Prospects of Biogas and Evaluation of Unseen Livestock Based Resource Potential As Distributed Generation in India

Gagandeep Kaur
I.K.Gujral Punjab Technical University Jalandhar, Kapurthala, India

Naveen Kumar Sharma
I.K.Gujral Punjab Technical University Jalandhar, Kapurthala, India

Jaspreet Kaur
Sardar Beant Singh State University, Gurdaspur, India

See next page for additional authors

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Authors
Gagandeep Kaur, Naveen Kumar Sharma, Jaspreet Kaur, Mohit Bajaj, Hossam Zawbaa, Rania A. Turky, and Salah Kamel

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Gagandeep Kaur [a], Naveen Kumar Sharma [a], Jaspreet Kaur [b], Mohit Bajaj [c], Hossam M. Zawbaa [d,e,*], Rania A. Turky [f], Salah Kamel [g]

[a] I.K.Gujral Punjab Technical University Jalandhar, Kapurthala, India
[b] Sardar Beant Singh State University, Gurdaspur, India
[c] National Institute of Technology Delhi, India
[d] Faculty of Computers and Artificial Intelligence, Beni-Suef University, Beni-Suef, Egypt
[e] Technological University Dublin, Dublin, Ireland
[f] Electrical Engineering Department, Faculty of Engineering and Technology, Future University in Egypt, Cairo 11835, Egypt
[g] Electrical Engineering Department, Faculty of Engineering, Aswan University, 81542 Aswan, Egypt

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ABSTRACT

The power sector of developing countries is the backbone of the economy, and robust implementation of energy policies can play a significant role in its expansion. India is blessed to have ample natural resources; the only necessity is to identify these unseen resources comprehensively. India is an agricultural country with plenty of livestock generated biomass, which is renewable and easily accessible in rural India. The paper estimated the potential of electrical energy through biogas production from livestock generated dung in all states of India. Estimation of biogas from the gross livestock dung generation from all states and largely populated livestock species of the country is annually 2633 million tons which correspondingly projects the annual biogas potential of 265,542 million m^3. This magnificent potential unbolts the proposals and implementation of biogas plants as a distributed generation to strengthen India's power sector.

1. Introduction

India, the fastest developing country, is high in economic growth, industrial spread, and energy needs. The major challenge for the authorities is to meet the ever increasing energy demand due to rapid growth in population and rising living standards. India's NITI Aayog, formerly planning commission, initiated the NEP 2017 aims to devise an "omnibus energy policy" to meet the four interrelated goals of achieving energy access at affordable prices, ensuring economic development of India's manufacturing capacity, improving energy security & independence and meeting the goals of greater sustainability [1–3]. As a solution to this, the Indian Government has shown commitment in the 13th five years plan to make an addition of 100 GW from conventional sources, and the target for grid connected renewable electrical energy has been increased to 175 GW (100 GW solar, 60 GW wind, 10 GW biomass, 5 GW small hydro by 2022 [1,4]. The total estimated potential of renewable power in the country is 1,097,465 MW of which solar 68.2%, wind 27.5%, small hydro 1.9%, biomass 1.6%, cogeneration & bagasse 0.5% and waste to energy 0.2% as on 31.03.2020 [1]. The all India installed capacity of renewable power plants is 103,055.25 MW as on 31.10.2021, having a share of installed capacities from central, state and private owners as 1632.30 MW, 2403.27 MW and 99,019.67 MW, respectively. The contributions of renewable energy sources in this installed capacity are as; solar power 476,656 MW, wind power 39,990 MW, biopower 10,176 MW, small hydro 4822 MW and waste to energy 402 MW [2]. Renewable energy in India is fast emerging as the key source

* Corresponding author at: Technological University Dublin, Park House, 191 N Circular Rd, Cabra East, Grangegorman, Dublin D07 EWV4, Ireland.

E-mail addresses: gaganee@ptu.ac.in (G. Kaur), dr.naveensharma@ptu.ac.in (N.K. Sharma), Jaspreetkaur@bcetgsp.ac.in (J. Kaur), mohitbajaj@nitdelhi.ac.in (M. Bajaj), hossam.elsayed@tudublin.ie (H.M. Zawbaa), rania.turky@fue.edu.eg (R.A. Turky), skamel@aswu.edu.eg (S. Kamel).

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Nomenclature

NEP	*National Energy Policy*	P_a	*Animal population*
GW	*Giga watt*	D_d	*Dung/ day (kg)*
TPES	*Total Primary Energy Source*	*i*	*State or UT*
TWh	*Terawatt hour*	*j*	*Animal type*
AD	*Anaerobic Digestion*	*Ns*	*Number of states or UTs*
LPG	*Liquid Petroleum Gas*	*Na*	*Animal species or type*
GHG	*Green House Gas*	e_g	*Quantity of electricity generated (kWh/ year)*
DG	*Distributed Generation*	E_{rg}	*Yet to be converted raw energy in the biogas (kWh/year)*
UT	*Union Territory*	η	*Overall conversion efficiency*
MJ/kg	*Megajoule per kilogram*	E_g	*Biogas in terms of calorific value (kWh/ m^3)*
kWh/ m^3	*Kilowatt hour per meter cube*	m_b	*Quantity of biogas produced (m^3 /year)*
Kg/day	*Kilogram per day*	M_n	*Net cumulative amount of procurable/collectable dung (kg/ year)*
B_{GT}	*Gross theoretical potential of biogas (m^3 / year)*	B_U	*Total rural household utilization (kg/year)*
M_{gr}	*Gross cumulative amount of procurable/collectable dung (kg/year)*	B_{AC}	*Average per capita consumption (kg/year)*
TS	*Total solids (%)*	B_{TP}	*Net theoretical potential of biogas/year m^3*
AC	*Availability coefficient*	B_{SP}	*Surplus potential of biogas/ year m^3*
B_g	*Biogas quantity generated/kg of TS (m^3 / kg)*	B_{UU}	*Utilized potential of biogas / year in m^3 for small off grid biogas plants*
TS	*25% for (large and small animal dung), 29% (pigs)*	N_B	*Number of biogas plants*
AC	*70% (large animals), 20% (small animals), 60% (commercial piggery)*	$B_{C(k)}$	*capacities of biogas plant (m^3)*
B_g	*0.6 (large animal), 0.4(small animal), 0.8 (pig)*		

for power generation, and biomass is the second major energy source.

Bio residue available by crop waste, vegetation, forest residue, agro-industrial waste and organic waste are defined as biomass. India has an abundance of biomass resources in different forms. Their classification is simply based on the way of natural availability as fruits & vegetables, aquatic plants, grasses, woody plants and manures. The categorization of distinct sources of biomass energy is like crop residue, forest, industrial & municipal waste and livestock based bio-waste [5]. Biomass is also the largest source of biofuels such as ethanol, methanol, biodiesel etc. [6–8]. The efficiency of biomass power plant depends on the efficiency of boiler, engine or generator and conversion technique. Generally, the efficiency of biomass plant falls in the range of 30–35%. Livestock (domesticated/ diary animals) based bio waste is dung from livestock, which comprises more excreta and less urine, and still discover its use as an important, renewable plus sustainable sign for production bio-fertilizer, biogas, and dung cakes [9]. Biogas-based energy generation from biomass is more common in rural areas, as the biggest constraint is the non-availability of conventional fuel at the rural level [10]. The greatest benefit of biogas is that it can be extracted from organic matter using AD's economical and straight forward technique. This technique owns the capability of enough amount of yield as practicably usable biogas. Biogas is a renewable and green source of energy with major contributions from methane (60–75%) and carbon dioxide (35–40%) [11–12].

Literature Review: In the last decade, many researchers contributed to bioenergy source identification, potential estimation, assessment, conversion and policy making in the Indian context for the planning of future biomass based renewable energy systems. Singh et al. [13] have mentioned the scope, biomass conversion to energy, biomass potential, i.e. agriculture, agro waste, municipal solid waste, and animal waste, availability in India and cumulative power generation from these biomass sources till 2009. Mula Sigiro [14] investigated the porous carbon derived from banana peels as part of bacterial activity available in natural biowastes. Rao et al. [15] have identified and estimated the biogas generation potential in India as a renewable energy option by including all possible biomass sources, i.e. municipal solid waste, agriculture waste, waste water, animal manure, industrial waste. Batidzirai et al. [16] have evaluated the approaches and methodologies for the assessment of bioenergy potential. Surendra et al. [17] have studied biogas as a sustainable energy source by biomass resources and biogas potential. Singh NB et al. [18] have presented the potential production of biomass from an Indian perspective and its utilization as an energy source. Hiloidhari et al. [19] have appraised the estimation of potential bioenergy from crop residue biomass considering all provinces of India. Kumar et al. [5] have reviewed the installed potential of biomass, conversion technologies and policies in India. Thomas et al. [20] have examined the potential of biomass with its scope and opportunities to boost the Indian economy by adopting proper conversion techniques. Kaur et al. [21] have evaluated and estimated the potential of livestock biomass for biogas and further power generation in provinces of India in 2012. Mittal et al. [22–23] have reviewed the barrier to biomass technologies in India and, in another paper, done the bottom-up analysis of biogas potential in India up to 2040, considering all biomass resources. Agalgaonkar et al. [24] have evaluated various plans for distributed generation configurations like stand-alone, micro grid formations and hybrid operation. Buljit et al. [25] have mentioned technical and economic issues for decentralized generation using biomass gasification techniques in remote areas. Hiloidhari et al. [26] have done the spatial assessment of crop biomass and its power potential in the district of Assam. Deepak et al. [27] have made an optimal selection of distributed biomass power generation locations for decentralized energy planning in the rural region. Soumyabrata et al. [28] have optimized the distributed renewable sources with seasonal variations of load. Giorgio et al. [29] have promoted the energy access initiatives for rural energy users through distributed generation systems' economic aspect.

Research Gap: Previous research on biomass/ biogas resource assessment or evaluation in the context of India was carried for all possible sources, and data projections are short of region/ province wise comprehensive analysis of each source. Research also falls short in long-term biogas data projections, from potential contributor animal dung with a livestock population of 536.67 million [20th livestock census], for future planning and implementation of biomass plants. A research gap exists for thorough estimation of available animal dung sources in all regions of India and its planning as a distributed generation renewable source at the local level.

Motivation: In India, biogas is a boon for rural household applications and acts appreciably for getting better efficiency of cook stoves, small lighting and power generation. Further, with efficient techniques purification and upgradation of biogas up to 98% pure methane content project it as a green fuel. It also contributes to better air quality, avoiding local air pollution, and less dependence on conventional direct biomass fuels. The reduction in methane emission from agro and animal waste is also made through biogas production. The second largest source of GHG emission is methane, following carbon dioxide reporting for 19% of the whole anthropogenic GHG emission in 2012 [30]. Biogas generations may act as a backbone for remote locations, rural areas, or areas suffering from unreliable supplies through distributed generations (DG). Distributed generations are small electric power generation source (a few kW up to 50 MW) that is directly connected to the power distribution network or customer end. The study of this research signifies that it will support the renewable energy power planners for estimating biomass sources as a rich source of energy, for framing policy, project planning and commissioning, installing projects near load centres, and enhancing renewable resource potential in the country.

Organization of Paper: In Section 2, the power scenario of India presents the factual data of the power sector, Section 3 deals with renewable energy scenarios in the energy sector, in Section 3 highlights biomass energy achievements, In Section 4 presents the livestock scenario practiced in the country, In Section 5 discussed the energy conversion technique, In Section 6 problem formulation followed by Section 7 material and methods, Section 8 results and discussions followed by Section 9 conclusions.

2. Power scenario

India's spread is over 328 million hectares, with the seventh-largest land-mass and front runner to become the most populous nation. Presently India's subdivision is based on 36 states/ provinces and union-territories (UTs). The climate is quite conducive to various life formats due to significant geographical and geological features exceptions. These features are added to aquatic, vegetative, animal life forms that have an immense contribution to generating gigantic biomass and can be taken out as potential renewable energy sources. An economic boost has been seen in the last two decades, and projecting India as three times increase in GDP by the year 2040 [21]. In the race of the fastest developing countries, India is the one which is presenting the rapid growing GDP and consumption of electricity. The greatest concern is to accomplish the energy requirements of the ever growing rise of the economy and electricity consumption in a highly populated country. To meet consumers' demand, a smooth flow of electrical energy requires a well coordinated, efficient, robust, and economic system. For the development of this electricity system, it is vital to measure the present energy sources, their generation, identification of new resources, planning of generation and dispersal of generating energy to users end.

India's national energy scenario presents that the total installed capacity is 382,730 MW, out of which capacities of central, state and private sectors are 97,507 MW (25.4%), 103,870 MW (27.1 %) and 181,353 MW (47.3%), respectively, up to 30.4.2021 [2]. The electricity generation from these installed capacities thermal 11,385.33 BU, nuclear 43.880 BU, hydro 140.357 BU, RES 105.01 BU and Bhutan import 7.230 BU (2020–21). The overall grid connected generation including RES in the country has been augmented from 1110.458 BU (2014–15) to 1390.467 BU (2019–20), which includes the contribution from Thermal (230,190 MW), Nuclear (6780 MW), Hydro (45,399 MW) and RES (86,321 MW) up to 31.1.2020. The RES includes solar & wind sources, biomass sources, biomass gasifier, small hydro project, and Industrial waste. In the year 2019–20, the overall generation growth rate is 0.95% which includes thermal falls by 2.75%, and others nuclear, hydro and renewable increase by 22.90%, 15.48% and 9.12%, respectively, and rest compensated by an increase in import from Bhutan by 31.49% [31]. The year-by-year growth in conventional generation and renewable generation is presented in Fig. 1.

The target for generation from conventional sources has been fixed as 1330 BU for the year 2020–21, i.e. growth of around 6.33% over the actual conventional generation of 1250.784 BU for the year 2019–20. With each passing year, the conventional generation is increasing though the overall growth percentage is slightly declining. Energy generation from conventional sources is 1048.673 BU (8.43%) in 2014–15, 1107.822 BU (5.64%) in 2015–16, 1160.141 BU (4.72%) in 2016–17, 1206.306 (3.98%) in 2017–18, 1249.337 BU (3.57%) in 2018–19, 1250.784 BU (0.12%) in 2019–20, 1234.608 BU in 2020–21(-3.4 %0 [2,27]. Table 1 presents the energy requirement/ availability and peak power demand/met status in India.

The total installed capacity from all Indian states and UTs is 377,260.67 MW, and out of this renewable installed capacity is 92,550.74 MW. Figs. 2a and 2b depicts the graphical representation of potential Indian states in total installed capacity and renewable installed capacity till 31.01.2021 [32].

2.1. Renewable energy share in Indian power sector

MNRE, Government of India widely promoted renewable energy generations, and last three years (Fig. 1) have presented a remarkable increase in contributions of renewable generations [33]. The total renewable installed capacity for all states/UTs of India is 92,550.74 MW, with potential states installed capacity is shown in Fig. 2b. At the country level, sectors that contribute to renewable installed capacity are stated (2.72%), private (95.3%) and central sectors (1.89%), private sector players in different states/ UTs are leaders in cumulative renewable capacity. Fig. 3 is evidence of the success of RES programmes through grid connected RES of 92,970.48 MW as of February 2021.

The briefing of achievements in the renewable energy sector as per Fig. 3; in grid interactive power; wind 41.7%, solar 42%, hydro 5%, biomass 11%, waste to power 0.18%. The lower achievements are in the biomass grid interactive and off grid biogas plants, which indicates the potential availability and technical capabilities but lacks implementation.

2.2. Government of India initiative for promotion of renewable energy

To promote renewable energy and capacity addition of 32,713 MW during the 12th plan period in renewable energy-rich states of India, a special comprehensive initiative of the Green Energy Corridor has been implemented. The main focus of the scheme is for evacuation & integration of the renewable energy capacity in potential renewable states of Jammu and Kashmir, Himachal Pradesh, Rajasthan, Madhya Pradesh, Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu. For complete extraction of renewable potential from these states and capacity addition, a new green corridor transmission system for intra-state and interstate has been planned along with control, compensation, storage and Renewable Energy Management Centre. This project aims to synchronize renewable generation with conventional power plants in the grid [31].

The most important link between utilities and consumers is the distribution network. To improve the distribution network, the

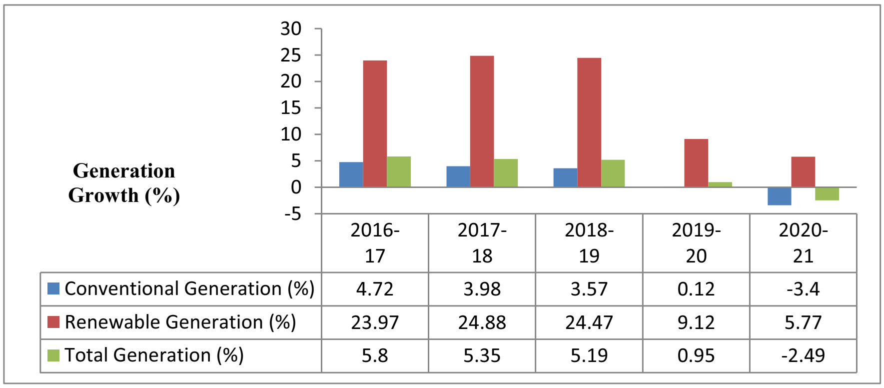

Fig. 1. Generation Growth Percentage in India.

Table 1
Energy Demand / Accessibility and Peak Requirement / Achieved Situation in India.

Year	Energy Demand	Energy Accessibility	Excess (+)/ Shortage (-)		Peak Requirement	Peak Achieved	Excess (+)/ Shortage t (-)	
	(BU)	(BU)	(BU)	%	(MW)	(MW)	(MW)	%
2016–17	1142.929	1135.334	−7.595	−0.7	159,542	156,934	−2608	−1.6
2017–18	1213.326	1204.697	−8.629	−0.7	164,066	160,752	−3314	−2.0
2018–19	1274.595	1267.526	−7.070	−0.6	177,022	175,528	−1494	−0.8
2019–20	1291.010	1284.444	−6.566	−0.5	183,804	182,533	−1271	−0.7
2020–21	1155.130	1150.891	−4.239	−0.4	190,198	189,395	−802	−0.4

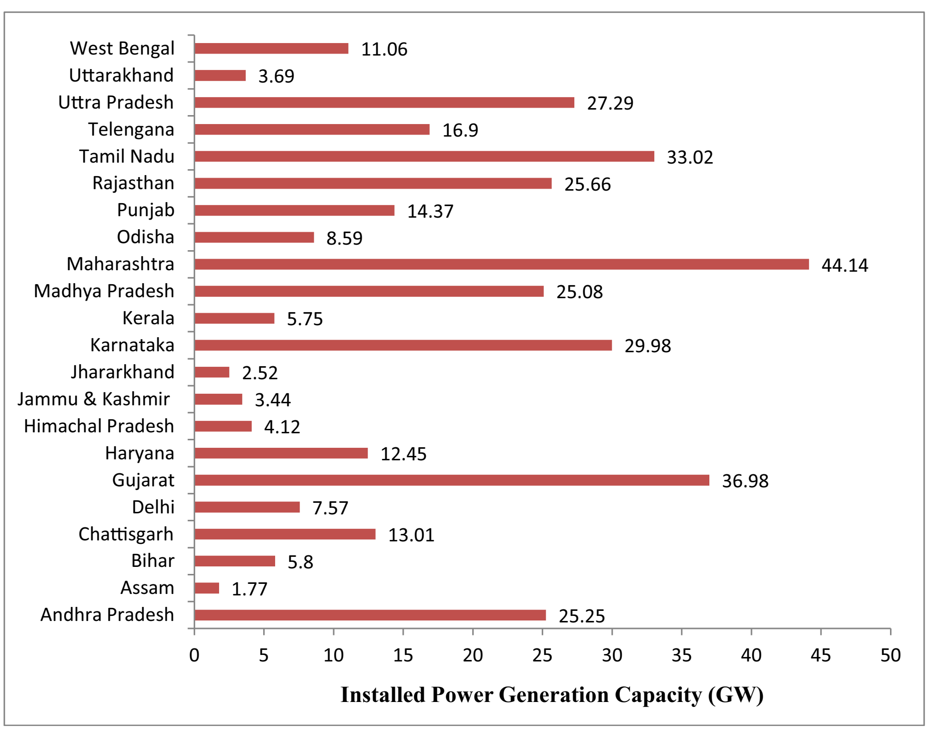

Fig. 2a. Total Installed Power Capacity in Indian States.

Government of India has provided assistance through various central sector schemes. The main objective of the Integrated Power Development Scheme (IPDS) is to strengthen the distribution network by IT enablement of the distribution sector for the 12th and 13th plan. Similarly, the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) Scheme is to strengthen Rural Electrification mainly. GOI launched this scheme for village electrification and providing electricity distribution infrastructure in the rural areas. The Agriculture and Rural Development Departments of the states and dairy cooperatives are in charge of implementing the BPGTP Scheme.

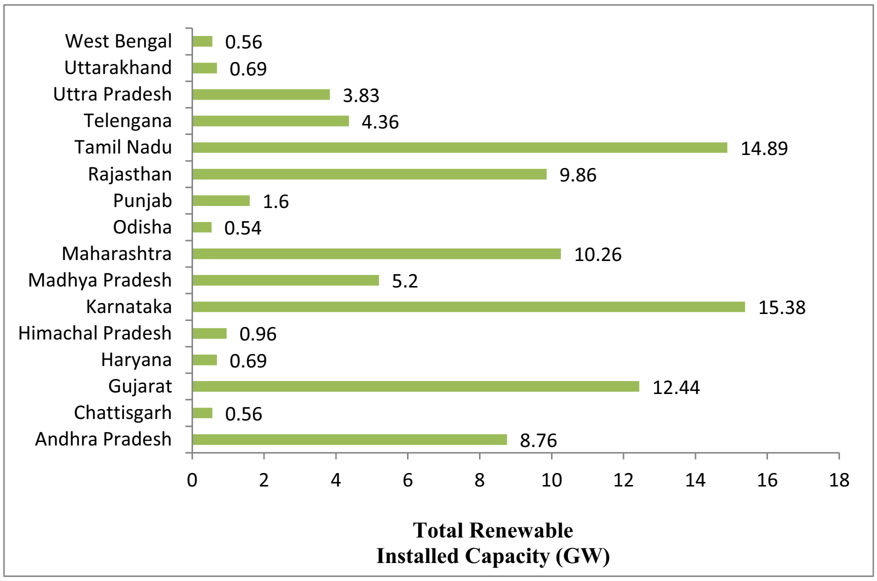

Fig. 2b. Renewable Installed Power Capacity in Indian States.

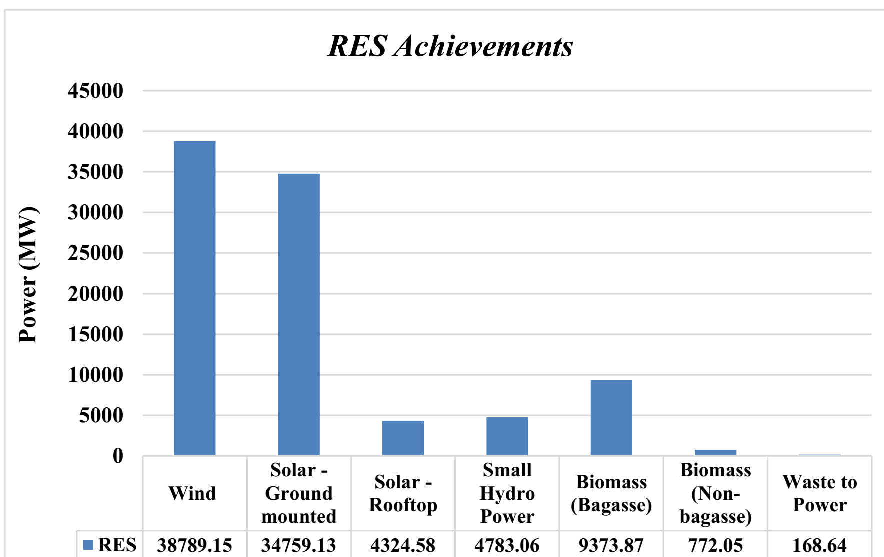

Fig. 3. Grid Connected RES.

3. Biomass energy achievements

Biomass: The socio-economic benefits of biomass have always made it a significant energy source for any country. It is renewable, carbon-neutral, available in a wide range, provides firm energy and the means to offer large employment in the rural sector. India is an agrarian country, with 70% of its population relying on biomass for their necessities, and biomass still accounts for around 32% of total primary energy consumption. Recognizing the potential and numerous functions of biomass energy in India, the MNRE launched a series of initiatives to develop efficient biomass conversion technology for use in many economic sectors, ensuring endless advantages. Biomass power and cogeneration programmes have been created to promote biotechnologies and the most efficient use of biomass for grid-connected power generation. For India, the present biomass availability is projected to be over 500 million metric tonnes per year. According to MNRE research, excess biomass from agriculture and forestry leftovers is expected to be approximately 120–150 million metric tonnes per year, equal to a capacity of roughly 18,000 MW. Bagasse cogeneration generates around 7000 MW of additional electricity from the country's 550 sugar mills [33].

Since the mid-1990s, the concerned ministry has been conducting a biomass power/cogeneration programme; as a result, over 500 biomass power and bagasse cogeneration facilities with a total capacity of 10,145 MW have been erected across the nation to supply electricity to the grid. Fig. 4 presents the total biomass cumulative installed capacity of biomass rich Indian states. Maharashtra is biomass energy leading state with a 2584.4 MW capacity. Fig. 5a presents the states of non-bagasse cogeneration with Punjab at the top with 173.95 MW capacity, and Fig. 5b states with bagasse cogeneration and again Maharashtra is leading with 2351 MW capacity [33–34].

Biogas: Biomass raw materials like crop waste, livestock dung, waste from municipal and sewage, waste from food waste etc., while decomposed in the absence of oxygen produce a gas named

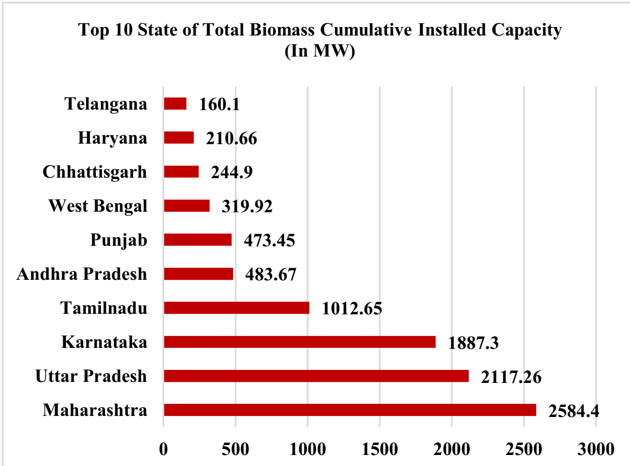

Fig. 4. Installed Biomass Power in Potential Indian States.

biogas, which is a further mixture of methane, carbon dioxide and some traces of hydrogen sulphide. The digested slurry is a by-product and treated as organic rich manure for use in agriculture. Out of these biomass materials, the livestock dung has ample potential for the establishment of biogas plants, considering a livestock population of 536.76 million (20th Livestock Census 2019).

MNRE Inventiveness for Biogas: By executing two Central Sector Schemes under Off-Grid/Distributed and Decentralized Renewable Power, the MNRE played a vital role in stimulating the building of biogas facilities, as shown in Fig. 6. With biomass's convenience, the design and capacity of biogas plants are modified from 0.5 to 1000 m3 unit size or more and several formats of applications for domestic usage, marginal farmers, dairy farmers, and commercial purposes. Based on the requirement and upgradation of technology, the unit size for biogas plants may go up to 15,000 m^3 to 20,000 m^3 productions per day for industrial and municipal wastes. Fig. 7 presents the state-wise cumulative achievements under biogas power (off grid) up to 31.3.2019 [33].

4. Livestock based biomass scenario

In rural India, the livestock sector is a significant source of employment for marginal and landless farmers. This sector meets the daily needs of the people of the country. Livestock has long been a life-saving benefit during emergency periods. Nearby 16.44 million human population is busy with activities of livestock handling. [National sample survey organization 35]. As per the 20th livestock census in 2019, the national livestock population stands at 536.76 million, showing an increase of 4.8% over the 19th livestock census, mainly cows, buffaloes, goats, sheep, pigs and other species [36]. Over time, the steady growth of the human population has resulted in vast amounts of livestock waste. This huge quantum of waste affects the atmospheric air pollution, contamination of ground water, and emits various strong gases like methane and nitrous oxide that can further lead to environmental pollution that causes serious public health issues. This depicts the urgency for the safe disposal of such enormous livestock otherwise organic and concrete scientific measures to stop environmental degradation and remove development barriers. For years, a very efficient way of dung disposal has been adopted in conventional Indian lifestyle by collecting from each house in a bulky mass at tactical areas in the village. Later, this bulky mass with bacterial degradation results in compost used as fertilizer in agriculture farms. The total moisture free form of dung (calorific value of 14 MJ/kg) has already been used for power generation across the globe [37]. The collective waste in the form of animal dung and waste water ranges from 3 to 6000 million tons per day. Generally, widely used practices for dung management are: dumped in open areas, landfill dumping, composting, disposal common effluent treatment plant, family type biogas plants and small biogas plants. The estimation reflects that from such huge dung, only 9% of total livestock generated dung is underutilization for biogas recovery [38]. As a remedial measure for utilization of livestock waste biomass, an eco-friendly, cost-effective and efficient energy technology is the solution to generate energy.

5. Anaerobic Digestion technique

Anaerobic Digestion is the most popular and widely used energy conversion technique among all efficient energy conversion techniques. Because of its competency, it is most suitable for converting dung-based biomass to biogas and then later to electrical energy. AD process deals with the degradation of dung or any other organic matter by microbial movement, transforming it into biogas under anaerobic conditions. The dung is collected in this system, which is already rich in microbes and mixed with required water to form a slurry, and the recovered biogas from this process and later combusted in a combustion engine to generate electricity. The generated biogas has a composition of methane (60–70%), car-

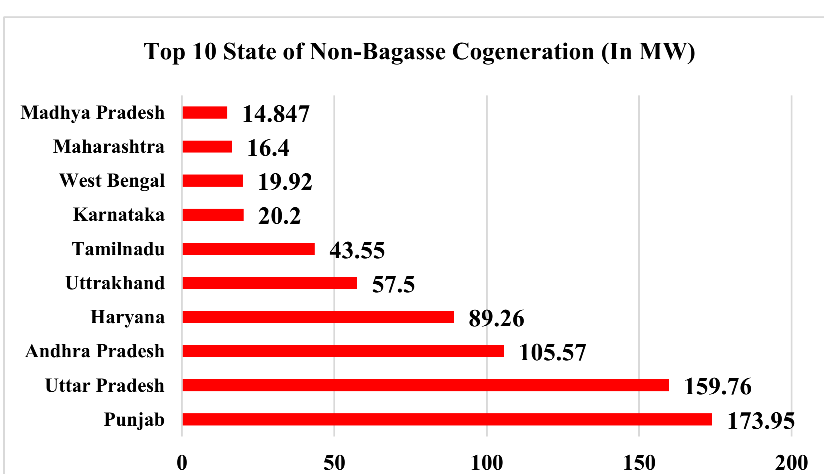

Fig. 5a. Installed Non-Bagasse Cogeneration in Potential Indian States.

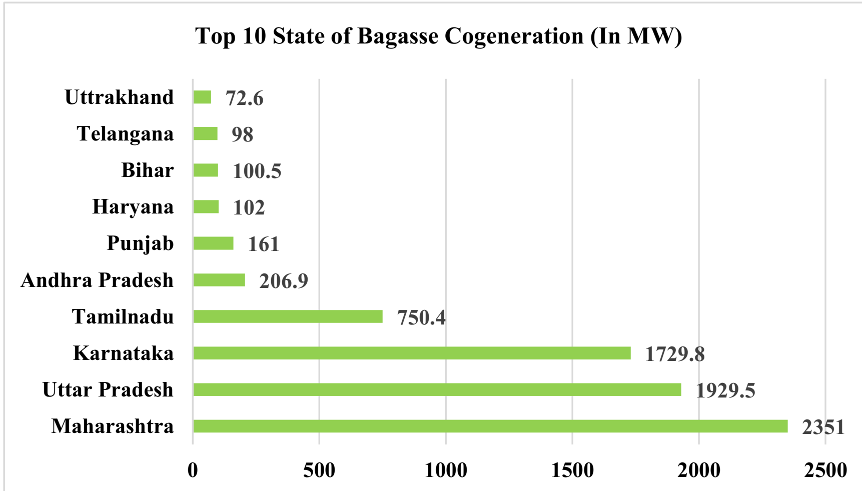

Fig. 5b. Installed Bagasse Cogeneration in the Indian States.

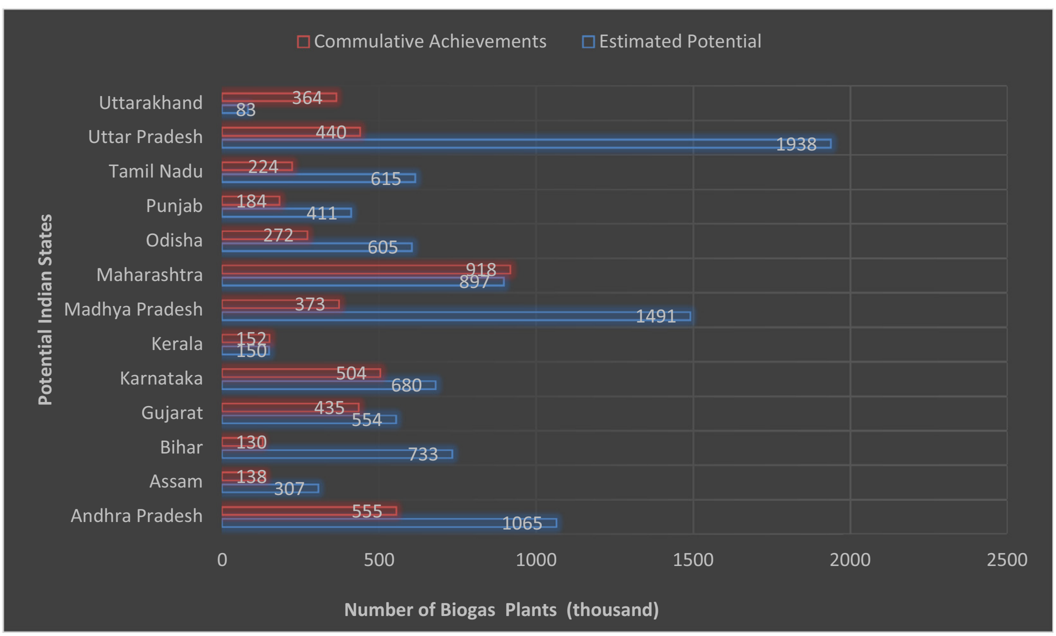

Fig. 6. Potential and Cumulative Achievement for Number of Biogas Plants in India's Potential States by MNRE.

bon dioxide (30–40%), hydrogen sulphide and ammonia (traces) and has a calorific value of 16–25 MJ/m^3 and the electrical energy content of biogas is 5–7 kWh/m^3 of biogas and biogas yield of 0.04 m^3/kg [18,39]. Hence, this technique utilizes produced methane gas as fuel for lighting, cooking and other electricity dependent machines. Experimental studies evident that mixture of dung and water in equal proportion of 1 kg kept for 55–60 days under anaerobic conditions and maintained at an ambient temperature of 24–26 °C yields 35–40 L of biogas [36]. While comparing the renewable energy generation source of biomass with other sources, the biomass alternative is economical as it requires less capital investment and per unit cost of production [16]. This brilliant outcome has raised immense inquisitiveness in biomass resources as a credible candidate for sustainable green energy generation. In the future renewable energy, requirements can be afforded majorly by bioenergy options. The livestock, dairy and poultry industry generates enormous waste on a yearly basis. Indian livestock sector manifest that inexcusable potential of dung biomass waste to energy can significantly meet current energy demand [5]. As a result, it necessitates exploring available livestock dung and its potential to convert biogas and furthering to generate electricity. The conversion of a variety of biomasses to energy has already been done by private agencies and notice to extend sufficient profit to farmers [5]. A comprehensive region-wise study has been carried out to ascertain the potential of biogas production so that recommendations applicable to biomass utilization and management can be formulated. The finding of this exercise may be a pathway for an invaluable and economical source for sustainable green energy.

6. Problem formulation

India being an agricultural country, has immense scope of power generation or other applications from biomass resources. Many researchers indicate the huge potential of biomass in the country, though the absence of standardized modelling for estima-

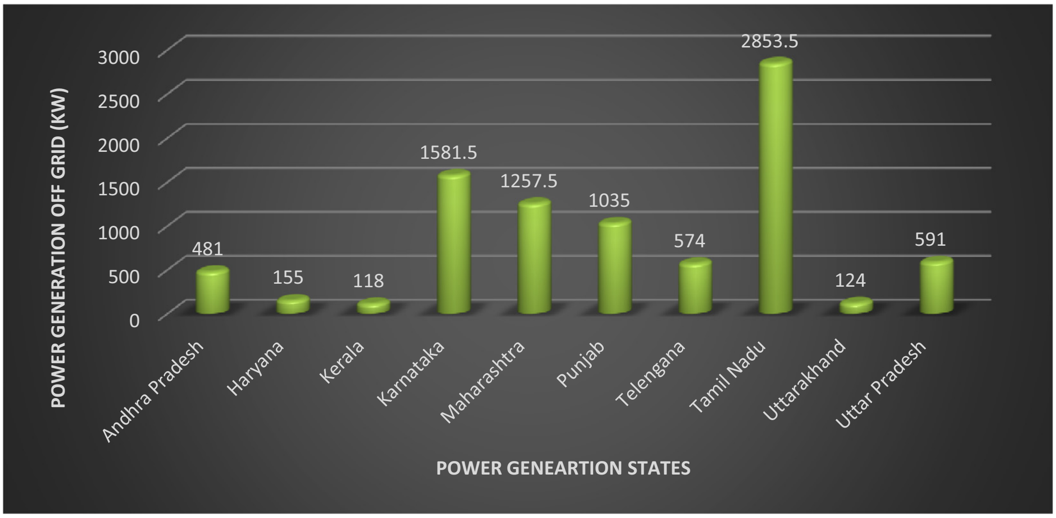

Fig. 7. State-wise Cumulative Achievements under Biogas Power Generation (Off grid).

tion of potential still continues. For precise estimation of biomass or biogas potential in states of India for further power generation projections; it is significant to have a model for power generation in a distributed generation frame. This research aims to strengthen the Indian states for distributed electrical power generation by identifying and proposing a model for unseen biogas resources of livestock dung. Formulation of modelling for estimation of power generation from livestock dung is proposed in this present study.

7. Material and methods

For comprehensive details of biogas production potential in India from the livestock, primary data is gathered from the Ministry of Fisheries, Animal Husbandry and Dairying, India [32]. As per the latest figures available, out of 36 States and Union Territories (UT) in India, 19 key states having a significant quantity of livestock generated waste, whilst 17 States/UTs labelled 'Other States' (Andaman & Nicobar Island, Arunachal Pradesh, Chandigarh, Dadar & Nagar Haveli, Daman & Du, Delhi, Goa, Kerala, Lakshdeep, Manipur, Meghalaya, Mizoram, Nagaland, Puducheery, Sikkim, Tripura and Uttarakhand) have marginal contributions in livestock waste. The statistical data comprises the population of total livestock, mainly including species like cattle, buffalo, sheep, goat, and pig. The less populated species like camels, donkeys, mithun, horses, ponies, yak etc., are not included in this study being scattered and only 1% share of livestock population. Even poultry being volatile has not been accounted for in this study. For estimation of biogas potential from this vast livestock dung, the factors considered for this study are annual livestock dung and average body weight of animal species under study. Other significant parameters have direct inter-dependence with the biogas generation potential total solids and animal dung availability. All relevant calculations for estimation are shown in the following subsections:

7.1. Methodology for gross estimation of generated livestock dung

For the determination of livestock dung produce in the country, the livestock population printed by the Ministry of Fisheries, Animal Husbandry and Dairying, India was accessed. India's current livestock population is 536.76 million (according to the latest 20th livestock census), including cattle/ cow 193.46 million, buffalo 109.85 million, goat 148.88 million, sheep 74.26 million, pig 9.06 million and other species (camel, horses & ponies, donkey & mules, dogs, rabbits, mithun and yak) 11.14 million and graphical representation is in Fig. 8.

The amount of generation of livestock dung habitually depends on many factors like animal species and its breed, animal farming keeping and management practices, ingredients of feed and most importantly weight and size of animal species [41] For the computation of the quantity of dung generation by all livestock; it is categorized by the size to calculate the average amount of dung generation by whole livestock; species were categorized by size like large animals (cattle & buffalo), small animals (sheep & goat), pig and other species. Past researchers identified that average dung generation from each animal depends on the body-weight of that animal such as animals dung range from 10 to 20 kg per day, 2 kg per day, 4 kg per day are cattle/cows & buffalo, sheep & goat, and pig respectively in Asain continent [42]. In the present study, the assumptions regarding body weight (average domesticated breeds in India) and corresponding calculated average dung production/animal/day were taken: for cattle/ buffalo 250 kg, goat/ sheep 40 kg and pig 80 kg; therefore, standard values in average form are 22.5 kg per day kg/day, 1.6 kg per day, and 2.5 kg per day were considered corresponding to above species [43–44].

7.2. Model for determination of biogas potential and power generation capacity

A dung model has been formulated to determine the cumulative biogas production from the animals to set standard procedures that depend on many important parameters: animal type, amount of dung, the typical content of total solid excreted in dung and availability of dung for biogas production. To produce biogas per unit in an idealized manner, uniform ways or techniques for collecting the dung from farms/ sites must be standardized [44–45]. Most importantly, the availability coefficient factor can only be calculated if standardized cumulative biogas volume is known. This feature can be considered and used for calculation for probable biogas yield and the gross cumulative amount of collectable dung determined as per equations (1) and (2):

$$B_{GT=}M_{gr} \times TS \times AC \times B_g$$

$$M_{gr}(i,j) = \sum_{\substack{i=1 \\ j=1}}^{NsNa} P_a \times D_d \times D$$

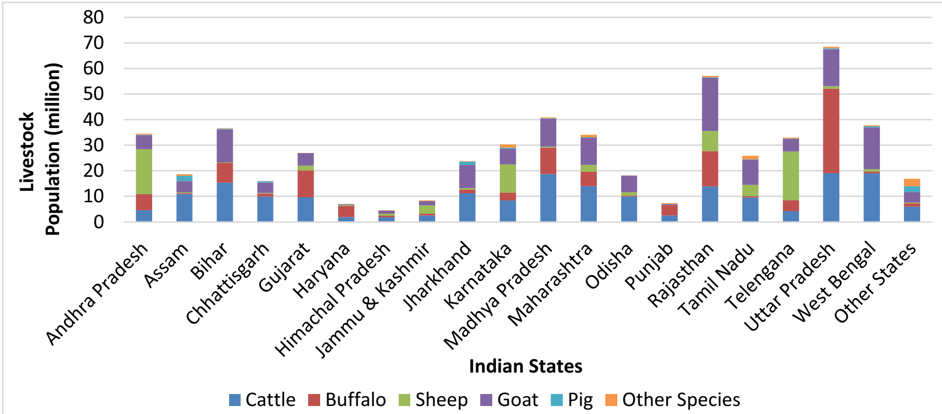

Fig. 8. Species wise Livestock Distribution in the Indian States.

Taken for study, TS = 25% for large and small animals dung and 29% for pigs

AC = 70% for large animals, 20% for small animals, 60% for pigs

B_g = 0.6 for large animal, 0.4 for small animal, 0.8 for pigs

The presence of methane components in produced biogas depends on the kind of dung used for the AD process. Several related works show that the methane component in average biogas recovered is 50%–70% from the AD of cattle dung and 40% to 50% from the AD of small animal dung. In the present study, average values of methane (as per expected Indian norms) content 60% and 45% were taken as probable generations for large and small animals, respectively. Heat conversion from this harvested methane was 90% and represented as heat conversion efficiency practised for boiler, assuming that calorific value of 36 MJ/ m^3 is for methane gas. For the computation of the generation of electricity from produced biogas, the equation is as follows (3):

$$e_g = E_{rg} \times \eta$$

The power plants operated with large turbine system the η value is generally taken between 35% and 42% and plants operating with small generators, η value is 25%. In this study, the assumed value for η was 30% [46]. The quantity of E_{biogas} is computed by using the following equation (4):

$$E_{rg} = E_g \times m_b$$

The assumptions regarding energy content in biogas are 6 kWh/m^3 by considering a calorific value of 21.5 MJ/m^3 biogas [46]. For the effectiveness of this study, multiple factors like biogas policy implications at the national level have been ignored. The main focus of this comprehensive analysis and estimation is to determine the electrical potential exclusively from biogas produced by livestock dung. While considering the utilization of dung at a local level for rural household applications and average per capita consumption of dung per day or consumption of biogas for small power plants, the net dung and surplus biogas are taken as equations (5), (6) and (7):

$$Mn = Mg(i,j) - B_U - B_{AC}$$

Net theoretical potential of biogas/year m^3 (B_{TP}):

$$B_{TP} = M_n \times TS \times AC \times B_g \cdots (6)$$

Surplus potential of biogas/ year m^3 (SPB):

$$B_{SP} = B_{TP} - B_{UU}$$

To compute the electrical energy potential from the surplus potential of biogas/year, the equations (3) & (4) used for gross electrical energy generations can be used. To calculate the number of biogas plants from the surplus potential of biogas equation (8) as per varied capacities of biogas plants as per availability of potential in each state from each animal species or type is as:

$$N_B = B_{SP}/B_{C(K)}$$

Here k means the various capacities of biogas plant in m^3 as per MNRE like 30 m^3 to 2500 m^3 per day, 0.5 m^3 to 1000 m^3 per day and 15,000 m^3 to 20,000 m^3 per day.

8. Results and discussions

8.1. Gross potential sources of livestock dung

According to the 20th livestock census, the potential states with enormous production of livestock dung are projected in Fig. 9. Data projections reveal that the yearly production of dung is nearly 2633 MT which is amazing as produced dung from presenting it as a significant unseen energy source. Out of this figure, the largest dung share 94.6% is from large animals, and the rest 5.4% is the contribution of small animals and pigs. Among the Indian states, the potential states which are producing to maximal dung production per year: Uttar Pradesh (436.40 MT), Madhya Pradesh (246.16 MT), Rajasthan (244.15 MT), Bihar (198.34 MT), West Bengal (172.53 MT), Gujarat (170.00 MT), Maharashtra (169.16 MT), Jharkhand (110.30 MT), Karnataka (104.30 MT), Andhra Pradesh (103.10 MT) considering 100 MT per year as criteria for the potential state. In terms of percentage contribution, the degree of dung production has been calculated as 16.57% Uttar Pradesh, 9.34% in Madhya Pradesh, 9.27% Rajasthan, 7.53% Bihar, 6.55% West Bengal, 6.45% Gujarat, 6.42% Maharashtra, 4.18% Jharkhand, 3.96% Karnataka, 3.91% Andhra Pradesh. In small animals, dung production per annum, the leading state is Rajasthan (17 MT, 12.8%), followed by Andhra Pradesh (14MT, 10.6%), Telengana (14MT, 10.6%), West Bengal (10 MT, 7.5%) and Karnataka (10 MT, 7.5%). Assam occupies the top position with the largest and highest pig dung production per year (2.07 MT, 23%).

8.2. Potential for biogas production and methane

The raw material livestock dung for biogas production has already been recognized as a potential source and plays a significant role in developing country India's renewable generation and sustainable progress. The approximate theoretical estimation of this underutilized source for biogas production is projected in Fig. 10. Overall biogas production of 265,542 Mm^3 was intended as an annual yield measured in a million m^3 (Mm^3) per year. Esti-

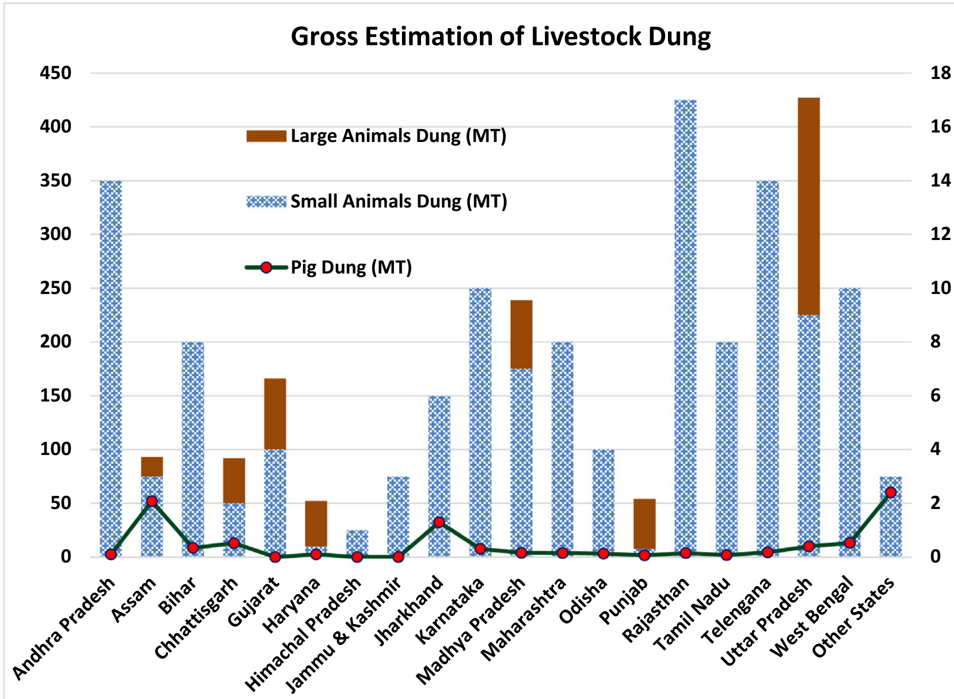

Fig. 9. Gross Estimation of Livestock Dung.

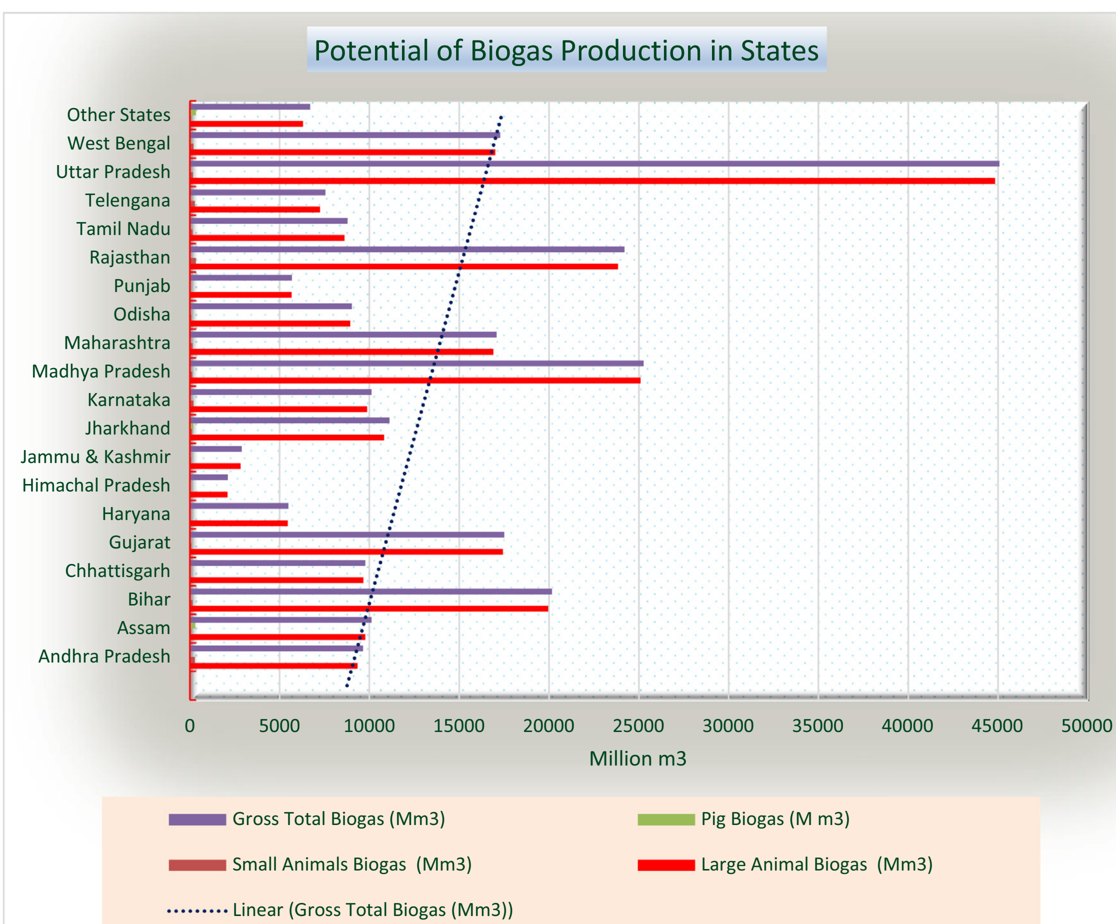

Fig. 10. Total Potential of Biogas Production in the Indian States.

mated yield of biogas per year, the front runner state is Uttar Pradesh (45,071 Mm^3), Madhya Pradesh (25,258 Mm^3), Rajasthan (24,196 Mm^3), Bihar (20,157 Mm^3), Gujarat (17,510 Mm^3), West Bengal (17,284 Mm^3), Maharashtra (17,087 Mm^3), Jharkhand (11,116 Mm^3), Assam (10,113 Mm^3), Karnataka (10,112 Mm^3).

The large animal's biogas generation (98.5%) is the major contributor to total biogas production per year as compared to small animals (1%) and pigs (0.5%). The maximum biogas production per year from small animals is from Rajasthan (340 Mm^3, 12.9%), followed by Andhra Pradesh (280 Mm^3, 10.6%), Telengana (280 Mm^3, 10.6%), West Bengal (200 Mm^3, 7.59%) and Karnataka (200 Mm^3, 7.59%). In pig biogas production per year, Assam plays a pivotal role with a major contribution of 288.14 Mm^3, with a percentage share of 23%. The presence of methane in biogas was computed by presuming the percentage of methane production (standard) from various sources of dung under study. Total estimation of yield from methane per year from all species of animal dung for the country was computed as 158,929 Mm^3. Calculations support that if this methane potential is utilized as a source of energy can yield heat energy of 5,181,117 Million MJ per year.

8.3. Estimation of potential of electrical energy

To estimate electrical energy potential, detailed calculations were carried out by utilizing biogas produced through animal dung as fuel. On the basis of available dung resources, the potential of power generation per year is compiled in Fig. 11. It has come from estimation that the highest electrical energy potential as recovered energy is in TWh on yearly basis exits in Uttar Pradesh 81.55 TWh (17%), Madhya Pradesh 45.68 TWh (9.5%), Rajasthan 43.67 TWh (9.1%), Bihar 36.44 TWh (7.6%), Gujarat 31.68TWh (6.6%), West Bengal 31.21TWh (6.5%), Maharashtra 30.88 TWh (6.4%), Jharkhand 20.08 TWh (4.2%), Karnataka 18.23 TWh (3.8%), Assam 18.29 TWh (3.8%). In India, gross total dung stands at 2633 MT per year, which has immense potential to produce biogas of 265,542 Mm^3 per year. The per year methane yield from biogas stands up 158,929 Mm^3, has a heating value of 5,181,117 million MJ, and has shown the potential to generate an additional 480 TWh of electrical energy per year, which is, by all ways is an important projection.

Reference [47] mentions that according to census 2011, 11% of total rural households use dung as primary cooking fuel. Sinha et al. [48] assumed an average per capita consumption of dung around 0.49 kg/per capita/day. Ministry of MNRE [29] presents that India has made an estimation potential of 12.3 million biogas plants, nonetheless achieved figures are 50.28 lakh family/small size biogas plants till 2018–19 The biogas off-grid power generation is 895.15 kW is achieved from 87,990 m^3 biogas. At the India level, gross animal dung generation is 2633 MT; out of this large animal's dung contribution is 2492 MT, which projects 261,660 Mm^3 of gross theoretical biogas potential. Mostly large animal dung (cattle/buffalo) is used for total rural household application (TRH), and 11% of its utilization reduces the gross large animal dung by 274.12 MT, and further reduces the dung for average per capita consumption (ACD) per year by 54.24 MT and net potential of large animal dung is 2164 MT per year, and this dung generation produces a net theoretical potential of biogas (NTPB) 209,042.4 Mm^3 per year biogas. This average per capita consumption per year 54.24 MT is supposed as the consumption for 50.28 lakh family type biogas plants established in India. The cumulative achievement of biogas off-grid power generation 895.15 kW till 2018–19 is through utilized biogas consumption (UPB) of 87,990 m^3 per year, and this consumption is reduced from NTPB, and get surplus per year biogas potential from large animals is 209,042.3 Mm^3, small animals 2634 Mm^3 and pig 1247.76 Mm^3. The combined total surplus (unutilized) potential of biogas (SPB) from all species under consideration is 212,924 Mm^3 per year which has the capability to generate 386 TWh per year further.

Rao et al. [15] have estimated that the potential for biogas from cattle and buffalo is 17,900 million Nm3 or 374,000 TJ for 2010. Mittal et al. [23] have estimated animal waste's biogas potential to be 166,000 Mm^3/year for low availability and 386,000 Mm^3/year

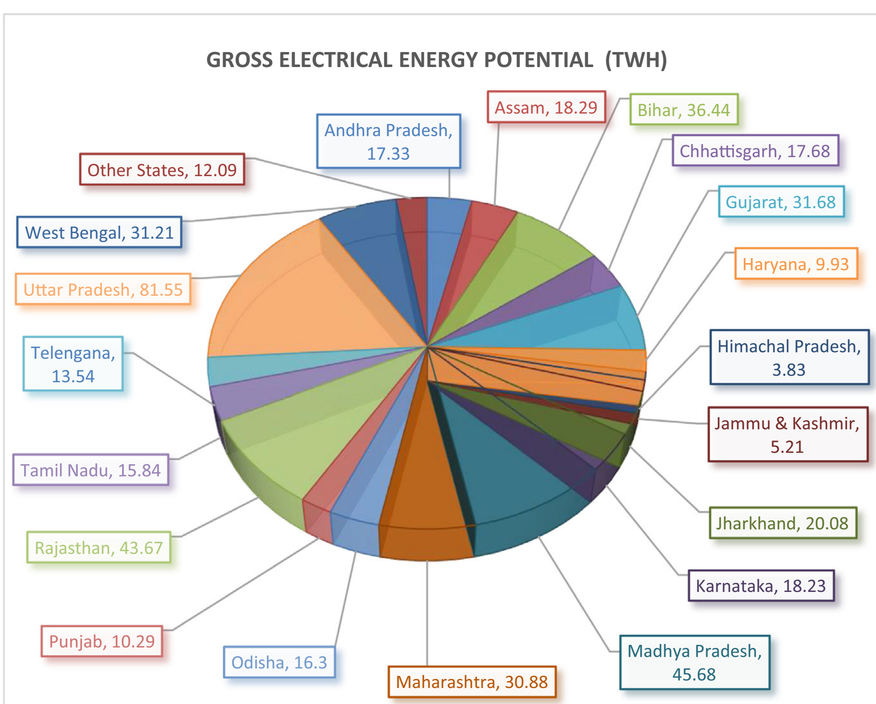

Fig. 11. Estimation of Gross Electrical Energy Potential.

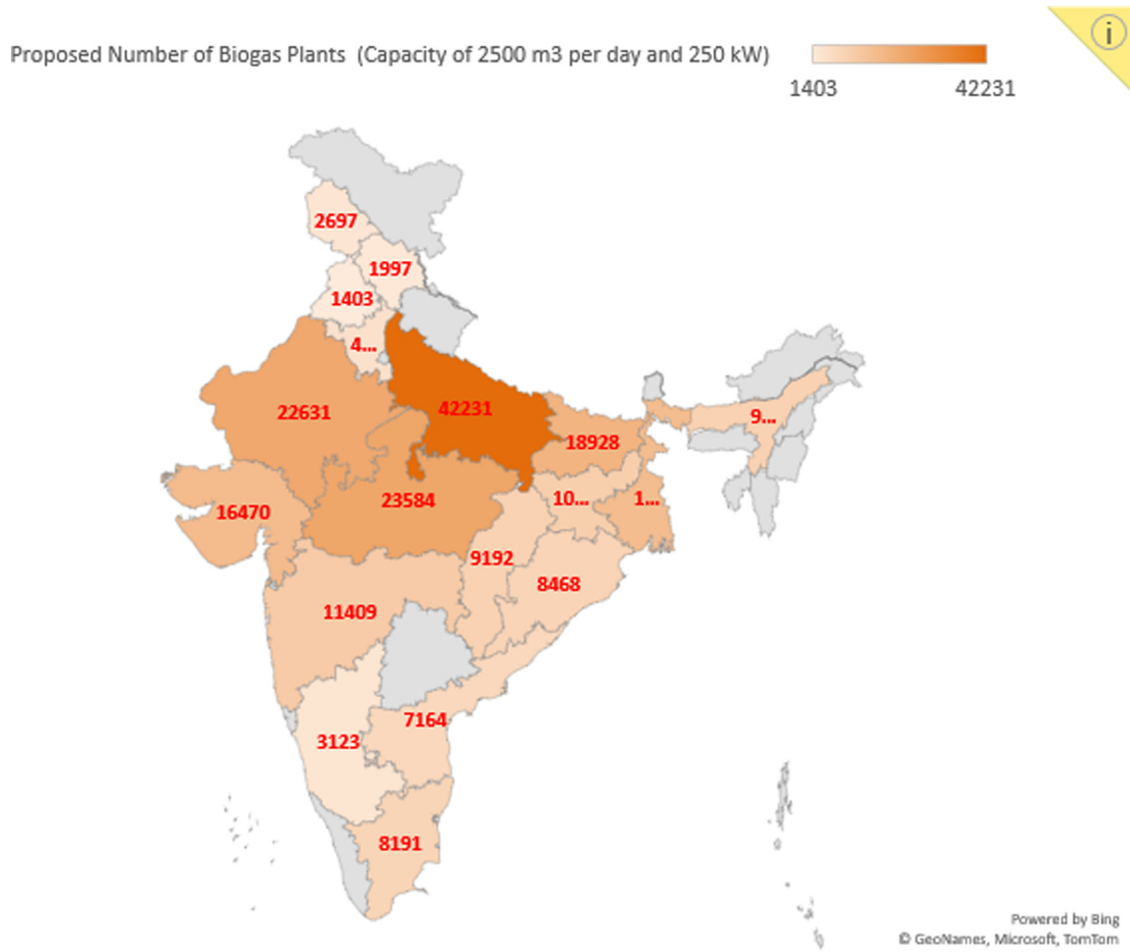

Fig. 12. Proposed Number of Biogas Plants in the Indian States.

for high availability in 2015. Kaur et al. [21] have estimated the biogas potential of 263,702 Mm^3/year in 2012. The present study takes into account the 20th livestock population census for 2019, considering all high population species for dung, taking average availability coefficient of 50% and estimated gross biogas potential of 265,542 Mm^3 per year and underutilized per year surplus potential of biogas is 212,924 Mm^3.

8.4. Rural India contribution in biogas production

Out of the total livestock population of 536.76 million as per 20th livestock population, urban livestock population 22.65 million (4.2%), whereas rural livestock population 514.11 million (95.8%). The combined cattle and buffalo population covers 56.5% of the total livestock population. In rural India, the cattle and buffalo species population is a great source of income and covers 95.8% of all India cattle + buffalo population. Corresponding to these figures, the trust area for the potential of biogas is in villages/ towns of India and projecting the gross potential of biogas 250,670 Mm^3 per year and unutilized net potential of 209,010 Mm^3 per year. Out of the target of 12.3 million biogas plants (as per MNRE estimation), only 50.28 million biogas plants (43% family size/ small biogas plants) have been established. This study's potential estimation highlights the massive potential of biogas through livestock dung for millions of future biogas plants. To strengthen the village level electrification and reliability of supply, this resource act as a great source of decentralized/ distributed generation.

8.5. Assessment of distributed generation

The estimation of unutilized biogas potential evident that there is an urgent need to establish decentralized and distributed generation plants in small capacities for power generation activities. The biomass energy route has various socio-economic advantages such as plant can be set up at any location where there is the availability of bulk animal excreta, availability of raw fuel throughout the year for continuity of supply, it is easily portable, cheap, renewable and cost-effective, local employment and reliable. The option of grid-connected and off-grid plants is also vulnerable, establishing a small capacity plant with micro-grid connectivity. Therefore, for rural India, the expansion of locally available biomass/ biogas resource usage to generate electricity is a logical strategy.

Reference [27] suggested the optimal location and size of distributed generation and clustering of biogas rich areas for an appropriate location. [28] Advanced Configuration of biomass plants has also been suggested by considering the actual load and peak load on that particular area. Authors have suggested the cost-effective allocation of distributed generation for rural electrification game theory [29]. This study estimates the decentralized and distributed generation plants keeping in view the region-wise assessment of biogas, and proposes state-wise ability of (NBP) number of biogas plants. Fig. 12 presents the proposal of off-grid decentralized biogas plants in potential states of India.

The proposed number of biogas plants as per this study estimation is 219,886, with the highest potential of a biogas plant in Uttar Pradesh (42,231), followed by Madhya Pradesh (23,584), Rajasthan (22,631), Bihar (18,928), Gujarat (16,470), West Bengal (16,094), Maharashtra (11,409) and Jharkhand (10,290). Except that Tamil Nadu has a surplus potential of 8191 biogas plants based on biogas potential. The proposals are based on considering one capacity of 2500 m^3 per day; the variation of capacities as per the power requirements of each state or UT. The study presents facts about the underutilized livestock generated dung, biogas production and potential for gross electrical energy and distributed generation as a valuable supporting estimation for future proposal and implementation schemes. This estimation practice has already been followed in many Asian countries and carries weight for policy planning and implementation in the Indian context.

9. Conclusion

India's power generation scenario presents that it is high in the economic rise and power requirements being a developing country. At present country has installed a capacity of 368,690 MW and generated 1376.095 BU up to March 2019. The overall generation growth is about 5.19% and out of this growth rate of 24.47% is renewable power generation. The government of India has taken several initiatives to promote renewable energy generation at the central and state level. MNRE is implementing biomass power/ cogeneration programmes, and the total installed capacity of 9806 MW has been installed with 50.28 lakh family/ small size biogas plants. To support the initiatives of MNRE for the promotion of biogas plants for decentralized generation, a countrywide estimation of biogas potential has been completed for electricity generation at the state level or rural areas.

The valuable estimation of biogas potential has been done based on the availability of dung from livestock species in various states of India. The estimation strongly recommends that rural India has immense unutilized biogas potential for power generation activities. The findings are a great addition to renewable generations and keep the capability and capacity to replace conventional generation to some extent. The result shows the magnificent potential of gross electrical energy of 480 TWh per year and proposes small biogas plants as distributed generation from underutilized biogas. This underutilized net biogas potential of 212,924 million m^3 per year has the capability to generate additional electrical energy of 386 TWh per year. This study highlights that assistance can be extended to renewable energy power planners for bio resource assessment for policy planning, policy implementation, and renewable power alleviation in India. The future scope of this study manifests that the model presented in this research for estimation of biomass can act as a standard for estimating the potential of biomass in any region, state or country. The study can be further extended for the preparation of an algorithm and optimization of parameters.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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