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RESEARCH ARTICLE

Analytic assessment of renewable potential in Northeast India and impact of their exploitation on environment and economy

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Abstract

The need for electricity all over the world is enhancing significantly. A major portion of this demand is met by fossil fuels leading to substantial mining, environmental pollution, and increment in global warming. The escalating rate of extraction is declining their reserves at an alarming rate and enhancing their price as well. Thus, it has become essential to shift to alternative resources for power generation. Northeast India has a superfluous reserve of renewable energy which can competently fulfill the electricity requirement in the region. The surplus can significantly contribute to supplying the demand of other states in the country. In addition, the use of clean energy can conserve fossil fuels and expenditure and at the same time can slow down environmental pollution. This paper comprehensively analyzes the potential of perennial assets in this area; projects their economic and ecological benefits; and also makes a brief comparison of the conventional systems with the probable green alternatives. Renewable capacity in this regime is found 66,682 MW out of which 99.51% is yet to be explored and Rs. 5.66×10^{12} will be required to extract them. Utilization of these boons can save 187.39 Mt of combustibles and 648.61 Mt of greenhouse gasses from emission. Capital, energy, and carbon that will be invested during the installation and operation of the systems will be paid back in 3.6, 2.3, and 2.25 years, respectively. The average levelized cost of this unremitting energy will be Rs. 4.80/kWh.

Keywords Northeast India · Renewable potential · GHG emission · Energy conservation · Levelized cost of energy · Economic benefits

Introduction

Electricity is the most preferred form of energy in the modern world. It is globally accepted due to its ease of use and convertibility. Usually, it is generated from primary energy sources like coal, diesel, natural gas, sunlight, and wind. Employment of fossil fuel for power generation has a threefold effect—(i) pollution of the environment (Sahu et al. 2021); for generation of 8543 GWh in 2009–2010, the emission of CO2 was 0.43 kg/kWh (cBalance Solutions Pvt. Ltd. 2013); (ii) depletion of their reserve; and (iii) significant expenditure on purchase, which otherwise could have been used for other noble causes. On the contrary, renewable energy is clean and eternal. A generating station using these resources is free from fuel cost and also requires minimum maintenance. Consequently, they have a significant impact on the economy and also have a low payback period. So, inexhaustible resources are getting more attention for power generation. Northeast (NE) India is generously blessed with renewable energy sources. There are many rivers, sufficient solar insolation (940 kWh/m2/year (Kalita et al. 2019)), abundant biomass (Sasmal et al. 2012), and considerable wind. Despite such a huge reserve, most of the power is generated from conventional sources. The total installed capacity in the region as of 30 June 2021 is 374199 MW (Wikipedia 2021a), out of which 61.82% (231,319 MW) is generated from natural gas, coal, and diesel and only 38.18 (142,878 MW) is generated from non-conventional resources (Wikipedia 2021a).

Very limited research has been done on the energy resources in NE India. In a study, Rahman and Chattopadhyay (2019) have investigated the prospective of wind

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power for electricity generation in Manipur. They have found that the mean wind power density is 1.214 W/m^2 which is too low for power generation by conventional horizontal axis wind turbine. In a similar work, Rahman et al. (2020) have assessed the feasibility of wind power generation in Shillong, the capital city of Meghalaya. They have observed that the daily mean wind speed varies between 0.5 and 3 m/s, monthly wind power density ranges from 1.42 to 28.26 W/m^2, and yearly average wind power density is 28.26 W/m^2.

Some researchers were interested in solar energy. Maisanam et al. (2020) have estimated global solar radiation descending at Silchar (an important city of Assam) using statistical analysis. They have noticed that considerable solar power averaging 4231.5 W/m^2/day is received at the site. In another work, Kalita et al. (2019) have made a study on the feasibility of installing megawatt range grid-connected solar PV (SPV) in the state capitals of NE India. They have concluded that seven out of eight sites are technically and economically suitable for such installations.

Some other scientists preferred working with biomass. Taran et al. (2016) have identified the species of fuelwood plant and their utilization pattern by the Halam community of Tripura. They have selected 22 species and assessed their preferences as fuelwood by estimating the total value index and fuel value index. Sasmal et al. (2012) have characterized lignocellulosic materials—areca nut husk (*Areca catechu*), moj (*Albizia lucida*), and bonbogori (*Ziziphus rugosa*) for energy production. The results show that the calorific values of the biomasses were in the range of 17 to 22 MJ/kg. In a different work (Saikia et al. 2007), the investigators have carbonized eight selected bamboo species to determine the yield of charcoal, tar, gas, and condensable liquid. It was found from the experiment that the carbon content of the samples was low and, hence, was suitable for charcoal production meant for domestic purposes only.

Some scientists in other parts of the world have also shown interest in subjects related to the present topic. Sharifzadeh et al. (2019) have made a case study on the interaction between the electricity-water nexus and greenhouse gasses (GHG) footprint regarding geographical observations in China. Vidinopoulos et al. (2020) have exposed the sustainable prospect in ASEAN countries by inspecting the gaps between the energy mix and 100% dependence on them. Gorgulu (2019) has carried out research to ensure electrical energy security in TR61 dominion of Turkey at reduced hazardous effects. Shorabeh et al. (2021) have identified the optimal site for the establishment of solar, wind, biomass, and geothermal-based farms in the eastern realm of Iran. In a similar work, Wojtarowski et al. (2021) have explored possible locations for marine power generation in the north of the Yucatan Peninsula, Mexico. They have analyzed the environmental impact in Río Lagartos Biosphere Reserve and the approach of local inhabitants towards the implementation of ocean energy devices.

The renewable potential of NE India is multiple times its necessity. Their extraction can power other states following the demand of the localities. A comprehensive investigation is essential to expose the state-wise, source-wise, and total capabilities of green resources in this zone. Hitherto no prior literature has reported making in-depth exploration and analysis of them. Moreover, the benefits of their entanglement have not been estimated anywhere yet. This knowledge gap is identified as the scope of the work. The present research endeavors to showcase the possibilities of green power generation in the region and reduction in emission and expenditure. The payback period and return on investment of different parameters have also been calculated in the paper.

The analysis and discussions made in the paper focus on the following points pertinent to NE India:

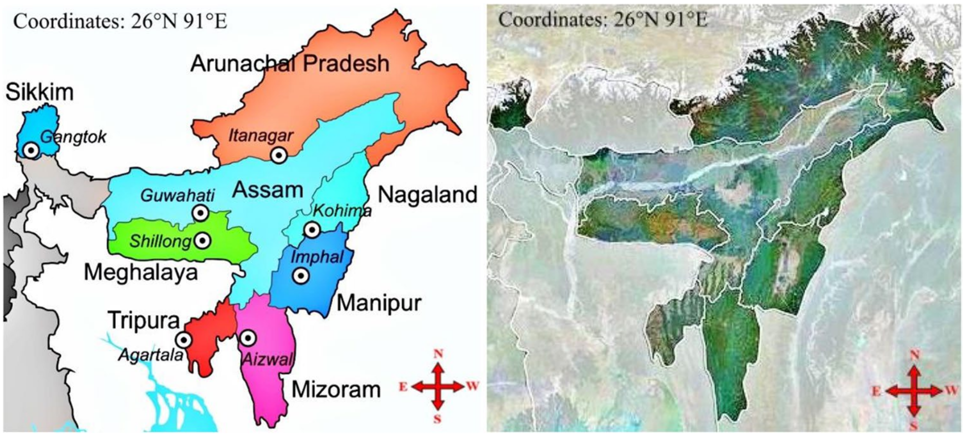
- The capabilities and utilization of energy resources for power generation
- Effects of using fossil fuels and the competence of alternative sources in meeting the electricity demand
- Probable economic and environmental benefits
- The feasibility of harnessing the inexhaustible resources and the possibility of complete dependence on them

Study area

NE India is comprised of Tripura, Sikkim, Nagaland, Mizoram, Meghalaya, Manipur, Assam, and Arunachal Pradesh. The political demarcation is shown in Fig. 1a (Wikipedia 2021b) and the satellite view in Fig. 1b (Alamy 2016). This territory is spread over 262,179 km^2 with a population density of 174 persons/km^2 (North Eastern Council Secretariat 2015). Two-third of it is hilly terrain (visible in Fig. 1b) with altitude ranging from sea level to 23,000 ft above mean sea level (MSL). This province experiences high seismic activity with heavy rainfall. These hostile conditions are responsible for its slow development.

Per capita electricity consumption is a distinguished parameter to ascertain the development of any jurisdiction. NE India is underdeveloped which is evident from its low average electricity consumption of 300 units per capita (Centre for Science and Environment 2016) compared to 1075 units per capita of the country in 2015–2016 (Central Electricity Authority 2016). The sluggish growth rate is apparent from the meager increment in per capita consumption of 2 units from 2012–2013 (298 units (Forum of regulators 2014)) to 2016 (300 units (Centre for Science and Environment 2016)). There are 8,790,913 households in this belt (North Eastern Council Secretariat 2015), out of

Fig. 1 Northeast India. **a** Political map; **b** satellite view



(a) Political map (b) Satellite view

which 91.96% have electricity supply (IIPS 2016) and the rest 8.04% are deprived of it. The national stats are worse; among the 1.35 billion population, more than 240 million (18.52%) do not have access to electricity (Acharya et al. 2021). The starvation of power is mainly due to (a) difficulty in extending utility connections owing to the antagonistic topography, (b) less exploitation, (c) lack of proper planning, and (d) remote location and inaccessibility.

Demand and generation—NE vis-à-vis country

Load generation balance reports of the central electricity authority (CEA) show that the peak demands of the whole country were 135,918 and 148,166 MW for 2013–2014 (CEA 2014) and 2014–2015 (CEA 2015), respectively. Out of these, 129,815 MW (CEA 2014) (95.5%) and 141,160 MW (CEA 2015) (95.27%) were supplied. It means that there was a shortfall of 4.50% and 4.73%, respectively. The peak demands of the NE region for those years were 2164 (CEA 2014) and 2528 MW (CEA 2015) of which 2048 and 2202 MW were supplied with a deficit of 5.4% (CEA 2014) and 12.9% (CEA 2015), respectively. In 2013–2014, the requirement and availability of power in the area was 1.26% and 1.23% (CEA 2014) of the country, whereas it had increased to 1.33% and 1.26% (CEA 2016) by 2014–2015. The zonal and national demand–supply scenario of the last 2 years is pivoted in Table 1 (CEA 2019, CEA 2020).

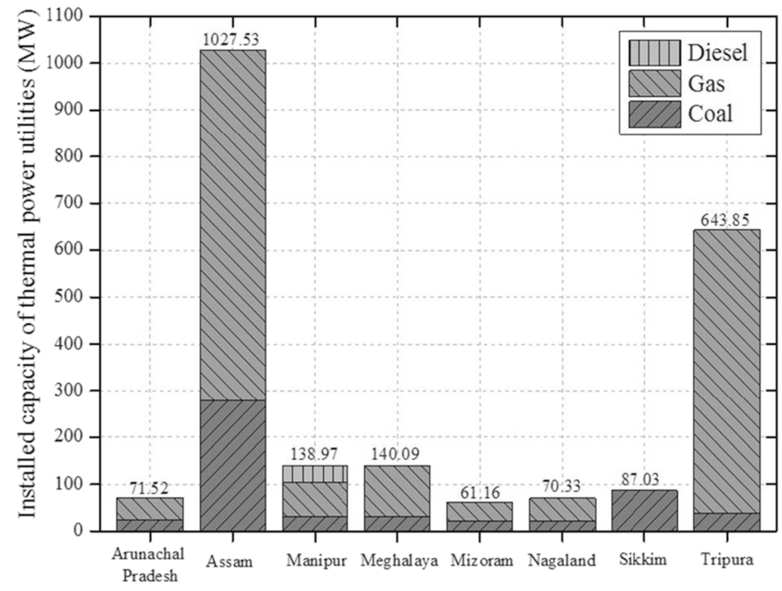
The situation of the study area in terms of exhaustible sources

NE part holds the fifth rank in petroleum and natural gas of India's total reserve (CDPS 2020). The estimated storage of coal, crude petroleum, and natural gas as of 31 March 2017 is 1.69 billion tonnes, 163.93 million tonnes, and 195.69 billion cubic meters (Central Statistics Office 2018), respectively. So, these are mostly used for electricity generation in this enclave. Associated information is graphically presented in Fig. 2. The fuel-wise generating capability of each state is presented in Fig. 2a. It is seen in the figure that the generating stations in Arunachal Pradesh, Assam, Meghalaya, Mizoram, Nagaland, and Tripura are based on coal and gas. On the contrary, Manipur has coal, gas, as well as diesel-based power plants, whereas Sikkim has only coal-based utilities. The contribution of each fuel in power generation is shown in Fig. 2b. Natural gas is observed to be the leading contributor (74.65%). Figure 2 c depicts the annual expenditure on these fuels for the generation of electricity. As seen in the figure, the maximum spent on individual combustible is Rs. 20,956,928,644.57 (gas), and the cumulative investment is Rs 44,002,950,281.30.

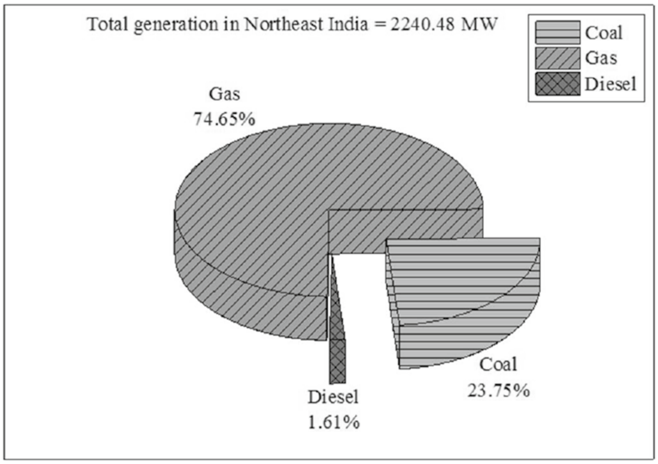
Table 1 Status of load and generation in NE and the country

Year	Jurisdiction	Energy (MU)			Peak (MW)		
		Required	Supplied	Deficit	Demand	Met	Deficit
2018–2019	NE	16,691	16,219	472	2,967	2,850	117
	India	1,274,595	1,267,526	7070	177,022	175,528	1494
2019–2020	NE	16,591	15,984	607	2,989	2,878	111
	India	1,291,010	1,284,444	6566	183,804	182,533	1271

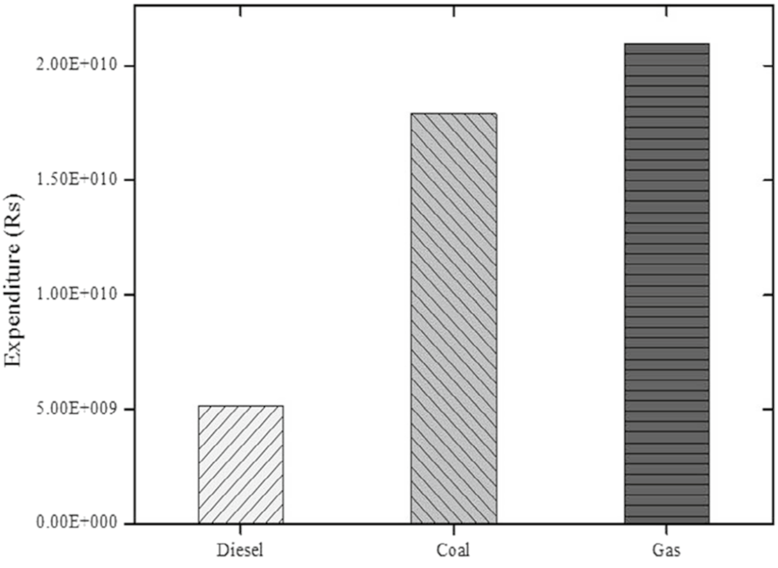
Fig. 2 Fossil fuel dossier. **a** State-wise installed capacity, **b** share in generation, and **c** expenditures on purchase



(a) State-wise installed capacity



(b) Share in generation



(c) Expenditures on purchase

The situation of the study area in terms of renewable energy

NE India has an abundance of sustainable energy as well. The estimated stock (considering wind power at 80 m) is 66682 MW (Central Statistics Office 2018) which is 39.43% of the total demand of the whole country in 2017–2018. The most omnipresent non-conventional resources are solar, wind, hydro, and biomass and, hence, are considered in this paper.

Reserve and extortion

The renewable energy program in this place was initiated in the early eighties but gained popularity during the nineties (Palit 2003). State-wise storage and extraction of each resource are portrayed in Fig. 3.

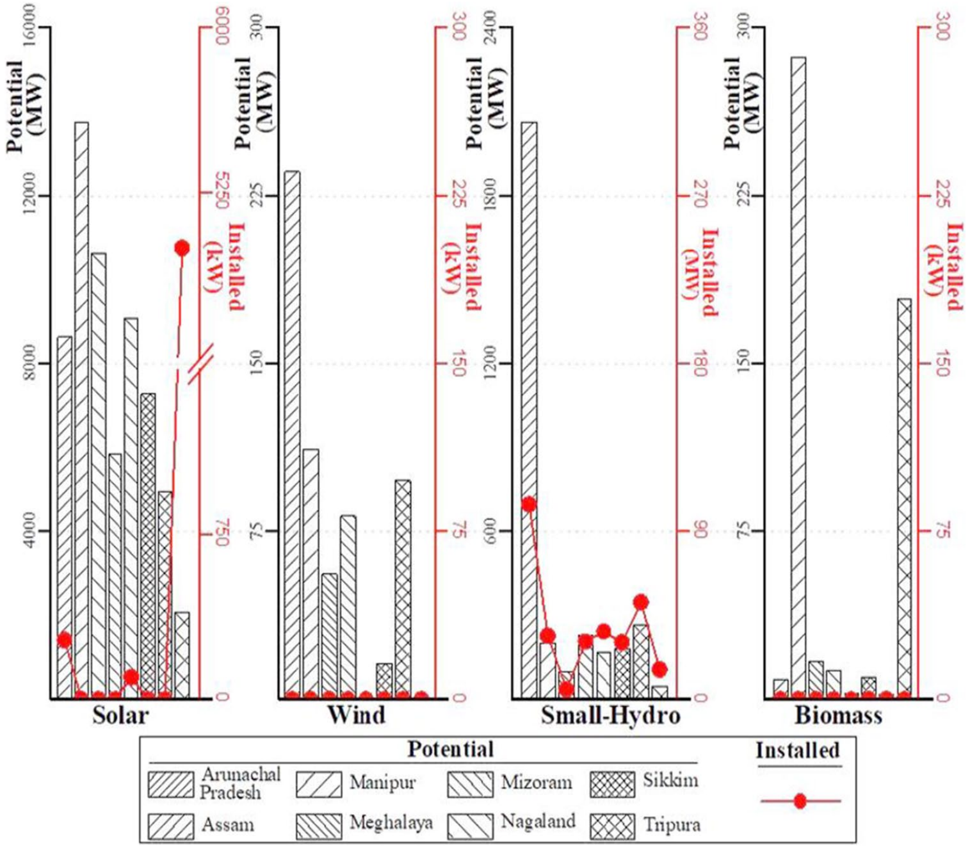
It is evident from the figure that, solar is the mightiest energy source having a cumulative ability of generating 62,300 MW. Yet, it is one of the most unexplored resources; merely 0.0086% is being captured. It implies that complete exploitation of this resource alone can yield electricity exponential to the demand of the territory. Although Assam has the highest cache of 13,760 MW, there is no grid-connected utility. On the contrary, Tripura receives the lowest sunshine (2080 MW) yet generates the highest (5 MW). Only two more northeastern states, i.e., Arunachal Pradesh and Mizoram are producing solar power. They are generating 0.27 and 0.1 MW from their treasure of 8650 MW and 9090 MW, respectively.

Hydropower has the second highest prospective with 2599 MW. Water bodies like Brahmaputra and Barak make it apposite for hydel power generation. Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura contribute 5.07, 16.89, 5.45, 13.49, 21.58, 16.85, 19.52, and 34.06%, respectively, of their capability for the collective production of 310.47 MW. Though it is merely 9.52% of the total available hydel power, yet, it is the highest utilized resource in the zone.

There is no wind power at the height of 100 m (Central Statistics Office 2018), but 600 MW can be harnessed at an altitude of 80 m (Central Statistics Office 2017). Although the states are small and close to each other, there is an uneven distribution of wind power. Arunachal Pradesh has the highest (236 MW), whereas Tripura and Mizoram do not have at all. Despite considerable zonal availability, generation is zero. The percentage of used and unused resources is shown in Fig. 4 and state-wise unexplored capacity is consolidated in Table 2.

From Fig. 4, it is evident that a negligible amount (0.49%) of inexhaustible resources has been exploited until today;

Fig. 3 State-wise availability and exploitation of different renewable resources



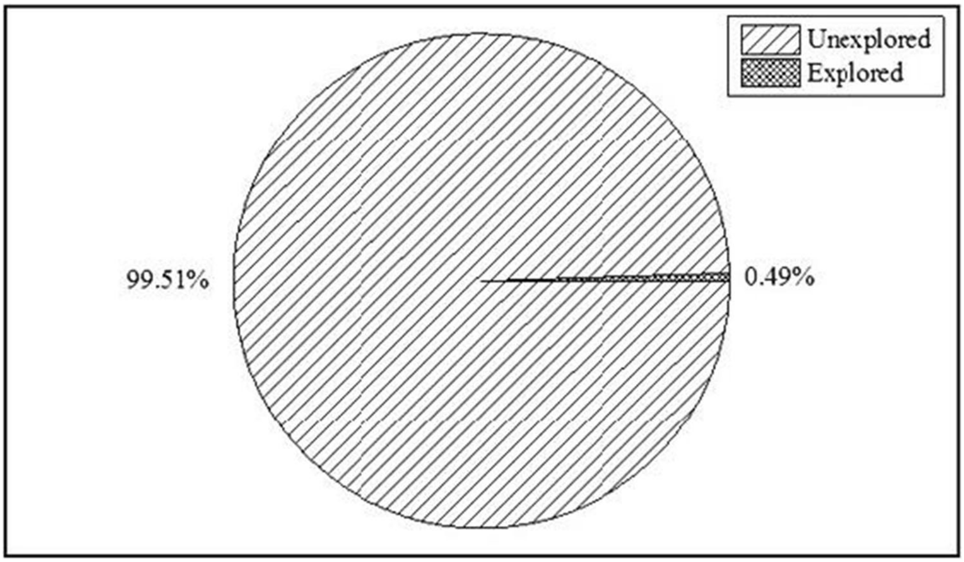


Fig. 4 Explored and unexplored renewable resources

Table 2 State-wise unexplored resources

State	Unexplored potential				
	Wind power (MW)	Small hydro-power (MW)	Total bio-mass (MW)	Solar power (MW)	State-wise total (MW)
Arunachal Pradesh	236	1960.38	9	8649.73	10,855.11
Assam	112	167.89	287	13,748.2	14,315.11
Manipur	56	94.55	17	10,630	10,797.52
Meghalaya	82	198.97	13	5859.99	6153.96
Mizoram	0	132.53	3	9089.9	9225.43
Nagaland	16	151.33	10	7289.5	7466.83
Sikkim	98	214.89	2	4940	5254.89
Tripura	0	30.99	179	2074.91	2284.9
Resource-wise total	600	2951.53	520	62,282.2	66,353.75

almost the whole potential remained unexplored. From Table 2, it is apparent that the highest amount of unused power (14,315.11 MW) is available in Assam. But from the perspective of percentage, the highest unused resource of 99.95% is existent in Manipur. It is also noteworthy in Fig. 3 and Table 2 that, biomass is not utilized at all in this expanse.

Data and methods used

Coals used in power plants for generation are of poor quality having low gross calorific value (GCV) with high undesired content. They are composed of 5.98% moisture and 38.63% ash apart from other volatile matter. The grades of coals used are D, E, and F having GCV ranging from 4200 to 4940, 3360–4200, and 2400–3360 kcal/kg (BEE 2015), respectively. The GCV of coal and gas considered in this investigation is 4000 kcal/kg and 8890.40 kcal/SCM (Acharya et al. 2020), respectively. One SCM weights 0.76 kg. Therefore, the GCV of gas in terms of kilogram turns out to be 11,697.89 kcal/kg. In this exploration, the GCV of diesel is assumed 10,800 kcal/kg (BEE 2015). Other assumptions and Eqs. (1 to 15) for the evaluation of different parameters are encompassed in Table 3 and Table 4, respectively.

Results and discussion

Emission

GHG plays a vital role in climatic change. They enhance global warming resulting in an increased number of catastrophes. So, to limit this awful discharge and its pernicious effect, an agreement of reducing the global temperature by 2° was signed by 195 countries in Paris on 12 December 2015.

Table 3 Assumptions

Parameter	Fuel	Value	Unit
Share of carbon (BEE 2015)	Coal	41.11	%
	Diesel	84	
	Natural gas	74	
Share of hydrogen (BEE 2015)	Coal	2.76	%
	Diesel	12	
	Natural gas	25	
Share of nitrogen (BEE 2015)	Coal	1.22	%
	Diesel	0	
	Natural gas	0.75	
Sulfur content (BEE 2015)	Coal	0.41	%
	Diesel	3	
	Natural gas	0	
Oxygen (BEE 2015)	Coal	9.98	%
	Diesel	1	
	Natural gas	0	
Mass of one carbon atom (Gelfand Center 2009)		12	Da
Mass of one oxygen atom (Gelfand Center 2009)		16	Da
Mass of one nitrogen atom (Gelfand Center 2009)		14	Da
Mass of one hydrogen atom (Gelfand Center 2009)		1	Da
Price of coal (Acharya et al. 2020)		7234.88/tonne	Rs
Price of diesel (Acharya et al. 2020)		82.79/kg	Rs
Price of natural gas (Acharya et al. 2020)		7.88/kg	Rs
Overall efficiency (Acharya et al. 2020)		33.44	%
The life span of a solar PV system (IRENA 2018)		25	Years
The life span of a wind system (Marimuthu and Kirubakaran 2013)		20	
The life span of a small hydropower system (Goel et al. 2010)		30	
The life span of a biomass system (Purohit and Chaturvedi 2018)		20	
Efficiency solar PV technology (Kittner et al. 2016)		13	%
Efficiency wind technology (Phoenix Energy 2020)		50	
Efficiency small hydropower system (Hatata et al. 2019)		70	
Efficiency biomass system (Indian Power Sector.Com. 2014)		75	
Operation and maintenance cost growth rate		5	%
Discount rate for calculation of LCOE (Deshmukh et al. 2017)		7	%

The principal byproducts of any hydrocarbon combustion are carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), nitric oxide (N_2O), water vapor (H_2O), volatile organic compounds (VOCs), and particulate matter (Pisupati and John 2017). Among them, CO_2, N_2O, and H_2O are the gasses that contribute directly to the "greenhouse effect," whereas SO_2 plays an indirect role. SO_2 in combination with the elemental carbon assists in the formation of aerosols which are very small particles of dust, salt, or liquid droplets. The aerosol increases the thickness and lifetime of clouds by increasing the water droplet concentration and thus contributes to the warming of the atmosphere. In the present research, the suspension of CO_2, H_2O, SO_2, and N_2O are calculated by the molecular mass method. The total emanation is computed by summing up the amount of each gas.

One of the major producers of GHG is the power sector as fossil fuels like coal and natural gas are combusted for power generation. Year-wise energy generation and percentage increment in extrusion for the period of 2009–2010 to 2016–2017 in NE India is depicted in Fig. 5. It is visible in the figure that there is notable growth in electricity production and consequently in the exhalation for the considered period. The generation has increased averagely 917.71 MU per year and emission by 8.55%. The highest and lowest incremental rate of dispensation is observed 10.81 and 5.8% respectively.

Figure 6 depicts the expulsion of different GHG. Figure 6 a shows the ejection for power generation in the year

Table 4 Important formulae and their explanations

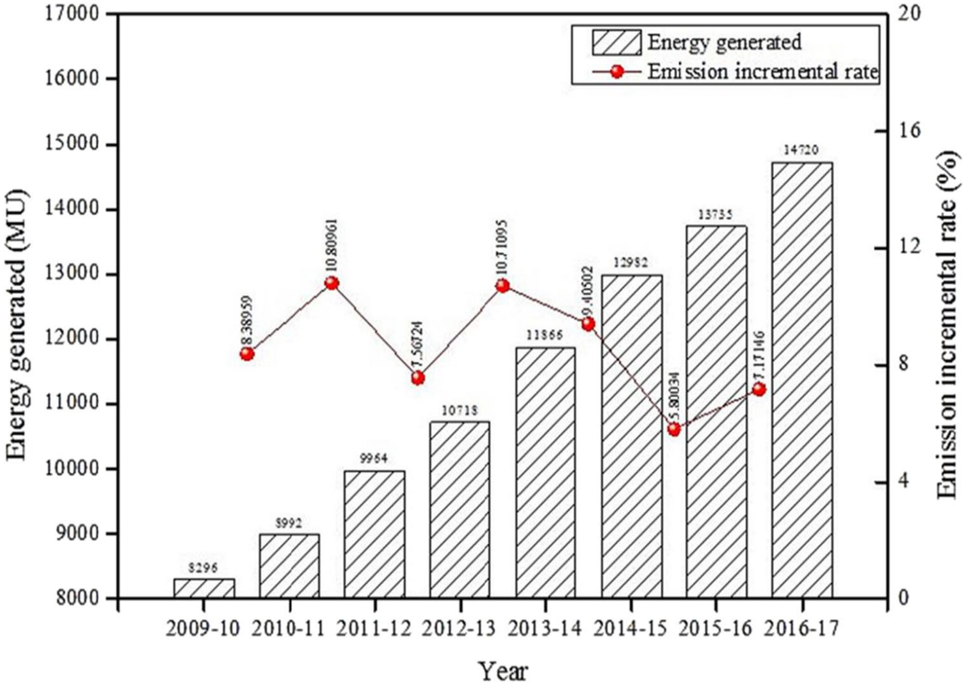
Parameter	Formula	Equation no	Delineation
Total yearly electricity from renewables (E_R) in MU	$E_R = \frac{PP_r \times 24 \times 365}{10^6}$	1	“PP_r” is the potential power of renewables in kW, “24” is the number of hours in a day, and “365” is the number of days in a year
Share of electricity generated from any fuel source (E_F) in MU	$E_F = F_s \times E_g$	2	“F_s” is the share (in %) of fuel in generated electricity and “E_g” is the total electricity generated by all the sources
Requirement of fuel per kWh generation (F_{ru}) in kg (Acharya et al. 2020)	$F_{ru} = \frac{H_r}{GCV}$	3	“H_r” is the heat rate and “GCV” is the gross calorific value of the fuel
Quantity of required fuel (F_r) in kg (Acharya et al. 2020)	$F_r = F_{ru} \times E_F$	4	
Expenses on procurement of fuel (C_f) in Rs. (Acharya et al. 2020)	$C_f = F_r \times R_f$	5	“R_f” is the fuel cost (Rs./unit)
GHG in kg	$CO_2 = C_m \times \frac{44}{12}$ $H_2O = H_m \times \frac{18}{2}$ $SO_2 = S_m \times \frac{64}{32}$ $N_2O = N_m \times \frac{44}{14}$	6 7 8 9	“C_m,” “H_m,” “S_m,” and “N_m” are the masses of carbon, hydrogen, sulfur, and nitrogen present in the combusted fuel, respectively General formula (Mittal 2012): Liberated GHG weight = total mass of the element in the incinerated fuel × (molecular mass of the emitted compound/molecular mass of the element)
Monetary payback period (MPBP) in years	$MPBP = \frac{I_T}{S_y}$	10	“I_T” is the total monetary expenditure on alteration, and “S_y” is the monetary saving per year in electricity bill
Energy payback period (EPBP) in years	$EPBP = \frac{E_E}{E_g}$	11	“E_E” is the embodied energy, and “Eg” is the yearly generated energy by the system
Carbon payback period (PBP) in years	$CPBP = \frac{C_E}{C_C}$	12	“C_E” is the embodied emission and “Cc” is the yearly prevention
Return on investment (ROI) in %	$ROI = \frac{S_y}{I_T}$	13	
Energy return on energy investment (EROEI)	$EROEI = \frac{E_g}{E_E}$	14	
Levelized cost of energy (LCOE) (IRENA 2018)	$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$	15	“I_t” is the investment expenditure in *t*th year “M_t” is the operation and maintenance expenditure in *t*th year “F_t” is the expenditure on fuel in *t*th year “E_t” is the energy generated in the *t*th year “r” is the discount rate “n” is the life span of the system in years

2016–2017. It is observed in the figure that maximum CO_2 (7.22 MT/year) and H_2O (5.98 MT/year) are emitted from natural gas as the majority of electricity (74.65%) is generated from it. Since natural gas contains an insignificant amount of sulfur, SO_2 expulsion is trivial and, hence, ignored in this paper. Coal acquires the first position in the production of SO_2 and N_2O with 84.48 and 60.21%, respectively. It is also responsible for the production of 33.49% of CO_2 and 9.22% H_2O of their total production. As seen in Fig. 2, diesel is least used for power generation in NE India. As a result, a small quantity of GHG is emitted from diesel. CO_2, H_2O, and SO_2 evictions from diesel are 0.19 MT, 0.07 MT, and 3.73 kT, respectively. Figure 6 b represents gas-wise yearly ousting for the period 2009–2010 to 2015–2016. It is evident from the figure that the greenhouse effect is mainly caused by CO_2 and H_2O. The average deportation of CO_2, H_2O, N_2O, and SO_2 is observed to be 7,845,172,481, 4,695,267,396, 110,989,643, and 16,918,434 kg, respectively. The average yearly accumulated emission from 2009–2010 to 2016–2017 is found 12.67 Mt.

Expenditure on the installation of the unconventional system

Figure 7 shows the probable expenditure for setting up different renewable technologies in NE India. According to a report by the World Institute of Sustainable Energy (WISE) (WISE 2017), the capital cost per megawatt of solar, small hydro, wind, and biomass power plant in India is Rs. 865, 706, 620, and 578 lakhs, respectively. Therefore, to exploit the complete capacity of each of these resources, Rs. 5.39×10^{12}, 2.08×10^{11}, 3.72×10^{10}, and 3×10^{10} will be required, respectively. The total sum that will be capable of exploring the whole energy is Rs. 5.66×10^{12}.

Fig. 5 Yearly generation and emission



Economic and environmental benefit analysis

Total 584,134.32 MU can be trapped per year from these green resources which is thirty-six times the requirement of 16,197 MU (CEA 2016)) in this terrain. For generating at par electricity by a conventional system, a substantial amount of money will be spared, and a significant quantity of GHG will be exhausted. This expenditure and emission can be avoided by exploiting the alternative opportunities in the subdivision. The yearly savings that can be realized is presented graphically in Fig. 8.

Generally, coal, diesel, and natural gas respectively generate 23.75, 1.61, and 74.65% of the total power in this locality. The statistics reveal that the generation in the regime is dominated by natural gas due to its ease and bulk accessibility. Consequently, expenditure and emission associated with it are more. Figure 8 a shows the possible monetary and fuel conservation. In proportion of their share in the generation, 89.24 Mt of coal, 2.24 Mt of diesel, and 95.91Mt of natural gas, (totaling 187.39 Mt) can be preserved. Subsequently, Rs. 1,586,937,916,932 (Rs. 645,642,684,077 from coal, Rs. 185,497,167,591 from diesel, and Rs. 755,798,065,264 from natural gas) can be saved in fuel purchase.

Figure 8 b depicts the GHG exhalation that can be prevented from discharging into the atmosphere. It is seen that natural gas would have released 478.31 Mt which would have been 73.74% of the overall and 2.97 and 50.58 times of emanation from coal (160.82 Mt) and diesel (9.45 Mt), respectively. Expulsion from natural gas is composed of 54.41% CO_2, 45.12% H_2O, and 0.47% N_2O. Coal would have liberated 134.51, 22.16, 3.42, and 0.73 Mt of CO_2, H_2O, N_2O, and SO_2, respectively. Due to limited usage of diesel in the region, exhaustion would have been minimum. It would have expelled 6.90, 2.24, and 0.13 Mt of CO_2, H_2O, and N_2O, respectively. Similar to natural gas, diesel also contains a trifling amount of sulfur, and hence, SO_2 extrication has not been considered. CO_2, H_2O, N_2O, and SO_2 would have contributed 61.93% (401.66 Mt), 37.06% (240.37 Mt), 0.88% (5.68 Mt), and 0.13% (0.87 Mt), respectively, in the anticipated overall shedding of GHG (648.58 Mt). Due to the low sulfur content of the fuels, SO_2 production would have been meager, and hence, they are crowding at the center in Fig. 8b.

Payback period and return on investment

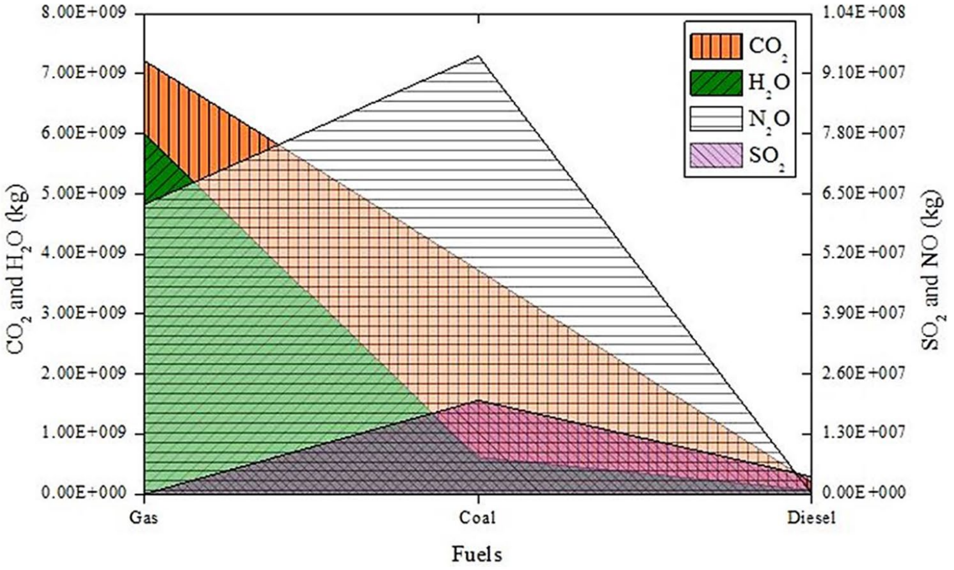
Monetary payback period and return on investment

Monetary payback period (MPBP) and return on investment (ROI) are two crucial techniques for evaluating the economic feasibility of any system (Acharya et al. 2020).

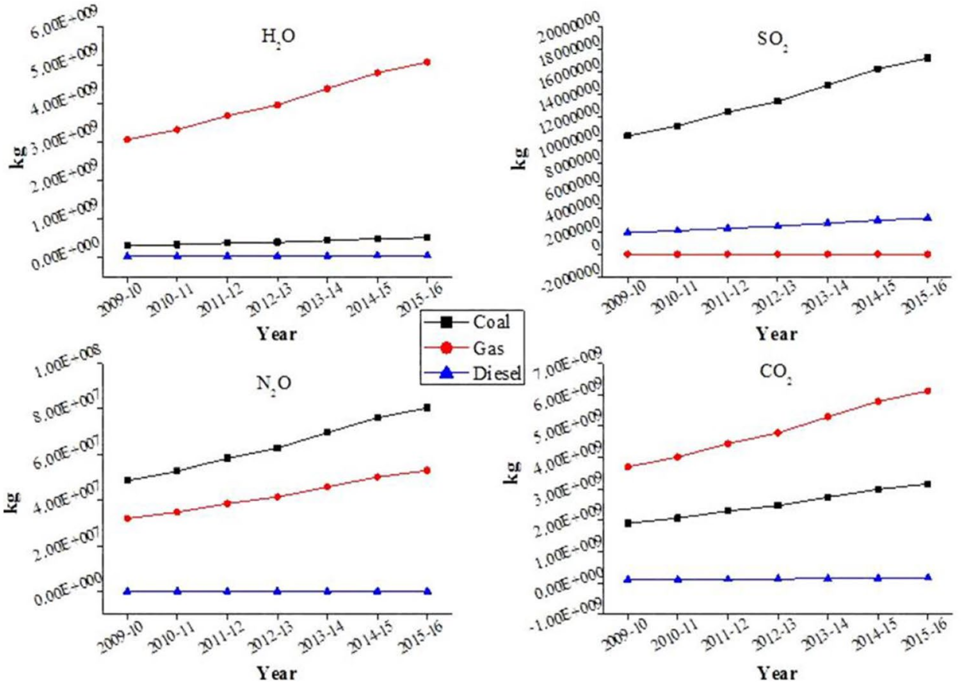
MPBP It is a vital method of computing the duration in which the invested money will be recovered, i.e., the project will break even. If the retrieving time is more than the lifespan of the system, then the project is non-profitable, and it is not judicious to implement that system. The MPBP for implementing clean technologies in NE India is evaluated as 3.6 years.

ROI It is a decisive analytical tool used to estimate the recovery rate. ROI is a ratio that calculates the profits of

Fig. 6 GHG emission. **a** Fuel-wise, for 2016–2017; **b** yearly



(a) Fuel-wise emission for 2016-17



(b) Yearly emission

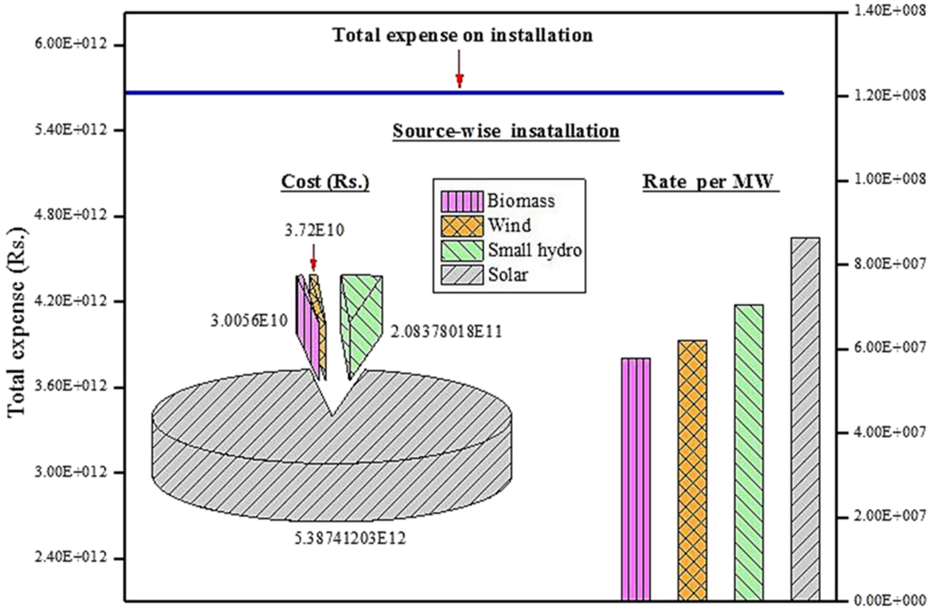
an investment as a percentage of the original cost. It shows how efficiently the money invested in a project is producing a profit. In the present study, ROI is estimated as 28.02%.

Energy payback period and energy return on energy investment

Energy payback period (EPBP) and energy return on energy investment (EROEI) are two parameters that deal with energy and, hence, are very significant, especially for power generating systems. They are used to validate the viability of a system.

EPBP EPBP is the time taken by a system to generate energy equal to the cumulative power invested over its lifecycle. The embodied energy required for generating 1 kW of solar PV, 1 MW wind, 1 kW small hydro, and 1 kW biomass power is 3183.39 kWh (Marimuthu et al. 2014), 30725 GJ (Crawford 2007), 32.77 GJ (Goel et al. 2010), and 70.45 GJ (Yang et al. 2018; Breeze 2010), respectively. With the assumed system

Fig. 7 Installation expenses



efficiency (Table 3), The EPBP for exploring the solar, wind, hydro, and biomass resources will be paid back in 2.80, 1.95, 1.48, and 2.98 years, respectively. If all the embodied energies associated with each technology are considered as a whole, then 2.3 years will be required for its compensation.

EROEI EROEI refers to the ratio of lifetime yield to the life cycle embodied energy of the power plant (Larraín and Escobar 2012). Depending upon the consumption and generation, three conditions may arise.

Condition 1: EROEI is less than unity—It implies that the power plant cannot repay the energy absorbed during its lifecycle. Hence, it is not viable to operate that plant.
Condition 2: EROEI is unity—It means that the power plant will generate as much as it will devour. It will not yield any profit, and thus, power plant having unity EROEI is also not attractive.
Condition 3: EROEI is more than unity—It indicates that the system will deliver more power than it will consume in its lifetime, i.e., it will be profitable in terms of energy to implement a power plant having EROI more than unity.

The assessed EROEI for harvesting solar, wind, hydel, and biomass are 8.94, 10.26, 20.21, and 6.71, respectively. The hydropower plant is observed to have the highest EROEI as it has the second highest potential with the best efficiency. On the contrary, the highest amount of embodied energy (19569.05 kWh/kW) is associated with biomass, and consequently, EROEI is minimum. The evaluated average EROEI for implementing all the technologies is 11.53.

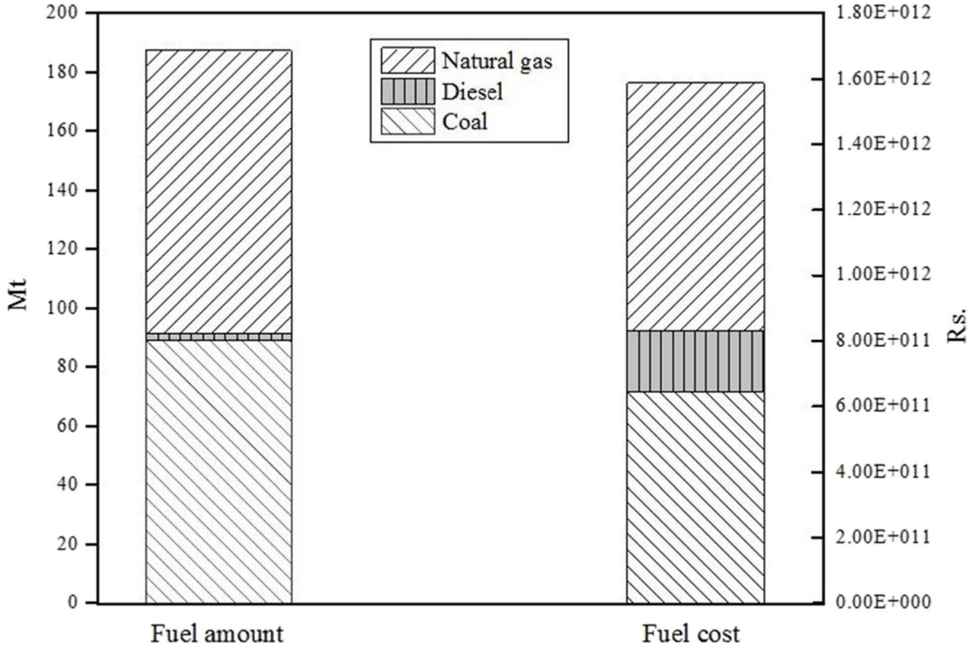
Carbon payback period

GHG in a different form is released during the manufacturing, operation, and decommissioning of a power plant. The carbon payback period (CPBP) is a measure of time taken by a conventional power plant to unleash carbon equal to the lifecycle emission of an alternative system while generating at the same rate. This parameter is essential from the environmental point of view. High CPBP means more emissions and consequently more pollution which is not desirable. The embodied carbon equivalent entailed with solar PV, wind, and small hydro technologies are 666.39 kg/kW (Marimuthu et al. 2014), 4.64 g/kWh (Marimuthu and Kirubakaran 2013), and 18.5 g/kWh (IHA 2018), respectively. Reckoned CPBP for apprehending these resources are 25, 1.52, and 6.08 days, respectively. A biomass gasification system releases 1.08 Mt of carbon equivalent for generating 109 MU of electricity over its lifecycle (Yang et al. 2018; Breeze 2010) which turns out to be 9.91kg/kWh. For entrapment of the biomass energy, 45.14 Mt of carbon equivalent will be emitted, and 8.92 years will be required for its reparation. The total carbon equivalent of all the technologies will be reimbursed in 2.25 years.

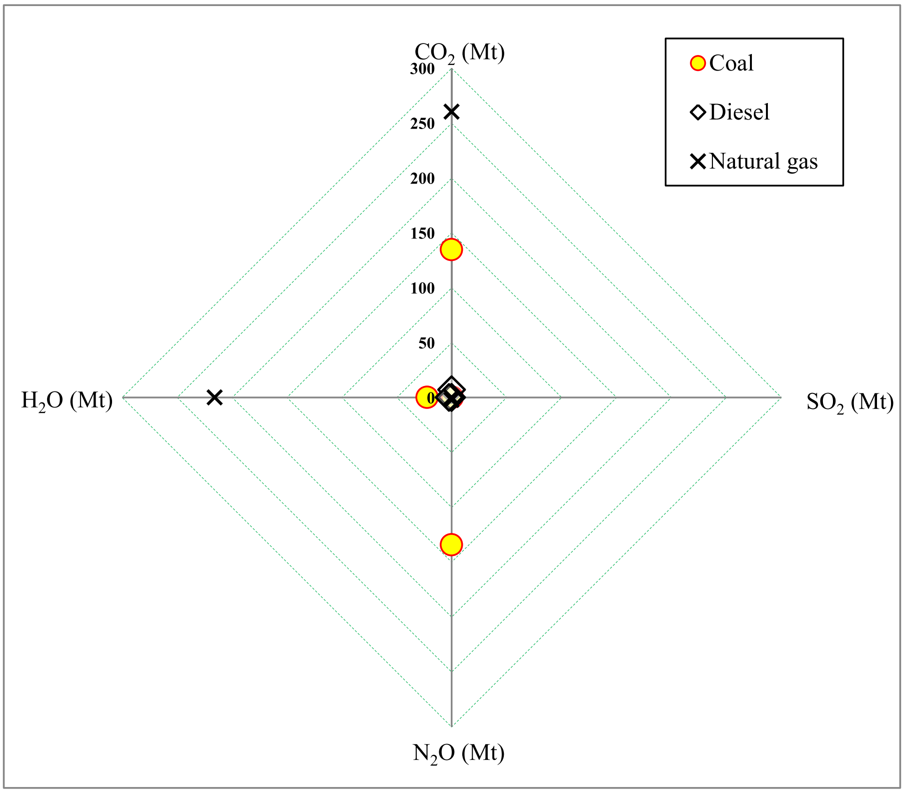
Levelized cost of energy

Levelized cost of energy (LCOE) is the average minimum cost at which the generated energy must be sold to counterbalance the total monetary investment over its lifetime (Ouyang and Lin 2014). It is a vital measurement standard that indicates whether the venture is profitable or not.

Fig. 8 Savings. **a** Fund and fuel; **b** GHG emission



(a) Fund and fuel



(b) GHG emission

Computed results reveal that solar, wind, small hydro, and biomass energy individually will cost Rs. 13.10, 2.63, 2.02, and 1.45 per kWh, respectively; whereas, on average, it will cost Rs. 4.80/kWh.

Conclusion

The paper analyzes the prospective of primary sustainable sources for power generation in NE India. The impact of using traditional fuels and the benefits of using alternative resources has been discussed in the research. It is observed that electricity generation in this part is dominated by conventional fuels. Among these, natural gas is the leading contributor and is responsible for 74.65% of the total electricity in the regime. Purchase of fossil fuels leads to substantial expenditure: annually Rs. 44,002,950,281.30 is spent for that purpose. Moreover, their combustion initiates a profuse emission. An estimated yearly average of GHG exhaustion for electricity generation in the province from 2009–2010 to 2016–2017 is 12.67 Mt.

NE India has proliferated surplus to requirements of inexhaustible energy which can be transmitted to other needy states of the country. The total opportunity is 66682 MW out of which only 0.49% has been extorted up until now. Amid the states, Assam has the highest reserve of 14361 MW followed by Arunachal Pradesh (10,960 MW) and Manipur (10,803 MW), respectively. Resource-wise, solar has the highest capacity of 62,300 MW out of which only 0.0086% has been entangled. On the contrary, hydropower has an ability of 3262 MW but has the highest productivity of 310.47 MW. Even though there is considerable wind (600 MW) and biomass (520 MW), they are yet to be captured. Calculations disclose that, Rs. 5.66×10^{12} will be required to harness the unexplored green potential of the area, and the investment will be paid back in 3.6 years at an ROI of 28.20%. The combination of all the technologies will averagely generate 11.53 times the total energy that will be spent on them. The energy and carbon that will be consumed during the production and installation of different non-conventional technologies will be neutralized in 2.3 and 2.25 years, respectively. Thus, it is apparent from the study that a hundred percent renewable penetration is quite feasible in the power sector of NE India.

Author contribution Not applicable.

Data availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The author declares no competing interests.

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