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4 authors:


Vikas Nimesh
Alliance for an Energy Efficient Economy (AEEE)


Debojit Sharma
Indian Institute of Technology Kharagpur


V. Mahendra Reddy
Indian Institute of Technology Kharagpur


Arkopal Goswami
Indian Institute of Technology Kharagpur

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Implication viability assessment of shift to electric vehicles for present power generation scenario of India

Vikas Nimesh [a], Debojit Sharma [b], V. Mahendra Reddy [c, *], Arkopal Kishore Goswami [a]

[a] Ranbir and Chitra Gupta School of Infrastructure Design and Management, Indian Institute of Technology Kharagpur, West Bengal, 721302, India
[b] School of Energy Science and Engineering, Indian Institute of Technology Kharagpur, West Bengal, 721302, India
[c] Department of Mechanical Engineering, Indian Institute of Technology Kharagpur, West Bengal, 721302, India

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A B S T R A C T

The rapid increase in population and urbanization has led to an enormous increase in the overall vehicular demand. In India, most vehicles run on conventional fuels producing harmful gases and particulate matter, causing an adverse effect on the human health & environment. Most urban cities in India are witnessing a rapid increase in the level of urban air pollution, which can be largely attributed to the continuous surge in the number of on-road vehicles. According to a KPMG report, it is estimated that by 2030 there will be a 100% incremental adoption of electric vehicles which will lead to the minimization of the pollution level generated from the conventional cars. However, in India, 57.3% of electricity is produced through coal thermal power plant. It cannot be denied that coal leaves behind harmful by-products upon combustion. The emissions from the coal power plants in India increased from 901.7 g CO_2/kWh in 2005 to 926 g CO_2/kWh in 2012. This is much higher than global averages in the same period, which were 542 g and 533 g CO_2/kWh, respectively. The increase in the number of electric vehicles is likely to increase the demand for electricity, which may result in a rise in emissions from thermal power plants, thus offsetting the reductions in tailpipe emissions. This study deals with assessing the impact of shifting the fleet from internal combustion engine vehicles (ICEVs) to electric vehicles (EV) on power generation sources, i.e., coal power plants, and its impact on the environment in India. The implication viability of electric vehicle over internal combustion engine vehicle has been assessed with exergy analysis, taking into account the total emissions involved from well to wheel. In the current power generation scenario of India, a comparative analysis of direct and indirect emissions from internal combustion engine vehicles and electric vehicles (powered with coal power generation) shows that electric vehicles emit less CO_2 and CO, whereas SO_2 and Oxides of nitrogen (NO_x) emisions (indirectly from the thermal power plant), are higher.

1. Introduction

In the last two decades, India has experienced rapid urbanization along with significant growth in motorized vehicle ownership and usage. While there has been a tremendous increase in mobility and accessibility in urban areas, it has also led to various issues such as an increase in congestion, delay, accidents, energy wastage, noise & air pollution, etc. [1]. Air pollution is a significant concern for India as well as the world, as it has a severe impact on human health and the environment [2]. The emergence of the electric vehicle is being seen as an alternative to the internal combustion engine vehicles (ICEVs) that will reduce vehicular pollution and in-turn improve air quality. Various governments and advocacy groups across the world have promoted the adoption of hybrid and electric vehicles as a significant part of the portfolio of technologies required for reducing greenhouse gases (GHG) emissions and energy use [3–5]. The National Electric Mobility Mission Plan (NEMMP) – 2020 has been launched by the Government of India in 2013, which aims to achieve national fuel security by promoting hybrid and electric vehicles in the country. There is an earnest target to achieve 6–7 million sales of electric and hybrid vehicles year on year from 2020 onwards [6]. However, this increase in EVs is likely to lead to an increase in the overall electricity demand. India being majorly dependent on coal for power generation, an

* Corresponding author.
E-mail address: mahi791@gmail.com (V.M. Reddy).

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Nomenclature

EI_{ICEV}	Emission index of Internal combustion engine vehicles (ICEVs)
$\hat{E}_{ICEV}$	Total emissions (Well to wheel per unit fuel)
$\hat{E}_{wtt}$	Well to tank per unit emissions of vehicle fuel
η_E	Energy efficiency of ICEV
$\eta_{II,ICEV}$	Exergy efficiency of ICEV
$\hat{E}_t$	Per unit emission in transportation fuel
$\hat{E}_{ex}$	Per unit emissions occurred in the excavation of fuel
$\hat{E}_{ref}$	Per unit emissions in the refining of fuel
EI_{EVC}	Emission Index of the electric vehicle when powered with coal power plant
$\hat{E}_{EVC}$	Coal mines to wheel per unit emissions for an electric car when powered with coal power generation source
$\hat{E}_{CEE}$	Per unit emissions due to coal extraction activities
$\hat{E}_{CTE}$	Per unit emissions during transportation of coal
$\hat{E}_{EVl}$	emission per unit due to the losses in electric vehicle
$\hat{E}_{PE}$	Per unit emissions at coal power plants
EI_{EVM}	Emission index of the electric vehicle when powered with mix energy sources
I_{rev}	Thermal losses due to irreversibility
I_{tot}	Total destructive exergy
Ex_{aux}	Exergy of the auxiliary components
η_{comb}	Efficiency of coal combustion
$\eta_{turbine}$	Efficiency of steam turbine
η_{Boiler}	Efficiency of Boiler
$\eta_{II,EV}$	Exergy efficiency of electric vehicle
η_u	Exergy efficiency of the coal thermal powered battery vehicle unit
η_m	Efficiency of motor
η_T	Efficiency of transmission
$E_{l(o)}$	Other energy losses at coal power plant i.e. Condenser losses flue gasses losses etc.
m_i	Mass potential of species i
$\mu_{o,i}$	Chemical potential of species i
P_o	Reference pressure of the environment (atm)
T_o	Reference temperature of the environment (K)
V	Volume of the system contents
S	Entropy of the system contents
$dV/d\theta$	Rate of change of cylinder volume with crank angle
m_f	Masses of the fuel contents
m	Masses of total cylinder contents
$a_{f,ch}$	Fuel chemical exergy
$\dot{S}_{gen}$	Rate of entropy production in the cylinder due to irreversibility (J/K)
m_b	Burned masses of cylinder contents
m_u	Unburned masses of cylinder contents
$\dot{Q}_J$	Heat transfer through the boundary at the temperature T_j at location j
$\dot{W}$	Work rate
e_i	Total exergy of each chemical species i
e^{ph}	Physical exergy
W_{ind}	Indicated work output
E_{max}	Maximum extractable exergy
V_B	Terminal voltage of the battery
I_B	Terminal current of the battery

increase in electricity demand will place additional energy burden on the coal (thermal) power plants. In addition, the current quality of coal in India is poor as compared to other countries [7,8], which results in the emission intensity being almost double that of the global average. The electricity emissions intensity from the thermal power plant in India was 901.7 gCO_2/kWh in 2005 which has increased to 926 g CO_2/kWh in 2012, which is much higher than global averages in those years, which were 542 g and 533 g CO_2/kWh, respectively [9]. This scenario is an area of concern while implementing the switch to electric vehicle in India.

In most of the Asian cities, including India, where the majority of the urban population is exposed to poor air quality, air pollution has been considered as one of the serious environmental concerns. Various health-related problems such as cardiovascular diseases, respiratory diseases, risk of developing cancer and other serious ailments, etc. take place as a result of poor air quality [10]. Air pollution has reached a critical stage in recent years, where in most of the Indian cities the air quality has failed to meet the safe limits as stipulated by (World Health Organization) WHO. According to WHO, New Delhi heads the list of most polluted cities in the world, and the list also includes 12 other Indian cities [11,12]. India is among the group of countries that has the highest particulate matter levels of PM_{10} and $PM_{2.5}$. New Delhi has the highest level of airborne particulate matter $PM_{2.5}$, which is at a level of more than 150 µg, which is six times more than the WHO “safe” limit of 25 µg, for which the unrestricted vehicular growth appears to be the primary reason [2].

In the present study, a general mathematical model is developed to calculate the degree of viability (φ) of implementation of electric vehicles. In the mathematical model, a numerical code is developed to calculate the emission index for ICEVs and EVs. The emission index is derived by considering destructive exergy and emissions generated in the process of delivering power to a vehicle from the coal mines and oil wells. The emissions generated in all the processes of production of fuel to the end user is determined from different literary sources. The emissions index for ICEV is estimated by considering all the emissions generated due to combustion in-vehicle and during the production, refining and transportation of fuel, whereas the emission index for EV is estimated by considering the emissions generated at the thermal power plant and during the process of coal extraction, transportation, storage etc. Thereafter, a non-dimensional number, the degree of viable implication (φ), is introduced, which indicates the sustainability and effective implementation of EVs over ICEVs. ICEV and EV of the same configuration are studied and compared. The degree of viable implication (φ) is determined for different energy mix scenarios. Thereafter, emissions in each scenario are estimated and compared.

2. Emissions assessment

2.1. Petroleum production process and associated emissions

Petroleum refining is an industrial process in which crude oil is extracted from the ground and converted into desired products, i.e. gasoline, diesel, kerosene, naphtha, LPG and heavy fuel oil, etc. [13–15]. Crude oil is a naturally available, unrefined petroleum product composed of organic materials and hydrocarbon deposits [14]. After extraction of crude oil, it is then transported to refineries where it undergoes various processes, including fractional distillation, for separating the petroleum fuel and the extraction of the desired products [16–19]. Thereafter, the required product is then transported to the fuel station. Fig. 1 describes the steps involved in

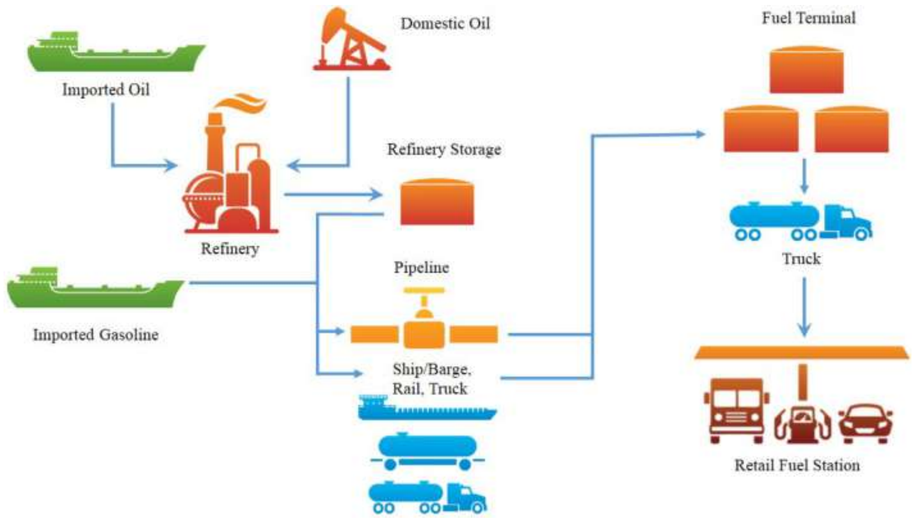

Fig. 1. Line diagram for petroleum well to end-user.

the whole process. Every step consumes a certain amount of energy and generates emissions in the process. The study by Furuholt, 1995, quantifies the energy consumption and emissions involved in the production of gasoline and diesel. Table 1 shows the well to tank GHG (equivalent CO_2) emissions involved in each process of production of petroleum-based fuel [17].

Table 2 shows the total energy consumption and related emissions for the production of 1000 L of fuel, in which all the process steps have been considered. These values are used in the study for calculating the Emission Index (EI) and total emissions generated from an ICEV.

Tables 1 and 2 indicates the total energy that is consumed and lost during different stages of fuel production. All the energy losses of an engine (ICEV) are in the range of 68–72%. Exhaust heat, pumping, friction, engine cooling and incomplete combustion are the sources in engine loss in vehicles [20]. Thereafter, drive train or transmission system leads to 5–6% energy loss [21].

2.2. Coal power plant emission

Nearly 60% of India's total energy requirements are met from coal [22]. According to Ministry of coal, Government of India has 319 billion tonnes of coal resources. The available coal reserves in India are sufficient to meet the demand for at least another 100 years. India now stands at second position amongst the coal producing countries in the world [22]. The production of coal was 662.79 million metric tons (730.60 million short tons) in 2016-17, which is a growth of 4.69% over the previous year. The production of lignite was 45.23 million metric tons (49.86 million short tons) in 2016-17, a growth of 3.17% over the previous fiscal year [23]. However, India also imports a certain amount of coal from other countries, since Indian coal contains a high level of ash. Sensitive and critically polluted areas are required to use coal with a maximum of 34% ash level for which imported coal is required [24]. The actually installed coal–capacity and its predicted growth pattern can be visualized in Fig. 2 [25].

In coal-fired plants, when coal burns, the chemical energy converts to heat energy followed by many chemical reactions that produce toxic airborne pollutants and heavy metals into the environment [26]. Coal combustion majorly releases carbon monoxide (CO), carbon dioxide (CO_2), Nitrogen oxides (NO_x), Sulphur dioxide (SO_2), and particulate matter (PM). The major and minor contributors of particulate matter are coal fly ash, sulfates & nitrates respectively. Along with these major air pollutants, coal contains a trace of impurities of Radon (Rd), Thorium (Th), Uranium (U) and other radioactive metals [27,28]. On burning the coal, these radioactive contaminants are released in the environment. Burning of coal in large quantities, such as for a nation's power generation, increases the traces of such radioactive elements to a considerable amount [23]. In the process of power generation from coal, various losses take place starting from the coal mines to the end users' locations. Each activity of mine to end-user produces emissions and consumes power. Fig. 3 describes all the processes and losses involved in mine to end-user. The study of Agrawal et al. [29], shows that the total GHG emission from coal is 1127 g CO_2 eq. per KWh of electricity generated. This is a result of the various input and output processes in electricity generation such as mining or extraction of fuel, transportation of fuel, and combustion in thermal power plants to calculate the total GHG emissions from coal power

Table 1
Well to tank GHG emissions (equivalent of CO_2) of petroleum-based fuel production [17].

Activity	CO_2 Generated for gasoline (g/l)	CO_2 Generated for Diesel (g/l)
Crude oil extraction	41.064	58.286
Overseas transportation	32.016	35.512
Petroleum refining	298.932	102.676
Domestic transportation	14.268	14.282
Total	397.764	210.756

Table 2
Total energy consumption and emission for production of 1000 L of fuel [17].

Activity	Gasoline	Diesel
Energy consumption (MJ)	3030	1960
CO (kg)	0.021	0.023
NO_x (kg)	0.54	0.57
SO_2 (kg)	0.22	0.25
VOC (kg)	6.33	2.26

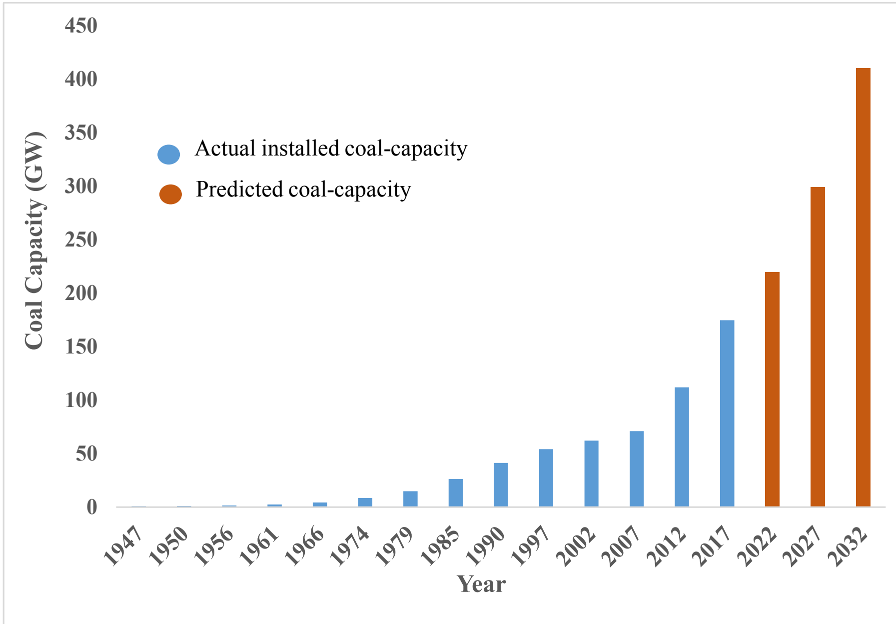

Fig. 2. Coal-capacity (MW) in India.

production [30,31]. In addition, various major process during coal excavation, i.e. exploration drill, coal drilling, and blasting etc. also leads to losses and emissions [32,33]. Thereafter, various emissions and losses take place in transporting the coal to power plant depending upon the type of mode used for transportation. Finally, at the time of electricity generation, emission from the combustion process takes place along with various losses such as coal storage loss, boiler loss etc. [32]. Emissions involved in the above all activities are considered by the study in calculating the EI of EVs. The study performed by Mittal et al., and Chakraborty et al. have reviewed to identify the pollutants and their emission coefficients from Indian coal power plants [34,35], as is shown in Table 3.

3. Methodology

This study deals with assessing the impact of the switch in

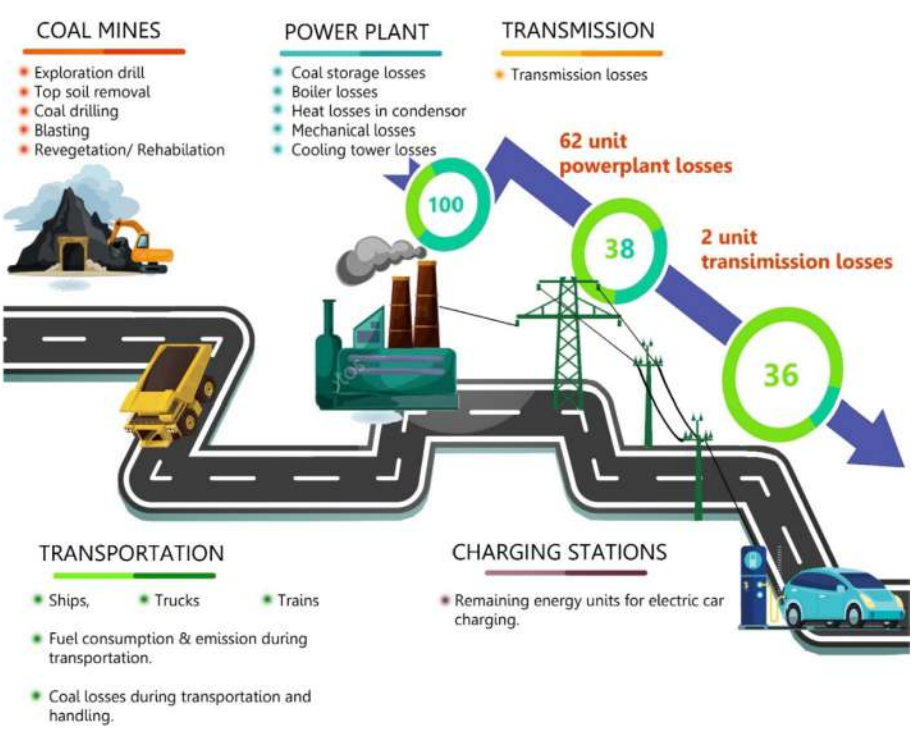

Fig. 3. Coal thermal energy production process.

Table 3
Emission coefficient from coal power plants [34,35].

Pollutant	Range of measured emission coefficient	
	(Mittal and Sharma 2003)	(Chakraborty et al., 2008)
CO_2 (kg kWh^{-1})	0.8–1.8	0.776–1.49
SO_2 (g kWh^{-1})	4–18	5.210–15.99
NO (g kWh^{-1})	6–13.1	1.540–3.263
CO (g kWh^{-1})	Not available	0.055–24.49

ridership from internal combustion engine vehicles (ICEV) to the electric vehicles (EVs) on power generation source and subsequently on the environment. For assessing this impact, the relationship between the emissions and the factors responsible for the emissions are identified. Power losses and exergy destructives are calculated through exergy analysis. Thereafter, Emission Index (EI) equations are developed for ICEVs and EVs. Emission index is defined as emission (m_i) released per unit of energy value (KWh).

$$EI = \frac{m_i}{KWh} \tag{1}$$

The emission index is derived by considering "emissions per unit energy" – which is generated in delivering the power from coal mines and oil wells to the vehicles. However, energy analysis can be misleading sometimes for its inability to address the quality form of energy. To identify these areas, energy and exergy analysis is taken into account [36,37]. With exergy analysis, the more limited concept of a thermal energy reservoir is extended to a general reference-environment model. Exergy is calculated with respect to a reference-environment model, with the exergy of a flow and system being dependent on the intensive properties of the reference environment. The exergy of the reference environment is zero, and the exergy of a stream or system tends to zero when it is in equilibrium with the reference environment [38].

Subsequently, the term degree of viable implication (φ) is developed to analyze the sustainable implementation of EVs in place of ICEVs. Two variants of Mahindra Verito are considered, since this car model is available in both ICEV and EV in India. The study has considered energy consumption and emissions generated from the processes involved in power generation i.e., Mines to EVs and Well to ICEVs.

3.1. Emission index for I.C. engine vehicle

Emission index of ICEVs is a function of combustion efficiency, engine efficiency (includes exergy efficiency), and transmission efficiency. Also, emissions resulting from fuel extraction and refinery process, per unit of fuel produced, for IC engine are accounted in the EI calculations.

Emission Index of ICEVs:

$$EI_{ICEV} = f\left(\sum \hat{E}_{ICEV}\right) \tag{2}$$

$$\hat{E}_{ICEV} = f\left(\hat{E}_{wtt}, \eta_{comb.}, \eta_{II,ICEV}, \eta_T\right) \tag{3}$$

$$\hat{E}_{wtt} = f\left(\hat{E}_t, \hat{E}_{ex}, \hat{E}_{ref}\right) \tag{4}$$

The emission index of an I.C. engine vehicle (EI_{ICEV}) is a function of the total well to wheel emissions per unit fuel produced ($\hat{E}_{ICEV}$)). This in turn is dependent on well to tank emissions per unit of vehicle fuel produced ($\hat{E}_{wtt}$), combustion efficiency of ICEV ($\eta_{comb.}$), exergy efficiency of ICEV ($\eta_{II,ICEV}$) and efficiency of transmission (η_T). Further $\hat{E}_{wtt}$ depends on per unit emission in the transportation of fuel ($\hat{E}_t$), per unit emissions occurring in the excavation of fuel ($\hat{E}_{ex}$) and per unit emissions in the refining of fuel ($\hat{E}_{ref}$).The terms $\eta_T, \eta_{II,ICEV}$, in equation (3) are significant factors affecting the major emission concentrations discussed through detailed exergy analysis.

Exergy is defined as the maximum theoretical work that can be obtained from the system when the system comes into thermodynamic equilibrium with the environment. The system equilibrium is achieved when it is thermally, mechanically and chemically in equilibrium [39]. The maximum available work from a closed system emerges as the sum of two contributions: thermomechanical exergy (A_{tm}) and chemical exergy (A_{ch}) [40]. Thermomechanical exergy is defined as the maximum work extractable from the system under thermal and mechanical equilibrium with the surroundings. The mathematical relation includes Mass potential of species i(m_i), Chemical potential of species i($\mu_{o,i}$), Reference pressure of the environment (P_o) , and Reference temperature of the environment (K), (T_o) as shown below [39]:

$$A_{tm} = E + p_o V - T_o S - \sum_i \mu_{o,i} m_i \tag{5}$$

where, $E = U + E_{kin} + E_{pot}$, the total internal, kinetic and potential energy; V is the volume and S is the entropy of the system contents; m_i and $\mu_{0,i}$ are the mass and chemical potential of species i, which are calculated at restricted dead state conditions, and p_o and T_o are the fixed pressure and temperature of the environment.

The initial conditions correspond to a system which is in thermal and mechanical equilibrium with the environment. However, no work potential, existing between the system and environment due to temperature and pressure gradients are considered. The chemical equilibrium is difficult to establish as reacting components of the system are not allowed to mix with each other. The difference between the compositions of the system at the initial conditions and that of the environment can be used to obtain additional work, in order to reach chemical equilibrium. The maximum work obtained in this way is called as chemical exergy, given as [39,41]:

$$A_{ch} = \sum_i \left(\mu_{o,i} - \mu_i^o\right) m_i \tag{6}$$

If, the initial system is in thermal, mechanical and chemical equilibrium with the environment; by using equations (5) and (6), the total exergy (A) can be calculated as [30]:

$$A = A_{tm} + A_{ch} = E + p_o V - T_o S - \sum_i \mu_i^o m_i \tag{7}$$

The rate of exergy loss or gain by the internal combustion engine vehicles can be interpreted in terms of crank angle degree (CAD), which is the most comprehensive way to identify the significant locations of thermodynamic losses leading to high values of emissions. The rate of exergy loss/gain for the engine cylinder in a differential form on a crank angle basis is represented as [42]:

$$\underbrace{\frac{dA}{d\theta}}_{1} = \underbrace{\left(1 - \frac{T_o}{T}\right)\frac{dQ}{d\theta}}_{2} - \underbrace{\left(\frac{dW}{d\theta} - p_o\frac{dV}{d\theta}\right)}_{3} + \underbrace{\frac{m_f}{m}\frac{dx_b}{d\theta}a_{f,ch}}_{4} - \underbrace{\dot{I}_{tot}}_{5} \tag{8}$$

The first term in equation (8) is the rate of change in the total exergy of cylinder contents. The second term represents exergy transfer with heat. The third term shows exergy transfer by means of indicated work transfer, where $dV/d\theta$ is the rate of change of cylinder volume with crank angle. The fourth term corresponds to the burned fuel exergy, where m_f and m are the masses of fuel and total cylinder contents, respectively, and $a_{f,ch}$ is the fuel chemical exergy. The last term in the equation illustrates exergy destruction in the cylinder due to combustion and heat transfer. It is calculated as:

$$\dot{I}_{tot} = T_o \dot{S}_{gen} \tag{9}$$

The destructive entropy generated due to combustion inside the engine cylinder contributes to the approximately one third of exergy losses. The entropy balance can be represented in terms of the rate of entropy production in the cylinder due to irreversibility ($\dot{S}_{gen}$), unburned masses of cylinder contents (m_u) and entropy values of unburned gas (s_u) as [42]:

$$\dot{S}_{gen} = \frac{d}{d\theta}(m_u s_u) + \frac{\dot{Q}_b}{T_b} + \frac{\dot{Q}_u}{T_u} \tag{10}$$

where, Q_b and Q_u are heat losses from burned and unburned gasses, and T_b and T_u are temperatures of the burned and unburned gas zones, respectively. The exergy efficiency of the ICEV ($\eta_{II,ICEV}$) can be helpful in determining the irreversible thermodynamic losses as shown in equation (11), where W_{ind} is referred to as indicated work output and E_{max} as maximum extractable exergy.

$$\eta_{II,ICEV} = \frac{W_{ind}}{E_{max}} = \frac{W_{ind}}{W_{ind} + \dot{I}_{tot}} \tag{11}$$

The exergy efficiency stresses both on exergy transfer losses and internal exergy destruction due to irreversibility. Hence, $\eta_{II,ICEV}$ is a vital parameter that is affecting the degree of viable implication (φ).

3.2. Emission index for electric vehicle

Electric vehicle emissions depend on the source which is used to power the vehicle. As such, Emission Index (EI) of an electric vehicle is a measure of indirect emissions from EV according to the power source. Any nation does not solely depend on a single source of power generation. India is majorly dependent on power produced by thermal power plants operating with coal. Hence, in this study, different ratios of thermal power and renewable energy are considered and emissions index for the electric vehicles are calculated.

3.2.1. Emission index for electric vehicle powered with coal thermal power plant

Research has shown that more than 93% of the CO_2 is emitted from coal combustion and rest is emitted in the process before coal reaches for power plant operations [29,43]. The derivations below depict a scenario where the electric vehicle is powered using coal. Energy consumption, emissions, and exergy destruction will take place during several processes i.e. coal extraction, coal transportation, and coal power plant operations. Emission Index of EV (powered with coal thermal power plant) (EI_{EVC}) is a function of per unit emissions generated from coal mines to wheel powered with coal ($\hat{E}_{EVC}$). These emissions further depend upon per unit emissions due to coal extraction activities ($\hat{E}_{CEE}$), per unit emissions during transportation of coal ($\hat{E}_{CTE}$), per unit emissions at coal power plants ($\hat{E}_{PE}$) and exergy efficiency of electric vehicle ($\eta_{II,\,EV}$). Thereafter, the coal power plant emissions are a function of combustion efficiency of coal (η_{comb}), mechanical efficiency of turbine ($\eta_{turbine}$), and emissions due to other losses ($E_{l(o)}$).The exergy efficiency of the total power plant ($\eta_{II,EV}$) is dependent on the exergy efficiency of the coal thermal powered electric vehicle unit (η_u), efficiency of transmission (η_t), exergy efficiency due to power generation ($\eta_{p,gen,}$) and efficiency of auxiliary component (η_{aux}).

$$EI_{EVC} = f\left(\sum \hat{E}_{EVC}\right) \tag{12}$$

$$\hat{E}_{EVC} = f\left(\hat{E}_{CEE}, \hat{E}_{CTE}, \hat{E}_{PE}, \eta_{II,\,EV}\right) \tag{13}$$

$$\hat{E}_{PE} = f\left(\eta_{comb}, \eta_{turbine}, \eta_{Boiler}, E_{l(o)}\right) \tag{14}$$

$$\eta_{II,EV} = f\left(\eta_{p,gen}, \eta_u, \eta_{aux}, \eta_t\right) \tag{15}$$

The exergy lost in the process is due to heat dissipation in terms of chemical reaction, heat transfer, transmission and thermal losses. The exergy balance of the system by neglecting the changes in kinetic and potential energies is expressed as [44,45]:

$$\sum_i \dot{I}_{rev} = \sum_i \dot{Ex}_{in} - \sum_i \dot{Ex}_{out} = \left(\sum_i (\dot{m}_i e_i)\right)_{in} + \sum_j \left(1 - \frac{T_o}{T_j}\right)\dot{Q}_j - \dot{W} - \left(\sum_i (\dot{m}_i e_i)\right)_{out} \tag{16}$$

$$e^{ph} = \int_{(T_o,P_o)}^{(T,P)} \left[x_l\left(\sum x_i H_i^l - T_o \sum x_i s_i^l\right) + x_v\left(\sum y_i H_i^v - T_o \sum y_i s_i^v\right) \times\right] \tag{17}$$

$$e^{ch} = \left(x_{o,l} \sum x_i e_i^l + x_{o,v} \sum y_i e_i^v\right) \tag{18}$$

where, the environmental temperature and pressure (T_o and P_o) used in the present study are 298.15 K and 1.0 atm respectively. The overall exergy efficiency of the coal thermal powered electric vehicle is discussed in terms of exergy due to power generation and exergy of the electric vehicle unit.

According to the exergy balance of the coal thermal powered electric vehicle unit, the destructive exergy can be expressed:

$$\dot{I}_{tot} = \left(\sum_{k=(Coal,O_2)} \dot{m}_k\left(e^{ph} + e^{ch}\right)_k\right)_{in} + \left(1 - \frac{T_o}{T_B}\right)Q_{diss} - \left(\sum_{k=(products)} \dot{m}_k\left(e^{ph} + e^{ch}\right)_k\right)_{out} - V_B I_B \tag{19}$$

where, Q_{diss} refers to the heat dissipation from the electric battery to the atmosphere. The power consumption by the blower, fan and other electronic components are neglected. However, the effects of charging and discharging are taken into consideration. The exergy efficiency due to power generation, $\eta_{p,gen}$ can be expressed as [44]:

$$\eta_{p,gen} = \left(\frac{P_{B,dch}}{\frac{P_{B,dch}}{\eta_{battery}}}\right) \times \eta_{convertor} \times \eta_{invertor} \tag{20}$$

In general, the rechargeable battery capacity is affected by a number of charge/discharge cycles. The battery efficiency of the EV is assumed to be constant. For simplicity, $\eta_{convertor}$ and $\eta_{invertor}$ are assumed to be constant. The exergy efficiency of the coal thermal powered electric vehicle unit can be expressed as:

$$\eta_u = \frac{V_B I_B + \left(\sum_{k=(products)} \dot{m}_k \left(e^{ph} + e^{ch}\right)_k\right)_{out} - \left(1 - \frac{T_o}{T_B}\right) Q_{diss}}{\left(\sum_{k=(Coal,O_2)} \dot{m}_k \left(e^{ph} + e^{ch}\right)_k\right)_{in}} \tag{21}$$

The other auxiliary components of the electric vehicle components also contribute to the exergy efficiency. The exergy efficiency of the auxiliary components, η_{aux} can be termed as:

$$\eta_{aux} = \frac{\sum_i \dot{Ex}_{out}^{aux}}{\sum_i \dot{Ex}_{in}^{aux}} \tag{22}$$

Hence, the overall exergy efficiency of the electric vehicle can be represented as:

$$\eta_{II,EV} = \eta_{p,gen} \times \eta_u \times \eta_{aux} \times \eta_t \tag{23}$$

$\eta_{II,EV}$ is a crucial parameter affecting the degree of viable implication (φ).

3.2.2. Emission index for electric vehicle powered with mix energy (coal and renewable energy)

In India, approximately 65% of power is generated through thermal power plants. In which 56.5% is generated through coal, 7.1% through gas and 0.2% is generated through oil thermal power plants and rest is generated through hydro, nuclear and renewable energy sources [46].

The emission index of the electric vehicle when it is powered with mix energy sources:

$$EI_{EVM} = x_1 EI_{EVS_1} + x_2 EI_{EVS_2} + x_3 EI_{EVS_3} + \ldots + x_y EI_{EVSy} \; ; \; \sum_{i=1}^{y} x_i = 1 \tag{24}$$

Here,

- EI_{EVM} = Emission index of electric vehicle when powered with mix energy sources;
- x_i = *Share power generation Source*
- $EI_{EVS_1}, EI_{EVS_1}, EI_{EVS_1}$, *etc. are emission index of electric vehicle when powered with*
- *energy sources* S_1, S_2, *etc.*

3.2.3. Electric motor losses and efficiency

The propulsion system is the heart of an EV, and the electric motor sits right in the core of the system. The motor converts electrical energy that it gets from the battery into mechanical energy which enables the vehicle to move [47]. An electric vehicle can use AC or DC motors; these motors have two types of losses i.e. constant or fixed losses and variable losses. Constant losses remain constant over a normal working range of induction motor, which includes iron or core losses, mechanical losses and brushes friction losses. Variable losses are called copper losses. These losses occur due to the current flowing in stator and rotor. Fig. 4 describes the losses in the entire process of running and also indicates the power remaining after these losses.

$$\eta = \frac{output\ power}{input\ power} = \frac{P_m}{P_i} \text{x } 100\% \tag{25}$$

3.3. Degree of viable implication

In this study, "degree of viable implication", denoted by (φ) has been introduced as a non-dimensional number which is the ratio of – Emission Index of the electric vehicle and Emission Index of the internal combustion engine vehicle. The viable implication of electric vehicle depends on the sources of power used in charging the vehicle. It varies according to the nature of power availability of a country, the country which has more renewable energy sources will have less emission index for electric vehicle and results of degree of viability will be less than 1.0.

$$\varphi = \frac{EI_{EVM}}{EI_{ICEV}} \tag{26}$$

In this study, the degree of viable implication (φ) indicates the sustainable and effective implementation of an electric vehicle over ICEVs.

The study assumed an ordinal scale from 0 to 1, which was further divided into two equal halves, i.e. 0–0.5 and 0.5–1.0 [48,49] as shown in Table 4.

Further, the study also asserts that for the best outcome and to mitigate the problem of vehicular emissions, the degree of viability should be as close to 0 as possible.

Fig. 5 illustrates the mathematical models and process used to

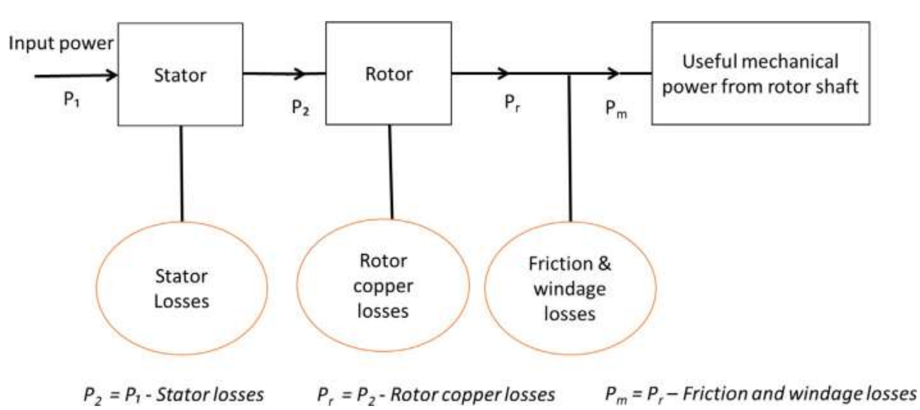

Fig. 4. Losses in electric motor.

Table 4
Classification of degree of Viable Implication.

Degree of viability emissions (electric/ conventional)	Viability	Explanation
$\varphi > 1$	Not viable	This implies that the indirect emissions from electric cars (through coal power plants) are higher than the current emissions from conventional vehicles.
$0.50 < \varphi \leq 1$	Viable	This implies that the indirect emissions from electric cars (through power generation) are less than current emissions from conventional vehicles. Therefore, the lesser the degree of viability will be, the lesser will be the emissions from total on-road vehicles.
$\varphi < 0.5$	Most Viable	In this scenario, electric car implementation will be effectively avoiding almost 70% of emissions referred from the results, Figs. 7 and 8

calculate the emissions and viability in the form of a flowchart. In the first step, the emission index of ICEV and EV was calculated depending upon their fuel type. This data is further used to calculate the degree of viable implication (φ) using equation (26). If $\varphi< 1$: the electric vehicles are emitting fewer pollutants than conventional vehicles. Hence, the implication of electric vehicle is viable. However, if $\varphi > 1$, it means the electric vehicle is emitting indirectly more pollutants than the conventional vehicles. Therefore, it is not a positive implication, which can be achieved by increasing the share of renewable energy in the total energy mix. Iterations can be carried out until the value of φ is less than 1.

The Indian EV market is in a budding stage and only a few companies like Hyundai, Mahindra, Tata etc. have introduced plug-in EVs. Further, only Mahindra and Tata have introduced car variants in both electric as well as I.C. engine i.e. Mahindra Verito and Tata Tigor. Although, there is a difference in the maximum power outputs between the two variants of both the models, it is comparatively lower for Mahindra Verito. On the contrary when we look at the conventional engine car with the same power output as of its electric variant, its passenger and luggage capacity and dimensions are considerably reduced. The efficiency of conventional diesel engines is in the range of 40–45%. However, Electric vehicles are much more efficient in the range of 85–90% which is majorly due to the absence of hydrocarbon emissions and lesser internal irreversibility [50]. Therefore, for a healthy comparison between the different variants of the same model, it will be erroneous to select them only on the basis of the same power output. From the customer's perspective, they tend to shift within the same price range, size, luggage capacity and passenger capacity [51]. Therefore, we have compared variant of Mahindra Verito in this study as it has less difference in power output between the variants than Tata Tigor and other models.

In this study, both the variants of Mahindra's Verito – ICEV and EV have been considered for analysis; technical details of both the variants are given in Tables 5–7. The mileage for conventional and electric car mentioned by car manufacturer was considered. The car company in India follows the "Modified Indian Driving Cycle" (MIDC) as per Bharat stage norms with certification from ARAI for

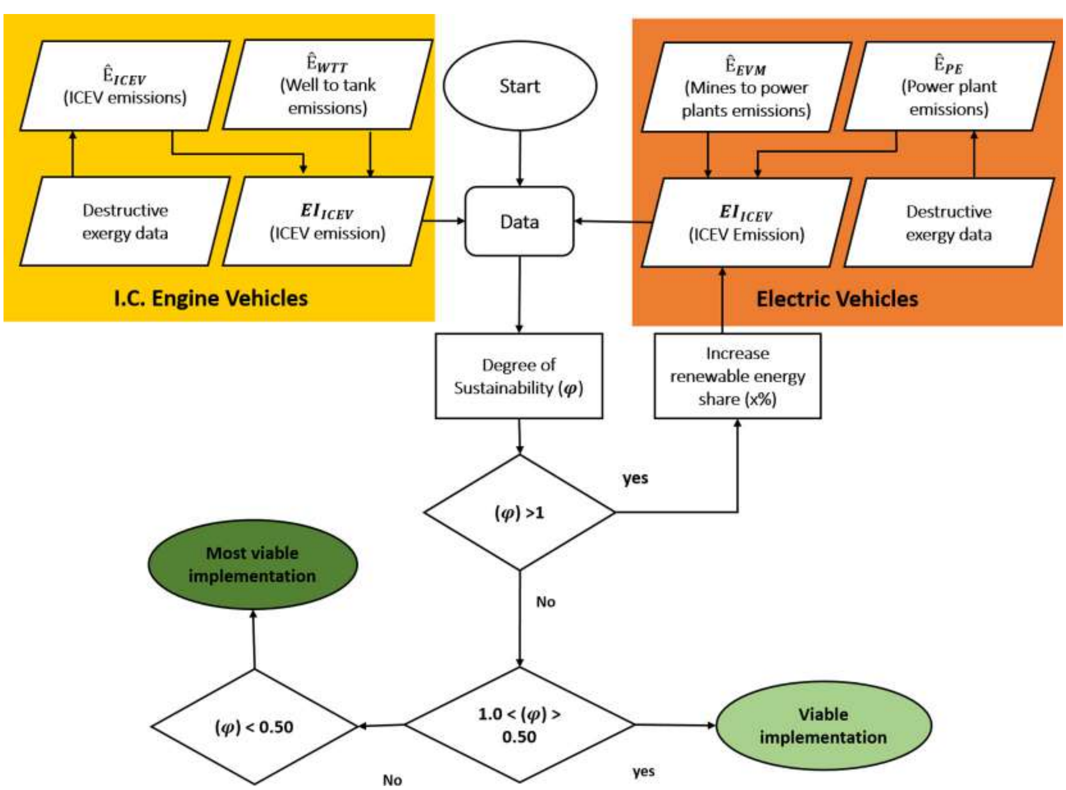

Fig. 5. Flowchart for EV implication calculation.

Table 5
Electric vehicles (EVs) versus I.C. Engine vehicles [52,53].

Specification	Mahindra Verito (ICEV)	Mahindra Verito EV (EV)
Length (mm)	4277	4247
Width (mm)	1740	1740
Height (mm)	1540	1540
Kerb Weight (kg)	1140	1265
Mileage	21 Kmpl	18 KWh/100 km
Car body	Sedan	Sedan

Table 6
Electric vehicle specification.

ELECTRIC VEHICLE	
Driving range	
Certified range as per MIDC (km)	181
With Revive ® (km)	8
CHARGING TIME @ 25 °C	
Normal Charging (0–100%) (h)	11 HOURS 30 MIN (±15 MIN)
Fast Charging (0–80%) (h)	1 h 30 min
Motor	
Construction	3 Phase AC Induction Motor
Power (kW)	31 kW @ 4000 r/min
Torque	91 Nm @ 3000 r/min
Controller	550 A
Battery	
Installed Capacity (Ah)	288
Technology	Lithium Ion
Total Installed On-board Power (kWh)	21.2
GEAR BOX	
Type	Direct Drive
No of Forward Ratios	1
Gear Ratios	10.83:1

Table 7
I.C. Engine vehicle specification.

I.C. ENGINE VEHICLE	
Engine	1.4L MPFI
Displacement/Cubic Capacity	1390 cc
Type	4 Stroke
Bore x Stroke	79.5 × 70.0 mm
No of Cylinders	4
Compression Ratio	9.5:1
Max. Engine Output (kW @ rpm)	65 Bhp @4000 rpm
Max. Torque (Nm @ rpm)	160 Nm @2000 rpm
Power/Weight Ratio	57.01 Bhp/ton
Torque/weight ratio	140.35 Nm/ton

fuel consumption performance. Further, this average mileage was considered and the emissions were calculated for per 100 km distance.

4. Results and discussion

In the present study, the degree of viable implication is mathematically derived. The degree of viable implication indicates the sustainable switch of ridership from I.C. engine vehicles to electric vehicles. It includes the emission index of electric vehicle and I.C. engine vehicles. All the emissions involved in all activities from coal mines to wheel for electric vehicle and oil well to wheel for I.C. engine vehicles, as well as exergy destructive in both the cases are considered in the analysis. The electric vehicle and I.C. engine vehicle of the same configuration (Mahindra Verito) is taken as a case. The emissions are calculated and compared for I.C. engine vehicle and electric vehicle per 100 km. Finally the degree of viability is calculated and compared for an Indian scenario.

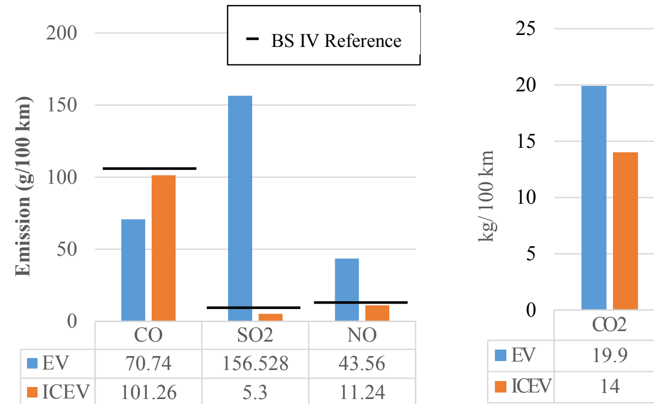

Fig. 6. Emissions comparison of EV and ICEV.

4.1. Emissions comparison

Emission comparison of I.C. engine vehicles and electric vehicle (powered with coal power) is described in Fig. 6. Bharat stage IV (BS IV) emission standards are taken as reference. The comparison results indicate that NO emissions from electic vehicle are 4 times more than the BS IV standards for I.C. engine vehicles. The indirect sulphur dioxide (SO_2) emissions from the electric vehicle are 30 times more than I.C. engine vehicles. According to BS IV standards, there should not be any SO_2 emissions from I.C. engine vehicles [54]. The SO_2 emissions shown in Fig. 6 are generated during the production of fuel for ICEVs and during electric power generation for EVs from coal power plants. The CO emissions are less in electric vehicles as compared to I.C. engine vehicles.The CO_2 emissions from electric vehicles are approximately 40% higher than I.C. engine vehicles. The emissions in coal burning are higher because of the difference in the calorific value of coal and gasoline. The lesser calorific value of coal generates higher emissions.

4.2. Degree of implication viability

The degree of implication viability (φ) for an electric vehicle over I.C. engine vehicle according to the net emissions and energy destructive is calculated and shown in Fig. 7 for different ratios of thermal power to renewable energy. The results indicate that if power generation from thermal power plant share is more than 65%, the viability φ will be more than 1.0. Increase in the thermal power generation share leads to $\varphi > 1.0$, resulting in neither sustainable and nor beneficial in switching to EVs. The results indicate that India's current energy mix ratio of 57% thermal and 43% renewable is somewhat viable ($\varphi = 0.9$) to implement EVs over ICEVs as shown in Fig. 8. This analysis shows that the current situation in India is viable. But the viability score is nearer to 1 and at a verge of non-viability. This means the greenhouse gas emissions will certainly decrease by around 17% if India shifts to electric vehicles as per the current power generation scenario. The viability (φ) is unity at 65% share of thermal power production in the Indian scenario. This implies, at 65% share of thermal power generation, it will not affect the net emission generated but only will shift the emissions from the roads of the city to the thermal power plant regions. These emissions at a power plant can get dispersed due to wind and can spread to the city as well. During the dispersion, the intensity might be more at nearby region than the emissions generated due to I.C. engine vehicles. This intensity might be more harmful to human health. However, further study is required to determine the exact nature of this impact.

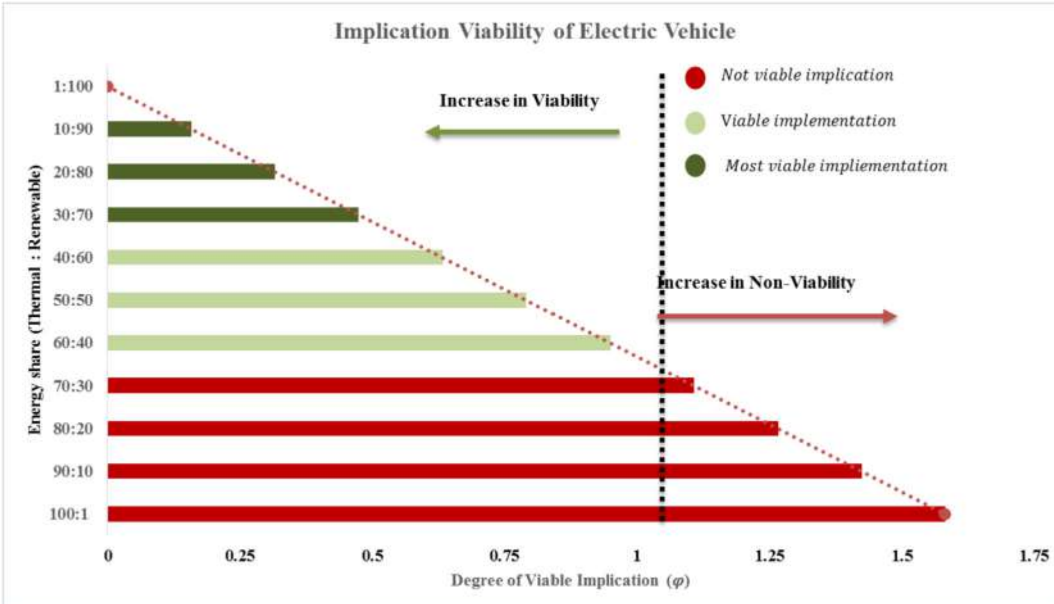

Fig. 7. Implication viability of electric vehicles.

The level of emissions for different degree of viable implications is shown in Fig. 8. The reference line of BS IV is indicated in Fig. 8. The BS IV reference line for SO_2 and NO indicates that these emissions are more when shifting to an electric vehicle at a high share of thermal power generation. The result indicates that these emissions can be decreased by decreasing the share of coal thermal energy generation and increasing the share of renewable energy generation. The CO emission is higher in I.C. engine vehicle as compared to electric vehicle and implies the positive side of shifting to electric vehicle.

The current situation of power generation (Fig. 8) in India i.e. 57% of total power generation is thermal power, corresponds to a degree of viable implication of 0.90. The results reflect that in the current scenario, CO_2 emissions from electric vehicles are 11.58 kg per unit vehicle per 100 km whereas the corresponding CO_2 emissions from ICEV is 14 kg per unit vehicle per 100 km. This corresponds to a decrease in 17% of CO_2 emissions for the current power generation scenario in India. However, the SO_x emissions from electric vehicles are 89.22 g per vehicle per 100 km, which is negligible in case of I.C. engine vehicles nowadays, and NO_x

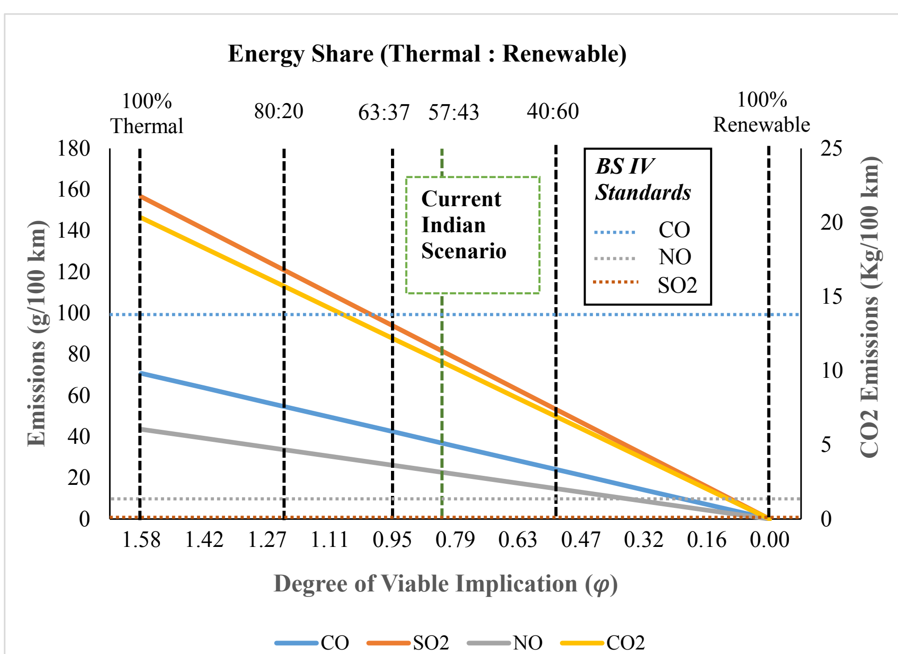

Fig. 8. Emissions per unit vehicle according to the degree of viable implication.

emissions are 24.82 g per electric vehicle per 100 km, which is 1.2 times of NO_x generated from I.C. engine vehicles. If these were tailpipe emissions, they would be violating the current Bharat Stage IV emission standards. In the future, if thermal power generation dependency continues to increase, and reaches 100%, i.e. corresponding to a degree of viable implication of 1.58, the CO_2 emissions are likely to increase to 20.32 kg per unit electric vehicle per 100 km, which is a 75% increase from the current scenario. The NO_x emissions can be brought into the limits of emission standard by increasing the renewable energy share to more than 70% of total electricity generation. According to the BS IV standards, there should not be any SO_x emissions from tail pipe of ICEV. Since the coal power plants are a major source of electricity in India, therefore the SO_x emissions cannot be completely eliminated. However, the SO_x emissions can be decreased at a very significant rate by increasing the renewable energy share, improving the quality of coal and implementing new technologies in thermal power plants of India.

5. Conclusion and recommendation

As India gears up to make the shift from internal combustion engine vehicles to electric vehicles, there is a need to understand its implications on the environment. The electric vehicles, on the one side promises to eliminate emissions along roads, however the additional electricity demand that it will generate may result in an increase in emissions at the power generation source. This study develops a technique to determine the total emissions generated, from oil wells and coal mines to wheels, for both I.C. engine vehicle as well as for electric vehicle. Furthermore, the exergy analysis in this study shows the power loss potential for each of the activities, from fuel extraction to the power delivered at wheels. Subsequently, the degree of viable implication shows the impact on the environment, as a result of the shift to electric vehicle from I.C. engine vehicles. As such, the major conclusions of the study are mentioned below:

- **Introduction of electric vehicle in India will decrease CO_2 and CO emissions**

In the current scenario, the results of degree of viability assessment (φ) show that shifting from conventional vehicle to electric vehicle will lead to an overall decrease in CO & CO_2emissions by 60% and 17% per unit vehicle respectively. However, this decrease in emissions is likely to be greater in the city core as compared to the urban periphery, where the emissions are likely to be greater. This situation may arise because the increase in electricity demand as a result of electric vehicles is likely to increase the load on coal fired thermal power plants, which are situated in the outskirts of urban areas. This in-turn may not have a positive impact on the rural/suburban population of the region.

- **Switching to the EV is not a panacea for reducing all types of emissions**

The power demand for EV will be fulfilled by the power grid mix, which currently is 57% coal, and the rest 43% are a mix of other sources, including renewable sources of energy. The coal power plant generates SO_2 at a very significant rate. The study results reveal that 89.22 g of SO_2 is emitted per electric vehicle per 100 km, whereas such emissions are negligible in the current conventional ICEV fleet. In addition, the 24.82 g of NO_x is emitted per electric vehicle per 100 km, which is 1.2 times more than that of conventional ICEV vehicles. Thus, in the current scenario of energy production mix, the introduction of electric vehicles is likely to increase the SO_2 and NO_x emissions of the region.

- **Power generation scenario renders EV viability at the verge of unsustainability**

The current electricity generation scenario in India is dominated by coal-fired thermal power plants. The implication viability assessment conducted in the study indicates that the degree of viability (φ) of electric vehicles in India is currently at 0.9, which makes the scenario marginally viable for a shift to electric vehicles. As more fleet shifts from conventional to EV, the electricity demand will increase, and a majority of this additional burden is likely to be met by the coal thermal power plants. The study indicates that when the share of coal-fired thermal power production increases to 65%, the degree of viability (φ) will be 1, in which case electric vehicles will no longer be viable for the Indian scenario.

- **EV as a viable option over ICEV in future if power energy grid shifts to clean mix.**

A clean energy grid is a necessity for a sustainable implementation of electric vehicles. A degree of viability (φ) of up to 0.63 can be attained by increasing the share of renewable sources to 60% of total power generation. This scenario will witness a reduction of around 72% in CO and 42% in CO_2 when electric vehicles are introduced. However, there is still a rise of 6.18 g and 57.3 g per unit vehicle per 100 km in the case of NO_x and SO_x respectively. The emission of these gases cannot be completely omitted from thermal power generation but can be decreased by adopting better quality of coal and new technologies to increase the efficiency of the thermal power plant.

Hence, to achieve a sustainable and eco-friendly transition from I.C. engine vehicles to electric vehicles, shifting to renewable energy sources of power generation is a necessity. As a future scope, the methodology provided in the study can be used by researchers for conducting viability assessment of electric vehicles in a more holistic manner at the national level by considering the forecasted data of different proportion and type of electric vehicle fleet. Also, the study provides a platform to researchers to carry out in depth research to analyze the quantitative as well as qualitative effects of "spatial shift of emissions" to the periphery of the city as well as on the environment due to introduction of electric vehicles in the mainstream traffic. Further research will also be required to assess the viability of increasing the energy generation from renewable sources, and their subsequent use by electric vehicles.

Declaration of competing interest

None.

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References

[1] Sharma RD, Jain S, Singh K. Growth rate of motor vehicles in India-impact of demographic and economic development. J Econ Soc Stud 2011;1:137.
[2] Badami MG. Transport and urban air pollution in India. Environ Manag 2005;36:195–204. https://doi.org/10.1007/s00267-004-0106-x.
[3] Andrich MA, Imberger J, Oxburgh ER. Inequality as an obstacle to sustainable

electricity and transport energy use. Energy Sustain Dev 2013;17:315–25. https://doi.org/10.1016/j.esd.2013.04.002.
[4] Martínez-Lao J, Montoya FG, Montoya MG, Manzano-Agugliaro F. Electric vehicles in Spain: an overview of charging systems. Renew Sustain Energy Rev 2017;77. https://doi.org/10.1016/j.rser.2016.11.239.
[5] Dhar S, Pathak M, Shukla PR. Electric vehicles and India ' s low carbon passenger transport: a long-term co-bene fi ts assessment. J Clean Prod 2017;146: 139–48. https://doi.org/10.1016/j.jclepro.2016.05.111.
[6] Gulati V. National electric mobility mission plan 2020. Minist Heavy Ind Public Enterp Gov India 2012. https://doi.org/10.1017/CBO9781107415324.004. 0–186.
[7] Kumar P, Jain S, Gurjar BR, Sharma P, Khare M, Morawska L, et al. New directions: can a “blue sky” return to Indian megacities? Atmos Environ 2013;71:198–201.
[8] Prakash R, Henham A, Bhat IK. Gross carbon emissions from alternative transport fuels in India. Energy Sustain Dev 2005;9:10–6. https://doi.org/10.1016/S0973-0826(08)60488-3.
[9] Shearer C, Fofrich R, Davis SJ. Future CO2 emissions and electricity generation from proposed coal-fired power plants in India. Earth's Futur 2017;5:408–16. https://doi.org/10.1002/eft2.201.
[10] Zhang K, Batterman S. Air pollution and health risks due to vehicle traffic. Sci Total Environ 2013;451:307–16. https://doi.org/10.1016/j.scitotenv.2013.01.074.
[11] Goyal SK, Ghatge SV, Nema P, Tamhane SM. Understanding urban vehicular pollution problem vis-a-vis ambient air quality–case study of a megacity (Delhi, India). Environ Monit Assess 2006;119:557–69.
[12] Gurjar BR, Aardenne JA Van, Lelieveld J, Mohan M. Emission estimates and trends (1990 – 2000) for megacity Delhi and implications. Atmos Environ 2004;38:5663–81. https://doi.org/10.1016/j.atmosenv.2004.05.057.
[13] Elgowainy A, Rousseau A, Wang M, Ruth M, Andress D, Ward J, et al. Cost of ownership and well-to-wheels carbon emissions/oil use of alternative fuels and advanced light-duty vehicle technologies. Energy Sustain Dev 2013;17: 626–41. https://doi.org/10.1016/j.esd.2013.09.001.
[14] Walsh MP. Motor vehicle pollution and fuel consumption in China: the long-term challenges. Energy Sustain Dev 2003;7:28–39. https://doi.org/10.1016/S0973-0826(08)60377-4.
[15] Nielsen. All India study on sectoral demand of diesel & petrol, petroleum planning and analysis cell. 2014.
[16] Wang M, Lee H, Molburg J. Allocation of energy use in petroleum refineries to petroleum products. Int J Life Cycle Assess 2004;9:34–44.
[17] Furuholt E. Life cycle assessment of gasoline and diesel. Resour Conserv Recycl 1995;3449:251–63.
[18] Bharadwaj A. Technological and socio-economic issues in the global automobile industry. Transp Dev Econ 2015;1:33–9. https://doi.org/10.1007/s40890-015-0005-2.
[19] Hooftman N, Oliveira L, Messagie M, Coosemans T, Mierlo J Van. Environmental analysis of petrol , diesel and electric passenger cars in a Belgian urban setting. Energies 2016;3. https://doi.org/10.3390/en9020084.
[20] Ganesan V. Internal combustion engines. McGraw Hill Education (India) Pvt Ltd; 2012.
[21] Baglione Melody, Mark Duty GP. Vehicle system energy analysis methodology and tool for determining vehicle subsystem energy supply and demand. 2007.
[22] Ministry of Statistics and Programme Implementation. Energy Statistics 2018 2018.
[23] Ministry of statistics and program implementation. Energy statistics (twenty fifth issue), vol. 5; 2018. New Delhi.
[24] Mathur R, Chand S, Tezuka T. Optimal use of coal for power generation in India. Energy Pol 2003;31:319–31. https://doi.org/10.1016/S0301-4215(02)00067-8.
[25] World Institute of Sustainable Energy. Future of coal electricity in India and sustainable alternatives. 2013. Pune.
[26] Spath PL, Mann MK, Kerr DR. Life cycle assessment of coal-fired power production. 1999.
[27] Reddy MS, Basha S, Joshi HV, Jha B. Evaluation of the emission characteristics of trace metals from coal and fuel oil fired power plants and their fate during combustion. J Hazard Mater 2005;123:242–9. https://doi.org/10.1016/j.jhazmat.2005.04.008.
[28] Mandal A, Sengupta D. An assessment of soil contamination due to heavy metals around a coal-fired thermal power plant in India. Environ Geol 2006;51:409–20. https://doi.org/10.1007/s00254-006-0336-8.
[29] Agrawal K, Jain S, Jain AK, Dahiya S. Assessment of greenhouse gas emissions from coal and natural gas thermal power plants using life cycle approach. Int J Environ Sci Technol 2014. https://doi.org/10.1007/s13762-013-0420-z.
[30] Ghose MK. Air pollution due to opencast coal mining and the characteristics of air-borne dust-an Indian scenario. Int J Environ Stud 2010:7233. https://doi.org/10.1080/00207230210927.
[31] Andress D, Nguyen TD, Das S. Reducing GHG emissions in the United States' transportation sector. Energy Sustain Dev 2011;15:117–36. https://doi.org/10.1016/j.esd.2011.03.002.
[32] Ghose MK, Majee SR. Assessment of dust generation due to opencast coal mining– an Indian case study. Environ Monit Assess 2000:255–63.
[33] Williams RH. Toward zero emissions from coal in China. Energy Sustain Dev 2001;5:39–65. https://doi.org/10.1016/S0973-0826(08)60285-9.
[34] Chakraborty N, Mukherjee I, Santra AK, Chowdhury S, Chakraborty S. Measurement of CO2 , CO , SO2 , and NO emissions from coal-based thermal power plants in India. Atmos Environ 2008;42:1073–82. https://doi.org/10.1016/j.atmosenv.2007.10.074.
[35] Mittal ML. Estimates of emissions from coal fired thermal power plants in India. Proc Int Emiss Invent Conf Florida, USA 2010;39:1–22.
[36] Mascarenhas S, Chowdhury H, Thirugnanasambandam M, Chowdhury T, Saidur R. Energy, exergy, sustainability, and emission analysis of industrial air compressors. J Clean Prod 2019;231:183–95. https://doi.org/10.1016/j.jclepro.2019.05.158.
[37] Hawkins TR, Gausen OM. Environmental impacts of hybrid and electric vehicles — a review. 2012. p. 997–1014. https://doi.org/10.1007/s11367-012-0440-9.
[38] Rosen MA, Dincer I. Exergy analysis of waste emissions 1999;1163:1153–63.
[39] Zhang S. The second law analysis of a spark ignition engine fueled with compressed natural gas. University of Windsor; 2002.
[40] Van Gerpen JH, Shapiro HN. Second-law analysis of diesel engine combustion. J Eng Gas Turbines Power 1990;112:129–37.
[41] Caton JA. The thermodynamics of internal combustion engines: examples of insights. 2018. https://doi.org/10.3390/inventions3020033.
[42] Sezer I, Bilgin A. Exergy analysis of SI engines. Int J Exergy 2008;5:204–17.
[43] Mann MK, Spath PL. The net CO2 emissions and energy balances of biomass and coal-fired power systems. In: Proc. fourth biomass Conf. Am.; 1999. p. 379–85. Oakland, California.
[44] Wang Yanan, Jiekang W, Xiaoming M. Exergy analysis of cogeneration system for the wind–solar–gas turbine combined supply. Appl Sol Energy 2018;54: 369–75. https://doi.org/10.3103/s0003701x18050213.
[45] Sengupta S, Datta A, Duttagupta S. Exergy analysis of a coal-based 210 MW thermal power plant. 2007. p. 14–28. https://doi.org/10.1002/er.
[46] Ministry of Power CEA. Annual report 2017-2018. 2018.
[47] De Almeida AT, Ferreira FJ, Fong JAC. Standards for efficiency of electric motors. IEEE Ind Appl Mag 2010;17:12–9.
[48] Brown JD. Likert items and scales of measurement. Statistics (Ber) 2011;15: 10–4.
[49] Allen IE, Seaman CA. Likert scales and data analyses. Qual Prog 2007;40:64–5.
[50] Smith WJ. Can EV (electric vehicles) address Ireland's CO2 emissions from transport? Energy 2010;35:4514–21. https://doi.org/10.1016/j.energy.2010.07.029.
[51] Liao F, Molin E, Wee B Van. Consumer preferences for electric vehicles: a literature review, vol. 1647; 2017. https://doi.org/10.1080/01441647.2016.1230794.
[52] Mahindra E-Verito n.d. https://www.mahindraverito.com/everito/discover-the-new-verito.aspx (accessed July 27, 2019).
[53] Mahindra Verito n.d. https://www.mahindraverito.com/(accessed July 27, 2019).
[54] The Automotive Research Association of India (ARAI). Indian emissions regulations. 2018. Pune, India.