Abstract—Use of HEMMs in mining is predominant key activity which results in increased CO$_2$ emission and thus contributing to the GHG due to diesel combustion in engine cylinder of HEMMs. This study involves the theoretical estimation of stoichiometric CO$_2$ emission based on the stoichiometric combustion of diesel consumed during the mining in India. Moreover, ethanol-diesel blending was simulated and reduction in theoretical CO$_2$ emission due to different blending fraction was estimated based on total fuel consumption by opencast coal mining industry in India. According to this study the increasing trend of diesel consumption and associated theoretical CO$_2$ emission was observed due to opencast mining as compared to present scenario in India. Average percentage reduction of theoretical CO$_2$ emission for simulated ethanol-diesel blending fraction E5, E10, E20, E25, E35 and E40 are 1.95, 3.95, 7.76, 9.79, 13.82 and 15.80% respectively.

Index Terms—HEMMs emission, GHG inventory, diesel combustion, ethanol blending.

I. INTRODUCTION

Climate change is among more discussed issues now a days. Greenhouse gases (GHG) are considerably contributing to the climate change due to global warming effect. CO$_2$ is one of the important GHG which is mainly contributed to the atmosphere due to anthropogenic activities [1]. Combustion of fossil fuel like diesel and gasoline are the main anthropogenic activity contributing to the CO$_2$ emission to the atmosphere.

Vehicular emission are of utmost concern now a days due to gaseous and particulate emissions [2]. During the recent years vehicular contribution to the CO$_2$ emission was found to be increasing [3]. Mining activities also includes the use of different heavy mining machineries. Generally, use of high speed diesel and their combustion inside the engine cylinder of heavy earth moving machineries (HEMMs) is the major cause of CO$_2$ emission due to mining.

Environmental concern due to emissions from combustion engines motivated the researchers to think about the possible alternative nonpetroleum fuels. Ethanol being a green, renewable and biodegradable fuel is used as an alternative fuel in combustion engines [4]-[7]. Different researchers tested the diesel engine fueled with ethanol–diesel blends to know the exhaust emission characteristics [8], [9]. Ethanol is blended with gasoline or diesel to control the engine exhaust emissions [10], [11].

This study is focused on the theoretical estimation of CO$_2$ emission based on the stoichiometric combustion of diesel consumed by the mining and quarrying industries in India. Ethanol and diesel blending was simulated to obtain different blending fraction and theoretical CO$_2$ emission factor was developed based on the stoichiometric equation. Further average percentage reduction in theoretical CO$_2$ emission for different blending fraction of blended fuel (BF) was estimated based upon the forecasted diesel consumption data.

II. METHODOLOGY

IPCC has reported various guidelines to estimate the GHG inventory for various sectors which are internationally accepted [12]. In this study, those guidelines are considered as the baseline for the GHG emission (mainly CO2) estimation. Detailed methodology for CO2 emission estimation is shown in Fig. 1.

Overall approach is divided in the different sections. First section deals with the collection of the activity data from various sources or activities. All these selections are based upon the different SCOPEs defined by the IPCC, 1996 guidelines [13] which are SCOPE-I, II & III. Another section deals with the consideration of the emission factor for different type of emissions based upon different category of activity. Emission factors are required to quantify the GHG emission by multiplying it with the corresponding activity data gathered from different category of sources. Selection of emission factor for specific activity of different categories is based upon the three approaches i.e. TIER-I, II & III, defined in the IPCC, 2006 guideline. Among all the approaches, activity data are directly multiplied with the activity data in
order to estimate the GHG emission inventory.

A. Activity Data

Theoretical Estimation of CO₂ emission based on the general stoichiometry equation of combustion inside internal combustion engine (ICE) requires different activity data. Initial requirement is type of fuel being used, Carbon (C) present in the fuel composition are mainly responsible for total amount of CO₂ emission. For this study purpose, stoichiometric combustion of diesel fuel \((\text{C}_2\text{H}_5\text{OH})\) and ethanol \((\text{C}_2\text{H}_4\text{OH})\) are considered to estimate the theoretical CO₂ emission rate. Moreover other major responsible factors are amount of available Oxygen (O₂) in air supplied during combustion, air-fuel ratio (A/F) supplied during combustion and type of combustion. Various activity data required for calculation purpose are listed below (Table I).

| TABLE I: DETAIL OF ACTIVITY DATA REQUIRED FOR THE ESTIMATION OF STOICHIOMETRIC EMISSION OF CO₂ |
|-------------------------------------------------------------|
| **Type of fuel** | **Unit** | **Details** | **Source** |
| Chemical formula of Diesel | -- | \(\text{C}_2\text{H}_5\text{OH}\) | [14],[15] |
| Density of Diesel | kg/m\(^3\) | 835 | National Market |
| Cost of Diesel | Rs/liter | 67 | National Market |
| Thermal Energy (Calorific Content) of Diesel | kWh/kg | 12.9 | [16] |
| Chemical formula of Ethanol | -- | \(\text{C}_2\text{H}_4\text{OH}\) | |
| Density of Ethanol | kg/m\(^3\) | 782 | National Market |
| Cost of Ethanol | Rs/liter | 41 | National Market |
| Thermal Energy (Calorific Content) of Ethanol | kWh/kg | 8.3 | [16] |
| Combustion type | | Complete combustion | |
| Volume of Oxygen in Air | % | 21 | |
| Volume of Nitrogen in Air | % | 79 | |

In this study coal production and fuel consumption data for the opencast coal mines in India are considered as the major activity (Table II). Coal production data during last two decade were collected from a report by Directorate General of Mines Safety (DGMS) [17]. Diesel consumption data for the opencast mining activity was estimated by multiplying the coal production data by specific fuel consumption (SFC) by diesel equipments like HEMMs. SFC for the diesel equipments in some of the opencast mines was reported by [18]. Average value of SFC by the diesel equipments was 2.835 liter per tonne of coal produced, which was used for calculation purpose. Diesel consumption during the mining operations mainly depends upon the total operating hours of the HEMMs, road gradients etc. Moreover trip distance is also one of the major factor in deciding the diesel consumption in dumpers. SFC are considered without including the influence of all of these factors along with various other factors of the country.

All the calculation are based upon the assumption of complete combustion of considered fuel. One kg of fuel was considered for calculation purpose. Air composition considered to contain mainly Oxygen and Nitrogen with volume percentage of 21% and 79% respectively. General stoichiometric equation used for hydro fuel combustion is given as below [19].

\[
\text{C}_2\text{H}_5\text{OH}\text{O}_2\text{N}_2 = (a + \frac{b}{4} - \frac{c}{2})\text{C} + \frac{79}{21}\text{O}_2 + \frac{b}{2}\text{H}_2\text{O} + 3.76\left(a + \frac{b}{4} - \frac{c}{2}\right)\text{N}_2
\]

Total amount of theoretical Oxygen and Air required per kg of fuel combusted was calculated. Based upon those values theoretical CO₂ emission per kg of fuel combusted under stoichiometric condition was estimated.

| TABLE II: COAL PRODUCTION AND ESTIMATED DIESEL CONSUMPTION DATA IN THE OPENCAST COAL MINING INDUSTRY IN INDIA |
|----------------------------------------------------------|
| **Year** | **Average coal production** | **Diesel consumed** |
| | (million tonnes) | (000 tonnes) |
| 1991 | 167 | 395 |
| 1992 | 179 | 423 |
| 1993 | 187 | 443 |
| 1994 | 197 | 466 |
| 1995 | 216 | 511 |
| 1996 | 234 | 554 |
| 1997 | 248 | 586 |
| 1998 | 251 | 595 |
| 1999 | 247 | 585 |
| 2000 | 268 | 635 |
| 2001 | 277 | 657 |
| 2002 | 298 | 705 |
| 2003 | 316 | 747 |
| 2004 | 347 | 822 |
| 2005 | 357 | 845 |
| 2006 | 369 | 874 |
| 2007 | 419 | 991 |
| 2008 | 440 | 1042 |
| 2009 | 492 | 1165 |
| 2010 | 532 | 1259 |
| 2011 | 538 | 1274 |
| 2012 | 554 | 1311 |
| 2013 | 525 | 1242 |
| 2014 | 586 | 1388 |

*Only coal production by opencast mines in India. (Source: Statistics of Mines in India, volume-1 (Coal), 2014).

| TABLE III: SIMULATED ETHANOL BLENDING WITH DIESEL PER KG OF FUEL WITH VARYING PERCENTAGE |
|----------------------------------------------------------|
| **Ethanol Blending** | **Blending Percentage** | **Blending fraction (E - D)** |
| | | Diesel | Ethanol |
| **Notation** | % | kg | kg |
| E0 | 0 | 1 | 0 |
| E5 | 5 | 0.95 | 0.05 |
| E10 | 10 | 0.9 | 0.1 |
| E15 | 15 | 0.85 | 0.15 |
| E20 | 20 | 0.8 | 0.2 |
| E25 | 25 | 0.75 | 0.25 |
| E30 | 30 | 0.7 | 0.3 |
| E35 | 35 | 0.65 | 0.35 |
| E40 | 40 | 0.6 | 0.4 |
| E45 | 45 | 0.55 | 0.45 |
| E50 | 50 | 0.5 | 0.5 |
A. Simulation for Diesel-Ethanol Blending

Blending of diesel with ethanol was simulated. Blending fraction during blending simulation was varied from 0 to 50% mixing of ethanol with diesel. Mixing of ethanol with diesel was simulated at an interval of 5%. Thus the observed blending fraction of ethanol-diesel blending per kg of blended BF is tabulated below (Table III).

Blending of ethanol with diesel results in change in properties of the blended fuels with different BF. Some of the properties of the blended fuels with different BF are presented below (Table IV & V).

| Blend fraction | Relative Density | Density (kg/m³) | CV | Viscosity (mPa.s) | Flash point (˚C) | Pour point (˚C) |
|----------------|-----------------|----------------|----|-----------------|-----------------|----------------|
| E0             | 0.8458          | 843.08         | 44.52 | 4.69         | 74              | -36            |
| E5             | 0.8365          | 833.81         | 43.63 | 4.49         | 24              | -5             |
| E10            | 0.834           | 831.32         | 43.19 | 4.25         | 25              | -7             |
| E15            | 0.8318          | 829.13         | 42.75 | 4.00         | 27              | -10            |
| E20            | 0.8314          | 828.73         | 41.87 | 3.87         | 25              | -13            |
| E25            | 0.8266          | 825.95         | 41.00 | 3.44         | 25              | --             |
| E30            | 0.8286          | 825.94         | 40.58 | 3.07         | 26              | --             |

These change in properties of the blended fuels also result in their combustion behavior and thus emissions after combustion. Various researchers reported about the effect on combustion, performance and exhaust emissions due to blending of ethanol with diesel [22]-[24]. Blending fractions E5 to E20 of ethanol with diesel have acceptable properties for use as supplementary fuel to diesel engines [20]-[23].

B. Emission Factor

Theoretical CO₂ emission factor estimated using the stoichiometric equation during the complete combustion condition of hydrocarbon fuel is tabulated below (Table VI). Stoichiometric emission factor obtained for CO₂ emission was compared to the emission factor developed by different organisations like Intergovernmental Panel on Climate Change (IPCC) and Department for Environment, Food and Rural Affairs (DEFRA).

| Default Emission Factor | Stoichiometry | IPCC | DEFRA |
|-------------------------|---------------|------|-------|
| kg of CO₂ per liter Fuel (Diesel) | 2.640 | 2.550 | 2.717 |
| kg of CO₂ per kg Fuel (Diesel) | 3.162 | 3.054 | 3.254 |

C. Forecasting using ETS and HW Method

Forecasting for the total coal production and diesel consumption in opencast coal mining industry in India and associated theoretical CO₂ emission due to their stoichiometric combustion was performed using univariate ETS (Exponential Smoothing) and Holt-Winters (HW) forecast models through R [25]. These forecasting methods were performed for the available activity data to forecast the total coal production and diesel consumption in India due to opencast coal mining until 2039.

III. RESULTS AND DISCUSSION

A. Forecasting of Coal Consumption

Forecasting trend of coal production by two different approaches is shown in Fig. 2. Mean of forecasted coal production through both the approach was used for predicting the diesel consumption by the opencast coal mining industry in India. Result reveals that coal production and thus associated diesel consumption in next two decades will be doubled as compared to the present scenario (Fig. 2).

B. CO₂ Emission Prediction

Total amount of theoretical CO₂ emission due to opencast coal mining in India was estimated based upon the predicted total diesel consumption till 2039. Theoretical CO₂ emission for diesel consumption was estimated by multiplying the diesel consumption data of different years with the CO₂ emission factor due to complete combustion of diesel under stoichiometric condition. Further, CO₂ emission was estimated for the simulated fraction of ethanol and diesel blend. Comparison of predicted CO₂ emission till 2039 for diesel and blending fraction E5, E10, E20, E25, E35 & E40 are presented below (Fig. 3).
Theoretically interpreted result reveals that blending of ethanol to diesel in different fraction result in reduction in CO\textsubscript{2} emission. Average percentage reduction in CO\textsubscript{2} emission for different blending fraction (E5, E10, E20, E25, E35 and E40) as compared to diesel fuel is shown below (Fig. 4). Percentage reduction in CO\textsubscript{2} emission was more with increase of ethanol in blending fraction.

Simulated fraction of blending fuel shows that the percentage fuel consumption per kWh of energy produced under stoichiometric combustion increases with increasing fraction of blending fuel (Fig. 6).

Four. Conclusions
Forecast result shows the increasing trend of diesel consumption and associated CO\textsubscript{2} emission due to opencast coal mining as compared to present scenario in India. Average percentage reduction of theoretical CO\textsubscript{2} emission was more economical with 16 % (approx.) reduction in theoretical CO\textsubscript{2} emission. Whereas in practical E5 to E15 are the most suitable for the diesel engines based on consumption and cost analysis per kWh of energy generation. According to this study use of blended fuel E40 will be more economical with 16 % (approx.) of energy generation. According to this study use of blended fuel E40 will be more economical with 16 % (approx.) reduction in theoretical CO\textsubscript{2} emission. Whereas in practical E5 to E15 are the most suitable for the diesel engines based on the different literatures.

C. Fuel Consumption and Cost Analysis per kWh Energy Produced
Theoretical reduction in CO\textsubscript{2} emission and increase in fuel consumption and cost for each blending fraction of ethanol – diesel BF per kWh of energy produced from blended fuel under stoichiometric condition is shown below (Fig. 5). Increase in BF consumption and cost per kWh of energy produced curves intercept at E40 which represents the optimum condition.

Simulated fraction of blending fuel shows that the percentage fuel consumption per kWh of energy produced under stoichiometric combustion increases with increasing fraction of blending fuel (Fig. 6).

Fig. 6. Simulated impact (% increase or decrease per kWh) of ethanol and diesel blending on CO\textsubscript{2} emission (% decrease), fuel cost (% increase) and fuel consumption (% increase) per kWh.

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