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ORIGINAL RESEARCH ARTICLE

Energy recovery potential of urban solid waste of Solan district, H.P, India

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ABSTRACT

Energy recovery from waste can provide a safe technologically advanced means of waste disposal that reduces greenhouse gases and generates clean energy. The study describes the characteristics of urban solid waste (USW) produced in five urban areas of the Solan district of Himachal Pradesh as well as its potential for energy recovery and power generation. Physical characterization of the USW generated at the study locations showed high percentages of organic/food waste. The results revealed that the organic fractions were 52.12%, 50.68%, 50.51%, 50.34%, and 49.41% for Arki, Nalagarh, Baddi, Parwanoo and Solan respectively. The energy content of solid waste produced in various urban locations ranged from 11,532.432 to 14,850.416 $kJ \cdot kg^{-1}$, and the waste is appropriate for energy generation when the heating value of the garbage is at least 6,000 to 7,000 $kJ \cdot kg^{-1}$. The values of energy recovery potential through biochemical conversion were 959.988 kWh, 933.395 kWh, 930.269 kWh, 927.111 kWh, and 910.036 kWh per annum for Arki, Nalagarh, Baddi, Parwanoo and Solan. The power generation potential of different urban areas ranged from 37.918 to 39.999 kW. It is anticipated that these findings would be informative and enhance collaboration among the various parties involved in the intermunicipal arrangements. Future studies about innovative consortia approaches that take energy recovery into account in their projects should be stimulated by the characterization and calculation of energy recovery and power generating potential.

Keywords: Energy Recovery Potential; Methane Emission Potential; Power Generation Potential; Urban Solid Waste

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1. Introduction

Solid waste production is a significant by-product of socioeconomic activity. Nations have various concepts of what constitutes solid waste. Urban solid waste (USW) often includes waste from industrial, commercial, residential, institutional, and municipal services. The amount of USW produced is strongly impacted by the constantly expanding population, fast urbanization, and industrialization[1]. Mismanagement of solid waste is a significant environmental risk that affects both developing and developed countries' rapidly expanding cities[2]. Improper waste disposal can lead to adverse health outcomes, for example, through water, soil and air contamination[3]. Urbanization, economic growth, and higher living standards in cities all contribute to an increase in the volume and complexity of solid waste production[4]. According to Hoornweg *et al.*[5], the pace of garbage generation has increased tenfold since the turn of the century and is expected to double by 2025. From six million tonnes in 1947 to 48 million tonnes in 1997 to 90 million tonnes in 2009, it's projected to rise to 300 million tonnes by 2047, and the amount of solid garbage being produced in Indian cities has skyrocketed[6]. Continuous municipal solid waste disposal is quick and associated with poverty, poor management, urban development, population increase, poor health, low levels of environmental awareness, and insufficient environmental awareness management[7]. People have moved from villages to cities as a result of India's rapid industrialization and population growth, which produces 276,342 tonnes per day (TPD) of USW every day. The 2014 report by the task force on Waste to Energy (WtE) under the planning commission estimates that urban India will generate 450,132 TPD of waste by 2031 and 1,195,000 TPD by 2050. The buildup of USW in every nook and cranny is the result of insufficient collection and transportation[8]. It is feared that improper handling of municipal solid waste could pose a serious threat to environmental damage. Due to a lack of records and the frequently informal nature of waste management and disposal, insufficient data on waste management, handling, and screening in developing nations can be blamed for the ineffectiveness of their urban waste management systems[9]. According to Senzige *et al*.[10], pertinent information on waste disposal would alert waste management authorities to potential environmental risks as well as the possibility of recycling, composting, and energy efficiency, which would reduce the amount of waste that managers would need to dispose of at landfills. In order to comply with waste management problems and protect the environment, adequate programs (reduction, reuse, and recycling, or R3) and proper disposal are needed[11]. The first step in the successful implementation of a planned waste management strategy in any city, according to Thanh *et al*.[12], is the collection of trustworthy data on the disposal of municipal solid waste. The waste characteristics must be taken into consideration when selecting a WtE technology. WtE technology comes in many forms, including biochemical and thermochemical ones, for turning solid waste into energy (steam or electricity). Each location has its own unique solid waste characteristics and volume. Average income levels, available resources, population, social status, climate, industrial production, and the market for waste disposal are all factors that affect quantity and composition[13]. Asian developing nations share a number of similarities in the mix and characteristics of their garbage. Low calorific value is caused by the high moisture content caused by the high percentage of organic waste component. Due to this, it cannot be heated, making it ideal for biological processes like composting and anaerobic digestion. The use of waste energy content may be one of the most important concepts for such advancement in waste management, especially where existing waste management tends to be subpar. By using thermochemical processes (such as combustion, pyrolysis, or gasification) or biological processes, the energy content of waste can be recovered (anaerobic digestion).

Processes for thermochemical conversion are helpful for waste that has a high proportion of organic matter and little moisture. Biochemical conversion processes, on the other hand, are preferred to waste with a high percentage of biodegradable (putrescible) and high levels of moisture/water content, which facilitates microbial activity. The trajectory of the global temperature has shifted as a result of rising greenhouse gas (GHG) emissions, affecting both human health and ecology[14]. Methane produced from landfills is one of the biggest sources of GHGs. Methane (CH_4) is one of the most important GHGs due to its ability to cause global warming, which is 28 times more than that of CO_2[15] over a 100-year period. Over the last few millennia, the amount of CH_4 in the atmosphere has rapidly increased. Urban solid waste can contribute up to 11% of all anthropogenic emissions, which are a major factor in global warming. In terms of the state's urban population, Solan, one of Himachal Pradesh's fastest-growing districts, is ranked second. Due to urbanization, waste production in the area has increased. As per the prevailing system, the biodegradable waste is disposed of in pits at Salogara, while the non-biodegradable waste is sent to a Shimla-based plant. The major goals of this study were to evaluate USW's potential for energy recovery, power generation, and methane emissions.

2. Material and methods

2.1 Study area

The current study was carried out in the Solan district of Himachal Pradesh during the years 2018 and 2019 and is located within the North Latitude of 30°44'53" to 31°22'01" and the East Longitude of 76°36'10" to 77°15'14". There are four distinct seasons in the district's sub-tropical to sub-temperate climate throughout the year. The spring season runs from March through April and ends in May, followed by the summer season from June through August, the autumn season from September through November, and the winter season from December through February. In this region, the monsoon season, which lasts from June to September, is when 70% of rain falls. Around 1,140 mm of rain falls on the district each year on average. Between 4 °C and 40 °C are the average lowest and maximum temperatures. Five urban areas were chosen for the study namely: Arki, Baddi, Parwanoo, Nalagarh, and Solan (**Figure 1**).

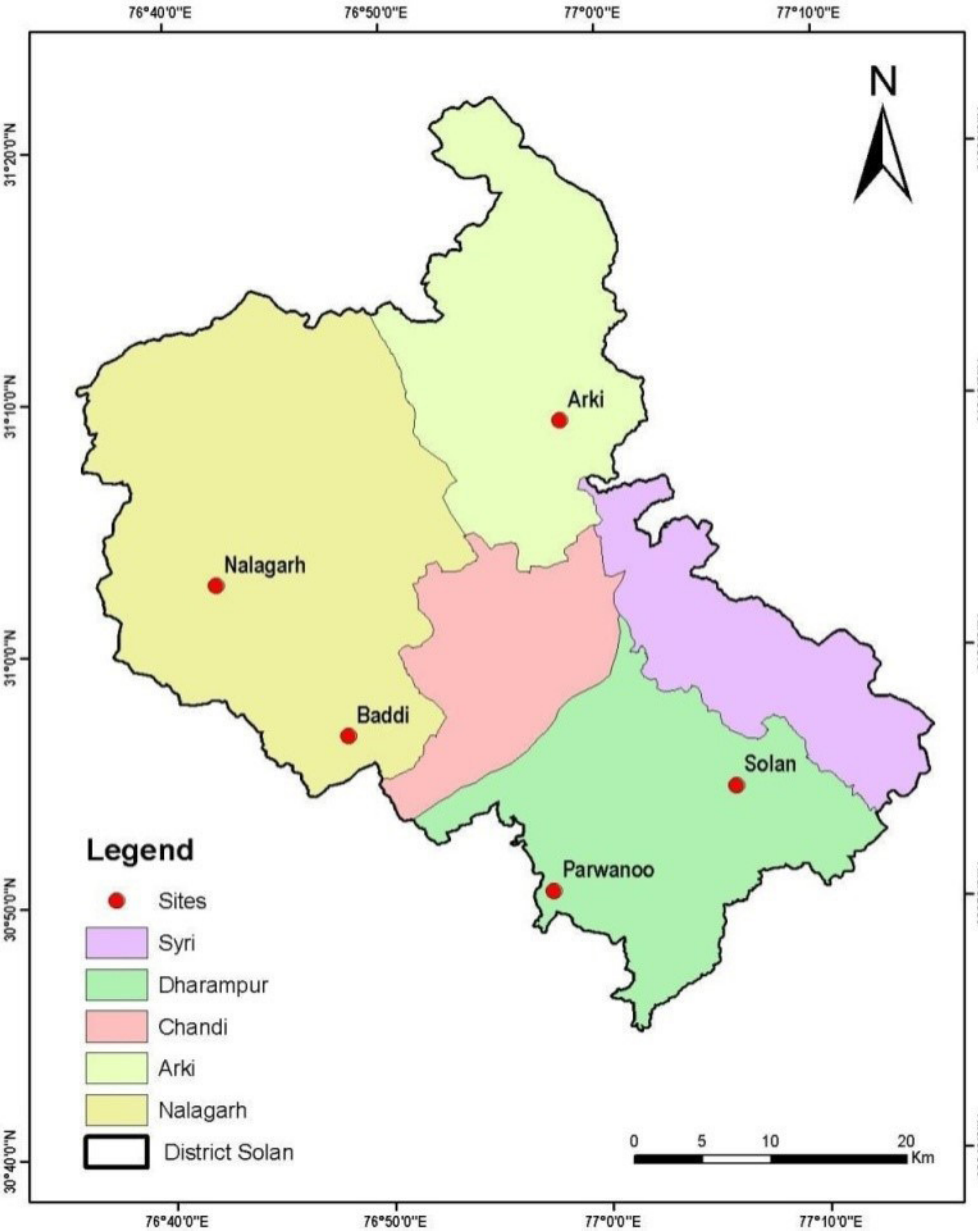

Figure 1. Location map of study area.

2.2 Quantification and characterization of waste

In order to compile fundamental data, evaluate working conditions, and analyze the state of solid waste management at the moment, the survey was carried out in the study region. A 10% sample from various urban locations was taken based on the survey. By using a stratified random sampling technique, the samples were collected from various locations. Physical sorting was done manually to separate various components after estimating the total waste generated separately for each site. The segregated components included food waste (fruits, vegetables, leftover food, eggshells, and dairy products), paper waste (packaging cardboard, newspapers, magazines, tissue paper, and tetra packs), plastic waste (bottles, packaging, bags, lids, plastic cutlery, toys, and gift wraps), glass waste (bottles, jars, broken glassware, light bulbs, and colored glass), metal waste (cans, foil, and appliances), textiles waste (linens, towels, and thread waste), rubber/leather waste (shoes and bags) and other wastes (batteries, ash, stone, rock, diapers, medicines, and paint boxes).

2.3 Energy content

Using the following equation, provided by Khan and Abu Gharah[16], the energy content of urban solid waste was determined.

$$\text{HHV } (\text{kJ}\cdot\text{kg}^{-1}) = 53.5\,(F + 3.6\,CP) + 372\,PLR$$

Where, F = Food (%); CP = Cardboard & paper (%); PLR = Plastic, leather and rubber in a waste mixture (%).

2.4 Energy recovery potential through biochemical conversion

Energy recovery potential of urban solid waste was assessed from its organic fraction as per method detailed by CPHEEO[17]. Only the biodegradable portion of the organic matter can contribute to the energy output during biochemical conversion.

Total waste quantity: W (tonnes per day);

Total Organic/Volatile Solids: VS = 50%; say Organic bio-degradable fraction: approx. 66% of VS = 0.33 × W;

Typical digestion efficiency = 60%;

Typical bio-gas yield: B (m^3) = 0.80 m^3/kg of VS destroyed;

= 0.80 × 0.60 × 0.33 × W × 1,000 = 158.4 × W;

Calorific Value of bio-gas = 5,000 kcal/m^3 (typical);

Energy recovery potential (kWh) = B × 5,000/860 = 921 × W;

Power generation potential (kW) = 921 × W/24 = 38.4 × W;

Typical conversion efficiency = 30%;

Net power generation potential (kW) = 11.5 × W.

2.5 Methane emission potential of urban solid waste

According to IPCC[18] methodology, methane emissions were determined based on the volume of waste disposed of in various types of solid waste disposal sites, the portion of degradable organic carbon that actually breaks down, and the proportion of CH_4 in landfill gas. The following formular was used to calculate it:

$$\text{Methane emissions } (\text{Gg}\cdot\text{yr}^{-1}) = (USW_T \times USW_F \times MCF \times DOC \times F \times 16/12 - R) \times (1 - OX)$$

Where, USWT = total urban solid waste generated ($\text{Gg}\cdot\text{yr}^{-1}$); USW_F = fraction of urban solid waste disposed to solid waste disposal sites; MCF = methane correction factor (default value is 0.6); DOC = degradable organic carbon (fraction); F = fraction of CH_4 in landfill gas (default is 0.5); R = recovered CH_4 ($\text{Gg}\cdot\text{yr}^{-1}$); OX= oxidation factor (default value is 0).

2.6 Carbon dioxide (CO_2) equivalent estimation

Comparing differing GHG emissions often involves converting them to carbon dioxide equivalents. According to IPCC[19], CO_2 equivalents were calculated based on their potential to cause global warming. The CO_2 equivalents were estimated by multiplying CH_4 (Gg) with its global warming potential (21).

3. Results and discussions

3.1 Physical characterization of urban solid waste and its energy content

According to Pandit and Bhardwaj[20], the generation of solid waste in various urban regions ranged from 0.896 to 19.527 $\text{t}\cdot\text{day}^{-1}$. Solan (19.527 $\text{t}\cdot\text{day}^{-1}$) generated the most urban solid waste, followed by Baddi (13.905 $\text{t}\cdot\text{day}^{-1}$), Nalagarh (3.177 $\text{t}\cdot\text{day}^{-1}$), Parwanoo (2.682 $\text{t}\cdot\text{day}^{-1}$) and Arki (0.896

t·day^{-1}). The generation of solid waste in various urban regions ranged from 0.896 to 19.527 t·day^{-1}. Solan's higher rate of urban solid waste generation may be attributed to the area's increased commercialization and growth. New commercial areas have also been added to keep up with the region's growth and to accommodate the modern needs of the expanding population. Further, it may be attributed to higher income and standards of life causing an increase in the consumption of goods and services, thereby resulting in increased proportions of disposable materials, especially packaging materials as reported by Medina[21]. Out of total waste generated in Solan, the percentage of food waste (49.41) was discerned to be maximum followed by paper (24.71), plastic (16.75), glass (4.26), others (1.66), textiles (1.29), metal (0.97) and rubber/leather waste (0.96). The percentage of different components of solid waste generated in Baddi followed the order: food waste (50.51) > plastic (20.67) > paper (18.00) > glass (4.48) > others (2.82) > metal (1.52) > rubber/leather (1.13) > textiles waste (0.87). Out of total waste generated in Nalagarh food waste percentage (50.68) was found to be maximum followed by paper (21.62), plastic (18.79), glass (4.19), others (1.64), metal (1.26), textiles (1.04) and rubber/leather waste (0.79). The percentage of different components of solid waste generated in Parwanoo followed the order: food waste (50.34) > paper (21.29) > plastic (19.54) > glass (3.62) > others (2.16) > metal (1.12) > rubber/leather (1.01) > textiles waste (0.97). Out of total waste generated in Arki, the percentage of food waste (52.12) was perceived to be maximum followed by paper (25.33), plastic (15.51), glass (2.57), others (2.01), metal (1.00), rubber/leather (0.89) and textiles waste (0.67). The waste energy content was perceived to be maximum in Baddi (14,850.416 kJ·kg^{-1}) followed by Parwanoo (14,110.210 kJ·kg^{-1}), Solan (13,369.065 kJ·kg^{-1}), Nalagarh (12,376.783 kJ·kg^{-1}) and Arki (11,532.432 kJ·kg^{-1}) as depicted in **Table 1**. The maximum value of Baddi may be ascribed to the maximum percentage of manufactured materials such as paper and plastics as these components contribute to its higher energy content. According to Tsheleza *et al.*[22], it may also be linked to increasing income and standards of living, which lead to higher levels of consumption of products and services and, in turn, higher proportions of waste materials, particularly packaging materials. Baddi (14,850.416·kJ·kg^{-1}) was classified to have the highest waste energy content, followed by Parwanoo (14,110.210 kJ·kg^{-1}), Solan (13,369.065 kJ·kg^{-1}), Nalagarh (12,376.783 kJ·kg^{-1}) and Arki (11,532.432 kJ·kg^{-1}). The highest percentage of manufactured materials, including paper, metals, plastics, etc., can be attributed to Baddi's highest value because they all contribute to higher energy content. The outcomes are consistent with Nandan *et al.*[23] conclusions. Waste produced in the various urban centers of the Solan district is ideal for energy recovery since the heating value of waste must be at least 6,000 to 7,000 kJ·kg^{-1} for energy generation[24].

Table 1. Energy content of urban solid waste (t·day^{-1}) of Solan district, Himachal Pradesh

Urban areas	Energy content (kJ·kg^{-1})
Arki	11,532.432
Baddi	14,850.416
Nalagarh	12,376.783
Parwanoo	14,110.210
Solan	13,369.065

3.2 Energy recovery and power generation potential of urban solid waste

The energy recovery potential of solid waste produced in Solan district's various urban areas ranged from 910.036 to 959.988 kWh (**Table 2**). It was found to be maximum in Arki (959.988 kWh) followed by Nalagarh (933.395 kWh), Baddi (930.269 kWh), Parwanoo (927.111 kWh) and Solan (910.036 kWh). The maximum value of Arki may be attributed to the maximum biodegradable/food fraction (52.12% kWh) of the urban solid waste generated. The power generation potential of different urban areas ranged from 37.918 to 39.999 kW and followed the order Arki (39.999 kW) > Nalagarh (38.891 kW) > Baddi (38.761 kW) > Parwanoo (38.630 kW) > Solan (37.918 kW). The net power generation potential of different urban areas varied from 10.304 to 224.561 kW. It was perceived to be highest in Solan (224.561 kW), Baddi (159.908 kW), Nalagarh (36.536 kW), Parwanoo (30.843 kW) and Arki (10.304 kW). The highest net power generation potential of Solan may be ascribed to the maximum solid waste generated (19.527 t·day^{-1}) as detailed in section 3.1.

Table 2. Energy recovery and power generation potential of urban solid waste of Solan district, Himachal Pradesh

Urban areas	Energy recovery potential (kWh)	Power generation potential (kW)	Net power generation potential (kW)
Arki	959.988	39.999	10.304
Baddi	930.269	38.761	159.908
Nalagarh	933.395	38.891	36.536
Parwanoo	927.111	38.630	30.843
Solan	910.036	37.918	224.561
Total	4,660.799	194.199	462.152

3.3 Methane emissions potential

According to the data in **Table 3**, total methane emissions and carbon dioxide equivalent (CO_2 eq.) from urban solid waste ranged from 0.016 to 0.319 Gg per year and 0.337 to 6.697 Gg per year, respectively. Solan (0.319 Gg·yr^{-1}) had the greatest estimated methane emission, which was followed by Baddi (0.232 Gg·yr^{-1}), Nalagarh (0.053 Gg·yr^{-1}), Parwanoo (0.045 Gg·yr^{-1}), and Arki (0.016 Gg·yr^{-1}). A similar trend was observed in terms of CO_2 eq.: Solan (6.697 Gg·yr^{-1}) > Baddi (4.859 Gg·yr^{-1}) > Nalagarh (1.106 Gg·yr^{-1}) > Parwanoo (0.936 Gg·yr^{-1}) > Arki (0.337 Gg·yr^{-1}) as illustrated in **Table 3**. The reason Solan has the highest methane emissions may be attributed to the city's quick urbanization and economic development, which changed people's lifestyles and living conditions generally and consequently increased the production of urban solid waste. The results are in conformity with the findings of Singh *et al.*[25]. The present methane emission of Solan is 0.319 Gg·yr^{-1} which is much less than that of the national average of 65,052.47 Gg·yr^{-1} as advocated by INCCA[26]. It is perceptible from **Figures (2–6)** that by 2025, the methane emissions would be 0.019 Gg·yr^{-1}, 0.253 Gg·yr^{-1}, 0.054 Gg·yr^{-1}, 0.055 Gg·yr^{-1}, 0.373 Gg·yr^{-1} for Arki, Baddi, Nalagarh, Parwanoo and Solan respectively if the methane emissions from urban solid waste continue at the same rate. According to INCCA[65], Solan currently emits 0.319 Gg of methane per year, which is significantly less than the 65,052.47 Gg per year national average.

Table 3. Methane emission potential of urban solid waste of Solan district, Himachal Pradesh

Urban areas	Methane emission (Gg·yr^{-1})	Carbon dioxide equivalent (Gg·yr^{-1})
Arki	0.016	0.337
Baddi	0.232	4.859
Nalagarh	0.053	1.106
Parwanoo	0.045	0.936
Solan	0.319	6.697

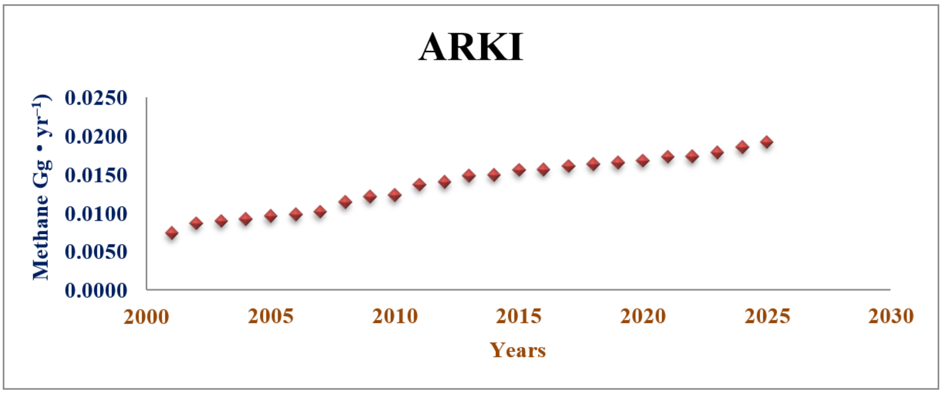

Figure 2. Projected methane emissions (Gg·yr^{-1}) for Arki.

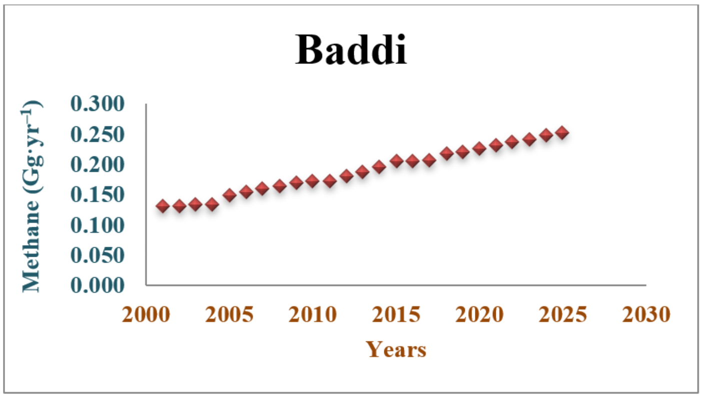

Figure 3. Projected methane emissions ($Gg \cdot yr^{-1}$) for Baddi.

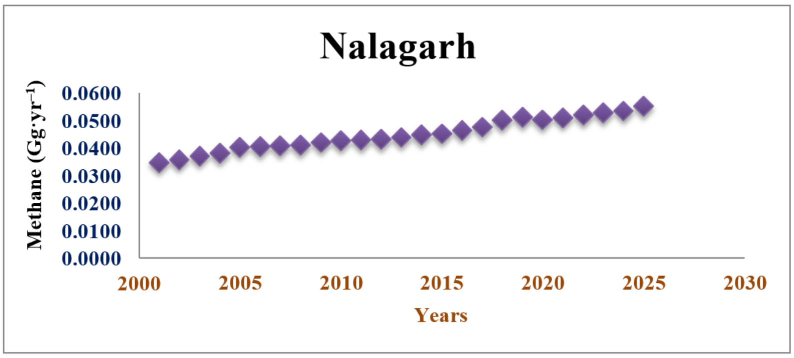

Figure 4. Projected methane emissions ($Gg \cdot yr^{-1}$) for Nalagarh.

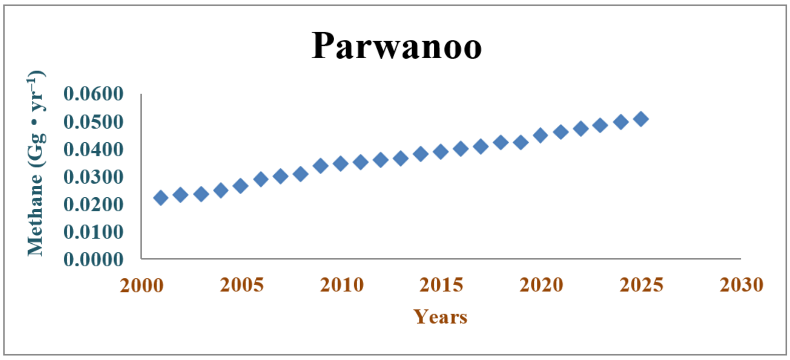

Figure 5. Projected methane emissions ($Gg \cdot yr^{-1}$) for Parwanoo.

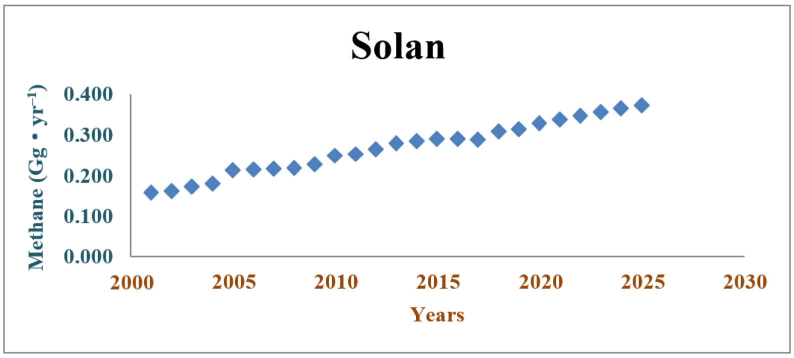

Figure 6. Projected methane emissions ($Gg \cdot yr^{-1}$) for Solan.

4. Conclusions

According to the study, waste production in the Himachal Pradesh district of Solan had increased as a result of urbanization. Since the characteristics of the created waste depend on both economic activity and human lifestyle, they differ depending on the region from which the samples were gathered. The region's larger amount of organic waste has demonstrated the potential for biorecycling, the production of biogas, and the manufacture of biofuels. This assessment can also be used as a guide when selecting a potential course of treatment. For the district the potential of bio-chemical conversion for producing energy has been observed significantly which is about 4,660.799 kWh. This conversion of USW to energy and power generation will be instrumental in meeting energy demand and promoting sustainable waste management and energy security. Among the different thermal energy sources, USW is one of the least expensive and most environmentally responsible ways to generate electricity. Therefore, it is recommended that USW be used to fill the region's energy deficit and clean up its ecology. A high fraction of organics in urban solid waste implies its higher propensity for methane gas emissions which may contribute to climate change if not biorecycled for useful materials.

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Conflict of interest

There is no conflict of interest for this manuscript.

References

1. Avtar R, Tripathi S, Aggarwal AK, Kumar P. Population-Urbanization-Energy Nexus: A review. Resources 2019; 8(3): 136. doi: 10.3390/resources8030136.
2. Gutberlet J. Waste in the city: Challenges and opportunities for urban agglomerations. In: Ergen M (editor). Urban agglomeration. London: Intech Open; 2018. p. 191–208. doi: 10.5772/intechopen.72047.
3. Mohammed A, Elias E. Domestic solid waste management and its environmental impacts in Addis Ababa city. Journal of Environment and Waste Management 2017; 4(1): 194–203.
4. Rathi S. Optimization model for integrated municipal solid waste management in Mumbai, India. Environment and Development Economics 2007; 12: 105–121. doi: 10.1017/S1355770X0600341X.
5. Hoornweg D, Bhada-Tata P, Kennedy C. Environment: Waste production must peak this century. Nature 2013; 502: 615–617. doi: 10.1038/502615a.
6. Sharholy M, Ahmad K, Vaishya RC, Gupta RD. Municipal solid waste characteristics and management in Allahabad, India. Waste Management 2005; 27(4): 490–496. doi: 10.1016/j.wasman.2006.03.001
7. Rachel OA, Komine H, Yasuhara K *et al*. Municipal solid waste management in developed and developing countries—Japan and Nigeria as case studies [Internet]. Ibaraki: Geotechnical Engineering Laboratory; 2009. Available from: http://wwwgeo.civil.ibaraki.ac.jp/komine/mypapers/JGSPaper/2009/JGS2009(973)Rachel.pdf.
8. Singh S. Solid waste management in urban India: Imperatives for improvement. ORF Occasional Paper No. 283 [Internet]. Delhi: Observer Research Foundation; 2020 [published 2020 Nov 19]. Available from: https://www.orfonline.org/research/solid-waste-management-in-urban-india-imperatives-for-improvement-77129/.
9. Aslani H, Taghipour H. Seasonal characterization and quantification of municipal solid waste: Energy content and statistical analysis. Journal of Advances in Environmental Health Research 2018; 6(1): 34–43. doi: 10.22102/jaehr.2018.105728.1053.
10. Senzige JP, Makinde DO, Njau KN, Nkansah-Gyeke Y. Factors influencing solid waste generation and composition in urban areas of Tanzania: The case of Dar-es-Salaam. American Journal of Environmental Protection 2014; 3(4): 172–178. doi: 10.11648/j.ajep.20140304.11.
11. Ansah B. Characterization of municipal solid waste in three selected communities in the Tarkwa township of Tarkwa Nsuaem Municipality in Ghana [Master's thesis]. Ashanti, Ghana: Kwame Nkrumah University of Science and Technology; 2014.
12. Thanh NP, Matsui Y, Fujiwara T. Household solid waste generation and characteristic in a Mekong Delta city, Vietnam. Journal of Environmental Management 2010; 91(11): 2307–2321. doi: 10.1016/j.jenvman.2010.06.016.
13. Late A, Mule MB. Composition and characteri-

zation study of solid waste from Aurangabad city. Universal Journal of Environmental Research and Technology 2013; 3(1): 55–60.
14. Powell JT, Townsend TG, Zimmerman JB. Estimates of solid waste disposal rates and reduction targets for landfill gas emissions. Nature Climate Change 2016; 6: 162–165. doi: 10.1038/nclimate2804.
15. Stocker TF, Qin D, Plattner GK, *et al*. (editors). Climate change 2013: The physical science basis. Contribution of Working Group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge and New York: Cambridge University Press; 2013. p. 1535.
16. Ali Khan MZ, Abu-Gharah ZH. New approach for estimating energy content of municipal solid waste. Journal of Environmental Engineering 1991; 117(3): 376–380. doi: 10.1061/(ASCE)0733-9372(1991)117:3(376).
17. CPHEEO. Manual on municipal solid waste management. New Delhi, India: Ministry of Housing and Urban Affairs; 2000. p. 265.
18. Houghton JT, Meira Filho LG, Lim B, *et al*. (editors). Revised 1996 IPCC guidelines for national greenhouse gas inventories. Bracknell: IPCC/OECD/IEA; 1996.
19. Eggleston HS, Buendia L, Miwa K, *et al*. (editors). 2006 IPCC guidelines for national greenhouse gas inventories. Hayama: Institute for Global Environmental Strategies; 2006.
20. Pandit J, Bhardwaj SK. Quantification, characterization and footprint appraisal of solid waste in urban areas of Solan district in Himachal Pradesh. International Journal of Chemical Studies 2020; 8(5): 202–210. doi: 10.22271/chemi.2020.v8.i5d.10607.
21. Martin M. World's largest and most dynamic scavenger movement. Biocycle 2010; 51(10): 32–33.
22. Tsheleza V, Ndhleve S, Kabiti HM, *et al*. Vulnerability of growing cities to solid waste-related environmental hazards: The case of Mthatha, South Africa. Jàmbá: Journal of Disaster Risk Studies 2019; 11(1): a632. doi: 10.4102/jamba.v11i1.632.
23. Nandan A, Yadav BP, Baksi S, Bose D. Recent scenario of solid waste management in India. World Scientific News 2017; 66: 56–74.
24. Dolgen D, Sarptas H, Alpaslan N, Kucukgul O. Energy potential of municipal solid wastes. Energy Sources 2005; 27(15): 1483–1492. doi: 10.1080/009083190523820.
25. Singh CK, Kumar A, Roy SS. Quantitative analysis of the methane gas emissions from municipal solid waste in India. Scientific Reports 2018; 8: 2913. doi: 10.1038/s41598-018-21326-9.
26. Indian Network for Climate Change Assessment. India: Greenhouse gas emissions 2007. New Delhi: Ministry of Environment and Forests; 2010. p. 84.