iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** IX **Month of publication:** September 2022

DOI: https://doi.org/10.22214/ijraset.2022.46715

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

A Study of Challenges and Techno-Economic Assessment of Biogas Plants

Jaynil Atodaria
Civil Engineering Department, Institute of Technology, Nirma University, Ahmedabad, Gujarat-382481

Abstract: A promising sustainable method for generating energy from municipal, industrial, and animal wastes is biogas. The development of biogas can be combined with plans to enhance sanitation, lessen indoor air pollution, and cut greenhouse gas emissions. In addition to providing a techno-economic feasibility analysis of biogas plants, this research intends to identify technical and non-technological constraints preventing the widespread use of biogas in India. Different waste, renewable energy, and urban regulations have an impact on the distribution of biogas. Therefore, specific obstacles to India's current rural and urban biogas systems were identified. The findings demonstrate that there are significant differences in the nature and significance of obstacles amongst biogas systems due to variations in technological maturity, feedstock quality and availability, supply chain, awareness level, and policy support. The developed excel model also provides a full perspective of the economic factors used to assess the viability of a biogas plant project. Users may assess numerous situations and decide on the best course of action for their investment in the biogas sector by using a comparison and analysis technique.

I. INTRODUCTION

Biogas may play a role in the shift to a more environmentally friendly energy system. Modern waste management systems may benefit from the use of biogas, a sustainable energy source. Producing biogas can also aid in returning nutrients to crops. In addition to all of this, biogas is a locally generated energy source that has the potential to boost the efficiency of the use of global resources since it may result in increased value and decreased waste, as well as reduced adverse environmental consequences. Nevertheless, biogas production systems are complicated due to the variety of substrates, uses for digestate and biogas, and technological approaches for digestion, pre-treatment, and upgrading raw gas. There is a growing amount of energy demand in India from many industries. Biomass, which is one of the main energy sources in rural India and makes up around 75% of total energy consumption, is currently the new prospect in national programmes for a competitive energy source [1,2].

Due to its ecological sustainability and great efficiency, bioenergy, a major renewable energy source, is crucial in lowering carbon emissions [3]. Bioenergy differs from other renewable energy sources in several ways. As long as the utilization rate is lower than the growth rate, there are significant amounts of biomass feedstock that are available and stored on Earth. As a result, biomass may end up being the only organic resource that is renewable for making energy [4]. The carbon dioxide emissions from using bioproducts can also be countered by the carbon dioxide fixation and absorption from the regeneration of biomass resources since biomass is a biological substance obtained from living or recently lived organisms. Therefore, biomass utilization can realize carbon neutrality goals [5]. In addition, bioenergy can be converted into various types of energy carriers, such as biodiesel, biogas, and bioethanol, which could facilitate easier storage and utilization of such energy [6,7]. Thereby, biomass utilization follows the "waste-to-energy" model and is beneficial for establishing a sound material-cycle society.

Individual homes often operate small-scale plants to produce energy for self-use. On the other hand, large-scale biogas facilities that can produce more than 5000 m3 of biogas per day mostly use municipal sewage organic wastes to produce biogas, which may then be used to generate electricity, heat homes and businesses, and power vehicles. Large-scale commercial biogas plants are managed by entirely private or public-private partnerships to yield financial benefits through the sale of end products such as electricity, transport fuel, or heat. Family-type biogas plants are managed by individual households and require financial investment while only yielding non-monetary benefits, such as biogas used as a cooking fuel instead of gathered fuelwood.

Uncontrolled urbanization and the rapid pace of population expansion have seriously complicated the challenge of disposing of solid garbage. Food waste makes up a significant component of municipal solid wastes (MSWs), which are frequently dumped in landfills or other places and cause environmental issues, according to a study conducted by Baawain et al. [20]. However, because landfilling produces leachate, methane, and carbon dioxide as well as other annoyances like insects, odor, and vermin like birds and rats, it is expensive, takes up a lot of areas, and may have a severe influence on the environment if improperly managed.

Along with the release of methane, a strong greenhouse gas with a short-term global warming potential 84 times greater than carbon dioxide, leachate might potentially damage soil and subsurface water [21,22,23].

Knowledge exchange is a crucial component in the growth of biogas-producing systems. Clear analyses and comparisons of biogas-producing systems are required to promote this information exchange. Therefore, research is required to confirm the resource productivity of biogas production environments from many angles. The purpose of this project is to identify and assess technical and economic barriers to biogas production to develop capital and operational cost profile and estimate the potential economic feasibility of the biogas production process for achieving its commercial viability.

While there have been some studies concentrating on biogas in particular locations and hurdles to renewable energy in general, there is a dearth of information on the full scope of these barriers and the techno-economic viability of commercializing biogas energy. This initiative intends to close this gap and act as a roadmap for those making investment and adoption decisions in biogas energy.

II. LITERATURE REVIEW

In addition to producing energy and manure, the anaerobic digestion of biodegradable organic wastes has several positive social and environmental effects. The release of local air pollutants like dioxins and furans, as well as methane, a powerful greenhouse gas, are all negative externalities linked to organic wastes that biogas helps to mitigate [8,9].

One of the most popular methods for handling organic municipal solid waste (MSW) is anaerobic digestion (AD), which may produce biogas and methane as alternatives to natural gas and liquid petroleum gas (LPG). After the AD process is complete, the residue is a stabilized organic substance that may be used immediately on agricultural land as a bio-fertilizer (without ripening beforehand). This can replace synthetic or mineral fertilizers and provide the opportunity for nutrient recycling (nitrogen and phosphorus). Consequently, AD of bio waste combines energy generation with advantages for the environment.

The efficiency of AD throughout the biodegradation process, which improves while running at peak performance, is crucial to the generation of biogas. Temperature, organic loading rate, pre-treatment, inoculum, feeding pattern, hydraulic retention duration, and pH are significant parameters that affect biogas generation and have a significant impact on the AD process [19]. As biogas is created by four categories of microorganisms—fermentative, syntrophic, acetogenic, and methanogenic bacteria the microbial population and type of microbes have a major impact on AD and the composition of the gas [24,25].

These bacteria often exist in the natural environment and serve various functions in the anaerobic decomposition of garbage. Different varieties of microorganisms require various environmental conditions to exist. A kind of organism known as mesophilic bacteria thrives at temperatures between 20 and 45 °C, with 35 °C being the ideal temperature [27]. Thermophilic conditions typically occur between 50 and 65 °C, with 55 °C being ideal [28]. In contrast, thermophilic bacteria are a kind of organism that thrives and lives best in relatively hot temperatures (temperature range 41-122 °C). Microorganisms are essential to the breakdown of organic compounds and are crucial to the anaerobic degradation process [29]. Mesophilic AD is more stable than thermophilic digestion, according to the volumetric quantity of biogas generated in various digesters during the digestion process [30].

The use of biogas for energy production, power generation, and transportation in underdeveloped nations still requires improvement on all scales, from small-scale (home or domestic implementation) to large-scale implementation. For biogas to be used to its full potential in underdeveloped nations, there are issues with legislation, money, technical services, sustainability, awareness, and education [10].

There have been initiatives to advance biogas technology since the 1970s. The first oil crisis in the early 1970s showed Indian officials that commercial energy would continue to be out of the financial grasp of the poor in both the rural and urban areas [11]. India imported more oil products than it exported. In addition to increasing the pressure on the national budget to pay for rising energy subsidies for domestic fuels, especially kerosene, used by the rural and urban poor for very basic cooking and lighting needs, the combination of the global energy crisis and local energy shortages increased the risk to the country's energy security.

Based on the review, it was found that barriers differ in different regions depending on the degree of market maturity and availability of natural resources like biomass, land, and water. Barriers such as low ambient temperature and water unavailability in arid regions are area specific whereas others are specific to technological scale like lack of distribution infrastructure hindering the biogas expansion in a centralized system [31,32]. Socio-cultural barriers like objections toward using animal and human waste as raw materials are very specific to the local values and culture [33].

Cooking, lighting, and power production using clean fuels like biogas instead of fossil fuels and untreated conventional solid biomass would also assist reduce GHG emissions and indoor air pollution [12]. Numerous research has been done to evaluate technical advancements that increase biomass output, including physiochemical (extraction, carbonization), thermochemical (gasification, pyrolysis), and biochemical (anaerobic digestion) technologies [13,14].

In terms of techno-economic factors, such as energy usage, efficacy, and cost [15], Kamusoko et al. (2019) examined the effectiveness of biological, chemical, physical, and combination pre-treatments in enhancing biomethane synthesis from agricultural wastes. Additionally, Tabatabaei et al. 2020a and 2020b thoroughly assessed biological advancements and improvements in biogas production from three perspectives: upstream, mainstream, and downstream techniques, respectively [16].

The development of the biogas industry is influenced by a wide range of political, economic, and social variables, including regulations in the areas of energy, the environment, agriculture, banking, and education, among others. Both effective coordination between the decision-makers from the aforementioned domains and active participation of the professionals and associations of profile in the process of policy creation is necessary for the growth of this relatively new economic sector [26].

III. METHODOLOGY

The literature research is provided by the co-digestion economic analysis tool to prepare the MS Excel model for the techno-economic feasibility assessment. It was produced by the US Environmental Protection Agency. It is intended for those in decision-making positions who have technical expertise in anaerobic digestion, such as municipal managers, engineers, and anaerobic digestion system operators. Users can use it to assess the advantages and disadvantages of accepting and processing food waste, fats, oils, and greases (FOG), or other organic resources. It makes use of information and certain parameters from the institution being assessed. The application produces economic and operational statistics to help customers better understand the effects and costs of digesting various types of feedstocks at their plant. The data contains:

1) Fixed and recurring costs
2) Solid waste diversion savings
3) Capital investments
4) Biogas production and associated energy value

The challenges preventing the widespread distribution of biogas on a big scale in urban India have been studied. In-depth interviews with chosen stakeholders were thus performed in addition to the literature research to get the knowledge necessary to comprehend the underlying causes of each obstacle, particularly about the distribution of biogas in urban areas. Based on the total literature analysis, open-ended questions on hurdles and biogas policy were posed in a hierarchical order.

For the interviews, consultants and academics active in biogas projects of various sizes were chosen to better understand the main technological and market-related hurdles that exist in India. To further understand the existing policy environment and degree of cooperation between the national and subnational governments, officials participating in biogas policy-making processes at the national, state, and municipal levels of government were interviewed. Policymakers at the state and municipal levels in Gujarat were chosen for the interviews since this state was the first in India to declare a waste-to-energy program.

A qualitative and systemic approach was used to identify barriers to biogas penetration in India. The following steps were taken to extract the relevant literature. The penetration of biogas in India has been hindered, and this was determined using a qualitative and systematic method. The relevant literature was extracted using the procedures listed below.

a) First, a thorough search of research and review publications in the ASCE Library and Scopus database was done.
b) In addition to the literature study, interviews with specific stakeholders were performed to get the knowledge necessary to comprehend the underlying causes of each obstacle, particularly concerning the spread of biogas in India.
c) Conclusions on the difficulties with producing biogas in India were made based on the aforementioned processes.
d) Second, a review of previous studies and reference models was conducted to create an MS Excel model for the Techno-Feasibility analysis of biogas plants.
e) The developed excel model will next be verified using information gathered from prior literature reviews or a case study of a biogas plant.

IV. RESULT AND DISCUSSION

The level of technological advancement in the biogas industry varies greatly from one region to another and is influenced by a variety of variables, including the economic development of the nation, access to technology, the type and availability of feedstock, the need for the implementation of biogas technology, the education level of the populace, and their environmental awareness. As a result, depending on the market's level of development, different hurdles to the implementation of biogas projects may exist. While in moderate and immature markets, the main obstacles relate to the existence, stability, and dependability of the legal framework and support schemes, access to finance, absence of long-term strategies, lack of training, and lack of educational support, the main obstacles in mature markets relate to the availability of feedstock, public perception, indirect land use change (ILUC), and sustainability issues [17, 18].

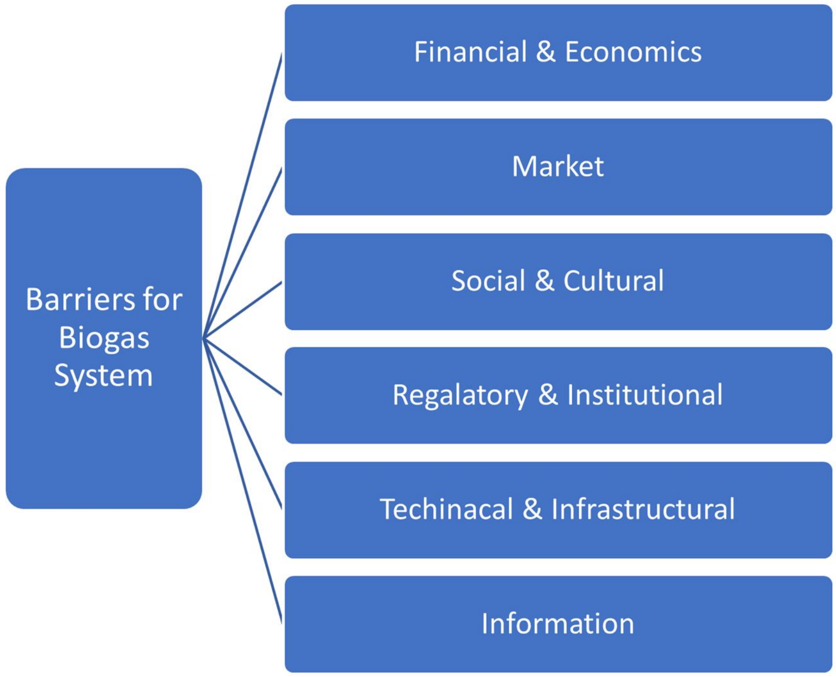


Figure 1-Type of Barriers for Biogas systems

Urban biogas systems face several obstacles since they typically include large-scale biogas plants. obstacles/challenges faced by the plant in fig. 2

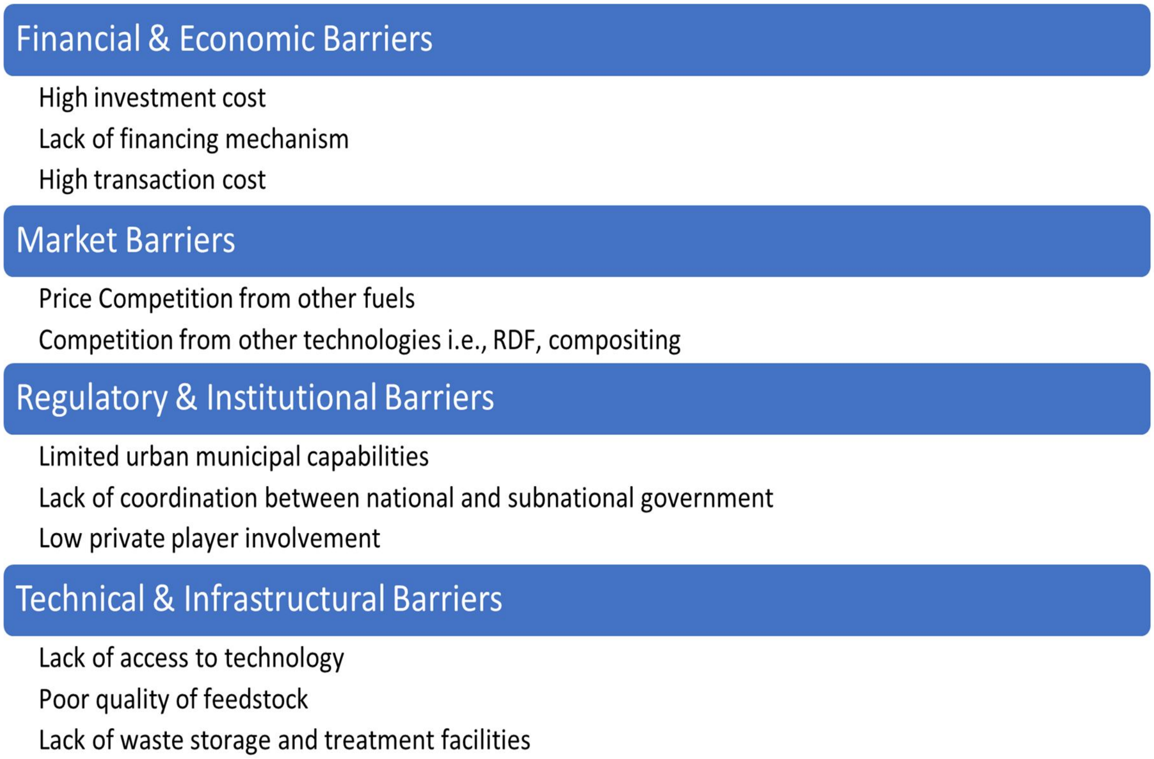


Figure 2 Barrier to Urban Biogas Plant

Since small-scale biogas plants are the norm in rural areas, barriers to biogas systems are difficult to overcome. obstacles/challenges that this plant must overcome, as seen in fig. 3.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

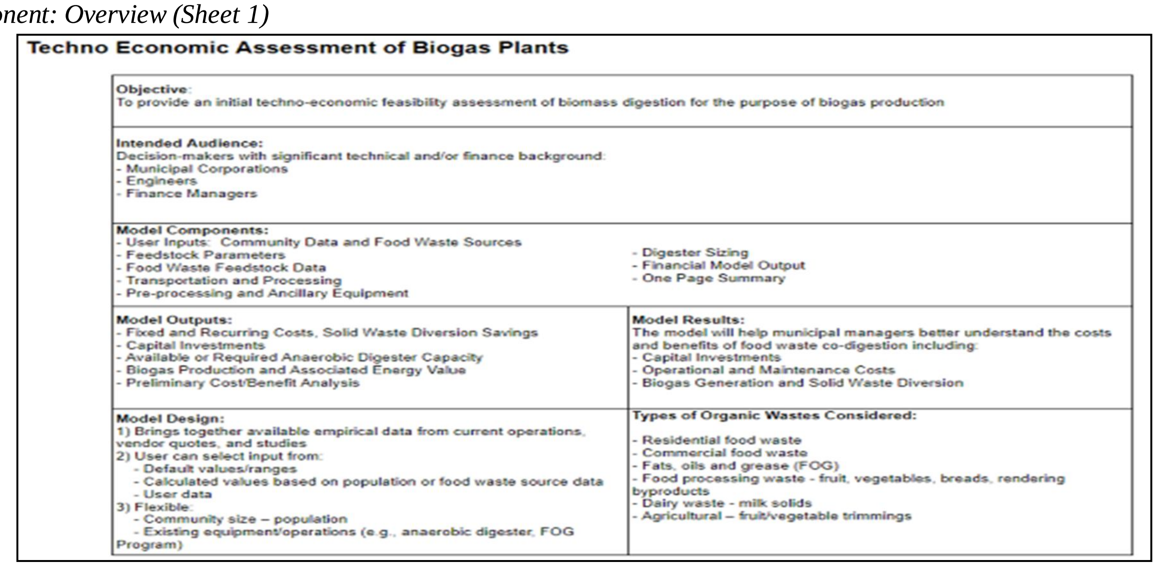
Figure 3 Barriers to Rural Biogas Plant

An excel model is created for the Techno-Economic Feasibility evaluation of biogas facilities, and it is discussed in this part. The Model offers a preliminary assessment of the physical and economic viability of biomass digestion for biogas generation. Because of the model's adaptability, users may change the costs and assumptions to suit their needs. For additional investigation and review, source data is offered wherever it is accessible.

Excel worksheets flow:

1) Overview
2) User Inputs
3) Feedstock parameter
4) Food Waste Feedstock Data
5) Transportation & processing
6) Financial Model Output
7) Summary

A. Component: Overview (Sheet 1)



Techno Economic Assessment of Biogas Plants

Objective:
To provide an initial techno-economic feasibility assessment of biomass digestion for the purpose of biogas production

Intended Audience:
Decision-makers with significant technical and/or finance background:
- Municipal Corporations
- Engineers
- Finance Managers

Model Components:
- User Inputs: Community Data and Food Waste Sources
- Feedstock Parameters
- Food Waste Feedstock Data
- Transportation and Processing
- Pre-processing and Ancillary Equipment
- Digester Sizing
- Financial Model Output
- One Page Summary

Model Outputs:	**Model Results:**
- Fixed and Recurring Costs, Solid Waste Diversion Savings - Capital Investments - Available or Required Anaerobic Digester Capacity - Biogas Production and Associated Energy Value - Preliminary Cost/Benefit Analysis	The model will help municipal managers better understand the costs and benefits of food waste co-digestion including: - Capital Investments - Operational and Maintenance Costs - Biogas Generation and Solid Waste Diversion
Model Design: 1) Brings together available empirical data from current operations, vendor quotes, and studies 2) User can select input from: - Default values/ranges - Calculated values based on population or food waste source data - User data 3) Flexible: - Community size – population - Existing equipment/operations (e.g., anaerobic digester, FOG Program)	**Types of Organic Wastes Considered:** - Residential food waste - Commercial food waste - Fats, oils and grease (FOG) - Food processing waste - fruit, vegetables, breads, rendering byproducts - Dairy waste - milk solids - Agricultural – fruit/vegetable trimmings

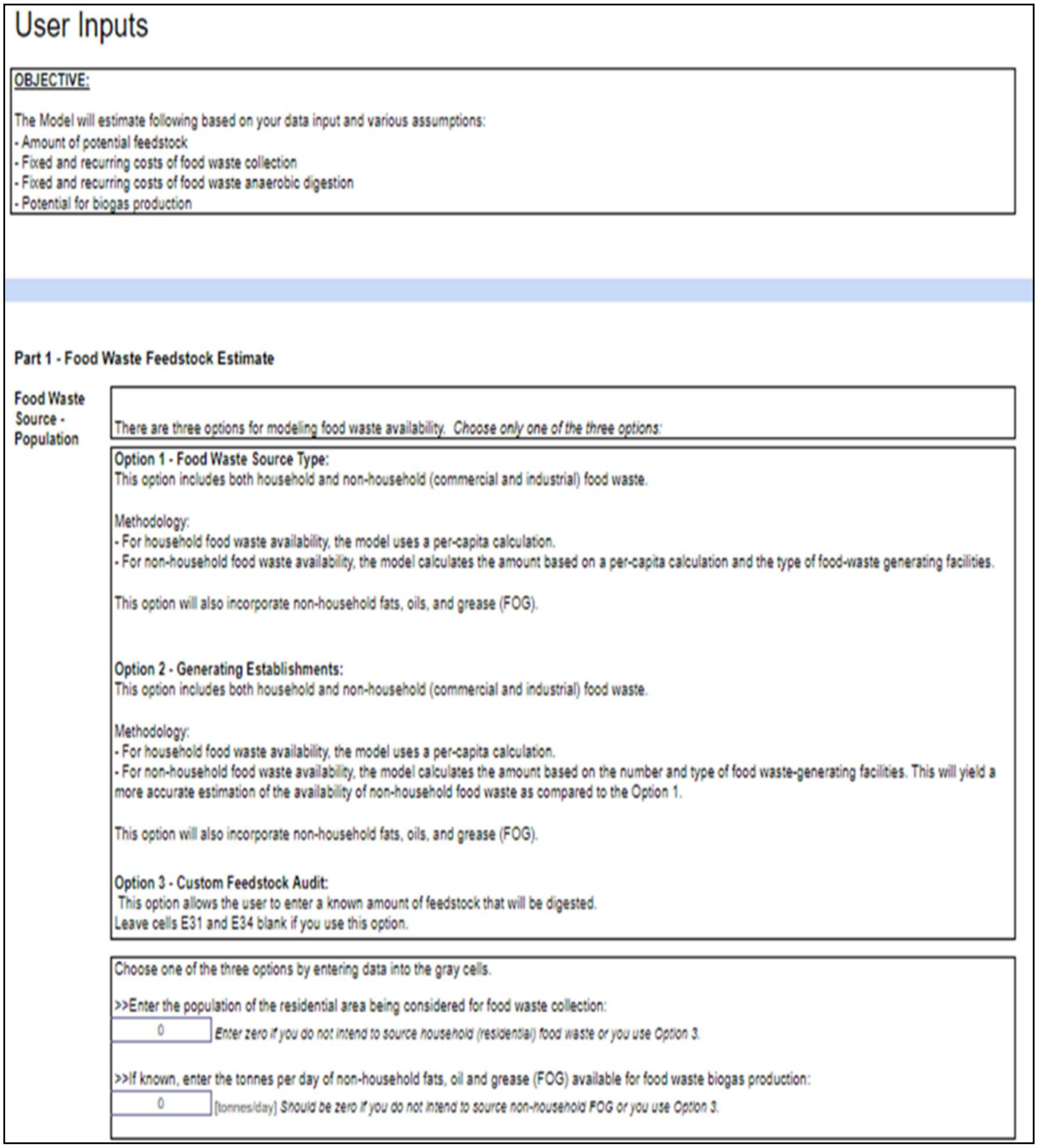
Figure 4 Overview Sheet

As shown in Fig. 4, a summary of the model is provided in this part to help new users understand its components, outputs, results, model design, and the types of organic waste it takes into account.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

B. Component: User Inputs (Sheet 2)

The calculations generated by the Model as a consequence of the inputs on this page are relevant to your city or organization. The worksheet titled "1-Page Summary" contains the final results. The Model may also be used to compare the outcomes of various strategies and simulate "what if" scenarios.



User Inputs

OBJECTIVE:

The Model will estimate following based on your data input and various assumptions:
- Amount of potential feedstock
- Fixed and recurring costs of food waste collection
- Fixed and recurring costs of food waste anaerobic digestion
- Potential for biogas production

Part 1 - Food Waste Feedstock Estimate

Food Waste Source - Population

There are three options for modeling food waste availability. *Choose only one of the three options:*

Option 1 - Food Waste Source Type:
This option includes both household and non-household (commercial and industrial) food waste.

Methodology:
- For household food waste availability, the model uses a per-capita calculation.
- For non-household food waste availability, the model calculates the amount based on a per-capita calculation and the type of food-waste generating facilities.

This option will also incorporate non-household fats, oils, and grease (FOG).

Option 2 - Generating Establishments:
This option includes both household and non-household (commercial and industrial) food waste.

Methodology:
- For household food waste availability, the model uses a per-capita calculation.
- For non-household food waste availability, the model calculates the amount based on the number and type of food waste-generating facilities. This will yield a more accurate estimation of the availability of non-household food waste as compared to the Option 1.

This option will also incorporate non-household fats, oils, and grease (FOG).

Option 3 - Custom Feedstock Audit:
This option allows the user to enter a known amount of feedstock that will be digested.
Leave cells E31 and E34 blank if you use this option.

Choose one of the three options by entering data into the gray cells.

>>Enter the population of the residential area being considered for food waste collection:
0 *Enter zero if you do not intend to source household (residential) food waste or you use Option 3.*

>>If known, enter the tonnes per day of non-household fats, oil and grease (FOG) available for food waste biogas production:
0 [tonnes/day] *Should be zero if you do not intend to source non-household FOG or you use Option 3.*

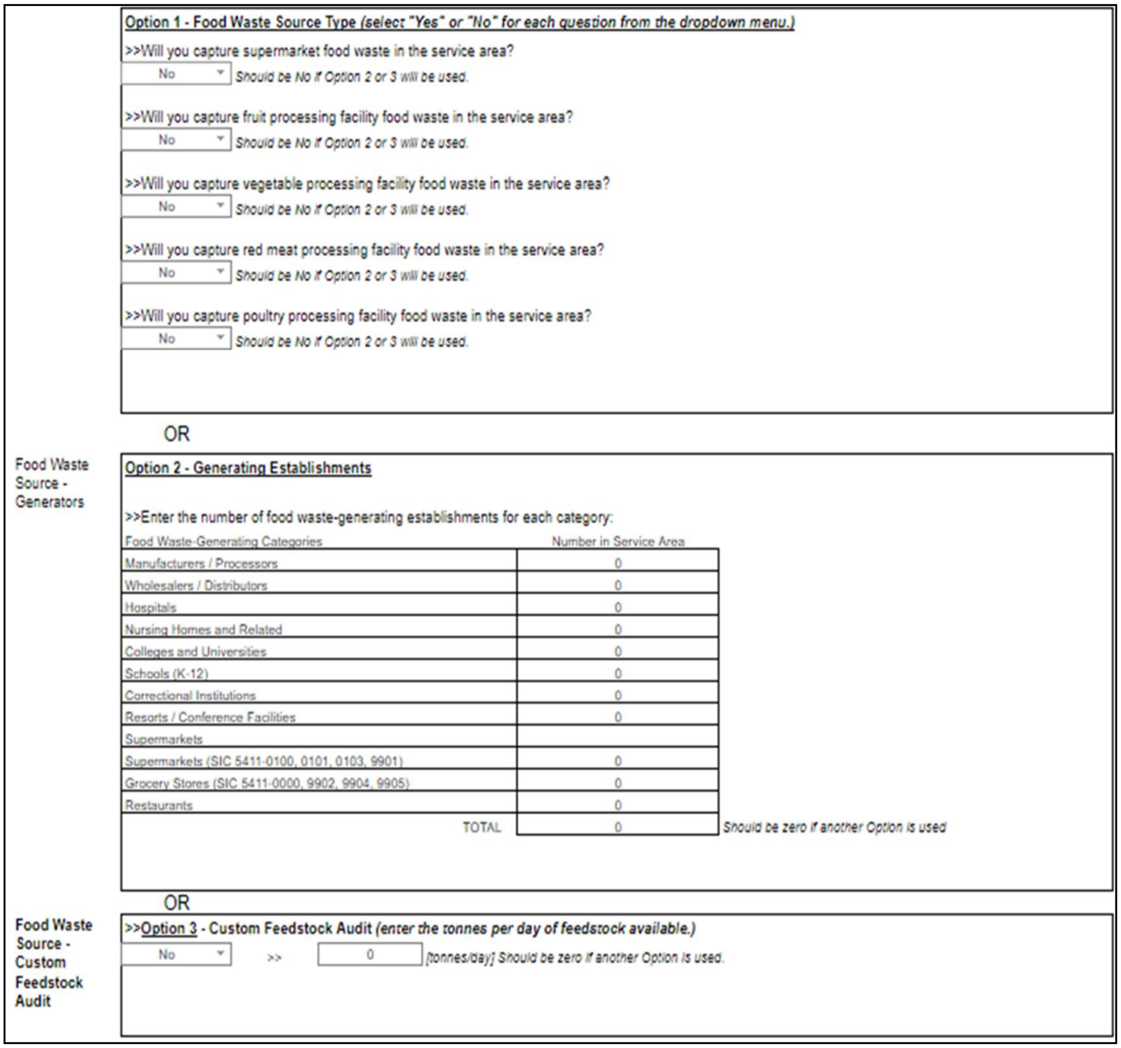
Figure 5 User Inputs – Food Waste Source I

The three alternatives the model offers for predicting the feedstock data from food waste are shown in Fig. 5.

1) Option 1: Source Type for Food Waste
2) Option 2: Creating Establishments
3) Option 3 - Custom Feedstock Audit (User may directly input the amount of total feedstock in tonnes/day)

The model will produce the predicted data when the user selects just one of these alternatives based on personal preferences.
The sheet "Food Waste Feedstock Data" supports the food waste feedstock estimates for Option 1 and Option 2. If you have more specific information, you can input it directly into the "Feedstock Parameters" worksheet.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com



Option 1 - Food Waste Source Type *(select "Yes" or "No" for each question from the dropdown menu.)*

>>Will you capture supermarket food waste in the service area?
No — *Should be No if Option 2 or 3 will be used.*

>>Will you capture fruit processing facility food waste in the service area?
No — *Should be No if Option 2 or 3 will be used.*

>>Will you capture vegetable processing facility food waste in the service area?
No — *Should be No if Option 2 or 3 will be used.*

>>Will you capture red meat processing facility food waste in the service area?
No — *Should be No if Option 2 or 3 will be used.*

>>Will you capture poultry processing facility food waste in the service area?
No — *Should be No if Option 2 or 3 will be used.*

OR

Food Waste Source - Generators

Option 2 - Generating Establishments

>>Enter the number of food waste-generating establishments for each category:

Food Waste-Generating Categories	Number in Service Area
Manufacturers / Processors	0
Wholesalers / Distributors	0
Hospitals	0
Nursing Homes and Related	0
Colleges and Universities	0
Schools (K-12)	0
Correctional Institutions	0
Resorts / Conference Facilities	0
Supermarkets	
Supermarkets (SIC 5411-0100, 0101, 0103, 9901)	0
Grocery Stores (SIC 5411-0000, 9902, 9904, 9905)	0
Restaurants	0
TOTAL	0

Should be zero if another Option is used

OR

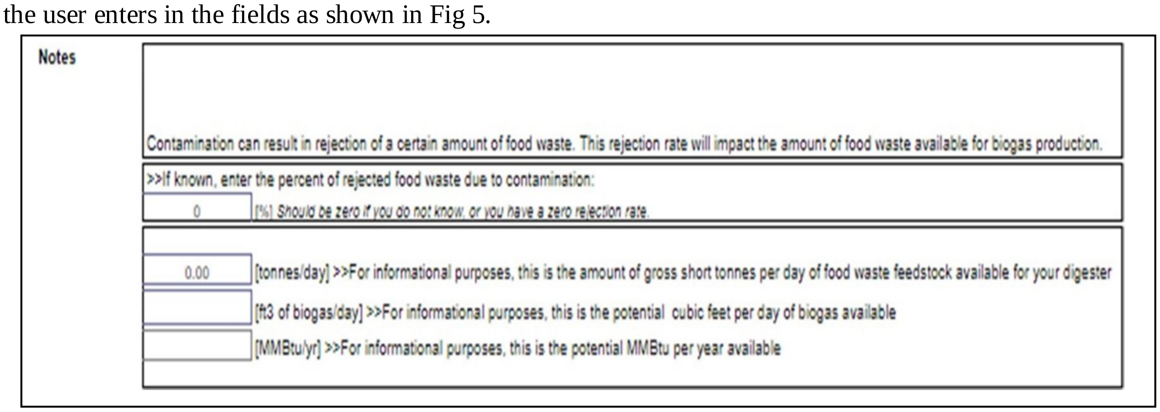
Food Waste Source - Custom Feedstock Audit

>>**Option 3 - Custom Feedstock Audit** *(enter the tonnes per day of feedstock available.)*
No >> 0 *[tonnes/day] Should be zero if another Option is used.*

Figure 6 User Inputs – Food Waste Source II

The values that must be input by the user for options 1, 2, and 3 are shown in Fig. 6.

In option 3, the amount of food waste must be manually input; however, in options 1 and 2, data will be generated based on the values that the user enters in the fields as shown in Fig 5.



Notes

Contamination can result in rejection of a certain amount of food waste. This rejection rate will impact the amount of food waste available for biogas production.

>>If known, enter the percent of rejected food waste due to contamination:
0 *[%] Should be zero if you do not know, or you have a zero rejection rate.*

0.00 [tonnes/day] >>For informational purposes, this is the amount of gross short tonnes per day of food waste feedstock available for your digester
[ft3 of biogas/day] >>For informational purposes, this is the potential cubic feet per day of biogas available
[MMBtu/yr] >>For informational purposes, this is the potential MMBtu per year available

Figure 7 User Inputs - Notes

The 'Feedstock Parameters' page will compute the estimated input feedstock for creating biogas if a known user can enter the rejection % of food waste owing to contamination, as per the number supplied here in Fig. 7.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

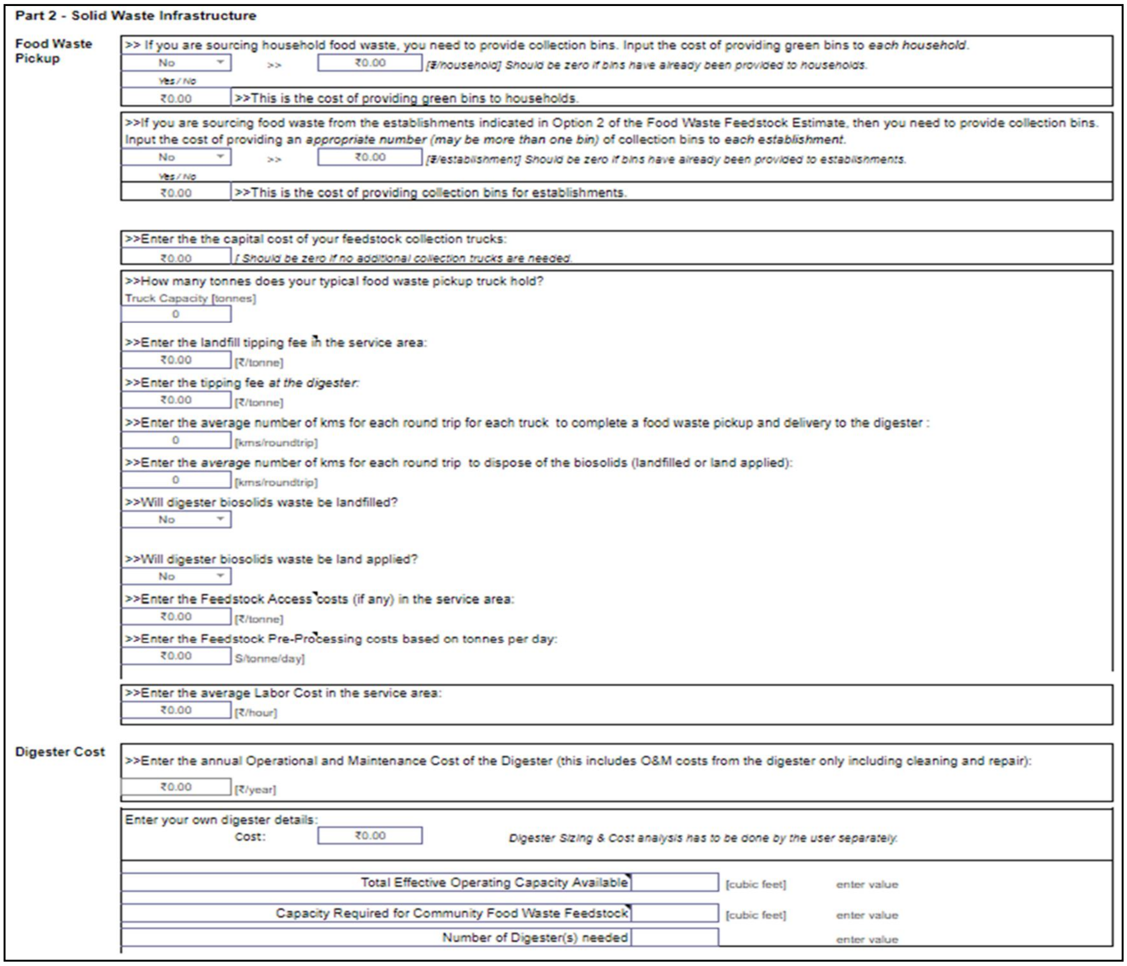

Part 2 - Solid Waste Infrastructure
Food Waste Pickup
>> If you are sourcing household food waste, you need to provide collection bins. Input the cost of providing green bins to *each household*.
No >> ₹0.00 *[₹/household] Should be zero if bins have already been provided to households.*
Yes / No
₹0.00 >>This is the cost of providing green bins to households.
>>If you are sourcing food waste from the establishments indicated in Option 2 of the Food Waste Feedstock Estimate, then you need to provide collection bins. Input the cost of providing an *appropriate number (may be more than one bin)* of collection bins to *each establishment*.
No >> ₹0.00 *[₹/establishment] Should be zero if bins have already been provided to establishments.*
Yes / No
₹0.00 >>This is the cost of providing collection bins for establishments.
>>Enter the the capital cost of your feedstock collection trucks:
₹0.00 *[Should be zero if no additional collection trucks are needed.*
>>How many tonnes does your typical food waste pickup truck hold?
Truck Capacity [tonnes]
0
>>Enter the landfill tipping fee in the service area:
₹0.00 [₹/tonne]
>>Enter the tipping fee *at the digester*:
₹0.00 [₹/tonne]
>>Enter the average number of kms for each round trip for each truck to complete a food waste pickup and delivery to the digester :
0 [kms/roundtrip]
>>Enter the average number of kms for each round trip to dispose of the biosolids (landfilled or land applied):
0 [kms/roundtrip]
>>Will digester biosolids waste be landfilled?
No
>>Will digester biosolids waste be land applied?
No
>>Enter the Feedstock Access costs (if any) in the service area:
₹0.00 [₹/tonne]
>>Enter the Feedstock Pre-Processing costs based on tonnes per day:
₹0.00 $/tonne/day]
>>Enter the average Labor Cost in the service area:
₹0.00 [₹/hour]
Digester Cost
>>Enter the annual Operational and Maintenance Cost of the Digester (this includes O&M costs from the digester only including cleaning and repair):
₹0.00 [₹/year]
Enter your own digester details:
Cost: ₹0.00 *Digester Sizing & Cost analysis has to be done by the user separately.*
Total Effective Operating Capacity Available [cubic feet] enter value
Capacity Required for Community Food Waste Feedstock [cubic feet] enter value
Number of Digester(s) needed enter value

Figure 8 User Inputs – Part II

As seen in fig. 8, the calculation for Part 2's solid waste infrastructure is done for the region where food waste pickup is decided by giving each home a green bin, giving collecting bins to surrounding areas, etc. Fees for landfill dumping, feedstock access, pre-processing, collection, etc. are also included in the transportation cost.

The user must also input additional digester information, such as cost, O&M expenses, the needed number of digesters, etc. If the user doesn't have access to this information, he or she can use the answers from "Feedstock Parameters" as a starting point to figure out digester sizing individually.

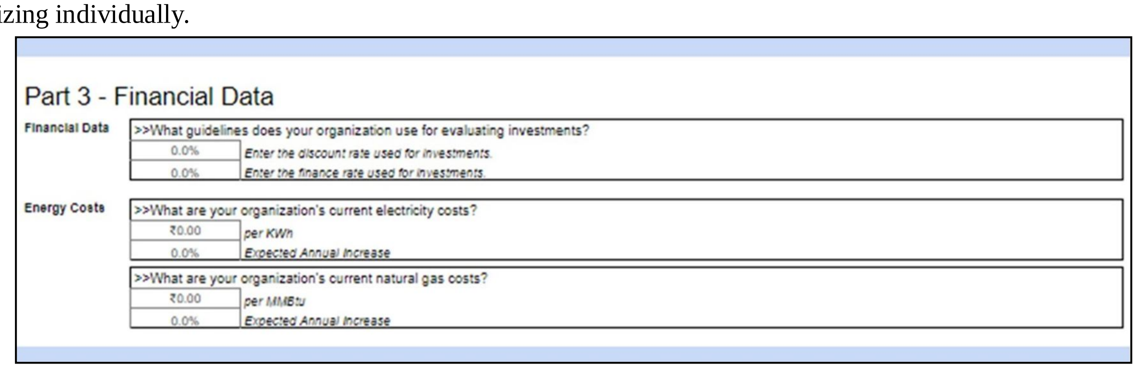

Part 3 - Financial Data
Financial Data
>>What guidelines does your organization use for evaluating investments?
0.0% *Enter the discount rate used for investments.*
0.0% *Enter the finance rate used for investments.*
Energy Costs
>>What are your organization's current electricity costs?
₹0.00 *per KWh*
0.0% *Expected Annual Increase*
>>What are your organization's current natural gas costs?
₹0.00 *per MMBtu*
0.0% *Expected Annual Increase*

Figure 9 User Inputs – Financial Data

Part 3 is about financial data, as seen in fig. 9. To analyze their investment, users must provide financial information such as the discount rate and finance rate that they or their company will utilize. Additionally, the user must input current, the cost of electricity (per KWh), and the cost of natural gas (per MMBtu).

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

C. Component: Feedstock Parameters (Sheet 3)

Feedstock Parameters

This worksheet calculates volatile solids available in the feedstocks (municipal wastewater, food waste, and FOG) for biogas production

Data calculated from data entered in other worksheets is highlighted in blue cells

The data from sheet 'Feedstock Parameters' and 'Food Waste Feedstock Data' can further be used by the user separately to do digester sizing and cost analysis.

VS = volatile solids TS = total solids

Waste Profile	tonnes/Day	TS [%]	VS/TS Ratio	VS [tonne/day]	TS [tonne/day]
Generator Establishment Foodwaste Mix	0.00	30%	89.5%	0.0	0.0
Option 3 -Custom Feedstock Audit	0.00	30%	89.5%	0.0	0.0
Household Meat Feedstock	0.00	30%	92.0%	0.0	0.0
Household Fats, Oils, Greases (FOG)	0.00	29%	96.0%	0.0	0.0
Household Fruits and Vegetables Feedstock	0.00	30%	88.0%	0.0	0.0
Household Sugars Feedstock	0.00	30%	92.0%	0.0	0.0
Supermarket Vegetable and Fruit Feedstock	0.0000	30%	88.0%	0.0	0.0
Supermarket Meat Feedstock	0.0000	30%	92.0%	0.0	0.0
Food Processing - Fruit	0.00	30%	88.0%	0.0	0.0
Food Processing - Vegetable	0.00	30%	88.0%	0.0	0.0
Food Processing - Red Meat Rendering	0.00	30%	92.0%	0.0	0.0
Food Processing - Poultry Rendering	0.00	30%	92.0%	0.0	0.0
Fats, Oils, Greases (FOG)	0.00	29%	96.0%	0.0	0.0

Output Food Waste Mass (Solids)	0.0	tonne/day
Output Food Waste Mass Loading after Contamination Removed (Solids)	0.0	tonne/day
Output Food Waste Solids Content	#DIV/0!	% TS
Output Food Waste VS Content (%)	#DIV/0!	

Input Required

Feedstock Requirements		
Biogas Production based on VS Destroyed		ft³ biogas/day
Heat Value Estimate		MMBtu/yr
KWh Value Estimate		KWh/yr

Figure 10 Feedstock Parameters Sheet

To compute the output food waste mass before and after contamination removal, as well as the output food waste solids content vs. Content percent, a set of established parameters known as the "feedstock parameters" must first be taken into consideration as shown in Fig. 10.

D. Component: Food Waste Feedstock Data (Sheet 4)

Food Waste Feedstock Data

This worksheet calculates the amount of food waste feedstock that is available in your community based on your user inputs. This calculation informs the feedstock parameter worksheet which calculates the amount of biogas potential.

The data from sheet 'Feedstock Parameters' and 'Food Waste Feedstock Data' can further be used by the user separately to do digester sizing and cost analysis.

Population Based Feedstock Availability Source Data
Source: http://www.ers.usda.gov/Data/FoodConsumption (based on calendar year 2007)

Residential Feedstocks (supports Option 1 and Option 2)	Pounds Per Capita/Per Year
Household Food Scraps - Red Meat	37.01
Household Food Scraps - Poultry	27.26
Household Food Scraps - Fresh and Frozen Fish	3.62
Household Food Scraps - Canned Fish and Shellfish	4.02
Household Food Scraps - Total Tree Nuts	0.31
Household Food Scraps - Eggs	3.49
Household Food Scraps - Total Dairy	44.28
Household Food Scraps - Total Fats, Oils, Greases (FOG)	14.46
Household Food Scraps - Fruit	60.86
Household Food Scraps - Vegetable	84.87
Household Food Scraps - Grains	35.6
Household Food Scraps - Sugars, Honey, Sweeteners	24.3

Total Generation of Household Feedstock *from User Input* (lbs./yr)		tonnes/year
Meats, Nuts, Eggs and Dairy	0	0
FOG	0	0
Fruits, Vegetables, Grains	0	0
Sugars	0	0

Food Processing Feedstocks (supports Option 1)	Pounds Per Capita/Per Year
Food Processing - Fruit	50.80
Food Processing - Vegetable	130.97
Food Processing - Red Meat Rendering Byproducts	48.92
Food Processing - Poultry Rendering Byproducts	43.25

Total Generation of Food Processing Feedstock *from User Input* (lbs./yr)		tonnes/year
Food Processing - Fruit	0.00	0
Food Processing - Vegetable	0.00	0
Food Processing - Red Meat	0.00	0
Food Processing - Poultry	0.00	0

USDA Analysis Per Capita Retail Loss Rates for Perishables

Supermarket Feedstocks (supports Option 1)	Retail Weight (lbs per capita/per year)	Weight Available to Consumer (lbs per capita/per year)	Feedstock available (lbs per capita/year)
Fresh Vegetables	180.3	162.9	17.4
Fresh Meats, Poultry, and Seafoods	195.1	186.3	8.8
Fresh Fruits	119.4	105.8	13.6

Total Generation of Supermarket Feedstock *from User Input* (lbs./year)		tonnes/year
Fresh Vegetables	0.00	0
Fresh Meats, Poultry, and Seafoods	0.00	0
Fresh Fruits	0.00	0

Figure 11 Food Waste Feedstock Data Sheet

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

Generating Establishments Based Feedstock Source Data (note: this table supports Option 2: Generating Establishments).
Source: Identification, Characterization, and Mapping of Food Waste and Food Waste Generators In Massachusetts, September 2009
SSOM = Source Separated Organic Materials

Generator Category (supports Option 2)	Number of Establishments	Total SSOM Generation (short tonnes/yr)	SSOM Generation Per Establishment (short tonnes/yr)	Percent of total SSOM	Generation of SSOM category from User Input (tonnes/yr)
Manufacturers / Processors	727	493,698	679.09	56.12	0
Wholesalers / Distributors	304	44,688	147.00	5.08	0
Hospitals	126	14,538	115.38	1.65	0
Nursing Homes and Related	507	27,409	54.06	3.12	0
Colleges, Universities	101	24,458	242.16	2.78	0
Independent Preparatory Schools	20	955	47.75	0.11	0
Correctional Institutions	17	1,762	103.65	0.20	0
Resorts / Conference Facilities	105	6,442	61.35	0.73	0
Supermarkets					0
Supermarkets (SIC 5411-0100, 0101, 0103, 9901)	408	90,604	222.07	10.30	0
Grocery Stores (SIC 5411-0000, 9902, 9904, 9905)	164	7,022	42.82	0.80	0
Restaurants	3,320	168,191	50.66	19.12	0
TOTAL	5,799	879,767	---		0.00

Figure 12 Food Waste Feedstock Data II

The supporting information needed to estimate values for Options 1 and 2 is shown in Figs. 11 and 12. The US-specific sample data shown here were obtained from the website of the US Department of Agriculture. The user can modify the parameters on this page to make it particular for the area where the biogas plant is located after they are comfortable with how the model functions.

E. Component: Transportation & Processing (Sheet 5)

Transportation and Processing

This worksheet calculates the transportation and disposal costs associated with collecting and processing food waste feedstock.
Considerations include:
- Feedstock collection infrastructure,
- Transportation Costs
- Access costs
- Tipping fees.

Data calculated from data entered in "User Input" worksheet is highlighted in blue cells.

Feedstock Collection System		
Residential Bins	₹0.00	Cost for green bin for population
Commercial Bins	₹0.00	Cost for providing bins to establishments
Feedstock Collection Trucks	₹0.00	Cost for feedstock collection trucks

Feedstock Access Costs		
tonnes Per Day to be Picked Up	0	tonnes/day
Access Cost/tonne	₹0.00	₹/tonne
Feedstock Access Costs	₹0.00	₹/day

Feedstock Transportation Costs		
Waste tonnes/Truck	0	tonnes/truck
tonnes/Day Required	0	tonnes/day
Trips Required/Day	#DIV/0!	trips/day
Average Miles / Round Trip	0	miles/trip
Transportation Costs/tonne-mile	0.18	₹/tonne-mile
Total Feedstock Transportation Costs	₹0.00	₹/day

Feedstock Processing Costs		
Waste tonnes Requiring Processing	-	tonnes/day
Processing Costs/(short tonne/day capacity)	₹0.00	₹/tpd
Total Feedstock Processing Costs	₹0.00	₹/day

Figure 13 Transportation Processing I

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

Waste Disposal Costs		
Initial Raw Biosolids Volume	0	tonnes/day
Reduction Expected through the Process	86%	
Output Waste Biomass	0	tonnes
Transportation costs/tonne-mile (from above)	₹400.00	₹/tonne-mile
Average miles /round trip	0	miles/trip
Waste Transportation Costs	₹0.00	₹/day
Waste Disposal Costs		
Landfill Tipping Fee per tonne	₹0.00	₹/tonne
Total Daily Tipping Fees Cost for biosolid disposal	₹0.00	₹/day
Waste Revenue		
Digester Tipping Fee per tonne	₹0.00	₹/tonne
Total Daily Tipping Fees Revenue at the Digester	₹0.00	₹/day
Avoided Daily Tipping Fees	₹0.00	₹/day
Total Daily Transport Processing and Disposal Cost	₹0.00	₹/day

Source: Cost Estimation for Solid Waste Management in Industrialising Regions 2 Precedents, Problems and Prospects Shantha R. Parthan, Mark W. Milke, David C.Wilson, John H. Cocks

Figure 14 Transportation Processing II

The worksheet determines the transportation and disposal expenses related to gathering and processing food waste feedstock and handling the resultant biosolids, as shown in Figs. 13 and 14. Infrastructure for collecting feedstocks, transportation, entrance fees, and tipping charges are all factors to be taken into account. The feedstock collecting system shall establish Feedstock Access Costs and Feedstock Transportation Costs.

F. Component: Financial Model Output (Sheet 6)

Financial Model Output

This worksheet takes the capital and O&M costs and projected potential benefits of biogas generation to project cash flows and calculate a Net Present Value (NPV) for the project.

ANALYSIS OF BIOGAS GENERATION PROJECT COST/BENEFIT - FINANCED CAPITAL SCENARIO

Capital Cost (Digester)	₹0.00	
Capital Cost (Feedstock collection)	₹0.00	
O&M Cost (Digester)	₹0.00	per year
O&M Cost (Feedstock)	₹0.00	per year
Feedstock Access Cost	₹0.00	per day
Feedstock Transportation Cost	₹0.00	per day
Feedstock Processing Cost	₹0.00	per day
Biosolids Transportation Cost	₹0.00	per day
Biosolids Disposal Cost	₹0.00	per day
Avoided Tipping Fees	₹0.00	per day
Feedstock Tipping Revenue	₹0.00	per day
Labor Cost *(Average labor cost in the service area)*	₹0.00	per year
Discount Rate (%)	0%	per year
Financing Rate	0.0%	per year

Figure 15 Financial Model Output I

This worksheet projects cash flows and computes a Net Present Value (NPV) for the project using predicted future benefits from biogas generation as well as capital and O&M costs as shown in Fig. 15. The main presumptions are the 15-year project timetable, the discount rate and finance rates supplied by the user on the user input page, and the substitution of biogas for natural gas in other applications.

Many alternative situations, particularly those involving the utilization of biogas, are conceivable. Examples include steam generation and the cogeneration of electricity. Users can alter the data in the spreadsheets to alter the Model after they are comfortable with the inputs, outputs, and data utilized to generate values.

Project Costs	NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Capital Costs																
Physical Plant (Digester)	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00
Physical Plant (Processing)	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00
Recurring Costs																
Feedstock Access	₹0.00	₹0.00														
Feedstock Transport	₹0.00	₹0.00														
Biosolids Transport	₹0.00	₹0.00														
Biosolids Disposal	₹0.00	₹0.00														
Total Cost (₹)	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00

Project Benefits	NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Savings																
Natural Gas Use Reduction (Biogas Replacement)	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00
Total Benefit (₹)	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00	₹0.00
NET BENEFIT OF PROJECT	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**	**₹0.00**

Figure 16 Financial Model Output II

In Fig. 16, the viewer may obtain an overall picture of the investments made year by year and calculate the project's net benefit using NPV analysis.

G. Component: 1-Page Summary (Sheet 7)

This sheet will summarize all the data for the user.

Summary

This page summarizes the data and results for your organization.

Organization/Food Waste Data:

Population of the area being considered for food waste biogas production:

0	number of people
0	number of establishments
0.00	gross tonnes per day of food waste feedstock available for your digester

	Cubic Feet per day of biogas potentially available
	MMBtu per year potentially available
	KWh per year potentially available

Anaerobic Digester(s):

Total Effective Operating Capacity Available		[cubic feet]
Capacity Required for Community Foodwaste Feedstock		[cubic feet]
Number of Digester(s) Needed		
Total Digester(s) Cost	₹0.00	[INR]

Figure 17 Summary - Organization/Food Waste Data

Fig. 17 displays an overview of organizational data and statistics on food waste.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

Financial Data

Organization's guidelines for evaluating investments

0.0%	*Discount rate used for investments*
0.0%	*Finance rate used for investments*

Capital Cost (Digester)	₹0.00	
Capital Cost (Feedstock collection)	₹0.00	
O&M Cost (Digester)	₹0.00	per year
O&M Cost (Feedstock)	₹0.00	per year

Feedstock Access Cost	₹0.00	per day
Feedstock Transportation Cost	₹0.00	per day
Feedstock Processing Cost	₹0.00	per day
Avoided Tipping Fees	₹0.00	per day
Feedstock Tipping Revenue	₹0.00	per day

>>Your organization's annual cost (+) or revenue (-) associated with avoided feedstock landfilling, tipping fees, access, collection, transport, processing, and biosolid waste transport and disposal
₹0.00 ₹/yr

>>Your organization's annual revenue savings from replacing natural gas with biogas
₹0.00 ₹/yr

>>Your organization's annual revenue savings from replacing grid supplied electricity with biogas electricity generation (internal combustion engine)
₹0.00 ₹/yr

Project Costs	Net Present Value
Capital Costs	
Physical Plant (Digester)	₹0.00
Physical Plant (Processing)	₹0.00
Recurring Costs	
Feedstock Access	₹0.00
Feedstock Transport	₹0.00
Biosolids Transport	₹0.00
Biosolids Disposal	₹0.00
Total Cost (₹)	₹0.00

Project Savings	Net Present Value
Natural Gas Use Reduction	₹0.00
Total Benefit (₹)	₹0.00
NET BENEFIT OF PROJECT	₹0.00

Figure 18 Summary - Financial Data

Fig. 18 presents a financial summary. It contains all the information necessary for the user to make an investment choice, including digester costing, feedback collection system costs, total project costs, and net present values.

By contrasting the net yearly value of the present process with that of the future process with various biogas usage possibilities, it is possible to ascertain whether the economics of accepting external feedstocks is a worthwhile investment. While this is the major outcome, further inferences from the model can be made through comparative analysis.

Analyze how your present process will be affected by modifying the biosolids handling parameters. Other outcomes might be inferred from the model's output; this is not an exhaustive list.

V. CONCLUSION

Particularly in small towns, a sizable amount of garbage is made up of biomass wastes. Thus, it is crucial to use biomass waste as a recyclable resource to advance a society that values cycles. There are several known methods for using biomass wastes, including composting, making biogas, and generating energy. Several policy proposals are made for removing these barriers in light of our findings.

The majority of the population in rural regions lives in low- and middle-income families, creating a higher demand for clean, inexpensive energy. The upfront installation cost of the biogas plant is the main impediment to the deployment of rural biogas plants among these families. This project's main finding is:

1) The limited adoption of biogas technology in India is the consequence of several financial and nonfinancial hurdles that also differ from region to region and from urban to rural regions.
2) This project can serve as a manual for new entrants in the biogas business by combining information about difficulties encountered in biogas generation with the use of the provided Excel model.
3) The model was created to offer a method for determining if building a biogas plant would be economically feasible. It is adaptable to make it simple for the user to input personalized data and assess the outcomes.

To help reduce the variations in feedstock quality, which could eventually lead to the standardization of technologies for a certain quality and composition of the waste, proper regulations regarding the segregation of organic and inorganic wastes should be enforced on the generators in the long term.

REFERENCES

[1] Khuman YSC, Pandey R, Rao KS. Fuel wood consumption patterns in Fakot watershed, Garhwal Himalaya, Uttarakhand. Energy 2011;36:4769–76.

[2] Habib G. New methodology for estimating biofuel consumption for cooking: atmospheric emissions of black carbon and sulfur dioxide from India. Global Biogeochem Cycles 2004;18::Gb3007. http://dx.doi.org/10.1029/ 2003gb002157.

[3] Meisam Tabatabaei, Mortaza Aghbashlo, Elena Valijanian, Hamed Kazemi Shariat Panahi, Abdul-Sattar Nizami, Hossein Ghanavati, Alawi Sulaiman, Safoora Mirmohamadsadeghi, Keikhosro Karimi, A comprehensive review on recent biological innovations to improve biogas production, Part 1: Upstream strategies, Renewable Energy, Volume 146, 2020.

[4] Zhaoqiu Zhou, Xiuli Yin, Jie Xu, Longlong Ma, The development situation of biomass gasification power generation in China, Energy Policy, Volume 51, 2012, Pages 52-57, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2012.05.085.

[5] Smith, M. T., and T. M. Everson. "Improving rural livelihoods through biogas generation using livestock manure and rainwater harvesting." WRC Report TT 645/15 (2016).

[6] Rajaeifar, Mohammad Ali, et al. "Attributional and consequential environmental assessment of using waste cooking oil-and poultry fat-based biodiesel blends in urban buses: a real-world operation condition study." Biofuel Research Journal 4.3 (2017): 638.

[7] Ahanchi, M., Tabatabaei, M., Aghbashlo, M., Rezaei, K., Talebi, A. F., Ghaffari, A., ... & Khounani, Z. (2018). Pistachio (Pistachia vera) wastes valorization: enhancement of biodiesel oxidation stability using hull extracts of different varieties. Journal of Cleaner Production, 185, 852-859.

[8] Ashutosh Kumar, M.P. Sharma, GHG emission and carbon sequestration potential from MSW of Indian metro cities, Urban Climate, Volume 8, 2014.

[9] Lewis et al., Biogas Stoves Reduce Firewood Use, Household Air Pollution, and Hospital Visits in Odisha, India, Environmental Science & Technology **2017** 51 (1), 560-569 DOI: 10.1021/acs.est.6b02466

[10] Regina J. Patinvoh, Mohammad J. Taherzadeh, Challenges of biogas implementation in developing countries, Current Opinion in Environmental Science & Health, Volume 12, 2019.

[11] P. Deo S. Modak P.R. Shukla 1991.Decentralized energy planning, New Delhi, India, Oxford and IBH Publishing Co. Pvt. Ltd.

[12] Pathak, H., Jain, N., Bhatia, A. et al. Global warming mitigation potential of biogas plants in India. Environ Monit Assess **157**, 407–418 (2009). https://doi.org/10.1007/s10661-008-0545-6

[13] Safoora Mirmohamadsadeghi, Keikhosro Karimi, Meisam Tabatabaei, Mortaza Aghbashlo, Biogas production from food wastes: A review on recent developments and future perspectives, Bioresource Technology Reports, Volume 7, 2019.

[14] Diyoke, Chidiebere, and Chunfei Wu. "Thermodynamic analysis of hybrid adiabatic compressed air energy storage system and biomass gasification storage (A-CAES+ BMGS) power system." Fuel 271 (2020): 117572.

[15] Kamusoko, Reckson, et al. "Comparison of pretreatment methods that enhance biomethane production from crop residues-a systematic review." (2019).

[16] Foong, Shin Ying, et al. "Valorizationa of biomass waste to engineered activated biochar by microwave pyrolysis: Progress, challenges, and future directions." Chemical Engineering Journal 389 (2020): 124401.

[17] European Commission (2017) Optimal use of biogas from waste streams, An assessment of the potential of biogas from digestion in the EU beyond 2020. https://ec.europa.eu/energy/en/studies/ optimal-use-biogas-waste-streams-assessment-potential-biogasdigestion-eu-beyond-2020. Accessed 9 August 9 2019

[18] Martinov M, Scarlat N, Djatkov D, Dallemand JF, Viskovic M, Zezelj B (2020) Assessing sustainable biogas potentials case study for Serbia. Biomass Convers Biorefin 10:367–381. https:// doi.org/10.1007/s13399-019-00495-1

[19] Li, Y., Jin, Y., Borrion, A., Li, H. & Li, J. Effects of organic composition on the anaerobic biodegradability of food waste. Biores. Technol. **243**, 836-845 (2017).

[20] Baawain, M., Al-Mamun, A., Omidvarborna, H. & Al-Amri, W. Ultimate composition analysis of municipal solid waste in Muscat. J. Clean. Prod. **148**, 355–362. https://doi.org/10.1016/j.jclepro.2017.02.013 (2017).

[21] Osman, A. I. Catalytic hydrogen production from methane partial oxidation: Mechanism and kinetic study. Chem. Eng. Technol. **43**, 641–648. https://doi.org/10.1002/ceat.201900339 (2020).

[22] Chen, H., Osman, A. I., Mangwandi, C. & Rooney, D. Upcycling food waste digestate for energy and heavy metal remediation applications. Resour. Conserv. Recycl. X **3**, 100015. https://doi.org/10.1016/j.rcrx.2019.100015 (2019).

[23] Osman, A. I., Abu-Dahrieh, J. K., McLaren, M., Laffir, F. & Rooney, D. W. Characterisation of robust combustion catalyst from aluminium foil waste. Chem. Sel. **3**, 1545–1550. https://doi.org/10.1002/slct.201702660 (2018).

[24] Nguyen, L. N., Nguyen, A. Q. & Nghiem, L. D. in Water and Wastewater Treatment Technologies (eds Xuan-Thanh, B., Chart, C., Takahiro, F., & Sunita, V.) 331–355 (Springer Singapore, 2019).

[25] Wang, Q. et al. Potential and optimization of two-phase anaerobic digestion of oil refinery waste activated sludge and microbial community study. Sci. Rep. **6**, 38245. https://doi.org/10.1038/srep38245 (2016).

[26] Mateescu, Carmen, and Andreea-Daniela Dima. "Critical analysis of key barriers and challenges to the growth of the biogas sector: A case study for Romania." Biomass Conversion and Biorefinery (2020): 1-14.

[27] Banks, C. J., Chesshire, M. & Stringfellow, A. A pilot-scale comparison of mesophilic and thermophilic digestion of source segregated domestic food waste. Water Sci. Technol. **58**, 1475–1481. https://doi.org/10.2166/wst.2008.513 (2008).

[28] Gebreeyessus, G. D. & Jenicek, P. Thermophilic versus mesophilic anaerobic digestion of sewage sludge: A comparative review. Bioengineering **3**, 15 (2016).

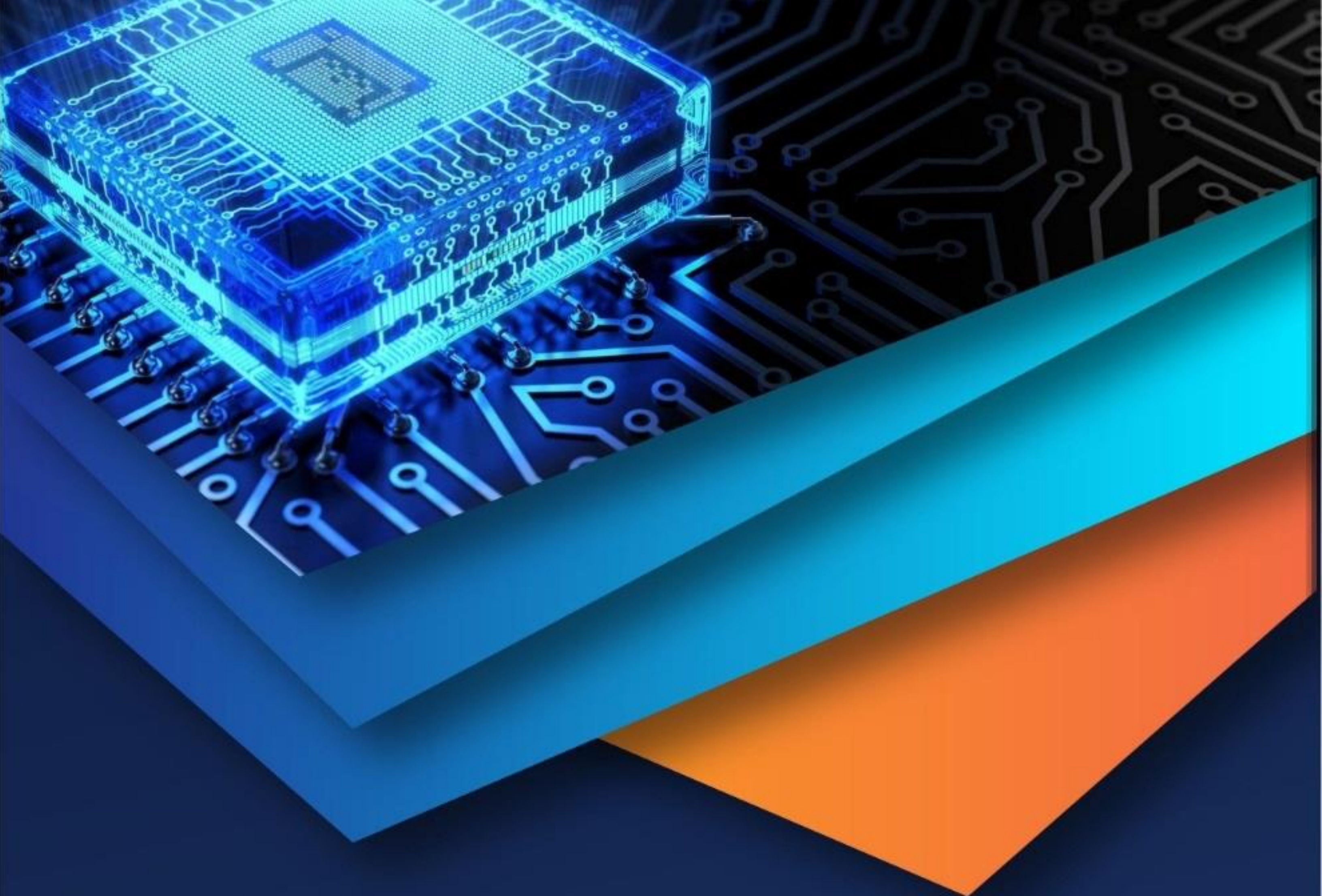
[29] Zarkadas, I. S., Sofikiti, A. S., Voudrias, E. A. & Pilidis, G. A. Thermophilic anaerobic digestion of pasteurised food wastes and dairy cattle manure in batch and large volume laboratory digesters: Focussing on mixing ratios. Renew. Energy **80**, 432–440. https://doi.org/10.1016/j.renene.2015.02.015 (2015).

[30] Moset, V., Poulsen, M., Wahid, R., Højberg, O. & Møller, H. B. Mesophilic versus thermophilic anaerobic digestion of cattle manure: Methane productivity and microbial ecology. Microb. Biotechnol. **8**, 787–800. https://doi.org/10.1111/1751-7915.12271 (2015).

[31] Shane, Agabu, Shabbir H. Gheewala, and George Kasali. "Potential, barriers and prospects of biogas production in Zambia." Journal of Sustainable Energy and Environment 6 (2015): 21-26.

[32] Lantz, Mikael, et al. "The prospects for an expansion of biogas systems in Sweden—Incentives, barriers and potentials." Energy policy 35.3 (2007): 1830-1843.

[33] Rupf, Gloria V., et al. "Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal." Renewable and Sustainable Energy Reviews 52 (2015): 468-476.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY