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RESEARCH ARTICLE

Automated Compact Biodigester for Anaerobically Transforming Kitchen Waste to Biogas and Organic Fertilizer: Impact Analysis for Various Sustainable Development Goals

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ABSTRACT

Anaerobic Digestion (AD) technology has emerged as a viable and universally adaptable solution for managing household kitchen waste (KW), with twin benefits of pollution reduction, and at source generation of biogas and organic fertiliser to support three sustainability pillars i.e., economic, environmental, and social. This study is an attempt to implement this technology at household level through "Automated compact biodigester" (ACBD) developed and patented specifically to convert KW into biogas and fertiliser as responsible household KW management that contributes to health and safety, improving quality of life in urban areas, and meeting some of the 17 SDGs. The findings reveal substantial progress, such as poverty reduction through job creation in entire ecosystem of ACBD from fabrication till final scrapping, bolstering economic growth (SDGs 1, 8, 10, 12) by reducing burden of KW management on municipal corporations, enhancing agricultural productivity (SDG 2) via promoting use of ACBD's effluent as bio fertiliser, advancing renewable energy usage and diminishing reliance on fossil fuels (SDG 7), fostering inclusive education and gender equality (SDGs 4, 5, 9), combating climate change (SDG 13), transforming cities into sustainable and harmonious environments (SDGs 11, 16, 17), and curbing environmental pollution (SDGs 3, 6, 12, 14, 15).

Keywords: Anaerobic digestion, biogas, kitchen waste, sustainable development goals.

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1. Introduction

Rapid population growth, economic development, and urbanization have led to the generation of various types of wastes, particularly municipal solid wastes [1]. Household kitchen waste is a significant proportion of the solid waste. Improper handling of kitchen waste leads to drain clogging, bad odour, filthy waste dumps and increased clean-up costs [2], along with loss of valuable nutrient rich resource. Solid organic waste is recognized as a significant sustainability challenge that is highlighted by inclusion of solid waste management in the United Nations Sustainable Development Goals (SDGs) [3].

Approximately, one-third of the food produced for human consumption globally is wasted, which is around 1.3–1.4 billion tonnes per year. Within South and South-east Asia, including developing economies like India and China, approximately 275 million tonnes of food are wasted every year. Food waste in India is primarily generated in various sectors such as hostels, restaurants, supermarkets, residential areas, airlines, cafeterias, and food processing industries. The Food Waste Index Report of UNEP, 2021 [4] mentions that in India, about 90 kg of food waste is produced per capita per year by the high-income group, while the figures stand at 68 kg and 63 kg for the middle- and low-income groups, respectively.

Municipal organic waste management is done using composting, landfill, incineration or anaerobic digestion (AD) technology [5]–[7]. Landfills due to their limited recovery and recycling capabilities, along with water contamination, negative impact on soil quality, and significant contribution to global warming are less suitable from sustainability point of view [8], [9]. Composting and incineration are effective but legacy waste, bad odour, space requirements, pollution are some of the challenges [10].

Anaerobic digestion (AD) has emerged as a promising approach for decomposing organic waste materials, which a multi-step biochemical processes mediated by microbes operating through various metabolic pathways. In the absence of oxygen, this process efficiently converts organic waste materials into valuable by-products, including biogas, hydrogen, and other energy-rich organic compounds [11]. Furthermore, AD technology can be applied across a spectrum of micro to macro level urban scales, offering flexibility and adaptability in its implementation [12]. AD technology with its recent advancements and benefits is finding increasing applications but there is need to understand its economic, environmental, and social aspects [13]. The SDGs approach, and the midpoint of their timeline (2015–2030), emphasize the need for further elucidation to unlock the potential of AD initiatives among various stakeholders, including policymakers, managers, and private operators [14].

Hence, this study seeks to explore these uncharted territories and offer a more comprehensive insight into the role of anaerobic digestion (AD) in addressing some Sustainable Development Goal (SDG) through the utilization of an indigenously developed Automated Compact Biodigester (ACBD), specifically tailored for the kitchen waste generated in Indian households.

The study was undertaken with the aim of determining the yield of biogas and effluent/digestate as an organic fertilizer, from the kitchen waste using the Automated Compact Biodigester (ACBD), which is patented by the authors. Further, aim was to explore the possibility of effluent/digestate use in place of chemical fertilizer for pollution abatement in agriculture, and impact analysis of the AD technology to examine as to which SDGs and associated targets are met.

2. Materials and Methods

2.1. *Estimating Average Family Size and Kitchen Waste Generation in Three States of India*

Field survey in 1090 families in three states (Delhi-NCR, Uttarakhand, and Himachal Pradesh) in India was conducted to assess family size and household kitchen waste (KW) generation using questionnaire method and door-to-door survey. This survey enabled a nuanced comprehension of KW generation dynamics across varied household contexts showing disparities within the states. Based on the data, standardized biodigester capacities were identified, poised to address the diverse KW management needs identified during the study.

2.2. *Estimation of Biogas Production from Kitchen Waste*

The Anaerobic Compact Biodigester (ACBD) of 30L working capacity was used (detailed description available; Indian Patent 371126) with suitable arrangements for feed inlet, gas collection, sampling ports and effluent outlet using kitchen waste as substrate. 7.5 kg chopped Kitchen Waste (KW) and 21.5 L water were fed into the digester and seeded with 1 litre cow dung slurry from a biodigester that was in operation for a long time in the laboratory and operated under ambient conditions (temperature 30°C–35°C). Once stable biogas generation started in the digester, it was fed each day with 1000 ml of substrate (250 g mixed KW and 750 ml Water) as described by the authors earlier [15], and same amount of effluent was drained out from each digester. The biogas was tested for its combustibility (with a blue flame), and volume of biogas collected each day was recorded.

2.3. *Study on Testing the Efficacy of the Biodigester Effluent/Digestate as Organic Fertilizer*

Usability of the digestate/effluent from the biodigester as a organic fertilizer was tested on growth and grain yield of wheat [Sunehri (PBW 766; 2020)], and compared with that getting chemical fertilizer. Seed treatment against termite was done using thiamethoxam 1 g Cruiser 70 WS/kg seed and dried in shade. Wheat crop was grown in two sets of test plots (1 m^2 each) in triplicates to which chemical fertilizer or the organic digestate from the ACBD digester were applied. The test plots were located in Dhillon farmhouse, village Mundia-Ani, District Udham Singh Nagar, Uttarakhand in Tarai region of Uttarakhand, India (minimum and Maximum temperatures 3°C–5°C, and 39°C–41°C, respectively; average annual rainfall 1433.4 mm)

The soil is alluvium, with medium phosphorus and potassium, and low organic matter.

For chemical fertilization, as per recommended dose, 9.6 g muriate of potash before sowing, and 13.2 g of DAP (18% N, 46% P_2O_5) were applied, while 10.8 g of urea was applied during 1^{st} and 2^{nd} irrigation. In the second set of plots, 0.6 kg of ACBD's slurry was sprayed using 600 mL digestate from the biodigester (recommended dose of 2.5 tonnes/Acre) during first and second irrigation. Standard flood irrigation method (7.5 cm) was used 4 times as: 1^{st} irrigation just after sowing (20^{th} November 2022), 2^{nd} (3rd January 2023), 3^{rd} (10^{th} February 2023) and 4^{th} irrigation (8^{th} March 2023). The crop was harvested on maturity and yield was compared.

2.4. *Analysing the Large-Scale Impacts of AD Technology on SDGs and Associated Targets*

Impacts of using the Automated Compact Bio-Digester (ACBD) for kitchen waste management on addressing Sustainable Development Goals (SDGs) encompasses several key steps. In-depth analysis of the use cycle and performance of the developed ACBD was done by studying its efficiency in converting solid waste into useful by-products such as biogas and organic fertilizer. Direct and indirect contribution to SDGs such as reduced waste generation, increased access to clean energy as direct, and improved public health, reducing poverty by new job opportunities, and environmental sustainability as indirect impacts were assessed.

3. Results and Discussion

3.1. *Household Kitchen Waste Generation*

Household kitchen waste (KW) generation trends across three states, namely Delhi-NCR, Uttarakhand, and

TABLE I: Household Kitchen Waste Generation in Delhi-NCR, Uttarakhand, and Himachal Pradesh, India

State	Number of households surveyed	Average family size (persons)	Average kitchen waste (KWAv) generation (g/day/household)	Population (2024) [16]	Estimated kitchen waste generated per state (tonnes/d)
Delhi NCT	370	5.21	581.57	1,93,01,096	2154
Uttarakhand	410	5.62	384.33	1,17,00,099	800
Himachal Pradesh	310	5.29	585.16	75,03,010	830

TABLE II: Average Biogas Production (L/d) from Kitchen Waste (1:3 ratio) Over 8 Weeks

Biogas production (L/d)								Mean
1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week	
3.79	3.43	3.17	3.34	3.46	3.23	3.41	3.31	3.39 ± 0.17

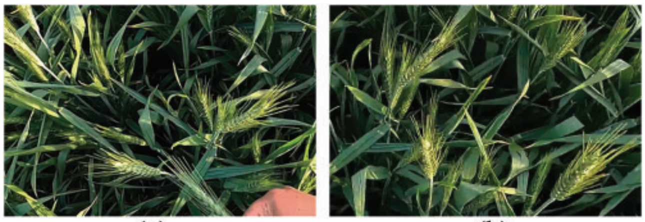
Himachal Pradesh are presented in Table I. The analytical data provide some insights into KW generation patterns across the states. Projected estimates of total KW generated by the states were calculated based on population, average family size, and per family waste production. KW generation was relatively more in households of Delhi-NCR region and Himachal Pradesh than in Uttarakhand, which is a hilly state with lesser amenities available to the local population. This could be the major factor for less waste generation.

The findings indicate that the average family size across the surveyed households is 5.37 (say five persons per family). On an average, across the three states, each household generates approximately 517 g of kitchen waste per day. Based on our survey, huge quantities of household kitchen waste are estimated to be generated per day by the people, which is 2154 tonnes/day in Delhi-NCT, 800 tonnes/d in Uttarakhand, and 830 tonnes/d in Himachal Pradesh. These wastes are just added to our municipal solid waste and ultimately add to dumpsites or reach the landfills. The nutrients present in the kitchen waste are completely lost and only add to environmental problems. Therefore, it is very important to convert the waste to biogas and organic fertilizer., for which the anaerobic biodigester is of tremendous use.

3.2. Biogas Production from the KW using Automated Compact Biodigester (ACBD)

Trial runs were conducted to optimize the parameters for biogas production from kitchen waste using automated compact biodigester. Based on the previously conducted experiments, a substrate (KW) to water ratio of 1:3 (250 g mixed KW and 750 ml Water) was found to be optimal for biogas generation. A reaction volume of 60 L was finalized as the most suitable volume for converting the average urban household kitchen waste into biogas [15]. Daily mean values of biogas production over 8 weeks run of the biodigester shows 3.17 L/d–3.79 L/d production (Table II).

Thus, from 250 g KW about 3.4 L of biogas can be produced per day. Considering the average KW generation of 4831 tonnes/day across the three states surveyed, the projected biogas production will be 4.5 MT/d $\times$ 10^5 MT/d (1 m^3 biogas is approx. 0.5 tonne), which will be a huge contribution to clean and affordable energy.



(a) (b)

Fig. 1. Wheat crop in test fields treated with (a) Chemical fertilizer (b) Biodigester effluent.

3.3. Efficacy of Biodigester Effluent as Organic Fertilizer

Growth and yield of a popular variety of wheat receiving chemical fertilizers and biodigester effluent as organic fertilizer were studied. Fig. 1 depicts the growth of the crop in the two types of test fields, which are almost similar.

Reported average yield of the variety as per ICAR report [17] is 23.1 q/acre. As per ICAR (kvk.icar.gov.in), the average recorded yield of Sunehri (PBW 766) crop is 554.4 g/m^2 (23.1 q/acre). In the present study, the test field receiving the chemical fertilizers produced 676.3 g/m^2 yield, which is 27.31 q/acre whereas ACBD effluent receiving test field yielded 662.8 g/m^2 wheat yield, which is 26.82 q/Acre (Fig. 2, Table III). Thus, the test field where the effluent of the Automated Compact Bio-Digester (ACBD) was used demonstrated a noteworthy increase of approximately 20% compared to the average and almost comparable to that receiving urea and DAP fertilizers.

Thus, the effluent derived from the ACBD exhibits comparable effectiveness to chemical fertilizers such as urea, muriate of potash and di-ammonium phosphate (DAP). This result is promising as it indicates that organic waste converted into organic fertilizer through the ACBD can contribute positively to agricultural productivity without reliance on synthetic chemicals. The nutrients locked up in organic wastes become available by microbial action [5], [6]. Also, the utilization of ACBD effluent in agricultural practices aligns with sustainable development goals by promoting environmentally friendly and resource-efficient farming techniques.

3.4. Design of Integrated Biodigester and Kitchen Cooking Gas Assembly

The integration of the Automated Compact Bio-Digester (ACBD) into Kitchen LPG Cooking System as

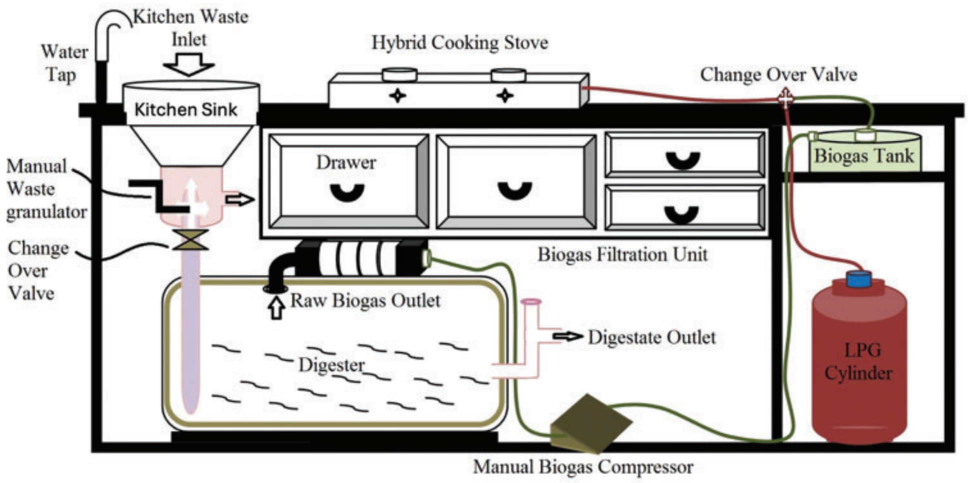


Fig. 2. Design of ACBD fitted into Modern Household kitchen cooking stand.

TABLE III: Yield of Sunehri (PBW 766) Wheat Crop with Chemical Fertilizer and Biodigester Effluent

Field/Fertilizer treatment	Grain yield (g/m^{2})	Grain yield (q/acre)
Test field (chemical fertilizers)	676.37 ± 2.82	27.3 ± 2.77
Test field (organic fertilizer from biodigester)	662.8 ±3.87	26.8 ± 1.93

a module will be a promising technology advancement in waste management. This design depicted in Fig. 2 can directly address the challenge of household organic waste management while also providing a solution to the shortage of clean fuel for cooking and organic fertilizer for farms and gardens. By incorporating anaerobic digestion technology within the Kitchen Cooking System, the proposed design offers a practical alternative for converting organic waste into biogas and organic fertilizer.

This innovative approach overcomes the limitations associated with conventional biogas techniques, which often require large open spaces and sunlight to operate efficiently. By integrating the ACBD into the kitchen LPG cooking system, the system can function effectively within the confines of a household, eliminating the need for external space and sunlight. Additionally, the modified bioreactor design helps mitigate the foul smells typically associated with anaerobic digestion processes, making it suitable for indoor use.

3.5. *Anaerobic Digestion Technology and SDGs*

This comprehensive approach of using AD technology using Anaerobic compact biodigester (ACBD) in kitchen has the potential for addressing several issues that will be effective towards various sustainable development goals, such as, reducing waste disposal problems, recovering renewable biogas energy from the kitchen waste, reutilisation of the nutrients locked up in the waste as organic fertilizer for plants, along with management of the solid waste. The integration of the ACBD into the Kitchen LPG Cooking System holds promise for addressing waste management challenges and meeting energy needs partially at the household level. By providing a convenient method for converting organic kitchen waste into valuable resources, this technology has the potential to contribute significantly to sustainable development goals related to waste management, clean and affordable energy access, and improved agricultural productivity required to meet the SDG of zero hunger. Further research and development efforts in this area can help refine the design and optimize its performance for widespread adoption.

According to data provided by the Delhi Pollution Control Committee, the average per capita Municipal Solid Waste (MSW) generation is 680 g and kitchen waste constitutes approximately 32% of the total waste. This implies that an average of 224.4 g per capita of MSW is generated in the form of kitchen waste, which can be easily reduced if we use ACBD technology. This approach not only offers environmental benefits but also economic advantages. By treating kitchen waste at the source, households can save up to 32% of the cost associated with MSW collection, segregation, treatment, and disposal.

Moreover, implementing source-level treatment of kitchen waste can address various challenges associated with MSW management. It has the potential to reduce the population of stray animals, minimize the risk of bioleaching, curb the spread of infections, and mitigate unpleasant odours commonly associated with waste disposal. These benefits underscore the significance of adopting decentralized waste management strategies, such as treating kitchen waste at the source, to achieve more sustainable and efficient MSW management practices. The ACBD technology, when scaled up for larger installations in hotels, mess, canteens, and restaurants at large scale would need human intervention at various stages, including kitchen waste collection, operation of ACBD facilities, and management of by-products. This will also create job opportunities, providing income and livelihoods for individuals and communities affected by extreme poverty, ultimately aiding in breaking the cycle of poverty.

Implementation of ACBD systems will thus contribute towards addressing several Sustainable Development Goals (SDGs). Firstly, by generating biogas as a clean fuel (SDG 7), ACBD systems help mitigate the adverse effects of household waste while reducing the discharge of waste leachate into surface and groundwater resources, thereby addressing pollution in water bodies (SDG 6 and SDG 14). In addition, ACBD technology offers a sustainable solution to waste management challenges, reducing soil and air pollution and minimizing the need for large landfill sites (SDG 15). Moreover, on a larger scale, anaerobic digestion can mitigate adverse environmental impacts associated with urban waste management (SDG 12), including air pollution, health risks, water pollution, and land use change. Various impacts of AD technology on sustainable development have been critically reviewed recently highlighting its importance [18].

Furthermore, anaerobic digestion has the potential to mitigate conflicts stemming from greenhouse gas emissions and improper waste management practices, thereby contributing to the achievement of SDGs related to peace, justice, and strong institutions (SDG 16). This comprehensive understanding may help policymakers, financers, and investors to allocate resources strategically or foster collaborations with organizations, governments, and communities. Moreover, the research outcomes are expected to benefit the academic community specializing in AD research, empowering them to consolidate ongoing or future studies related to the nexus between AD and SDGs, thereby garnering support from governmental bodies and private industries alike.

4. Conclusion

Comprehensive assessment of household kitchen waste (KW) generation trends across three states of India, namely, Delhi-NCR, Uttarakhand, and Himachal Pradesh has shown that an average family size of five persons produces approximately 517 g kitchen waste per day. Household kitchen waste in a substrate to water ratio of 1:3 and a reaction volume of 60 L capacity biodigester can produce about 3.4 L/d biogas using 250 g KW substrate every day employing the Automated Compact Bio-Digester (ACBD) system. This biogas can substantially supplement the energy needs in our kitchen by developing a modular ACBD integrated to Kitchen LPG system. The slurry from the biodigester is nutrient rich, which can be used as organic fertilizer in garden, kitchen garden or crop fields as it has been found to boost crop growth and yield in test plots growing Sunehri wheat. Its performance is as good as chemical fertilizers added together as urea, DAP and muriate of potash. The organic fertilizer is environmentally safe and free from the side effects of synthetic fertilizers that cause nitrate pollution of ground water, eutrophication of surface waters and has energy costs involved along with carbon emissions during production. The ACBD technology meets several Sustainable Development Goals (SDGs) by generating job opportunities, clean fuel, reducing pollution, help boost crop production and promoting sustainable waste management practices.

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Conflict of Interest

The authors declare that they do not have any conflict of interest.

References

[1] Sharma HR, Bhardwaj B, Sharma B, Kaushik CP. Sustainable solid waste management in india: practices, Challenges and the Way Forward. In *Climate resilience and environmental sustainability approaches: global lessons and local challenges*. Kaushik A, Kaushik CP, Attri SD, Eds. Springer Nature, 2021, pp. 319–49.

[2] Singh N, Poonia T, Siwal SS, Srivastav AL, Sharma HK, Mittal SK. Challenges of water contamination in urban areas. In *Current directions in water scarcity research*, vol. 6, Elsevier, 2022, pp. 173–202.

[3] Paes MX, de Medeiros GA, Mancini SD, Bortoleto AP, de Oliveira JAP, Kulay LA. Municipal solid waste management: integrated analysis of environmental and economic indicators based on life cycle assessment. *J Clean Prod*. 2020;254:119848.

[4] UNEP Food Waste Report. unep-food-waste-index-report-2021. 2021. Available from: www.unep.org. (accessed on 1.5.2024).

[5] Sangwan P, Garg VK, Kaushik CP. Growth and yield response of marigold to potting media containing vermicompost produced from different wastes. *Environmentalist*. 2010;30(2):123–30.

[6] Karwal M, Kaushik A. Bioconversion of lawn waste amended with kitchen waste and buffalo dung into value-added vermicompost using *Eisenia fetida* to alleviate landfill burden. *J Mater Cycles Waste Manag*. 2022;23:358–70.

[7] Tsui TH, Wong JW. A critical review: emerging bioeconomy and waste-to-energy technologies for sustainable municipal solid waste management. *Waste Disposal Sustain Energy*. 2019;1:151–67.

[8] Bajar S, Singh A, Kaushik CP, Kaushik A. Statistical assessment of dumpsite soil suitability to enhance methane bio-oxidation under interactive influence of substrates and temperature. *Waste Manag*. 2017;63:188–95.

[9] Osazee IT. Landfill in a sustainable waste disposal. *European J Environ Earth Sci*. 2021;2(4):67–74.

[10] төлөгөнова А, тотубаева Н, Маймеков З. Assessment of the possibility of processing municipal solid waste with biocompost production. *Наука, новые технологии и инновации Кыргызстана*. 2019;11:55–61.

[11] Castillo-Leon NY, Tarazona-Romero BE, Gamarra MC, Acosta-Cardenas OA, Quizena-Fernandez YP, Alarcon-Guerrero MY. Evaluation of the anaerobic digestion process for low and micro-scale biogas production: a review. *IOP Conf Series: Mater Sci Eng*. 2024;1299(1):012008. IOP Publishing.

[12] Archana K, Visckram AS, Kumar PS, Manikandan S, Saravanan A, Natrayan L. A review on recent technological breakthroughs in anaerobic digestion of organic biowaste for biogas generation: challenges towards sustainable development goals. *Fuel*. 2024;358:130298.

[13] Hussain Z, Mishra J, Vanacore E. Waste to energy and circular economy: the case of anaerobic digestion. *J Enterp Inf Manag*. 2019;33(4):817–38.

[14] Babu MM, Dey BL, Rahman M, Roy SK, Alwi SFS, Kamal MM. Value co-creation through social innovation: a study of sustainable strategic alliance in telecommunication and financial services sectors in Bangladesh. *Ind Mark Manag*. 2020;89:13–27.

[15] Bhardwaj B, Kaushik A, Kaushik CP, Bhardwaj N. Development of indigenous household kitchen waste biogas digester, energy sources, part A: recovery. *Util, Environ Eff*. 2024;46(1):607–20.

[16] Current Population of India 2024. last accessed 2024 May 10. Available from: www.indiacensus.net.

[17] Available from: https://kvk.icar.gov.in. (last accessed 2024 May 1).
[18] Piadeh F, Office I, Behzadian K, Rizzuto JP, Bywater A, C´ordoba-Pach´on JR, *et al.* A critical review for the impact of anaerobic digestion on the sustainable development goals. *J Environ Manag*. 2024;349:119458.