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Waste to Energy: Quantification of Biodegradable Household Waste to Useful Energy

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Abstract
As urban populations and economies expand, people generate more municipal solid waste than ever before. Unfortunately, due to variables like poor coordination among stakeholders, governance issues, and managerial deficiencies, controlling waste is frequently challenging. Land filling and uncontrolled open dumping grounds are popular ways to dispose of wastes. Waste to energy technologies might be key scientific ways to manage wastes. It provides an energy source that can be very useful in underdeveloped nations. The purpose of this paper is to investigate such technologies in generating bio-gas and electricity from biodegradable household waste. The research employs both qualitative and quantitative research methods. Quantitative methods are used to measure the quantity of waste from household and energy output from that biodegradable household waste. In ward 7 of Madhyapur Thimi, a survey is conducted among 44 households to determine the amount of waste produced each day. A weighing machine is used to measure the waste on site. Additionally, Bio-gas calculation tool software is used to calculate the bio-gas from the generated waste. The results showed that the average daily household waste is found to be 1260.27kg per day. A 63 m3 bio-gas plant generates 70.6 m3/day of bio-gas, generating 4.85 kWh of power, 6.47 kW of heat energy, and 262 kg of compost each day. The findings indicate that waste to energy technology (Anaerobic Digestion) can result in the production of usable energy, particularly bio-gas, in any area. Additionally, the study establishes a correlation between parameters such as income, family numbers with waste generation, as well as the amount of bio-gas generated. The results of this study suggest that such technologies can contribute significantly to the energy sector and help address waste management challenges.

Keywords
Municipal Solid Waste (MSW), Waste-to-Energy (WtE), Anaerobic Digestion, Biogas

1. Introduction

The fast expansion of lands and populations has resulted in an increase in household waste output. This has put a lot of strain on the current waste management systems, which are, regrettably, inefficient. As a result, the situation is worsening and health hazards are mounting. Nepal is dealing with the effects of actions such as dumping and burning, which cause environmental damage and health risks. However, in this context, the notion of using household waste to generate electricity and bio-gas using waste to energy technology provides optimism. The Municipal solid waste (MSW) generation is growing in lockstep with population growth, rapid urbanization, and rising community living standards and spending patterns [1].

The higher the technologies number and higher the variety of potential routes from gathering to removal, the more difficult it is to find the "optimal" answer. Furthermore, Municipal solid waste (MSW) handling is critical from an economic standpoint. One of the difficult environmental problems that many towns in Nepal must deal with is municipal solid waste. The increasing amounts of waste produced by an growing urban population and its effects on the environment and civic health in Nepal are beyond the capacity of the country's current practices and procedures. The worldwide waste calamity is a outcome of unprocessed, unsafe dumping and incompetent waste collection. World average waste production varies in 0.11 - 4.54 kg/person/d and the daily production of waste/capita will be increased by 40% for developing and 19% for developed countries by 2050 [2]. Solid waste production ranges from 0.3 kg/day to 1.0 kg/day [3], with a substantial proportion of organic waste- 66%, plastics- 12%, paper products- 9%, metals- 3% , and others- 5% [4].

Nepal is dealing with a growing waste management challenge, as solid waste output in urban areas increases. This situation poses significant threats to civic health and the environment. The country's lack of efficient waste management infrastructure has resulted in unproductive and unsustainable methods like as open dumping and burning, which exacerbates environmental degradation and health hazards in Nepal.Renewable energy sources (mostly organic waste materials converted to energy) are anticipated to be the most appealing replacements in the near future [5]. Waste-to-energy conversion is one of the most recent techniques of waste treatment, and it has a lot of advantages [2]. In Nepali context few of such technologies has been developed for waste management but in urban area, waste to energy technology can play significant role in production of useful energy which can be used by the society itself. Waste to Energy assures energy supply security, becomes an important aspect of contemporary waste management, and has the potential to minimize reliance on fossil fuels [6]. Energy from municipal solid waste (MSW) has been emerged as among the most important MSW management solutions. Waste-to-energy (WTE) conversion is now regarded as a significant strategy in waste management and economic development.

2. Objectives

The major objective of this research is to Investigate the Quantity of useful energy (bio-gas, heat and electricity) that can be generated from household waste. The specific objectives are as follows:

- To analyse the different types of household waste and its quantity for the production of energy.
- To study the relationship between the quantity of waste production and parameter such as income and number of family.

3. Scope and Limitation

The sample size for the survey was conducted in Ward 7 of Madhyapur thimi Municipality and Due to time and resource constraints, the study is restricted to ward no. 7 only. Since a random sampling distribution is used to conduct the research, the data interpretation will not encompass the entire population but will instead show specific settlement distribution pattern. It is crucial to emphasize that the survey data may not be entirely authentic or reliable. This is because communication gaps between participants and the surveyor may have existed due to factors such as language barriers, opposing viewpoints, and varying levels of comprehension.

4. Methodology

The post-positivist paradigm views knowledge as temporary and open to adjustment in light of fresh information. This technique of producing knowledge prioritizes objectivity, empirical evidence, and the scientific process as essential elements. Social phenomena are complex and that there are multiple perspectives and interpretations of reality. In this context, a post-positivist approach to the topic, waste to energy might focus on the use of qualitative methods, such as interviews and case studies which helps to know the amount of waste that generated and types of waste.

The ontological claim in this research is that the prospects of generating useful energy from household waste are real and exist in the physical world. This claim is based on the assumption that waste is a physical phenomenon that can be transformed into energy through the use of appropriate technologies.To investigate the prospects of generating useful energy from waste, the research design would involve conducting a waste characterization, energy output, technology assessment. The total household in ward 7 is 1564 according to the Census 2011. Data were collected by surveying 44 number of houses in ward 7, Madhyapur Thimi municipality. and then data were analyzed, and conclusions was done based on the evidence. Quantitative methods were utilized to measure the quantity of waste and energy output, while qualitative methods were employed to assess waste characterization factors and evaluate the effectiveness of different waste to energy technologies.

Additionally, data was collected from a questionnaire survey using Kobo Toolbox to obtain waste characteristics. Direct waste analysis was conducted to find the waste types through sampling, sorting, and weighing the waste from the houses manually then Microsoft Excel is used to data analysis and also statistical package for the social sciences (SPSS). Alternate Energy Promotion Center's Biogas calculation tool was used to calculate quantity of energy generation from household waste. Further secondary data was collected through literature review and case studies to support the research findings.

5. Literature Review

5.1 Waste and Its type

According to Raveesh Agarwal, there are unavoidable aspects of the human experience [7]. Waste is described as residue that remains at the end of a product's life cycle and is then disposed of in landfills or other waste management facilities. Waste can be classified in a variety of ways, and its characterization can take numerous forms. Organic waste, which is generated from living creatures, is biodegradable. Organic waste is further subdivided into moist and dry waste.Food garbage, vegetable peels, fruit peels, and other organic matter are examples of wet waste, whereas paper, cardboard, wood, and other similar materials are examples of dry waste. Non-biodegradable waste is garbage that cannot breakdown naturally. Glass, plastics, metals, and other similar materials are examples of this sort of garbage. Non-biodegradable garbage is a major environmental issue since it takes a long time to breakdown and can remain in the environment for years, producing pollution and harm to animals. Waste collected by city authorities, which comprises residential waste, non-hazardous solids from industrial, commercial, and institutional trash, and non-pathogenic hospital waste is termed as municipal solid waste(MSW) [8]. They also noted that improper municipal solid waste management might have a negative impact on human health and the environment. Household waste, also known as domestic waste, is waste generated in the homes of people and families. It is made up of many things, including food waste, paper, cardboard, plastics, glass, metals, textiles, and other stuff.

5.2 Waste Generation Factors

Due to the impact of variables like the degree of industrialization, climate, and socioeconomic development, waste production rates and composition vary between countries and even between towns within a country. The composition of solid waste in household varies greatly depending on the socioeconomic class of the families [9]. There are several parameters that affects the production of solid waste in any household such as family size, Monthly income, Gender, House size and design, Education level of family members,Housekeeping activities etc. For useful energy production sufficient amount of organic biodegradable waste is needed and the waste generation are differ from one house to another because of such parameters which are also varied hence, these parameters need to be considered.

5.3 Waste To Energy

An innovative waste management strategy called “waste to energy” entails transforming different wastes into energy that can be used for various purposed. This novel method offers sustainable and green energy options in addition to aiding in the problem of garbage disposal. Utilizing cutting-edge technologies, the waste to energy process converts municipal solid waste, industrial waste, and agricultural waste into useful energy. This energy, which can take the shape of fuel, power, or heat, is a dependable replacement for conventional fossil fuels. The process known as waste to energy involves turning waste into fuel by converting it into a fuel source or using it as a source of power and/or heat. Waste-to-energy (WtE) is a technical technique that contributes to the recovery of energy from Municipal solid waste as heat, electricity, or other replacement fuels. Waste-to-energy (WtE) has recently come to be seen as an answer to the issues caused by rising garbage amounts in growing cities as well as rapidly rising energy consumption. Waste administrators and decision makers in developing and emerging nations must react to these new challenges. To address the environmental issue and the energy crisis, the Waste-to-energy (WtE) strategy and its technologies are advantageous for low-income nations because they can transform Waste into a usable form of energy [10].

5.3.1 Waste To Energy Technology

A variety of methods can be used to convert refuse into energy. Each of these waste to energy (WtE) options has unique qualities and varying degrees of viability based on a variety of factors. WTW-T is a module of Integrated Solid Waste Management Systems (ISWM-S) in the advanced world, which not only create other byproducts but also handle climate change and global warming. Waste to energy technologies is crucial for reducing environmental problems and promoting healthy garbage management on a global scale. Municipal solid waste can be transformed into energy from various Waste to energy conversion processes and most commonly used techniques are thermal treatment technology (thermochemical conversion) and biological treatment technology (biochemical conversion) for converting Municipal solid waste into energy [11] as shown in Figure 1. Thermochemical conversion is useful for waste with low moisture content, whereas biochemical conversion is the best choice for waste with high moisture content, including organic waste [11].

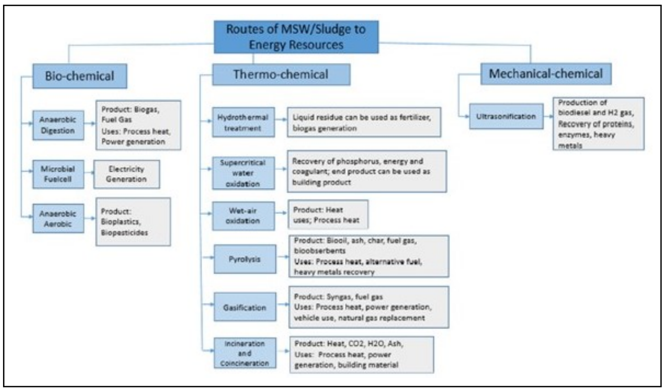

Figure 1: Waste to Energy Conversion Technologies with outputs [11]

5.3.2 Anaerobic digestion

Anaerobic digestion (AD) as WtE technology is appropriate option for changing organic Municipal solid waste into bio-gas (methane) and also generate electricity which then decrease the size of waste to be land filled. Anaerobic digestion happens naturally in oxygen-depleted environments such as lake sediments and can be used to generate bio-gas under regulated circumstances. A gas-tight vessel, known as an anaerobic digester provide auspicious circumstances for microbes to convert organic matter, the incoming feed-stock, into bio-gas and a solid-liquid sediment known as digestate. When the feed-stock is source isolated and non-contaminated organic refuse, the digestate can be used as organic fertilizer. Bio-gas is a gas combination that can be transformed into thermal and/or electrical energy. Bio-gas, which may be utilized as fertilizer or processed into other products, is produced as a result of this process and It contains 50–75% CH4, 25–50% CO2, and 1–15% of other gases, such water vapor, NH3, H2S, etc [12].

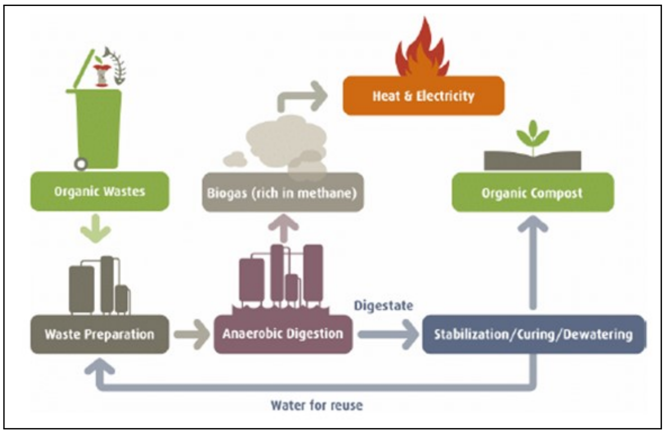

Figure 2: Anaerobic Digester Process [12]

Bio-gas may be used to generate heat directly or can be mixed with electricity in a combined heat and power plant; the latter process typically comes after desulfurization and drying and further choice is to convert bio-gas into biomethane, which may replace natural gas and has a methane concentration of about 98% [13]. A decent output of bio-gas from organic waste depends on a number of critical factors, including temperature, pH value, feedstock properties, C:N ratio, hydraulic retention duration, digester design, and operating conditions. The perfect range for the C:N ratio, which affects the generation of biogas, is between 16 and 25 and Mesophilic bacteria, with an average temperature of 27 degrees Celsius, do well at 30 to 40 degrees Celsius, whereas thermophilic bacteria, with an optimal temperature of 55 degrees Celsius, do best at 45 to 60 degrees Celsius [14]. The optimal pH range for producing large amounts of bio-gas is 6.5–7.5, and the hydraulic retention period is between 10 and 40 days [14].

6. Site Context

Thimi is merely a synthesis of newari culture, custom, art, and architecture. Madhyapur thimi is located in bhaktapur district, province no. 3 of nepal. It is ideally connected between the Kathmandu valley’s three regions. There are 9 total ward in

Madhyapur thimi , which are dispersed across 11 square kilometers of geographical area. Despite being only 11.47 square kilometers in area , thimi covers the sub-villages of Nagadesh, Lokanthali, Capacho, Balkumari,and Bode. This small historic burgh is located at an elevation of 1325m. The Total household in Thimi Municipality is 31966 and the total population according to the Census 2021, is 119756.

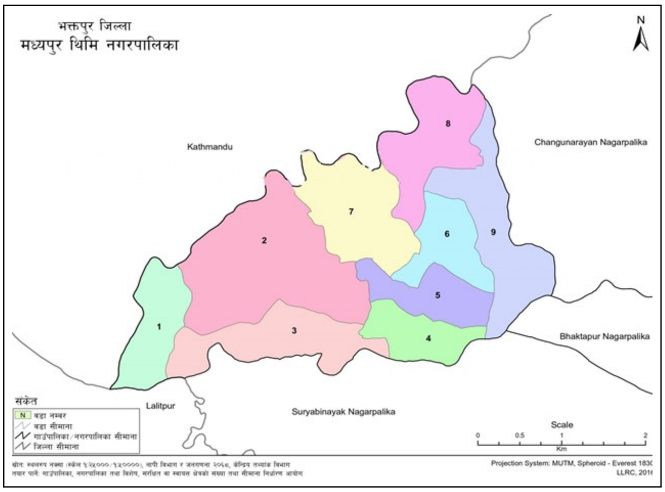

Figure 3: Map Of Madhyapur Thimi [15]

Ward no. 7 Nagadesh was selected and survey has been done. The total number of houses in Ward 7 was 1564 and the total population was 6783 as according to the Census 2011. 44 household were taken and surveyed with questionnaire and data were extracted from SPSS analysis.

7. Data Analysis

From the field survey, It was found that about 78% of waste is Organic food waste whereas plastic wastes are 19%, paper wastes are 2% and other waste are found to be 1%. In ward 7 the average family member is 4.7, with an average of 5.77 persons living in each dwelling. This population dynamic leads to daily waste creation, which averages 1.02 kg/household. This equates to 0.17 kg/capita of waste created daily by each individual in these houses. During the weighing waste on site, waste production climbed marginally to an average of 1.71kg/household . Within Ward 7, the total daily residential waste created totals 1595.28 kg, which equates to around 1.6 tons per day. Notably, food waste accounts for a considerable component of this waste stream, accounting for an average of 1260.27 kg each day, or nearly 1.26 tons shown in Table 1.

Table 1: Data from Field Survey

SN	Data Information(Avg)	value
1	No. of family member	4.7
2	No. of people living in house	5.77
3	Waste generation in (kg/household)	1.02
4	Waste generation (kg/capita)	0.17
6	Total household waste(in kg/day)	1595.28
7	Organic waste in ward 7(in kg/day)	1260.27

8. Result and Discussion

According to AEPC 2014, bio-gas output (0.35 m3/kg of VS), which contains 75% methane gas and is used for power generation. Furthermore, in Alternative Energy Promotion Center(AEPC's) "bio-gas calculation tool user's handbook" city organic refuse contains 20% total solid (TS) and 80% volatile solid (VS) [16]. That is, it is assumed that city organic has an average moisture level of 80% in Nepal. The bio-gas and methane gas yields are calculated using the BIOGAS CALCULATION TOOL provided by the Alternative Energy Promotion Center(AEPC). They developed the Excel spreadsheet-based calculating tool, which calculated the amount of waste to determine the amount of bio-gas. The excel file contains all the calculations, formulas, and parameters needed to produce usable energy with digester volume. The whole feed-stock of organic waste produced from ward 7 is added to this calculation tool sheet. According to the location-based bio-gas plant, several additional parameters and values have been changed. All of the parameter values—temperature, pH level, volatile solids, retention period, and C/N ratio—are obtained from researched literature as references. With the total feed-stock of 2801 kg/day in ward 7 which is the mixture of food waste and water can produce 70.6 m3 biogas per day in digester plant with volume of 63 m3 . This Biogas plant can produce 262 kg of compost per day as residue. From the 70.6 m3/day Bio-gas, 4.85KWh electricity and 6.47 KW heat energy is generated per day. About 32 gas cylinder can be distributed to the people in Ward 7 per month with that quantity of biogas.

During the survey, questionnaire on income, number of family member, house size and other parameters were asked and analysing those data with the generation of waste from each household. In this research two parameter income and family number was taken and the relation with waste generation have been done. It was found that the correlation between family number and waste production is highly significant and hence with higher the number of member in house can produce high amount of waste shown in table 2. But there is very less correlation between the income and waste generation that means with higher income wont be higher quantity of waste is shown in table 3. These can be very important parameters for understanding and identifying the key drivers behind waste generation and how it effect the generation and quantity of useful energy. With the lesser quantity of waste can result the lesser energy production. In Tables 2 and 3, N indicates the number of surveyed household.

The results indicate that utilizing Waste to Energy (WtE) technologies for biodegradable household waste which is 1260.27kg/day can result in the generation of usable energy as 70.6 m3 bio-gas = 4.85 KWh electricity = 6.47 heat energy = 32 gas cylinder/month. But this research was conducted on a small area in Thimi municipality so for a small land area, small biogas plant can be feasible for small number of user but in terms of whole people living in that ward can't use the energy. It can be useful in Public building cafeteria where large amount of gas is required and Street light can be the useful area for the use of electricity produced from the bio-gas plant. Compost manure as a by-product can be use by the farmers in that ward as agriculture is the major occupation in Nagadesh

Table 2: Correlation between Family member and waste generation

		No.of Family	Avg. Waste/day
No. of Family	Pearson Correlation	1	0.747
	Sig.(2 tailed)		0.000
	N	44	44
Avg. Waste/day	Pearson Correlation	0.747	1
	Sig.(2 tailed)	0.000	
	N	44	44

Table 3: Correlation Between Monthly income and Waste generation

		Avg. Waste/day	Income
Avg. Waste/day	Pearson Correlation	1	.003
	Sig.(2 tailed)		.987
	N	44	44
Income	Pearson Correlation	.003	1
	Sig.(2 tailed)	.987	
	N	44	44

ward 7 in Thimi Municipality. These results have been validated through various studies and outcomes from existing WtE projects. Moreover, various tools have been utilized to calculate the amount of bio-gas, heat, and electricity that can be generated from the process.

It is worth noting that in Nepal, the Anaerobic Digestion process need to be employed as a Waste to energy technology for urbanizing municipalities for the better management of waste to utilize useful energy in larger scale. Economical and Financial feasibility is important to consider for the larger scale bio-gas plant in municipality level for high quantity of bio-gas from larger amount of waste. Overall, The disposal of waste to landfills and streets of ward 7, Nagadesh, Thimi municipality, the waste can be used for the energy production through Anaerobic digestion technologies. Within small area, bio-gas plant can be built for the quantified energy production. The findings of this study provide valuable insights into the potential of Waste to energy quantification from waste to energy(WtE) technologies and need for further exploration and investment in this sector.

9. Conclusion

By harnessing the power of waste, waste-to-energy technology may assist sustainable energy generation while limiting the negative consequences of waste on urban areas. Finally, the research emphasizes the potential of Waste-to-Energy (WtE) technology for producing useable energy from biodegradable household garbage. The findings suggest that such technology can aid the energy industry and address waste management challenges. To attain optimal outcomes, there is a need for further investigation and use of various WtE technologies than Anaerobic Digestion. Furthermore, socioeconomic conditions and waste creation have a substantial influence on the amount of biogas produced, underscoring the need of taking such aspects into account when developing WtE projects.

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