Build margin $CO_2$ emission factor in year y ($tCO_2/MWh$)

$EG_{m,y}$ = Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)

$EF_{EL,m,y}$ = $CO_2$ emission factor of power unit m in year y ($tCO_2/MWh$)

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35 http://www.cea.nic.in/planning/c%20and%20e/government%20of%20india%20website.htm
36 http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v2.pdf
37 They typically include hydro, geothermal, wind, low-cost biomass, nuclear and solar generation.
38 Prospective power capacity addition in the Indian scenario has been considered as per Planning Commission Working Group Report for the power sector. Any other grid-connected future power generation projects denote power generation projects not envisaged under the Planning Commission Report for Power Sector.

m = Power units included in the build margin

y = year on which power capacity addition is taking place and for which power generation data is available

- Future projection values of power generation capacity and capacity addition in India have been considered from Planning Commission Working Group Report for the Power Sector.
- Share of supercritical coal based power capacity addition and corresponding efficiency[39] improvement in power generation has also been considered from 2011-12 onwards. The capacity addition share has been taken as per Planning Commission Working Group Report for the Power Sector.
- Future power capacity addition values for grid-interactive renewable resource have been considered from MNRE XI$^{th}$ Plan Report.
- Computation of Emission Factor (EF) for 2011-12 and 2016-17 is based on future power capacity addition projection.
- For the period between 2016-17 and 2041-42, previous EF values have been discounted with Compound Annual Growth Rate (CAGR) for renewable energy capacity addition during the same period. This is primarily due to the fact that with addition of more and more grid-connected renewable power capacity, the GHG emission intensity of the grid is would come down.

**Emission factors for computation of GHG emissions from use of fossil fuel –** GHG emissions due to fossil fuel consumption have been estimated using emission factors from IPCC 2006 guidelines[40].

[39] Source:- UMPP Risk Analysis Report, April 2007 which can be accessed at http://cdm.unfccc.int/UserManagement/FileStorage/53Z0WQYPA81NEC6XJOGSKHDT429UFV

[40] http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

## Annexure 2.1: Assessment of the GHG emission trends under No-DFC scenario

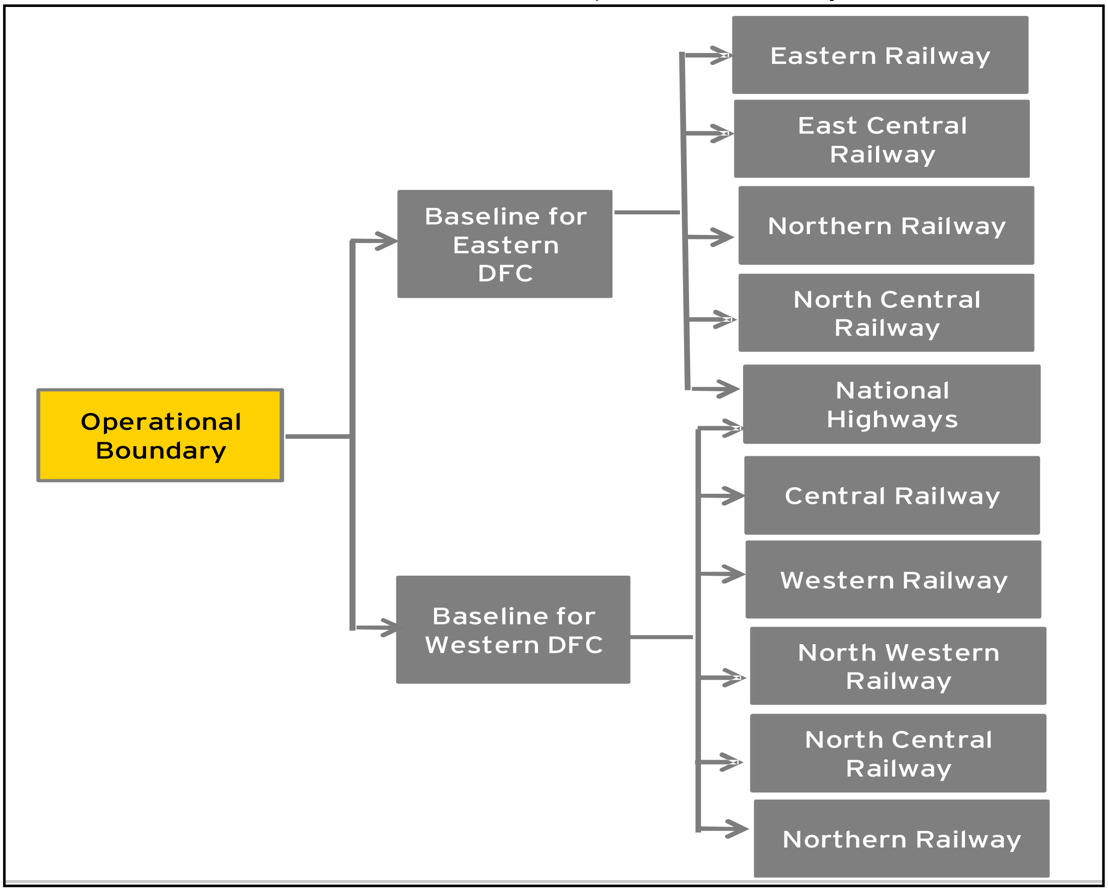
### a) Operational Boundary

The GHG emission estimation has been done considering the freight movement (which is expected in Eastern and Western DFC) through:

- Indian Railways
- National Highways, in case the freight volume cannot be adequately catered to by Indian Railways.

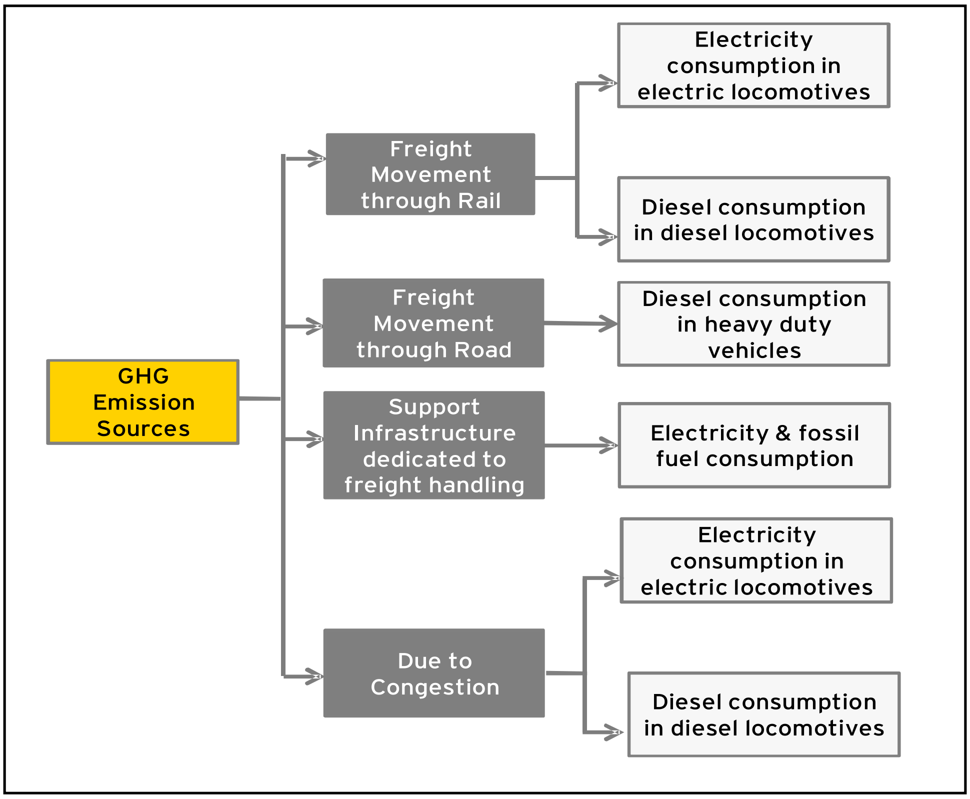
The Operational boundary has been described below:

**Exhibit 41: No-DFC scenario operational boundary**



b) Major GHG emission sources

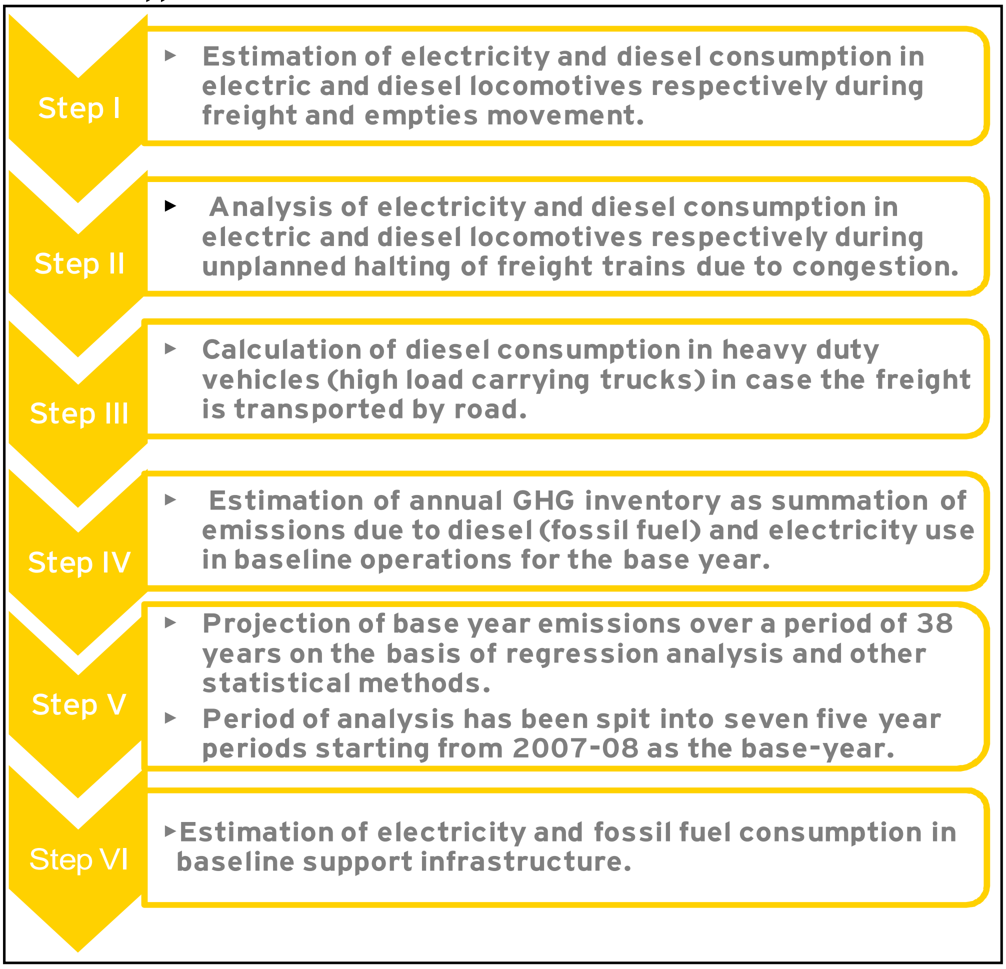
**Exhibit 42: No-DFC scenario GHG emission sources**



## c) Calculation Methodology and Approach

The methodology and approach as illustrated in the Inception Report have been broadly followed in the calculation.

**Exhibit 43: Approach used for assessment of No-DFC scenario GHG emission trends**




## d) Calculation Overview-

### *i. Rail – road share of freight*

The No-DFC scenario study deals with the freight movement along the present routes of Indian Railways in absence of the Eastern and Western DFC.

- A key consideration for this estimation was to assess whether the present route of Indian Railways could have borne the freight volume which the DFCs are expected to carry in the 30 years' period and then calculate the number of trips of freight train per day per section of the route.

- The tentative threshold year for each section when its rail freight carrying capacity reaches the saturation point is considered[41] and the corresponding number of trips per day per section which is the maximum possible for the section is estimated.
  - If 'y' is the threshold year for section 'n', then the freight volume it can bear in year 'y' will be equal to that of DFC of that section.
  - For the following years, the number of trips per day for that section has been projected considering the expected freight carrying capacity of that section (3% rail freight capacity increase in the first ten years period w.r.t. Base Year freight capacity, 2% increase in the next ten years period and 1% increase in the last ten years period).
  - In case the total No-DFC scenario freight volume is greater than the freight volume carried by No-DFC scenario rail the future years shall see a modal shift of freight from rail to road once any specific rail section reaches saturation.
  - The amount of freight transported by road will be equal to the difference in total freight volume to be transported (as per freight demand projections) *i.e.* total No-DFC scenario freight volume at a particular year and the maximum freight carrying capacity of that rail section during the same time period.
  - It is worthwhile to mention that RO-RO[42] traffic is hardly found in Indian Railway before implementation of DFC[43]. However the same has been considered for accounting GHG emissions from freight movement through road.

#### *ii. GHG emissions due to freight movement through rail*

Algorithm:

- Total freight and empties movement over the 30 years of assessment period (2016-17 to 2041-42) along the No-DFC scenario equivalent of a dedicated corridor in UP direction =

$$\left[\sum_{i=1}^{39}\{\sum_{c=1}^{x}\left(L_{t_{ci}}+W_{t_{ci}}\right)\times n)\times\sum_{s=1}^{m}(l_{si})\times\sum_{s=1,c=1}^{m,x}t_{sci}\}\ +\ \{\mathbf{n}\ \mathbf{x}\ \sum_{c=1}^{x}\left(W_{t_{ci}}\right)\times\sum_{s=1}^{m}(e_{si}\times l_{si})\}\right]$$

.......eqn. (3)

Where:

t = number of trips of a particular commodity (or container) in a day within a section (derived by multiplying the number of trips forecasted in DFC with the conversion multiplication factor[44])[45]

e = number of trips of empties in a day within a section

l = track length of the section (km)

$L_t$ = train load[46] (tonnes)

$W_t$ = weight of the train[47] (tonnes)

---

41 As per projections in the JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"– October 2007

42 Roll on Roll off (RO RO) Traffic. RO RO operation involves one vehicle riding piggyback on another, driving in or out on its own power.

43 IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009.

44 Multiplication factors for Train Conversion of Trains (Axle load 25 T to 22.9 T)

45 IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 gives the forecast upto 2036-37. The number of trips per day per section for the remaining five year period *i.e.* upto 2041-42 has been estimated by regression analysis based on the CAGR of the number of trips per day per section of the period 2011-12 to 2036-37.

46 Train load is the total weight of freight each train can carry which can be calculated by multiplying payload of the wagon with number of wagons.

n = number of days of operation per annum
c = commodity type
x = number of types of commodities
s = section along the route
m = number of sections along a route
i = concerned year

- Similarly, the total freight and empties movement in a year along the No-DFC scenario equivalent of a dedicated corridor in DOWN direction has been computed and the same has been projected over the assessment period of 30 years.
- If U tonne-kms and D tonne-kms are the total freight and empties movement in a year along a route in UP and DOWN directions:-

  GHG emissions from freight movement using electric locomotives in a year along a route = $(\boldsymbol{U}+\boldsymbol{D}) \times \% \, \boldsymbol{of\ electric\ locomotives} \times \boldsymbol{E_{sp}} \times \boldsymbol{EF_{ielec}}/\boldsymbol{10^3}$ ........eqn. (4)

  Where

  $E_{sp}$ = Specific electricity consumption[48] (kWh/tonne-km)

  $EF_{ielec}$ = National grid electricity emission factor ($tCO_2$/ MWh)

  GHG emissions from freight movement using diesel locomotives in a year along a route = $(\boldsymbol{U}+\boldsymbol{D}) \times \% \, \boldsymbol{of\ diesel\ locomotives} \times \boldsymbol{E_d} \times \boldsymbol{D} \times \boldsymbol{NCV_d} \times \boldsymbol{EF_d}$.......eqn. (5)

  $E_d$ = Specific diesel consumption[49] (litre/ton-km)

  D = Density of diesel (ton/litre)

  $NCV_d$ = Net Calorific Value of diesel (TJ/ton)

  $EF_d$ = Emission factor of diesel ($tCO_2$/ TJ)
- Percentage share of diesel locomotives and electric locomotives for the 30 years periods starting from 2007-08 have been estimated using linear regression analysis based on last five years' ratio[50].

### *iii. GHG emissions due to freight movement through road*

The total GHG emissions in a year due to freight transport by road = $\frac{\boldsymbol{D} \times \boldsymbol{NCV_d} \times \boldsymbol{EF_d} \times \boldsymbol{W}}{\boldsymbol{w_t} \times \boldsymbol{M_t}}$ .......
Eqn. (6)

Where

$W_t$ = Load carrying capacity of a heavy duty truck (tonnes)

---

[47] Weight of train is the total weight of the wagons including that of locomotive.

[48] The values have been considered from a simulation study done by a nodal agency of Indian Railways. Our railway experts having past experiences in such exercises collected the values from the nodal agency. We had requested DFCC to get these values from the aforementioned nodal agency of Indian Railways through an official communication. In this regard, DFCC had formally requested the nodal agency but till now no such formal communication has been received.

[49] The values have been considered from a simulation study done by a nodal agency of Indian Railways. Our railway experts having past experiences in such exercises collected the values from the nodal agency. We had requested DFCC to get these values from the aforementioned nodal agency of Indian Railways through an official communication. In this regard, DFCC had formally requested the nodal agency but till now no such formal communication has been received.

[50] Number of diesel and electric locomotives used in the last five years, *i.e.*, 2000 – 2005 has been sourced from the JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"– October 2007

W = tonne-kms of freight movement in a year through road
$M_t$ = Mileage of a heavy duty truck (kms/ litre)
D = Density of diesel (ton/litre)
$NCV_d$ = Net Calorific Value of diesel (TJ/ton)
$EF_d$ = Emission factor of diesel ($tCO_2$/ TJ)

### iv. ***GHG emissions due to congestion in rail routes***

The rail routes Delhi-Kolkata-Delhi and Delhi-Mumbai-Delhi are one of the busiest routes in Indian Railways network. These routes cater to huge volumes of passenger as well as freight traffic. Presently both passenger and freight trains are moving along a common rail track. Freight trains are often subject to unplanned halting during their journey due to precedence as passenger and mail trains are regarded as high priority traffic. Increasing passenger and freight traffic are now creating congestion of very high proportion which is making the unplanned halting more frequent. GHG emissions due to this congestion of freight traffic have been accounted for in the following way:

Approach:

We have considered only the energy consumption of rolling stocks at stationary condition. Acceleration and deceleration stages at the time of unplanned detention have not been taken into consideration because

- Energy consumption during acceleration or deceleration state at the time of unplanned detention is negligible compared to the total energy consumption.
- The equation for estimating energy consumption of rolling stocks during acceleration or deceleration state is theoretical. Actual energy consumption values may differ considerably. Actual values of relevant parameters required for estimating the energy consumption are not available in public domain.

Algorithm:

- GHG emissions due to congestion from electric locomotives per day = $\frac{T_e \times SE_E \times EF_{ielec}}{10^3}$..... eqn. (7)

Where
$T_e$ = Total unplanned stoppage time of electric locomotives per day (hrs)
$SE_E$ = Specific electricity consumption in stationary condition of electric locomotive (kW/hr)
$EF_{ielec}$ = National grid electricity emission factor ($tCO_2$/ MWh)

- GHG emissions due to congestion from diesel locomotives per day = $T_d X\ SE_d\ X\ D\ X\ NCV_d\ X\ EF_d$ .....eqn. (8)

Where
$T_d$ = Total unplanned stoppage time of diesel locomotives per day (hrs)
$SE_d$ = Specific diesel consumption in stationary condition of diesel locomotive (litre/hr)
Now,

- $T = T_{ei}\ or\ T_{di} = (\sum_{i=1}^{13} T_i \times t_i)$ ..... eqn. (9)

Where
T = Total unplanned stoppage time of electric or diesel locomotives per day (hrs)
$T_i$ = Unplanned stoppage time per trip per day in each route section (hrs)
$t_i$ = Total number of trips per day in each route section

i = Number of sections along a route which is 13 on each route (along Eastern DFC as well as Western DFC)

- $T_{ei} = l \times (\frac{1}{v_e} - \frac{1}{v_b})$ ......eqn. (10)

Where

$T_{ei}$ = Unplanned stoppage time of an electric locomotive per trip per day in each route section (hrs)

$V_e$ = Average speed of an electric locomotive along the route (km/hr)

$V_b$ = Booked speed of a freight train[51] (km/hr)

- $T_{di} = l \times (\frac{1}{v_d} - \frac{1}{v_b})$ ........ eqn. (11)

$T_{di}$ = Unplanned stoppage time of a diesel locomotive per trip per day in each route section (hrs)

$V_d$ = Average speed of a diesel locomotive along the route (km/hr)

$t_{ie}$ = Total number of trips per day in each route section x % of Electric locomotives

Where

$t_{ie}$ = Total number of trips of an electric locomotive per day in each route section

$t_{id}$ = Total number of trips per day in each route section x % of Diesel locomotives

### v. *GHG emissions from the No-DFC scenario Support Infrastructure*

Presently most of the facilities, *viz.*, stations, signaling systems, etc are catering to both passenger travel and freight movement. So a ratio of 70:30 has been considered for estimating energy consumption due to passenger travel and freight movement respectively[52].

The period of calculation for GHG emissions from No-DFC scenario support infrastructure has been split into six five-year periods. The study deals with trend analysis of GHG emission profile for a period of 30 years and variation of energy consumption is not significant on an annual basis.

Algorithm:

1. For calculating electricity consumption at the facilities:

- From lighting:

  Lumen requirement = Desired lux level x Area of coverage

  Power requirement = Lumen requirement x Luminous efficacy of the light source (e.g. CFL)

  Annual electricity consumption = $\textbf{Power requirement} \times \textbf{Annual operation days} \times \textbf{Daily operational hours} = \textbf{EL}$ ........ eqn. (12)

- From fan and/or exhauster operation:

  Annual electricity consumption = $\textbf{Number of fans} \times \textbf{Rated power of fan} \times \textbf{Annual operation days} \times \textbf{Daily operational hours} = \textbf{E}_F$ ........ eqn. (13)

  Electricity requirement for auxiliaries (e.g. electronic gadgets, water pumps, if any) has been considered 5% - 10% of the bulk requirement.

[51] Booked speed of a freight train is generally 90% of maximum permissible speed.

[52] Since facility utilization for passenger travel is much more than that for freight movement. This is also as per discussion with DFCC.

2. For calculating fossil fuel consumption at the facilities:

Indian Railways publishes the fuel consumption for each railway zone in terms of tonne of coal equivalents in their Annual Statistical Statement[53]. The same has been taken into account for each railway zone considered in the operational boundary.

The fossil fuel consumption expressed as tone of coal equivalents has been apportioned on the basis of freight traffic expressed in terms of tone-km to arrive at No-DFC scenario fossil fuel consumption.

Therefore, total annual GHG emissions due to fossil fuel consumption = $\boldsymbol{Tonne\ of\ coal\ equivalent\ consumed} \times \boldsymbol{NCV\ of\ coal} \times \boldsymbol{emission\ factor\ of\ coal}$ ..... eqn. (14)

3. For calculating electricity consumption at the facilities:

► Signaling system:

Signaling system consists of Absolute Signaling and Automatic Signaling. LED signaling arrangement has been considered.

Annual electricity consumption = $\boldsymbol{Wattage\ of\ LED\ signal} \times \boldsymbol{Number\ of\ signals} \times \boldsymbol{Annual\ operation\ days} \times \boldsymbol{Daily\ operational\ hours} = \boldsymbol{E_P}$........ eqn. (15)

► Stations:

Annual electricity consumption = $\boldsymbol{Number\ of\ stations} \times (\boldsymbol{E_L} + \boldsymbol{E_F}) = \boldsymbol{E_S}$ ........ eqn. (16)

► Staff quarters:

Annual electricity consumption =
$(\boldsymbol{Number\ of\ 40\ W\ CFLs\ per\ staff\ quarter} \times \boldsymbol{Wattage\ of\ CFLs} \times \boldsymbol{Daily\ operation\ hours} \times \boldsymbol{Annual\ operation\ days} + \boldsymbol{E_F}) \times \boldsymbol{Number\ of\ staff\ quarters} = \boldsymbol{E_W}$ ........ eqn. (17)

► Administrative Office:

Annual electricity consumption =
$((\boldsymbol{Number\ of\ 40W\ CFLs\ per\ office\ room} \times \boldsymbol{Number\ of\ office\ rooms} \times \boldsymbol{Wattage\ of\ CFL} \times$ ***Daily operational hours×Annual operation days+EF+(Electricity consumption due to*** $\boldsymbol{HVAC\ per\ sq\ ft} \times \boldsymbol{Total\ coverage\ area\ under\ air\ conditioning\ for\ each\ office})) \times \boldsymbol{Number\ of\ administrative\ offices\ along\ each\ corridor} = \boldsymbol{E_f}$ ........ eqn. (18)

Therefore, GHG emissions corresponding to electricity consumption in No-DFC scenario support infrastructure in a year = $(\boldsymbol{E_P} + \boldsymbol{E_s} + \boldsymbol{E_Y} + \boldsymbol{E_Z} + \boldsymbol{E_W} + \boldsymbol{E_f}) \times \boldsymbol{EF_{ielec}}/\boldsymbol{10^3}$ ........eqn. (19)

Where

$EF_{ielec}$ = National grid electricity emission factor ($tCO_2$/ MWh)

4. Total electricity and fossil fuel consumptions estimated for the Period 2007-08 to 2010-11, has been projected for the rest of the assessment period by considering a 5%[54] increase of the same in every ten years starting 2011-12 which will be effected by the expected capacity augmentation of Indian Railways, support infrastructure is a part of it.

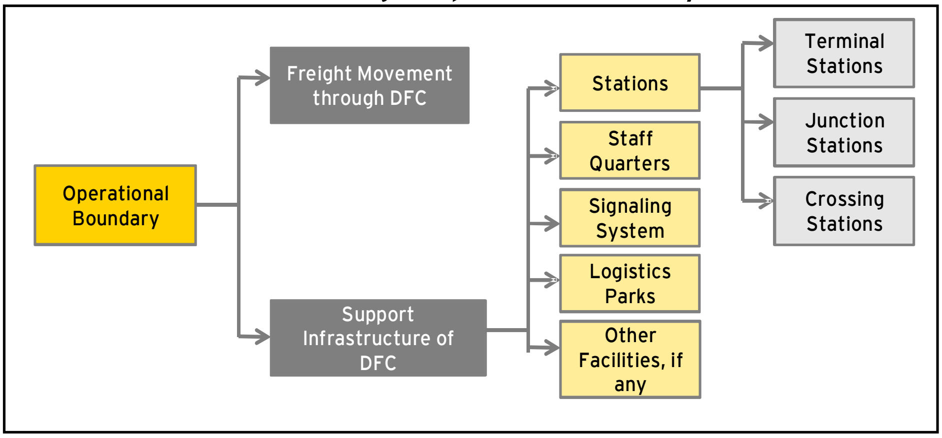
[53] http://www.indianrailways.gov.in/indianrailways/directorate/stat_econ/downloads/Final_Railway_08-09.pdf
http://www.indianrailways.gov.in/indianrailways/directorate/stat_econ/statistical-stmt-0607/st-20.pdf
[54] Opinion of Railway experts

# Annexure 2.2: Assessment of GHG emission trends under DFC scenario

## a) Operational Boundary

The GHG emission has been computed for the upcoming individual corridors of Dedicated Freight Corridor Corporation – Eastern DFC and Western DFC.
The Operational Boundary has been described below.

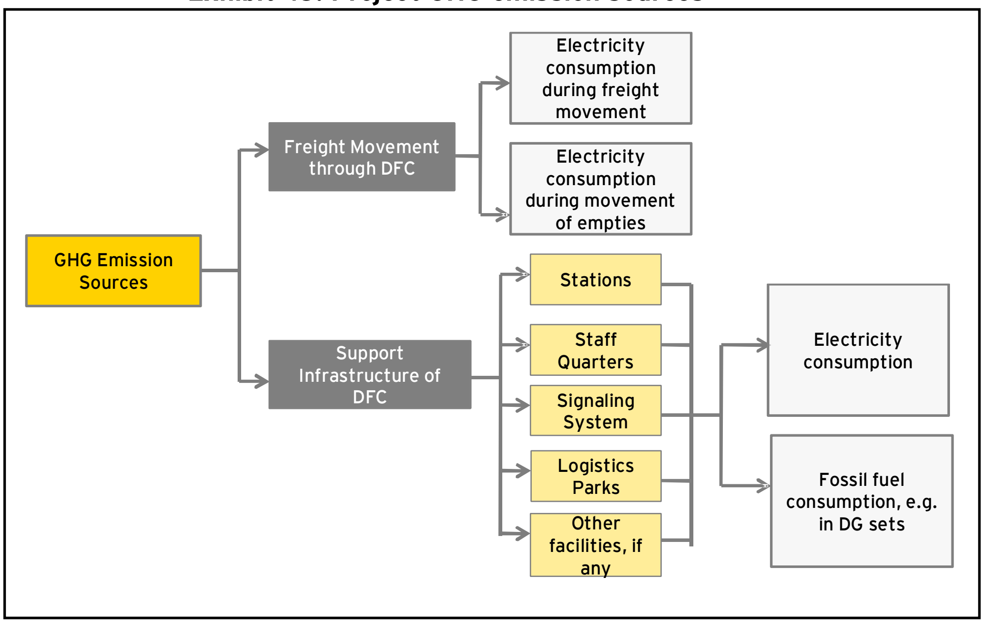
**Exhibit 44: Project operational boundary**




## b) Major GHG emission sources

The GHG emission sources included under the analysis are:

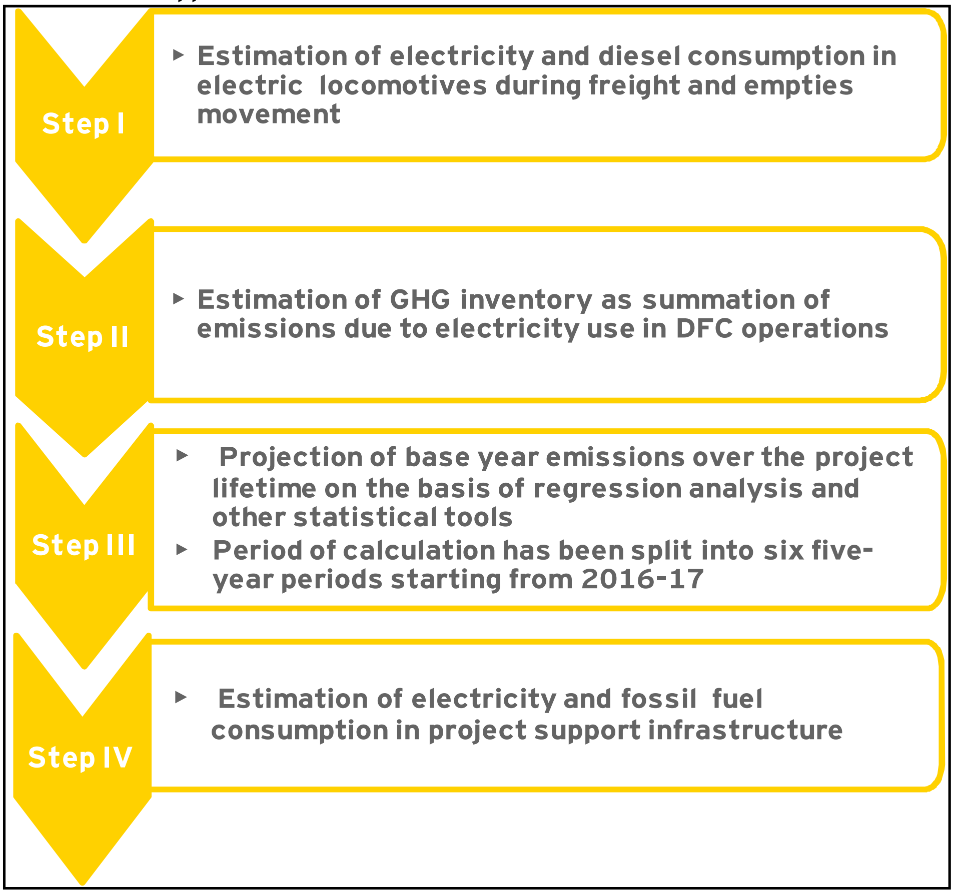
**Exhibit 45: Project GHG emission sources**



## c) Calculation Methodology and Approach

The methodology and approach as illustrated in the Inception Report have been largely followed in the calculation.

**Exhibit 46: Approach used for assessment of GHG emission trends for DFC**




## d) Calculation Overview

### i. *GHG emission due to freight movement*

2016-17 is expected to be the commissioning year for operation of DFC[55].

<u>Algorithm:</u>

- Total freight and empties movement over the assessment period of 30 years along a corridor in UP direction =

$$[\sum_{i=1}^{30}\{\sum_{c=1}^{x}(L_{t_{ci}} + W_{t_{ci}}) \times n) \times \sum_{s=1}^{m}(l_{si}) \times \sum_{s=1,c=1}^{m,x} t_{sci}\} + \{n \times \sum_{c=1}^{x}(W_{t_{ci}}) \times \sum_{s=1}^{m}(e_{si} \times l_{si})\}]$$ .......eqn. (20)

Where:

[55] IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009

t = number of trips of a particular commodity (or container) or empties in a day within a section[56]
l = track length of the section (km)
$L_t$ = train load[57] (tonnes)
$W_t$ = weight of the train[58] (tonnes)
n = number of days of operation per annum
c = commodity type
x = number of types of commodities
s = section along a corridor
m = number of sections along a route
i = concerned year

- Similarly, the total freight and empties movement in a year along a corridor in DOWN direction has been estimated and the same has been projected over the assessment period of 30 years.
- If U tonne-kms and D tonne-kms are the total freight and empties movement in a year along a corridor in UP and DOWN directions, therefore, GHG emissions from freight movement in a year along a corridor = $(\boldsymbol{U}+\boldsymbol{D})\times \boldsymbol{E_{sp}}\times \boldsymbol{EF_{ielec}}/\boldsymbol{10^3}$........eqn. (21)
  Where
  $E_{sp}$ = Specific electricity consumption[59] (kWh/tonne-km)
  $EF_{ielec}$ = National grid electricity emission factor ($tCO_2$/ MWh)

The brick van present at the tail end of a freight train in case of No-DFC scenario will be absent in the trains of the DFC scenario.

### ii. *GHG emission from Support Infrastructure*

The GHG emission from support infrastructure has been calculated on the basis of the under-mentioned algorithm:

The facilities considered for estimating energy consumption include stations (terminal/junction stations and crossing stations), signaling system (absolute and automatic), logistic parks, administrative office buildings and staff quarters.
Since the study focuses on estimation of GHG emission from the support infrastructure of DFC for 30 years, this period of calculation has been split into three ten-year periods starting from 2016-17, which is expected to be the commissioning year for DFC operation[60]. Ten year bands

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[56] IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 gives the forecast upto 2036-37. The number of trips per day per section for the remaining five year period *i.e.* upto 2041-42 has been estimated based on the CAGR of the number of trips per day per section of the period 2011-12 to 2036-37.
[57] Train load is the total weight of freight each train can carry which can be calculated by multiplying payload of the wagon with number of wagons.
[58] Weight of train is the total weight of the wagons including that of locomotive.
[59] The values have been considered from a simulation study done by a nodal agency of Indian Railways. Our railway experts having past experiences in such exercises collected the values from the nodal agency. We had requested DFCC to get these values from the aforementioned nodal agency of Indian Railways through an official communication. In this regard, DFCC had formally requested the nodal agency but till now no such formal communication has been received.
[60] As per Communication from DFCCIL

have been considered as the study deals with trend analysis of GHG emission profile for a period of 30 years and variation of energy consumption is not significant on an annual basis.

**For calculating electricity consumption at the facilities:**

- From lighting:

Lumen requirement = Desired lux level x Area of coverage

Power requirement = Lumen requirement x Luminous efficacy of the light source (*e.g* CFL)

Annual electricity consumption = Power requirement x Annual operational days x Daily operational hours = $E_L$ …….. eqn. (22)

- From fan and/or exhauster operation:

Annual electricity consumption = Number of fans x Rated power of fan x Annual operational days x Daily operational hours = $E_F$ …….. eqn. (23)

Electricity requirement for auxiliaries has been considered 5% - 10% of the bulk requirement (in most of the cases lighting and fans)

**For calculating diesel consumption at the facilities:**

Diesel consumption is primarily due to use of DG sets as back-up for power.

Annual diesel consumption = Power generation x Annual operational days x Daily operational hours x Specific power generation of the DG set = $E_D$ …….. eqn. (24)

**Facility wise analysis:**

- Signaling system:

Signaling system consists of Absolute Signaling and Automatic Signaling. LED signaling arrangement has been considered in the DFC operation.

Annual electricity consumption = (Wattage of LED signal x Number of signals along each corridor x Annual operational days x Daily operational hours) kWh = $E_P$ …….. eqn. (25)

- Stations (Crossing and Junction/Terminal):

Annual electricity consumption = (Number of stations along each corridor x ($E_L$ + $E_F$)) kWh = $E_s$ …….. eqn. (26)

Annual diesel consumption = (Number of junction/terminal stations along each corridor x $E_D$)

- Logistic Parks:

Annual electricity consumption = (Number of Logistic Parks along each corridor x ($E_L$ + $E_F$ + Electricity consumption in Crane operation)) = $E_y$ …….. eqn. (27)

Annual diesel consumption = (Number of Logistic Parks along each corridor x $E_D$)

- Staff quarters:

Annual electricity consumption = (((Number of 40 watt CFL lights per staff quarter x Wattage of CFL x Daily operational hours x Annual operational days) + $E_F$) x Number of Staff Quarters) = $E_W$ …….. eqn. (28)

- Administrative Office:

Annual electricity consumption = (((Number of 40 watt CFL lights per office room x Number of Office rooms x Wattage of CFL x Daily operational hours x Annual operational days) + $E_F$ +

(Electricity consumption due to HVAC per sq.ft x Total coverage area under air conditioning) x Number of Administrative Offices along each corridor) kWh = $E_f$ …….. eqn. (29)

Annual diesel consumption = (Number of Administrative Offices along each corridor x $E_D$)

Annual GHG emissions corresponding to electricity consumption in DFC support infrastructure

$= \boldsymbol{EF_{ielec}/10^3} \times (\sum_{i=1}^{s} \boldsymbol{E_{s,i}} + \sum_{i=1}^{w} \boldsymbol{E_{w,i}} + \sum_{i=1}^{p} \boldsymbol{E_{p,i}} + \sum_{i=1}^{y} \boldsymbol{E_{y,i}} + \sum_{i=1}^{f} \boldsymbol{E_{f,i}})$ …….. eqn. (30)

Total electricity and fossil fuel consumptions estimated in the Base Period (2016-17 to 2020-21) has been projected for the rest of the assessment period by considering a 5% increase of the same in every ten years which will be effected by the expected capacity augmentation of both the corridors, support infrastructure is a part of it.

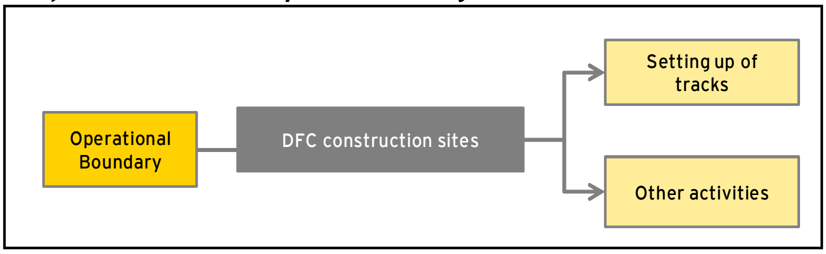
## Annexure 2.3: Assessment of GHG emission potential during construction of DFC

### a) Operational Boundary

The GHG emission from construction activities has been computed for the upcoming individual corridors of Dedicated Freight Corridor Corporation – Eastern DFC and Western DFC.
The Operational Boundary considered includes:

- Setting up of tracks along Eastern DFC and Western DFC[61]
- Other activities

**Exhibit 47: Operational boundary for assessing GHG emissions from construction**

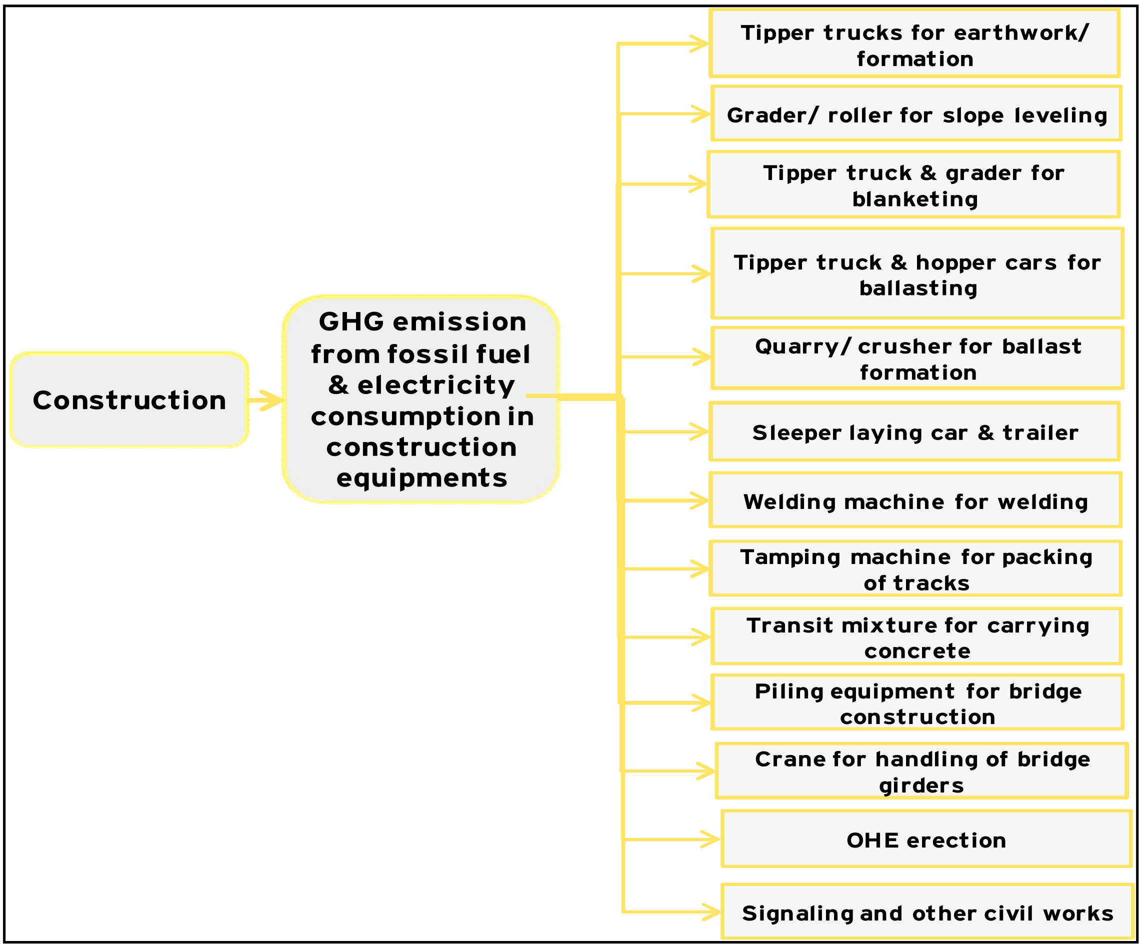



### b) Major GHG emission sources

The GHG emission sources included under the analysis are:

[61] Concrete preparation, *i.e.*, Batching process required for setting up of stations and staff quarters has not been included in the Operational Boundary because the batching plant for concrete preparation will not be under the purview of DFCC. Since vegetation cover along the route for Eastern and Western DFC is negligible, emissions from deforestation have not been considered in the emissions computation.

**Exhibit 48: Construction GHG emission sources**




## c) Calculation Methodology and Approach

The methodology and approach as illustrated in the Inception Report have been largely followed in the calculation. GHG emission calculation has been done for each major construction operation for:

i) Laying of tracks and OHE erection
ii) Construction of bridges
iii) Electrical works (including signaling)
iv) Civil works (construction of station buildings, approaches and staff quarters etc)

<u>Algorithm:</u>

**i) Laying of tracks and OHE erection**

GHG emission calculation has been done for each major construction operation for laying of 1 km of track and corresponding OHE erection. The GHG emissions on account of construction of 1 km of track and OHE erection are then multiplied with the total track length, considering both double line route and single line route along Eastern as well as Western DFC.

Earthwork/ formation and slope leveling

- Soil/ mud requirement for formation in case of single line = (Width of track x Depth of the formation)
- Number of trips of heavy duty tipper trucks = t = 2 x (Width of track x Depth of the formation)/ (Capacity of a extra heavy duty tipper truck)
- Diesel consumption due to movement of heavy duty tipper trucks in case of single line = t x d/ $M_t$ ....... Eqn. (31)

  Where

  d = average lead to be covered by the tipper trucks for carrying soil (kms)

  $M_t$ = Mileage of tipper trucks (kmpl)
- It is assumed that after laying 1 m thick layer of mud/soil, roller is passed for slope leveling.
- Diesel Consumption due to passing of roller over embankment per km of track = (2 X No. of passes of roller per km X Specific diesel consumption per hr)/ (Speed of roller) ....... Eqn. (32)
- Diesel Consumption due to slope leveling of embankment by grader per km of track = Specific Diesel consumption by grader per km ....... Eqn. (33)

Blanketing

- Soil/ mud requirement for blanketing in case of single line = (Width of track x Depth of the blanket) $m^3$
- Number of trips of heavy duty tipper trucks = t = 2 x (Width of track x Depth of the blanket)/ (Capacity of a extra heavy duty tipper truck)
- Diesel consumption due to movement of heavy duty tipper trucks in case of single line = t x d/ $M_t$ ....... Eqn. (34)

  Where

  d = average lead to be covered by the tipper trucks for carrying soil (kms)

  $M_t$ = Mileage of tipper trucks (kmpl)
- Diesel Consumption due to passing of roller over blanket per km of track = (2 X No. of passes of roller per km X Specific diesel consumption per hr)/ (Speed of roller) ....... Eqn. (35)
- Diesel Consumption due to slope leveling of blanket by grader per km of track = Specific Diesel consumption by grader per km ....... Eqn. (36)

Ballasting

- Average distance between stone quarry to proposed track line = d km
- Number of trips of trucks = 2 x (ballast requirement per km / capacity of trucks) = t
- Diesel consumption for to and fro movement of trucks carrying ballast = d x t/ $M_t$ ……. Eqn. (37)
- Diesel consumption due to movement of hopper cars for laying ballast = 1 x t/ (2 x $M_t$) ……. Eqn. (38)

Crusher/quarry for ballast formation

- Diesel consumption for ballast formation = (specific diesel consumption in crusher per ton of ballasts) x (total ballast requirement per km of track) x (density of ballasts) ……. Eqn. (39)

Track laying

- Diesel consumption for laying of 1 km of track = n x Sp ……. Eqn. (40)

  Where

  n = Number of sleeper cars required per km of track

  Sp = Specific diesel consumption per car (litres/km)

Rail laying

- Number of trips of trailers carrying rail = 2 x (Number of rails required per km) / (capacity of trailer) = t
- Diesel consumption due to laying of rails = d x t / $M_{trailer}$ ……. Eqn. (41)

  Where

  d = Average lead of trailers (km)

  $M_{trailer}$ = Mileage of a trailer (kmpl)

Welding of rails

- Diesel consumption for welding of rail per km of track = (specific diesel consumption of a welding machine per hour) x (Daily operational hours) x (operational days for welding rail per km of track) ……. Eqn. (42)

Packing of track

- Diesel consumption for packing of track by tamping machine = (Specific diesel consumption per hour) x (tamping hours per km) ……. Eqn. (43)

Vibrator roller for transit concrete mixing

- Number of trips of vibrator roller = t = 2 x (concrete requirement for 1 km bridge construction) / (capacity of vibrator roller)
- Diesel consumption due to movement of vibrator roller = d x t / $M_r$ ....... Eqn. (44)

  Where

  d = Average lead of trailers (km)

  $M_r$ = Mileage of a vibrator roller (kmpl)

OHE erection

- Diesel consumption during OHE erection due to movement of diesel locomotives = specific diesel consumption per km (litres) ....... Eqn. (45)

**ii) Construction of bridges**

GHG emission calculation has been done for each major construction operation for building of 1 km of bridge. The GHG emissions on account of construction of 1 km of bridge are then multiplied with the total bridge length.

Batching operation

- Diesel consumption in batching operation = (concrete requirement for 1 km bridge construction)/ (production of concrete per hour) x (specific diesel consumption per hour) ....... Eqn. (46)

Piling equipment

- Diesel consumption in piling equipments = (Number of pile rigs) x (diesel consumption per rig for construction of 1 km bridge) ....... Eqn. (47)

Handling of bridge girders

- Diesel consumption in cranes for handling of bridge girders for construction of 1 km bridge = (number of operational days) x (diesel consumption per day) ....... Eqn. (48)

**iii) Electrical works (including signaling)**

Transportation of Cables required for Signaling Works

- Diesel consumption for transportation of cables = 2 x (Cable requirement for one station)x (no. of stations)/(cable carrying capacity of 1 tipper truck) x (average lead of truck)/ mileage of truck) (litres) ....... Eqn. (49)

Transportation of Signaling Posts and Signaling Gears like transformer, generator, point machine, relays, computers, switchboards, batteries, location box etc. required for Signaling Works

- Diesel consumption for transportation = 2 x (Truck requirement for one station) x (no. of stations) x (average lead of truck)/ mileage of truck) (litres) .......Eqn. (50)

Testing of Signal

- Power requirement = (Power requirement for testing of signal in one station) x (no. of stations) (kWh) .......Eqn. (51)

**iv) Civil works (construction of station buildings, approaches and staff quarters etc)**

Construction of Station Building/staff quarter

- Diesel consumption due to movement of transit mixture for construction of building= 2 x (Concrete requirement for one station building) / (capacity of a transit mixture) x (no. of stations) x (average lead of transit mixture)/ mileage of transit mixture) (litres) .......Eqn. (52)

Earthwork for Road & Station Building Approaches & Surroundings

- Diesel consumption in JCB machines= (Hourly diesel consumption in one JCB machine / (total number of operational hours) x (no. of stations) (litres) .......Eqn. (53)

Illumination at Site during Construction of Station Buildings, Staff Quarters etc

- Diesel consumption for illumination= (Electricity generation in DG set) / (specific diesel consumption) x (no. of staff quarters/station buildings) (litres) .......Eqn. (54)

Other activities (building erection, masonry, carpentry, plumbing, *etc*) involved in construction of the buildings are expected to be done manually and hence according to WBCSD Protocol no GHG emission has been attributed to those activities.

# Annexure 3: Details of the GHG abatement levers

Detail analysis of each of the identified GHG abatement levers are as follows:

**a) Demand side GHG abatement levers**

<table>
<tr><th colspan="2">Title of GHG abatement lever</th><th colspan="2">Utilization of stainless steel and aluminum as superstructure</th></tr>
<tr><td colspan="4">Technical description</td></tr>
<tr><td>Technical features</td><td colspan="3">▸ Utilization of aluminum alloy or stainless steel particularly the AISI 409 (M) grade or high strength wieldable quality structural steel to IS 8500 Fe 570/540 instead of black steel as superstructure material<br>▸ Aluminum - highly resilient to corrosion and stainless steel particularly the AISI 409 (M) grade - superior corrosion-abrasion characteristics could be used in thinner section without sacrificing strength<br>▸ High strength wieldable quality structural steel to IS 8500 Fe 570/540 - almost 60%-80% higher yield strength than mild steel, could be used in thinner and lighter sections</td></tr>
<tr><td>How the abatement is achieved</td><td colspan="3">▸ Reduction in tare weight[62] (by 4.8 ton and 2.5 ton compared to the black steel due to utilization of aluminum alloy and stainless steel particularly the AISI 409 (M) grade respectively as super structure),<br>▸ The same will lead to reduction in number of trip required for equivalent quantity of freight transportation and subsequent reduction in electricity consumption<br>▸ Reduction in specific electricity consumption[63] (kWh/tonne km) to the tune of 3% and 8% for stainless steel and aluminum respectively (this abatement potential is suggested with respect to 0.008kWh/tonne km specific electricity consumption by proposed DFC – black steel as wagon super structure material) and subsequent reduction in GHG emission.</td></tr>
<tr><td rowspan="4">Other direct and indirect benefits</td><td>key competitive issues</td><td colspan="2">Role of abatement levers in resolving the above mentioned issues:</td></tr>
<tr><td>▸ Productivity</td><td colspan="2">▸ Improvement in capacity utilization of wagons , improvement rake carrying capacity by 278 ton (Aluminum wagon) or 145[64] ton (stainless steel)</td></tr>
<tr><td>▸ Revenue</td><td colspan="2">▸ Subsequent improvement in revenue generation (approx INR 134.85/rake km –aluminum wagon, INR 258.84/rake km )</td></tr>
<tr><td>▸ Competitive advantage</td><td colspan="2">▸ Reduction in freight carrying charge<br>▸ Improvement in customer satisfaction<br>▸ Stronger positioning in competitive market</td></tr>
<tr><td colspan="4">Technology penetration and global practice</td></tr>
<tr><td colspan="4">▸ Aluminum alloy gaining popularity over steel in construction of Coal hoppers and Gondola wagons, USA, Russia and China are using Aluminum wagons<br>▸ South Africa and Australia are extensively using stainless steel in coal hopper and Gondola wagons<br>▸ BHP Billiton Railways of Australia is designing a gondola wagon for iron ore using an alloy steel called BISPLATE having an UTS of 830MPA to give a pay to tare ratio of 6.44<br>▸ In India few special-purpose wagons (like BOXN-HL etc.) uses this material. However, the penetration is relatively low.</td></tr>
</table>

[62] Source: EY internal research
[63] The same has been computed assuming 0.008kWh/tonne km specific electricity consumption in case of proposed DFC. Other important assumptions: Axle load – 25T; Tare weight per wagon in case of DFC -20T
[64] Assuming 58 wagons in a rake

<table>
<tr><td colspan="9">Impact of abatement project along with indicative project return</td></tr>
<tr><td colspan="3">Project's impact</td><td colspan="6">Project's financial evaluation</td></tr>
<tr><td>Project capital investment</td><td>Million INR</td><td>NA</td><td>Project IRR</td><td>%</td><td>NA</td><td>Net Present Value (NPV)</td><td>Million INR</td><td>646[65] or 1144[66]</td></tr>
<tr><td>Improvement in freight carrying capacity</td><td>Ton/ rake</td><td>145[67] or 278[68]</td><td colspan="6">Assumptions used in IRR computation</td></tr>
<tr><td>Improvement in freight Revenue</td><td>INR/ rake</td><td>134.85[70] or 258.84[71]</td><td colspan="6" rowspan="3"><ul><li>The same has been computed based on commodity - 'coal' considering differential benefits (benefit of stainless steel or Aluminum wagon instead of black steel wagon) due to implementation of GHG abatement lever</li><li>IRR has been computed for 10 years</li><li>Railway throughput has been kept constant</li><li>Increase in revenue generation is happening through reduction in number of trip (due to implementation of GHG abatement lever)</li><li>No change in operational and maintenance cost due to the implementation of the lever</li><li>Cost of coal transportation other than fuel – 0.10[69] INR/ton km</li><li>Rate of Taxation – 33.99%</li><li>Depreciation – 5.28% (SLM method)</li><li>For NPV computation discounting factor 12%</li></ul></td></tr>
<tr><td>Improvement in O&M Cost</td><td>INR/ ton</td><td>0</td></tr>
<tr><td>Improvement in fuel/electricity cost</td><td>INR/ ton km</td><td>0.0018[72] or 0.0045[73]</td></tr>
<tr><td colspan="9">Key issues</td></tr>
<tr><td colspan="9"><ul><li>In case of aluminum upstream energy consumption (production side) is quite high, however considering the recyclability of aluminum (secondary aluminum), the GHG emission could be substantially low (over the span of entire lifecycle)</li><li>Demand-supply gap in stainless steel production could be an issue</li></ul></td></tr>
</table>

<table>
<tr><td>Title of GHG abatement lever</td><td>Double stack container</td></tr>
<tr><td colspan="2">Technical description</td></tr>
<tr><td>Technical features</td><td><ul><li>Incorporation of double stack 5 cars articulated unit or double stack on flat cars (5 car units)</li><li>In case of double stack 5 car articulated unit, configuration of containers is as follows<br>- Length over coupler face: 80860mm in case of container 40, and 88480mm in case of container 45<br>- No of units: 7 (for both containers 40 and 45)<br>- TEU's per unit: 20 in case of container 40, and 22.5 in case of container 45</li></ul></td></tr>
</table>

[65] In case of stainless steel wagon
[66] In case of Aluminum wagon
[67] In case of stainless steel wagon
[68] In case of Aluminum wagon
[69] Source: 'Business Proposal for Dedicated Freight Corridor'
[70] In case of stainless steel wagon
[71] In case of Aluminum wagon
[72] In case of stainless steel wagon (compared to black steel wagon), considering commodity coal
[73] In case of Aluminum wagon (compared to black steel wagon), considering commodity coal

<table>
<tr><td></td><td colspan="8">
- TEU's per train: 140 in case of container 40, and 157.5 in case of container 45<br>
- In case of double stack on flat cars (5 car units), configuration of containers is as follows<br>
  - Length over coupler face: 68632mm in case of container 40, and 76571mm in case of container 45<br>
  - No of units: 9 in case of container 40, and 8 in case of container 45<br>
  - TEU's per unit: 20 in case of container 40, and 22.5 in case of container 45<br>
  - TEU's per train: 180 (for both containers 40 and 45)
</td></tr>
<tr><td>How the abatement is achieved</td><td colspan="8">
- High pay to tare ratio will lead to reduction in number of trip required for equivalent quantity of freight transportation<br>
- Subsequent reduction in specific electricity consumption74 (kWh/tonne km) to the tune of 28% (this abatement potential is suggested with respect to 0.008kWh/tonne km specific electricity consumption of the double stack well type stand-alone containers which has been proposed for DFC) and subsequent reduction in GHG emission.
</td></tr>
<tr><td rowspan="4">Other direct and indirect benefits</td><td colspan="2">key competitive issues</td><td colspan="6">Role of abatement levers in resolving the above mentioned issues:</td></tr>
<tr><td colspan="2">- Productivity</td><td colspan="6">- Improvement in productivity by 9% in case of double stack 5 cars articulated unit and 40% in case of double stack on flat cars (5 car units)</td></tr>
<tr><td colspan="2">- Revenue</td><td colspan="6">- Subsequent improvement in revenue generation</td></tr>
<tr><td colspan="2">- Competitive advantage</td><td colspan="6">- Reduction in freight carrying charge<br>- Improvement in customer satisfaction<br>- Stronger positioning in competitive market</td></tr>
<tr><td colspan="9">Technology penetration and global practice</td></tr>
<tr><td colspan="9">- Used by US Railroads (specifically double stack container flat type with 5 cars)</td></tr>
<tr><td colspan="9">Impact of abatement project along with indicative project return</td></tr>
<tr><td colspan="3">Project's impact</td><td colspan="6">Project's financial evaluation</td></tr>
<tr><td>Project capital investment</td><td>Million INR</td><td>NA[75]</td><td>Project IRR</td><td>%</td><td>NA</td><td>Net Present Value (NPV)</td><td>Million INR</td><td>13[76] or 44[77]</td></tr>
<tr><td>Improvement in freight carrying capacity</td><td>%</td><td>9[78] or 40[79]</td><td colspan="6">Assumptions used in IRR computation</td></tr>
<tr><td>Improvement in freight Revenue</td><td>%</td><td>9[81] or 40[82]</td><td colspan="6">- The same has been computed based on commodity - 'coal' considering differential benefits (benefit of stainless steel or Aluminum wagon instead of black steel wagon) due to implementation of GHG abatement lever<br>- IRR has been computed for 10 years</td></tr>
</table>

[74] The same has been computed assuming 0.008kWh/ton km specific electricity consumption in case of proposed DFC.
[75] No incremental cost w.r.t. proposed DFCCIL
[76] Double stack 5 car articulated unit
[77] Double stack container (flat car five car unit)
[78] Double stack 5 car articulated unit
[79] Double stack container (flat car five car unit)

| | | | |
|---|---|---|---|
| Improvement in O&M Cost | INR/ ton | NA | ‣ Railway throughput has been kept constant<br>‣ Increase in revenue generation is happening through reduction in number of trip (due to implementation of GHG abatement lever)<br>‣ No change in operational and maintenance cost due to the implementation of the lever<br>‣ Cost of coal transportation other than fuel – 0.10[80] INR/ton km<br>‣ Rate of Taxation – 33.99%<br>‣ Depreciation – 5.28% (SLM method)<br>‣ For NPV computation discounting factor 12% |
| Improvement in fuel/electricity cost | INR /ton km | 0.0018[83] or 0.0081[84] | |
| Key issues | | | |
| ‣ Articulated units may require axle load up to 35.7t<br>‣ The same needs larger vertical clearances and lower operating speed due to higher centre of gravity | | | |

| | | |
|---|---|---|
| **Title of GHG abatement lever** | On board Rail and wheel lubrication | |
| Technical description | | |
| Technical features | ‣ Implementation of on-board rail and wheel lubrication<br>‣ Rail lubrication is realized by special lubricating vehicles | |
| How the abatement is achieved | ‣ Reducing in lateral friction between rail and wheel<br>‣ Subsequent reduction in electricity consumption<br>‣ Reduction in specific electricity consumption85 (kWh/tonne km) to the tune of 2% (this abatement potential is suggested with respect to 0.008kWh/tonne km specific electricity consumption in case of proposed DFC) | |
| Other direct and indirect benefits | key competitive issues | Role of abatement levers in resolving the above mentioned issues: |
| | ‣ Productivity | ‣ No improvement in productivity |
| | ‣ Revenue | ‣ The proposed GHG abatement level will lead to saving in electricity consumption and subsequent saving in electricity cost (INR 0.0004/ton-km). However no direct revenue generation is expected due to the implementation of this measure.<br>‣ Furthermore since the lever will reduce the operational and maintenance cost substantially |
| | ‣ Competitive advantage | ‣ Better customer service due to reduced maintenance requirement<br>‣ Improved customer satisfaction |
| Technology penetration and global practice | | |
| ‣ Japan, Australian and Sweden Railway | | |
| Impact of abatement project along with indicative project return | | |

[81] Double stack 5 car articulated unit
[82] Double stack container (flat car five car unit)
[80] Source: 'Business Proposal for Dedicated Freight Corridor'
[83] Double stack 5 car articulated unit
[84] Double stack 5 car articulated unit
[85] Source – Union of international Railway – UIC, EY internal research and external railway expert

<table>
<tr><th colspan="3">Project's impact</th><th colspan="6">Project's financial evaluation</th></tr>
<tr><td>Project capital investment</td><td>Million INR</td><td>0.05[86]</td><td>Project IRR</td><td>%</td><td>65</td><td>Net Present Value (NPV)</td><td>Million INR</td><td>120</td></tr>
<tr><td>Improvement in freight carrying capacity</td><td>Ton/ rake</td><td>NA</td><td colspan="6">Assumptions used in IRR computation</td></tr>
<tr><td>Improvement in freight Revenue</td><td>INR/ rake</td><td>NA</td><td colspan="6" rowspan="3"><ul><li>The same has been computed based on all commodity (up and down direction)</li><li>IRR/NPV has been computed for 10 years</li><li>Although there will be reduction in operational and maintenance cost due to the lever, the change in operational and maintenance cost has been considered zero while computing the IRR/NPV</li><li>Rate of Taxation - 33.99%</li><li>Depreciation - 5.28% (SLM method)</li><li>Number of lubrication system required 1000 (assumed)</li><li>For NPV computation discounting factor 12%</li></ul></td></tr>
<tr><td>Improvement in O&M Cost</td><td>%</td><td>10-20</td></tr>
<tr><td>Improvement in fuel/electricity cost</td><td>INR/ ton km</td><td>0.0004</td></tr>
<tr><td colspan="9">Key issues</td></tr>
<tr><td colspan="9"><ul><li>This is especially effective in curves but can also be applied on tangent tracks.</li><li>Energy consumption reduction may vary depending on specific circumstances such as curvature and the grade of the track. Even energy saving could be as high as 13% (the same was achieved in AAR/TTCI evaluation using a 5.3 km closed loop test track).</li><li>Reliability of the device is not so high. Locomotive-mounted lubricators may cause excess lubricant to migrate which increases the potential for fires and produces a difficult environment for maintenance operations.</li></ul></td></tr>
</table>

<table>
<tr><th>Title of GHG abatement lever</th><th>Aerodynamic profiling</th></tr>
<tr><td colspan="2">Technical description</td></tr>
<tr><td>Technical features</td><td><ul><li>Streamlining the outer shell</li><li>Aerodynamic front end design of the motive power</li><li>Switch over from body side/end stanchions from outside to the inside of the wagon body</li><li>Surface coatings for train sides and roofs that minimize surface friction</li><li>Under skirting, i.e. covering the rugged structures of under floor surface by a smooth cover</li><li>Providing Covers on open wagons - This consist of fiber glass Rail Wagon Covers which not only contain and protect bulk commodity shipped in Open Wagons, but significantly reduce wind drag and provide energy savings</li></ul></td></tr>
<tr><td>How the abatement is achieved</td><td><ul><li>Reduction in air resistance[87] is due to surface friction along the train sides and roofs, and to the air drag of the under floor equipment</li><li>Subsequent reduction in electricity consumption</li><li>Reduction in specific electricity consumption[88] (kWh/tonne km) to the tune of 1% (this abatement potential is suggested with respect to 0.008kWh/tonne km specific electricity</li></ul></td></tr>
</table>

[86] Million INR/lubricating system

[87] According to Swedish KTH railway group - In long trains surface friction from sides and roofs accounts for 27.0% of air resistance and the under floor equipment for an additional 7.5 %

| | | |
|---|---|---|
| | consumption in case of proposed DFC) | |
| Other direct and indirect benefits | key competitive issues | Role of abatement levers in resolving the above mentioned issues: |
| | Productivity | No improvement in productivity |
| | Revenue | The proposed GHG abatement level will lead to saving in electricity consumption and subsequent saving in electricity cost (INR 0.0002/ton-km). However no direct revenue generation is expected due to the implementation of this measure. |
| | Competitive advantage | Not applicable |

**Technology penetration and global practice**

- High speed trains of Europe, Japan, North America and Australia are featured with Aerodynamic profiling

**Impact of abatement project along with indicative project return**

| Project's impact | | | Project's financial evaluation | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project capital investment | Million INR | 100 | Project IRR | % | 12 | Net Present Value (NPV) | Million INR | 1 |
| Improvement in freight carrying capacity | Ton/ rake | NA | Assumptions used in IRR computation | | | | | |
| Improvement in freight Revenue | INR/ rake | NA | • The same has been computed based on all commodity (up and down direction)<br>• IRR/NPV has been computed for 10 years<br>• Rate of Taxation - 33.99%<br>• Depreciation - 5.28% (SLM method)<br>• For NPV computation discounting factor 12% | | | | | |
| Improvement in O&M Cost | % | NA | | | | | | |
| Improvement in fuel/electricity cost | INR/ ton km | 0.0002 | | | | | | |

**Key issues**

- Energy saving through aerodynamic profiling becomes significant only in those cases where the speed of rolling stock is more than 100 km per hour
- Since speed in case of DFC will be less than 100 km per hour energy saving through aerodynamic profiling, if implemented, will not be significant enough
- However as the same is considered as a good engineering practice in the global Railway Industry.

[88] Source – Union of international Railway – UIC, EY internal research and external railway expert

<table>
<tr><th colspan="3">Title of GHG abatement lever</th><th colspan="6">Regenerative braking</th></tr>
<tr><td colspan="9">Technical description</td></tr>
<tr><td>Technical features</td><td colspan="8">▸ Electric stock may recuperate energy during braking by using traction motors as generators. 50 Hz, 25 kV supply systems offer medium conditions for feeding back recovered energy<br>▸ The energy recovered by dynamic braking could be used for On-board purposes (auxiliary consumption)<br>▸ Recovered energy could be fed back into the national grid</td></tr>
<tr><td>How the abatement is achieved</td><td colspan="8">▸ Since the recovered energy will offset the energy usage in fleet operation and subsequent reduction in specific electricity consumption<br>▸ Reduction in specific electricity consumption[89] (kWh/tonne km) by 5% (this abatement potential is suggested with respect to 0.008kWh/tonne km specific electricity consumption by proposed DFC)</td></tr>
<tr><td rowspan="4">Other direct and indirect benefits</td><td>key competitive issues</td><td colspan="7">Role of abatement levers in resolving the above mentioned issues:</td></tr>
<tr><td>▸ Productivity</td><td colspan="7">▸ No improvement in productivity</td></tr>
<tr><td>▸ Revenue</td><td colspan="7">▸ The proposed GHG abatement level will lead to saving in electricity consumption and subsequent saving in electricity cost (INR 0.001/ton-km). However no direct revenue generation is expected due to the implementation of this measure.</td></tr>
<tr><td>▸ Competitive advantage</td><td colspan="7">▸ Not applicable</td></tr>
<tr><td colspan="9">Technology penetration and global practice</td></tr>
<tr><td colspan="9">▸ High speed trains of Europe, Japan, North America and Australia are featured with Aerodynamic profiling</td></tr>
<tr><td colspan="9">Impact of abatement project along with indicative project return</td></tr>
<tr><td colspan="3">Project's impact</td><td colspan="6">Project's financial evaluation</td></tr>
<tr><td>Project capital investment</td><td>Million INR/ locomotive</td><td>30[90]</td><td>Project IRR</td><td>%</td><td>NA</td><td>Net Present Value (NPV)</td><td>Million INR</td><td>NA</td></tr>
<tr><td>Improvement in freight carrying capacity</td><td>Ton/ rake</td><td>NA</td><td colspan="6">Assumptions used in IRR computation<br>▸ The same has been computed based on all commodity (up and down direction)<br>▸ IRR/NPV has been computed for 10 years<br>▸ Rate of Taxation – 33.99%<br>▸ Depreciation – 5.28% (SLM method)</td></tr>
<tr><td>Improvement in freight Revenue</td><td>INR/ rake</td><td>NA</td><td colspan="6"></td></tr>
</table>

[89] Source – Union of international Railway – UIC, EY internal research and external railway expert, University of Illinois

[90] Capital investment – for retrofitting INR 30 million per loco, for new loco INR 48 million per loco (Two permanently coupled locomotive of 2400KW )

| | | | |
|---|---|---|---|
| Improvement in O&M Cost | % | NA | For NPV computation discounting factor 12%<br>Number regenerating system – 100 (assumed)<br><br>The IRR or NPV is negative due to extremely high capital costs. However if we compute the IRR/NPV for 25 years, the same will be positive. |
| Improvement in fuel/electricity cost | INR/ ton km | 0.001 | |
| Key issues | | | |
| • Major share of braking power comes from the mechanical breaking in freight cars due to high average weights of freight trains and considering that only the locomotive axles are powered.<br>• Freight trains are much longer and heavier and have large mass to be braked by unpowered axles. Hence the potential to increase the share of regenerative braking energy seem to be limited for freight trains | | | |

| Title of GHG abatement lever | Bath tub and Monocoque design for Gondola cars | |
|---|---|---|
| Technical description | | |
| Technical features | • Incorporation of bath tub and Monocoque design for Gondola cars<br>• Here the floor on either side of the centre sill is depressed below the sole bar to provide substantial additional pay load space with very small increase in tare<br>• Resulting in high pay to tare ratio (almost 40%[91]) and low centre of gravity | |
| How the abatement is achieved | • High pay to tare ratio will lead to reduction in number of trip required for equivalent quantity of freight transportation and subsequent reduction in electricity consumption<br>• Reduction in specific electricity consumption[92] (kWh/ton km) to the tune of 6% (this abatement potential is suggested with respect to 0.008kWh/ton km specific electricity consumption of Gondola cars without bath tub and Monocoque design which has been proposed for DFC) and subsequent reduction in GHG emission. | |
| Other direct and indirect benefits | key competitive issues | Role of abatement levers in resolving the above mentioned issues: |
| | • Productivity | • Improvement in capacity utilization of wagons , improvement rake carrying capacity by 281[93] ton |
| | • Revenue | • Subsequent improvement in revenue generation (approx INR 261.33/rake km) |
| | • Competitive advantage | • Reduction in freight carrying charge<br>• Improvement in customer satisfaction<br>• Stronger positioning in competitive market |
| Technology penetration and global practice | | |
| • South African Railway has adopted this technology | | |
| Impact of abatement project along with indicative project return | | |
| Project's impact | Project's financial evaluation | |

[91] Source – EY internal research and external rail way expert
[92] The same has been computed assuming 0.008kWh/tonne km specific electricity consumption in case of proposed DFC. Other important assumptions: Pay load to tare ratio in case of DFC – 4
[93] The same has been computed only for the commodity coal (both up and down direction)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project capital investment | Million INR | NA | Project IRR | % | NA | Net Present Value (NPV) | Million INR | 323 |
| Improvement in freight carrying capacity | Ton/ rake | 281 | Assumptions used in IRR computation<br>‣ The same has been computed based on commodity - 'coal' considering differential benefits (only UP direction)<br>‣ IRR has been computed for 10 years<br>‣ Railway throughput has been kept constant<br>‣ Increase in revenue generation is happening through reduction in number of trip (due to implementation of GHG abatement lever)<br>‣ No change in operational and maintenance cost due to the implementation of the lever<br>‣ Cost of coal transportation other than fuel – 0.10[94] INR/ton km<br>‣ Rate of Taxation – 33.99%<br>‣ Depreciation – 5.28% (SLM method)<br>‣ For NPV computation discounting factor 12% | | | | | |
| Improvement in freight Revenue | INR/ rake | 261.33 | | | | | | |
| Improvement in O&M Cost | INR/ ton | 0 | | | | | | |
| Improvement in fuel/electricity cost | INR/ ton | 0.0015 | | | | | | |
| Key issues | | | | | | | | |
| ‣ Bathtub and Monocoque design will applicable for those tacks where axle load is 32t to 37t. | | | | | | | | |

| | | |
|---|---|---|
| **Title of GHG abatement lever** | Stub centre sill design | |
| Technical description | | |
| Technical features | ‣ Incorporation of stub centre sill design tank wagons, hopper wagons where the tank and hopper bottom are to be kept free from obstruction from structural members for easy unloading of cargo<br>‣ The design dispenses with through centre sill and adopts stub centre sill which extends from headstock to the bolster. The longitudinal forces are transmitted to the superstructure through a torsion box. Reduction in weight is achieved due to absence of through centre sill which is a substantially heavy member and cross bearers | |
| How the abatement is achieved | ‣ Reduction in tare weight (0.9 ton per wagon) in tank wagons, hopper wagons and subsequent increase in pay to tare ratio<br>‣ High pay to tare ratio will lead to reduction in number of trip required for equivalent quantity of freight transportation and subsequent reduction in electricity consumption<br>‣ Reduction in specific electricity consumption[95] (kWh/ton km) to the tune of 1.16% (this abatement potential is suggested with respect to 0.008kWh/ton km specific electricity consumption in case of proposed DFC) | |
| Other direct and indirect benefits | key competitive issues | Role of abatement levers in resolving the above mentioned issues: |
| | ‣ Productivity | ‣ Improvement in capacity utilization of wagons , improvement rake carrying capacity by 52.2 ton |

[94] Source: 'Business Proposal for Dedicated Freight Corridor'

[95] The same has been computed assuming 0.008kWh/tonne km specific electricity consumption in case of proposed DFC. Other important assumptions: wagon and freight type – tank wagon for POL transportation, tare weight of tank wagon in case of DFC – 23.32ton, Pay load to tare ratio in case of DFC – 4

| | | |
|---|---|---|
| | Revenue | Subsequent improvement in revenue generation (approx INR 48.55/rake km) |
| | Competitive advantage | Reduction in freight carrying charge<br>Improvement in customer satisfaction<br>Stronger positioning in competitive market |
| **Technology penetration and global practice** | | |
| The same has been pioneered by North America for tank cars | | |
| **Impact of abatement project along with indicative project return** | | |

| Project's impact | | | Project's financial evaluation | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project capital investment | Million INR | NA | Project IRR | % | NA | Net Present Value (NPV) | Million INR | 1.16 |
| Improvement in freight carrying capacity | Ton/ rake | 52.2 | Assumptions used in IRR computation | | | | | |
| Improvement in freight Revenue | INR/ rake | 48.55 | The same has been computed based on commodity - POL, considering differential benefits (only UP and DOWN direction)<br>IRR has been computed for 10 years<br>Railway throughput has been kept constant<br>Increase in revenue generation is happening through reduction in number of trip (due to implementation of GHG abatement lever)<br>No change in operational and maintenance cost due to the implementation of the lever<br>Cost of coal transportation other than fuel - 0.10[96] INR/ton km<br>Rate of Taxation - 33.99%<br>Depreciation - 5.28% (SLM method)<br>For NPV computation discounting factor 12% | | | | | |
| Improvement in O&M Cost | INR/ ton | 0 | | | | | | |
| Improvement in fuel/electricity cost | INR/ ton-Km | 0.00025 | | | | | | |

**Key issues**

- Application is only restricted to tank cars
- Predominant in USA, technology penetration of the same to rest of the world is not so high

| Title of GHG abatement lever | CBTC (Communication based train control) |
|---|---|
| **Technical description** | |
| Technical features | Incorporation of CBTC instead of traditional way side based control system<br>CBTC is a system in which train monitoring and train control are integrated into a single system via data links between vehicles, central office computers and wayside computers<br>OPERATION wise the system characteristic as follows - train location, speed detection, wayside controller, train-borne controller, train to way side radio communication, zero speed detection and roll back detection |
| How the abatement | Improvement in efficiency though better train management and control<br>Optimization of speed, reduction in congestion, further capacity enhancement<br>Subsequent reduction in electricity consumption |

[96] Source: 'Business Proposal for Dedicated Freight Corridor'

| | | |
|---|---|---|
| is achieved | ‣ Reduction in specific electricity consumption[97] (kWh/ton km) to the tune of 2% (this abatement potential is suggested with respect to 0.008kWh/ton km specific electricity consumption in case of proposed DFC – traditional way side signal has been proposed)<br>‣ Realization of more and more modal shift from road to rail and subsequently to improvement in energy efficiency during freight transportation | |
| Other direct and indirect benefits | key competitive issues | Role of abatement levers in resolving the above mentioned issues: |
| | ‣ Productivity | ‣ No improvement in productivity |
| | ‣ Revenue | ‣ The proposed GHG abatement level will lead to saving in electricity consumption and subsequent saving in electricity cost (INR 0.0004/ton-km). However no direct revenue generation is expected due to the implementation of this measure. |
| | ‣ Competitive advantage | ‣ More autonomous signaling<br>‣ Less probability of accidental hazards<br>‣ More customer satisfaction |

**Technology penetration and global practice**

- Korean Train Control System, European Train Control System, US train control system have their own version of CBTC, Denmark going for re-signal the entire national rail network with CBTC.

**Impact of abatement project along with indicative project return**

| Project's impact | | | Project's financial evaluation | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project capital investment | Million INR | NA[98] | Project IRR | % | NA | Net Present Value (NPV) | Million INR | NA |
| Improvement in freight carrying capacity | Ton/ rake | NA | Assumptions used in IRR computation | | | | | |
| | | | ‣ NA | | | | | |
| Improvement in freight Revenue | INR/ rake | NA | | | | | | |
| Improvement in O&M Cost | INR/ ton | NA | | | | | | |
| Improvement in fuel/electricity cost | INR/ ton-Km | 0.0004 | | | | | | |

**Key issues**

- Involves high investment, long implementation schedule (almost 20yrs)
- Many of the features of the system are still in R&D stage
- Potential impact of this new technology on energy efficiency improvement will depend on the type of application and their impact on individual system and activity, traffic mix, track configuration and the topography of the route etc.
- It also needs tighter monitoring to prevent train to-train collisions, over-speed derailments, incursions into established work zone limits, and the movement of a train through a switch left in the wrong position.

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[97] Source – Union of international Railway – UIC, EY internal research and external railway expert, University of Illinois

[98] Please refer to the following Exhibit for details

**Exhibit 49: Illustration of CBTC system architecture**

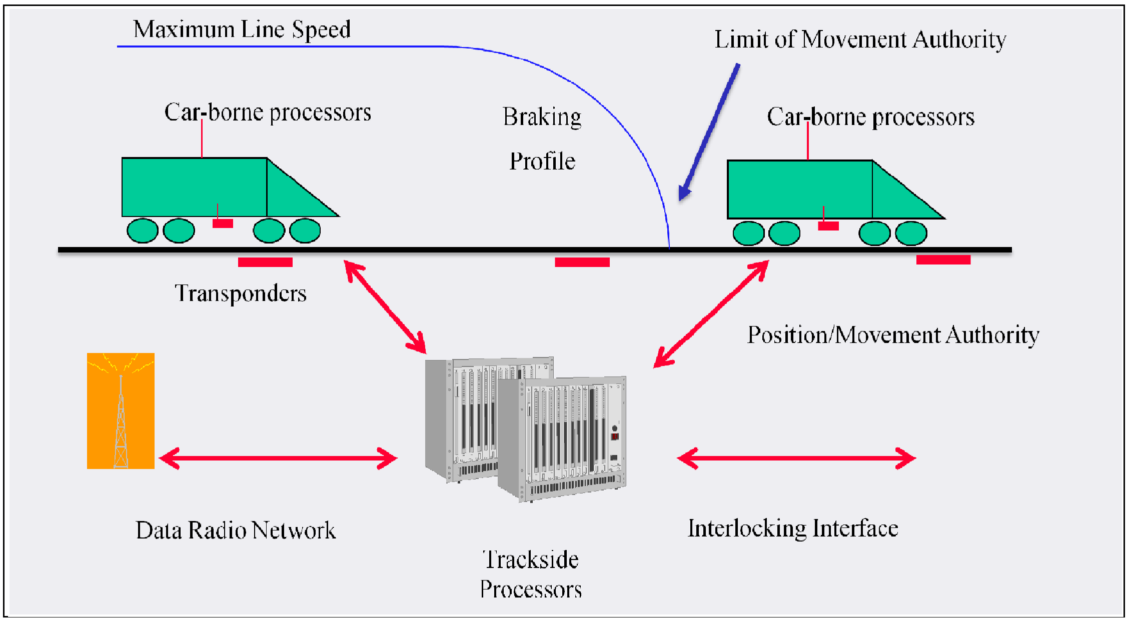
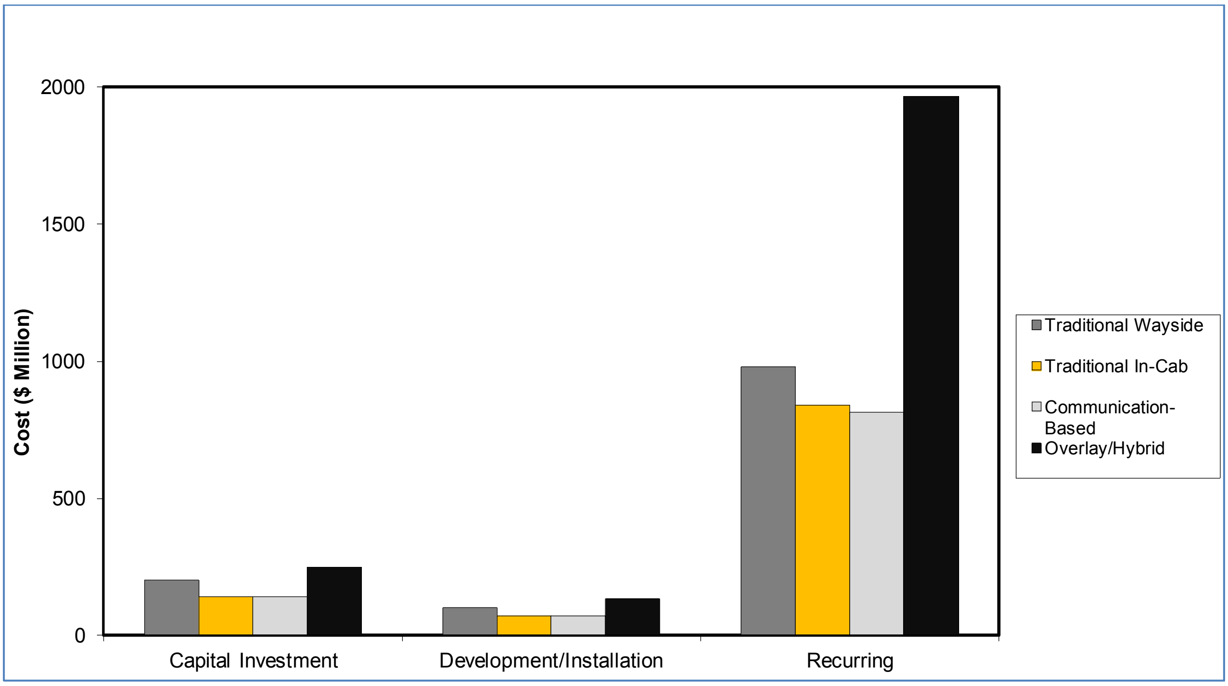



**Exhibit 50: Cost Elements of Train Control Technologies**



| Title of GHG abatement lever | Green building features | |
|---|---|---|
| **Technical description** | | |
| Technical features | ▸ In order to reduce electricity consumption in Heating-Ventilation-Air Conditioning (HVAC) system (the most energy intensive section in a building) several energy efficiency could be implemented which are as follows:<br>▸ To reduce the static load of the building –<br>- Installation of energy efficient glazing - utilization of modern double glazed glasses having low emissivity, lower U[99] value of fenestration, improved shading co-efficient. Insulating the space between the spandrel and the sill areas with insulating materials like glass wool slab with black tissue paper (reduces heat flux in the building).<br>- Installation of roof insulation - using low U value and high reflectivity of roof material, using glazed tiles on the roof surface. Terrace gardening could provide additional insulation.<br>- Installation of Heat Recovery Wheels (HRW) in Air Handling Units (AHUs) for recovering the cooling from part of return air being exhausted into atmosphere.<br>- Installation of energy efficient water cooled chillers with a high Coefficient of Performance (COP).<br>- Use of Compact Fluorescent Lamp (CFL), Light Emitting Diode (LED), T5 lamps etc, Use of lighting with occupancy sensors<br>▸ To reduce the variable heat load of the building :<br>- Installation of VFDs in the primary pumping system of the HVAC<br>- Installation of VFDs in the AHUs | |
| How the abatement is achieved | ▸ Substantial reduction in electricity consumption – almost 15%[100] compared to a conventional building<br>▸ Tremendous flexibility to run efficiently under part load conditions | |
| Other direct and indirect benefits | key competitive issues | Role of abatement levers in resolving the above mentioned issues: |
| | ▸ Productivity | ▸ Not Applicable |
| | ▸ Revenue | ▸ The proposed GHG abatement level will lead to saving in electricity consumption and subsequent saving in electricity cost. However no direct revenue generation is expected due to the implementation of this measure. |
| | ▸ Competitive advantage | ▸ Not Applicable |
| **Technology penetration and global practice** | | |
| ▸ There are 97 certified green buildings in India, 907 green building certifications are in process and total green building area is (certified + process) 394.24 million sq. ft. | | |

[99]Glass industry measures the energy efficiency of their products in terms of thermal transmission, or U-factor. U-factor measures the rate of heat transfer through a product. Therefore, the lower the U-factor, the lower the amount of heat loss, and the better a product is at insulating a building. Apart from conductivity, U-factor is also affected by the airflow around the window and the emissivity (e) of the glass. The lower the conductivity and emissivity of the glass, the lower the rate of heat loss and the lower the U factor.

[100] Source: EY internal research, United Nation Framework Convention on Climate Change (UNFCCC)

| Impact of abatement project along with indicative project return |
| --- |
| ‣ Capital investment – almost 6-8% higher than the that of conventional buildings<br>‣ Operation cost – Reduction in operational cost compared to that of conventional buildings |
| Key issues |
| ‣ Capital expenditure of green building is higher than that of conventional building.<br>‣ Lack of adequate legislative drivers (except few voluntary initiatives) |

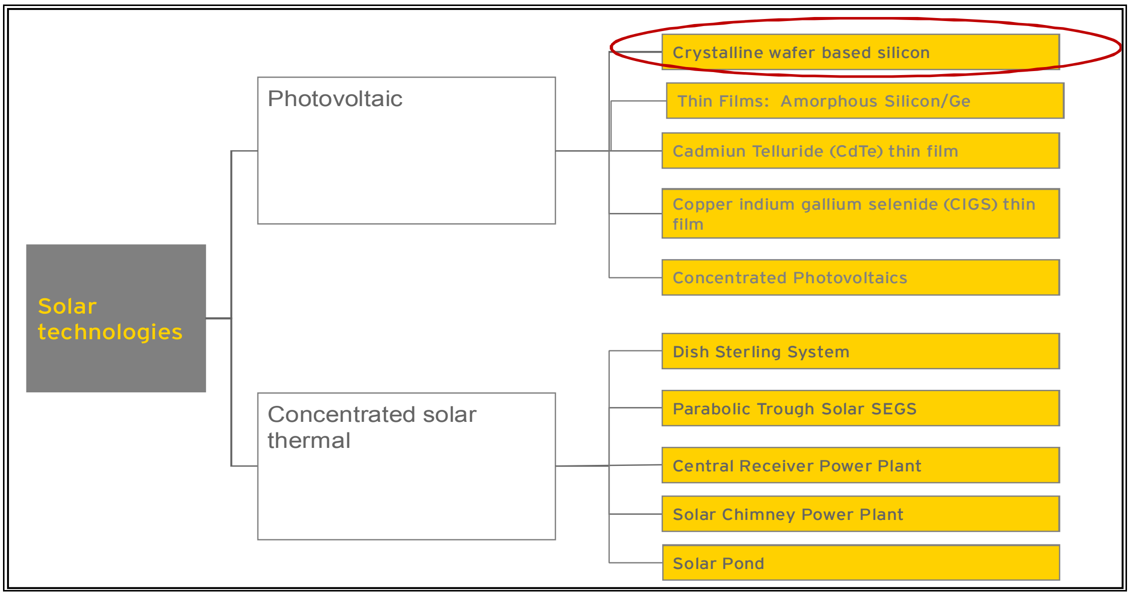
**b) Supply side GHG abatement levers**

**Power Generation:**

| Solar power | |
| --- | --- |
| Area of application | ‣ Power supply to support infrastructure like stations, staff quarters etc |
| Key technological attributes | ‣ Installation of solar Photovoltaic panels which will use the sunlight to generate electricity |
| Energy efficiency benefits | ‣ Solar power is carbon neutral. It will replace carbon intensive grid power |
| Technology penetration/Global practice | ‣ Solar PV based power generation is being encouraged in India. A number of incentives would be provided to the project developers.<br>‣ Globally solar power generation is a prevalent technology. European countries like Germany and Spain have close to 5GW and 2 GW of solar PV installed capacity.[101]<br>‣ Global installed base in 2008-09 close to 10 GW[102] |
| Economics | ‣ Capital investment – INR 120-170 million per MW[103]<br>‣ Operation cost - No fuel cost, low O&M cost<br>‣ In case of offset (supply of power to grid), a Feed in tariff of INR 17.44/kWh has been decided which improves the IRR to ~11%<br>‣ CDM benefits of 0.8 ton $CO_2$/MWh i.e. INR 580/MWh[104] |
| Key issues | ‣ Low PLF and subject to seasonal variations<br>‣ Very high capital costs |

[101] IEA, First Solar, Company Reports, EY analysis
[102] WEO 2008, 2009/GWEC 2008 (2008); Industry reports, IEA
[103] http://cercind.gov.in/Regulations/Final_SOR_RE_Tariff_Regulations_to_upload_7_oct_09.pdf
[104] 1 CER = € 12 and €1=INR 60

**Exhibit 51: Various solar technologies**




| Wind power | |
|---|---|
| Area of application | ▸ Power supply to support infrastructure like stations, staff quarters etc by wheeling<br>▸ Generation of carbon offsets |
| Key technological attributes | ▸ Installation of wind turbines which will use wind energy to generate electricity |
| Energy efficiency benefits | ▸ Wind power is carbon neutral. It will replace carbon intensive grid power |
| Technology penetration/Global practice | ▸ Established practice in India with 10.92 GW installed wind capacity in India[105]<br>▸ Global installed base in 2008-09 close to 120 GW[106] |
| Economics | ▸ Capital investment – INR 55.7 to 66.7 million per MW<br>▸ Operation cost - No fuel cost, low O&M cost<br>▸ CDM benefits of 0.8 ton $CO_2$/MWh i.e. INR 580/MWh |
| Key issues | ▸ Low PLF and subject to seasonal variations<br>▸ Site selection |

| Hydro power | |
|---|---|
| Area of application | ▸ Power supply to support infrastructure like stations, staff quarters etc |

[105] http://mnre.gov.in/annualreport/2009-10EN/Chapter%206/chapter%206_1.htm
[106] WEO 2008, 2009/GWEC 2008 (2008); Industry reports, IEA

| | |
|---|---|
| | by wheeling<br>▸ Generation of carbon offsets |
| Key technological attributes | ▸ Installation of small and micro hydel turbines which will use energy of moving water to generate electricity |
| Energy efficiency benefits | ▸ Hydro power is carbon neutral. It will replace carbon intensive grid power |
| Technology penetration/Global practice | ▸ Established practice in India with 36.86 GW installed hydro capacity in India[107]<br>▸ Global installed base in 2008-09 close to 960 GW[108] |
| Economics | ▸ Capital investment – INR 65 to 166.7 million per MW<br>▸ Operation cost - No fuel cost, low O&M cost<br>▸ CDM benefits of 0.8 ton $CO_2$/MWh i.e. INR 580/MWh |
| Key issues | ▸ Low PLF and subject to seasonal variations<br>▸ Site selection |

Note: Wheeling means the operation whereby distribution system and associated facilities of a transmission licensee or a distribution licensee, as the case may be, are used by another person for the conveyance of electricity on payment of relevant charges to be determined. Since the wind and hydro power sites may not be situated close to the support infrastructure, the power generated from these projects may be wheeled to the local grid and subsequently power drawn from the grid near the support infrastructure. The wheeling charge for renewable power is very nominal and varies from state to state.

The entire power requirement of the support infrastructure could be made carbon neutral. The power requirement is approximately 40 GWh per annum and increases by about 5% every 10 years. Assuming a solar PLF of 20%, the installed solar capacity would be about 20 MW. 10% of this capacity can be installed in the initial five year period. A solar capacity of 2 MW can be installed every five year period. Investments in wind energy (capacity of about 10 MW) and hydro power (capacity of about 10 MW) and wheeling of power would make the entire power consumption of the support infrastructure of DFC almost zero carbon.

107 http://www.cea.nic.in/power_sec_reports/executive_summary/2010_03/8.pdf
108 WEO 2008, 2009/GWEC 2008 (2008); Industry reports, IEA

## List of Appendices

### Appendix A – No-DFC scenario Information

**Data & information considered for No-DFC scenario GHG emission analysis from freight movement through rail**

<table>
<tr><th>Data type</th><th>Source</th><th>Remark (if any)</th></tr>
<tr><td>Number of trips of a particular commodity (or container) in a day within a section</td><td rowspan="6">IL&FS Final Traffic Report- “Project Development Consultancy for Preparation of Business Plan for DFC”, August 2009. It gives the freight traffic projection along the Eastern and Western Corridors for the 30 years period based on allocation of actual traffic flows on IR for the whole of 2007 08 and thereafter adopting a systematic methodology for commodity growth rate projections and traffic allocation to the DFC routes for subsequent reference years up to 2036-37, coinciding with the terminal years of successive five year plans. IL&FS have used two approaches to forecast the most likely commodity growth rates and the resultant projection of traffic on the DFC. These are Regression analysis and the econometric model approach. In their study they have considered:<br>▪ Ten different types of commodities and empties<br>▪ 13 sections along each corridor</td><td></td></tr>
<tr><td>Conversion multiplication factor</td><td></td></tr>
<tr><td>Number of trips of empties in a day within a section</td><td>For Miscellaneous and Additional Traffic, the value has been assumed considering the wagon type which constitutes the greater share of freight movement.</td></tr>
<tr><td>Track length of the section (km)</td><td>For Empties, Miscellaneous and Additional Traffic, value has been assumed considering the wagon type which constitutes the greater share of freight movement.</td></tr>
<tr><td>Payload of wagon for 25T axle load of each commodity type (including miscellaneous)</td><td>For Miscellaneous and Additional Traffic, value has assumed considering the wagon type which constitutes the greater share of freight movement.</td></tr>
<tr><td>Number of wagons of each commodity type (including miscellaneous) and empties</td><td>For Empties, Miscellaneous and Additional Traffic, value has been assumed considering the wagon type which constitutes the greater share of freight movement.</td></tr>
<tr><td>Weight of locomotive</td><td>IL&FS Final Traffic Report- “Project Development Consultancy for Preparation of Business Plan for DFC”, August 2009 and IRFCA</td><td>▪ The share of diesel and electric locomotives has been considered as per IL&FS Report.<br>▪ The weight of diesel and electric locomotives which are still running on Indian Railways has been considered as per IRFCA.<br>▪ Weight of locomotive has been calculated based on weighted average of diesel and electric locomotive</td></tr>
</table>

| Data type | Source | Remark (if any) |
|---|---|---|
| | | weights and their corresponding share in Indian Railways. |
| Tare weight of each wagon (tonnes) | http://www.irfca.org/faq/faq-stock2.html | Commodity-wise type of wagons has been considered to arrive at tare weight of the wagons. |
| Number of days of operation per annum | IL&FS Final Traffic Report- "Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 | |
| Specific electricity consumption | Simulation Study as provided by Railway experts | Simulation studies have been considered which plotted the electricity consumption in MWh w.r.t the distance travelled for different types of loads. |
| Specific diesel consumption | Simulation Study as provided by Railway experts | Simulation studies have been considered which plotted the diesel consumption in litres w.r.t the distance travelled for different types of loads. |
| Emission factor of electricity | | National grid emission factor has been projected over the period of 30 years, the procedure of which has been elucidated in section 3(c) |
| Density of diesel | http://cdm.unfccc.int/UserManagement/FileStorage/PS9316WGR2MEO5QUAYNJKCIH7T0ZD8 | |
| Net Calorific Value of diesel | IPCC 2006 Guidelines[109] | |
| Emission factor of diesel | IPCC 2006 Guidelines | |

[109] Intergovernmental Panel on Climate Change

**Data & information considered for No-DFC scenario GHG emission analysis from freight movement through road**

| Data type | Source | Remark (if any) |
|---|---|---|
| Load carrying capacity of a heavy duty truck | JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"- October 2007 | |
| Ton-kms of freight movement in a year through road | IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 | Payload of wagon (tonnes) for 25T axle load, no. of wagons, section length has been considered as per IL&FS- Final Traffic Report to arrive at ton-kms. |
| Mileage of a heavy duty truck | JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"- October 2007 | |
| Density of diesel | http://cdm.unfccc.int/UserManagement/FileStorage/PS9316WGR2MEO5QUAYNJKCIH7T0ZD8 | Density of diesel |
| Net Calorific Value of diesel | IPCC 2006 Guidelines | |
| Emission factor of diesel | IPCC 2006 Guidelines | |

**Data & information considered for No-DFC scenario GHG emission analysis for congestion**

| Data type | Source | Remark (if any) |
|---|---|---|
| Average speed of an electric/diesel locomotive along the route | Annual average speeds for both diesel and electric locomotives for the years 2005-06, 2006-07, 2007-08 and 2008-09 have been considered from the Annual Statistical Statements of Indian Railways. | Reported speeds of goods trains for the Railway Zones Central, Eastern, East Central, Northern, North Central, Western and North Western have been considered to arrive at future values by considering the growth rate of avg. speeds over the time period. |
| Booked speed of a freight train | JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"- October 2007 | Booked speed of a freight train is generally 90% of maximum permissible speed. The maximum permissible speed of a freight train has been considered to be same for diesel as well as electric locomotives. |
| Total number of trips of an electric/diesel locomotive per day in each route section | ▪ IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 for no. of trips/day/section<br>▪ JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"- October 2007 for diesel: electric locomotive share. | The no. of trips per day per section has been considered and the same has been multiplied with the individual share of diesel: electric locomotive share as provided in the IL&FS- Final Traffic Report. The past values have been regressed to arrive at the future projections. |
| Specific electricity consumption in stationary condition of electric locomotive | Inputs from Railway experts. | |
| National grid electricity emission factor | | National grid emission factor has been projected over the period of 30 years, the procedure of which has been elucidated in earlier section |
| Specific diesel consumption in stationary condition of diesel locomotive | Inputs from Railway experts. | |
| Emission factor of diesel | IPCC 2006 Guidelines | |

**Data & information considered for No-DFC scenario GHG emission analysis for support infrastructure**

| Data type | Source | Remark (if any) |
|---|---|---|
| Desired lux level | http://www.asda.gov.in/pdf/IGEA%20reports/IGEA%20Report%20-%20Railway%20Station.pdf | Expected average lux level |
| Area of coverage under lighting | | Considering Project |
| Luminous efficacy of CFL | http://en.wikipedia.org/wiki/Compact_fluorescent_lamp | CFLs are expected to be in use for lighting as they are energy efficient compared to ICLs |
| Daily operational hours of lighting | | Considering present practice; also seasonal variations have been taken into account |
| Annual operational days of lighting | As per DFCCIL's suggestion | |
| Number of fans/ exhausters in a facility | | Has been assumed taking into account the opinion of rail experts |
| Rated power of a fan/ exhauster | | Has been assumed taking into account the opinion of rail experts |
| Daily operational hours of fans | | Considering present practice; also seasonal variations have been taken into account |
| Annual operational days of fans/ exhausters | As per DFCCIL's suggestion | |
| Wattage of LED signal | Source: http://www.opticonsultinguk.com/Resources/lctis.pdf | Typical input power of a conventional light signal (SL 35 lamp) is 24 W. |
| Number of signals in No-DFC scenario case | | ▪ Signaling arrangement in case of No-DFC scenario has been considered same w.r.t DFC.<br>▪ In case of Absolute Signaling System, five signals in each direction per station and additional two signals per loop line have been considered.<br>▪ In case of Automatic Signaling System, signals at every 1 km have been assumed |
| Daily operational hours of signals | | Considering present practice |
| Annual operational days of signals | | Considering present practice |
| Total fossil fuel consumed | Annual Statistical Statement - Indian Railways- 2008-09 | Total fossil fuel consumed (expressed in terms of tonne of coal) in support infrastructures and total freight traffic (tonne-kms) on the concerned railway zones in 2007-08 have been considered from Annual |

| Data type | Source | Remark (if any) |
|---|---|---|
| | | Statistical Statement - Indian Railways- 2008-09. Then the fuel consumed (expressed in terms of tonne of coal) in the No-DFC scenario for the Base Year has been estimated based on the No-DFC scenario freight traffic (tonne-kms). |
| Number of stations | Annual Statistical Statement - Indian Railways- 2008-09 | Number of stations existing and total freight traffic (tonne-kms) on the concerned railway zones for 2007-08 have been considered from Annual Statistical Statement - Indian Railways- 2008-09. The number of stations in the No-DFC scenario for the Base Year has been estimated based on the No-DFC scenario freight traffic (tonne-kms). |
| Number of Staff Quarters | Annual Statistical Statement - Indian Railways- 2008-09 | Number of staffs housed in and total freight traffic (tonne-kms) on the concerned railway zones for 2007-08 have been considered from Annual Statistical Statement - Indian Railways- 2008-09. Then the number of staffs housed in the No-DFC scenario for the Base Year has been estimated based on the No-DFC scenario freight traffic (tonne-kms). |
| Number of 40 watt CFLs in use in each staff quarter | | Assumed on the basis of opinion of the rail experts |
| Number of Administrative Buildings | | Assuming equal number of administrative buildings for No-DFC scenario as well as DFC. |
| Power consumption of HVAC per sq.ft | Energy efficiency CDM Assistance Report, November 10, 2009 | Total electricity consumption due to HVAC has been divided by the coverage area of Ecospace Ambuja Campus of 697275 sq.ft |
| Coverage area under air conditioning | | Assuming 5000 sq.ft per floor of the office building and 4 floors of each building |

## Appendix B – Information pertaining to DFC operation

**Data & information considered for GHG emission analysis from freight movement through DFC**

| Data type | Source | Remark (if any) |
|---|---|---|
| Number of trips per day per section of DFC in both up and down directions for each commodity type (including miscellaneous) and empties | IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 | |
| Payload of wagon for 25T axle load of each commodity type (including miscellaneous) | | For Miscellaneous and Additional Traffic, value has been assumed considering the wagon type which constitutes the greater share of freight movement. |
| Number of wagons of each commodity type (including miscellaneous) and empties | | For Empties, Miscellaneous and Additional Traffic, value has been assumed considering the wagon type which constitutes the greater share of freight movement. |
| Weight of locomotive | Specification Standards for 1676 mm Gauge 9000 kW 8 axle IGBT based 3-phase drive Electric Freight Locomotive issued on 27.10.2008 – Chapter 02. | |
| Tare weight | Inputs from Railway experts; tare weight for RO-RO has been sourced from IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 | Tare weight of wagons for all the commodities has been assumed considering the axle load of 25 tons and payload as stated in the IL&FS- Final Traffic Report. |
| Operational hours | Inputs from DFCCIL | |
| Specific electricity consumption | Simulation Study as provided by Railway experts | Simulation studies have been considered which plotted the electricity consumption in MWh w.r.t the distance travelled for different types of loads. |
| Track length of each section | IL&FS Final Traffic Report-"Project Development Consultancy for Preparation of Business Plan for | |

| Data type | Source | Remark (if any) |
|---|---|---|
| | DFC", August 2009 | |
| Emission factor of electricity | | National grid emission factor has been projected over the period of 30 years, the procedure of which has been elucidated in earlier section |

**Data & information considered for GHG emission analysis for support infrastructure of DFC**

| Data type | Source | Remark (if any) |
|---|---|---|
| Desired lux level | http://www.asda.gov.in/pdf/IGEA%20reports/IGEA%20Report%20-%20Railway%20Station.pdf | Expected average lux level |
| Area of coverage under lighting | - Layout of a sample crossing station<br>- Rites' PETS report for Logistics Parks | Length of a junction/ terminal station has been assumed taking into confidence the opinion of the rail experts |
| Luminous efficacy of CFL | http://en.wikipedia.org/wiki/Compact_fluorescent_lamp | CFLs are expected to be in use for lighting as they are energy efficient compared to ICLs |
| Daily operational hours of lighting | | Considering present practice; also seasonal variations have been taken into account |
| Annual operational days of lighting | As per DFCCIL's suggestion | |
| Number of fans/ exhausters in a facility | | Has been assumed taking into account the opinion of rail experts |
| Rated power of a fan/ exhauster | | Has been assumed taking into account the opinion of rail experts |
| Daily operational hours of fans | | Considering present practice; also seasonal variations have been taken into account |
| Annual operational days of fans/ exhausters | As per DFCCIL's suggestion | |
| Specific power generation of a DG set | http://www.asda.gov.in/pdf/IGEA%20reports/IGEA%20Report%20-%20Railway%20Station.pdf | Expected from a well maintained DG set |
| Daily operational hours of DG sets | | Has been assumed taking into account the opinion of rail experts |
| Annual operational days of DG sets | | Has been assumed taking into account the opinion of rail experts |
| Wattage of LED signal | Source: http://www.opticonsultinguk.com/Resources/lctis.pdf | Typical input power of a conventional light signal is 24 W and overall percentage of electrical input power converted to useful optical power is 0.13%. Whereas for LED rail signal it is 30%. |
| Number of signals along each corridor | As per DFCCIL's suggestion | ▪ In case of Absolute Signaling System, five signals in each direction per station and additional two signals per loop line have been considered.<br>▪ In case of Automatic Signaling System, signals at every 1 km have been assumed |
| Daily operational hours of | | Considering present practice |

| Data type | Source | Remark (if any) |
|---|---|---|
| signals | | |
| Annual operational days of signals | | Considering present practice |
| Number of Crossing stations | JICA Final Report "The Feasibility Study on the Development of Dedicated Freight Corridor for Delhi-Mumbai and Ludhiana-Sonnagar in India"- October 2007 | As per Business Plan of DFCCIL, stations will be 40 kms apart. Route lengths for Eastern and Western DFC will be 1814 kms and 1500 kms respectively. |
| Number of Junction/ Terminal stations | IL&FS Final Traffic Report- "Project Development Consultancy for Preparation of Business Plan for DFC", August 2009 | |
| Rated power of a 100 ton crane | http://www.alibaba.com/product-gs/207587762/Truck_Crane_NCM_10_Tons_.html | Assuming capacity of a crane is 100 ton. |
| Operational hours of a crane per day | | Has been assumed taking into account the opinion of rail experts |
| Annual operational days of a crane | | Has been assumed taking into account the opinion of rail experts |
| Number of Logistic Parks along each corridor | Rites' PETS report | |
| Number of Staff Quarters | | As per DFCCIL Business Plan Presentation – January 19, 2010, staff strength is expected to be 11873. Individual accommodation has been considered. |
| Number of 40 watt CFLs in use in each staff quarter | | Has been assumed taking into account the opinion of rail experts |
| Number of Administrative Buildings | DFCCIL Business Plan | |
| Power consumption of HVAC per sq.ft | Energy efficiency CDM Assistance Report, November 10, 2009 | Total electricity consumption due to HVAC has been divided by the coverage area of Ecospace Ambuja Campus of 697275 sq.ft |
| Coverage area under air conditioning | | Assuming 5000 sq.ft per floor of the office building and 4 floors of each building |

## Appendix C - Information pertaining to construction of DFC

### Data & information considered for GHG emission analysis for construction of DFC

| Data type | Source | Remark (if any) |
|---|---|---|
| Width of Track and depth of formation for earthwork in case of single line | Inputs from Railway experts and DFCCIL Business Plan Report. | The width of track and depth of formation has been considered for single line track of DFC to arrive at the volume of soil/mud required per km of track. |
| Capacity of a extra heavy duty tipper truck | Inputs from Railway experts | The capacity of the tipper trucks is considered to arrive at the no. of trucks required. |
| Mileage of Tipper Truck | | Standard mileage of heavy duty tipper truck has been considered after discussion with Indian Railways to get the diesel consumption for earthwork. |
| Average lead to be covered by the tipper trucks for carrying soil | | An average distance between soil excavation site and proposed track laying site has been considered. |
| No. of passes of roller per km | | It is considered that 1 pass is for to and fro journey of roller on track for the purpose of slope leveling. |
| Specific diesel consumption per hr by roller | | |
| Speed of roller | | Speed of roller in terms of track length rolled per hr and the specific diesel consumption per hr by roller gives the amount of diesel consumed for rolling of track, once the no. of passes of roller are known. |
| Specific Diesel consumption by grader per km | | Diesel consumption due to slope leveling of embankment by grader per km of track is required to get the cumulative diesel consumption for rolling of track and grader movement along track for the purpose of slope leveling. |
| Depth of Blanket | DFCCIL Business Plan Report. | The volume of soil/mud required for blanketing is arrived considering width of single line track and depth of blanket required per km of track. |
| Average distance between stone quarry to proposed track line | Inputs from Railway experts | An average distance between site of ballast forming stone quarry/crusher and proposed track laying site has been considered. |
| Ballast requirement per km | | |

| Data type | Source | Remark (if any) |
|---|---|---|
| Capacity of trucks carrying ballast | | The volume of ballast requirement per km and ballast carrying capacity of each truck/hopper car gives the no. of truck/hopper car trips required for the purpose of carrying/laying ballast from the site of ballast forming stone quarry/crusher to the proposed track laying site by truck or laying ballast on track by hopper cars. |
| Capacity of hopper cars laying ballast | | |
| Mileage of trucks/hopper cars | | Standard mileage of trucks and hopper cars has been considered to be same after discussion with Indian Railways to get the diesel consumption for carrying and laying ballast. |
| Specific diesel consumption in crusher per ton of ballasts | | These two data parameters along with ballast requirement per km of track give the total diesel consumption for ballast formation. |
| Density of ballasts | | |
| Number of sleeper cars required per km of track | | The no. of sleeper cars in case of track laying of single line track and the specific diesel consumption per car in litres/km gives the diesel consumption for laying of 1 km of track. |
| Specific diesel consumption per sleeper car | | |
| Number of rails required per km | | Number of rails required per km in case of single line track is considered. |
| Capacity of trailer carrying rail | | Capacity of trailer is considered to get no. of trips of trailer for laying 1 km of track in case of single line. |
| Average lead of trailers | | |
| Mileage of a trailer | | Standard mileage of trailers has been considered after discussion with Indian Railways. |
| Specific diesel consumption of a welding machine per hour | | The specific diesel consumption of a welding machine together with operating hrs/day and operational days gives the diesel consumption for welding rails along 1 km of track. |
| Daily operational hours of a welding machine | | |
| Operational days for welding rail per km of track | | |
| Specific diesel consumption per hour by tamping machine | | Diesel consumption for packing of track by tamping machine is calculated from these two data parameters. |
| Tamping hours per km | | |
| Concrete requirement for 1 km bridge construction | | Concrete requirement for construction of 1 km of bridge in case of double line track has been considered. |
| Capacity of vibrator roller | | Standard capacity of vibrator roller carrying transit concrete mixture is considered. |
| Average lead of vibrator roller | | Average distance between vibrator roller and batching plant (concrete formation) is considered. |

| Data type | Source | Remark (if any) |
|---|---|---|
| Mileage of a vibrator roller | | Mileage of standard truck has been considered for arriving at the mileage of vibrator roller. |
| Production of concrete per hour in batch process in batching plant | | It is assumed that entire concrete produced from batching plant per hr shall be used for formation of 1 km of bridge on a cumulative basis. |
| Specific diesel consumption per hour for batching plant | | |
| Number of pile rigs | | No. of piles for construction of big bridge has been considered in case of double line track. |
| Diesel consumption per pile rig for construction of 1 km bridge | | |
| Number of operational days of crane for handling of bridge girders | | Diesel consumption in cranes for handling of bridge girders for construction of 1 km bridge has been considered. |
| Diesel consumption per day by the crane | | |
| Specific diesel consumption per km during OHE erection due to movement of diesel locomotives | | The value of specific diesel consumption per km multiplied by the total track length of DFC considering single line and double line route gives the total diesel consumption for the purpose of OHE erection for the entire corridor along eastern and western DFC. |