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Life Cycle Assessment of Perishable Wastes from Koyambedu Market

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ABSTRACT

India is the second largest country having highest population which leads to generation of large sum of wastes. Municipal solid waste generally consists of household and commercial waste. Most of the wastes are collected and dumped in the landfill sites but in certain cases these wastes are dumped in nearby empty places which causes environmental pollution and also leads to spreading of various diseases. Koyambedu Market situated in Chennai, Tamil Nadu is one of the largest markets in Asia having a total area of 295 acres with different shops selling vegetables, fruits, flowers and meats. Around 300 tons of wastes are generated in a day from the entire market. The collected data are analyzed using Life Cycle Analysis (LCA) to know the impact caused by the wastes that are disposed from Koyambedu. The methodology of LCA makes modelling simpler, gives more clearly defined system boundaries, and reduces the amount of data that is required in comparison to the conventional method of independently comparing two different criteria. The use of LCA is more feasible in order to find the life cycle of the wastes and to find which waste produces more harm to the environment. With the analyzes it was found the emission of methane is more in vegetable waste than in other wastes that are collected from the market. The electricity consumed by landfill is less compared to the biogas plant. It is suggested that small biogas plants can be built near the markets to extract the gases that are produced from the wastes.

1. Introduction

Professionals frequently utilise "life cycle assessment" (LCA) when talking about how a product, process, or service affects the environment over the course of its existence.

Investigations of the environmental effects of manufactured goods are conducted at all stages of production, from extraction and processing (the "cradle") to fabrication, distribution, use, recycling, and disposal (the "grave"). The energy and materials required for the entire industry or value chain of the good, process, or service are listed in an LCA along with the associated emissions. In conclusion, life cycle assessment (LCA) evaluates the effects of the environment across time. The primary objective should be to monitor and reduce a product's negative environmental effects. Two ISO 14000 environmental management standards—ISO 14040 and ISO 14044—provide generally recognised LCA procedures. While ISO 14044 offers "requirements and guidance," ISO 14040 offers

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"principles and framework." These rules were written with general management and practitioners in mind. From the procurement and production of raw materials to their use and disposal ("cradle to grave"), LCA assesses environmental factors and potential effects throughout a product's lifecycle. Early on in ISO 14040, this is noted. The review discusses the use of resources, human health, and ecological effects.

1.1 Inputs Parameters of the Project

LCA software for analysing the life of a product requires input on the data that are already available on the market. The data include energy input, types, and amount of waste that is generated.

(i) Energy Inputs
(ii) Bio-gas
(iii) Methane
(iv) Material Input

In material input all the different type vegetables and quantity of materials are inserted.

(i) Types of vegetables

Tomato, cauliflower, potatoes. Etc.

(i) Quantity of the materials
(ii) Transportation Inputs

The transportation inputs are collecting of waste from market and transport to the dumping yard with the help of trucks.

(i) Trucks
(ii) Cost of the diesel/petrol
(iii) Distance from market yard to dumping yard

1.2 Life Cycle Assessment (LCA)

Life cycle effects can also be categorised according to the many stages of a product's creation, distribution, consumption, and eventual disposal. There are three main classes of these results: initial effects, effects from use, and consequences at the end of life. The primary results of a project can be broken down into the following categories: raw material extraction; manufacturing; transporting the finished product to a market or site; building and installation; and initial usage or occupancy. The physical expenses of running the product or facility (such as power, water, etc.) and any necessary maintenance, remodeling, or repairs are also considered use implications. end-of-life effects, such as waste processing, item destruction, and recycling.

Important goals of life cycle interpretation include establishing the reliability of the data and disseminating it in a balanced, exhaustive, and correct fashion. Analysing the results of an LCA is more complicated than just saying "3 is better than 2" and "Alternative A is the best choice." During the interpretation phase, it is crucial to ensure that the data are accurate and in line with the study's objectives. To do this, one must first assess the completeness and consistency of the study, identify the data elements that significantly influenced each impact category, and then draw conclusions and make recommendations based on this in-depth knowledge of the LCA's methodology and output. Life cycle analyses are only as trustworthy as the information used to create them.

Environmental input-output (EIO) data and unit process data are the two main types of LCA data. Unit process data is gathered through in-depth interviews with the companies or factories responsible for producing the product under study. As the study's boundary conditions suggest, these discussions occur at the level of the unit process. In contrast, economic input-output (EIO) data are collected at the national level.

Life cycle analysis is an effective method for dissecting measurable systems down to their component pieces. However, not every possible factor can be assessed and accounted for in a model.

The systems thinking boundary critique explains how it is challenging to implement changes within a system due to its strict borders. The availability and trustworthiness of the data may also affect precision. Statistics gathered from broad processes could be based on guesswork or old research.

The data is gathered from Koyambedu Market, one of the largest markets in Asia. The view of Koyambedu market is shown in the Figure 1. This expansive market spans 295 acres and offers a diverse range of goods including vegetables, fruits, and flowers. With numerous shops dedicated to each section, the generation of waste is tied to the arrival of goods. Specifically, the market produces daily waste quantities of approximately 180 to 200 tons of vegetable waste, 90 tons of fruit waste (with around 60 to 70 tons consisting of banana stems), 5 to 7 tons of flower waste, and 60 to 80 tons of meat waste. These wastes are collected via door-to-door collection from individual shops and accumulated at Gate 18. From there, they are transported out of the market by trucks to the Kodungayur landfill, which serves as the designated disposal site under cooperation.

Fig. 1. Aerial view of Koyambedu market

1.3 Drawbacks of LCA

LCA utilised for marketing is criticised for yielding biased results that favour the business. An ISO-standard was established to counteract this; however, it's essential to bear in mind the study's commissioner. Assumptions and choices in system boundaries can influence the favoured outcomes. Despite the ISO standard's intention to provide an impartial assessment, subjectivity will always persist due to the necessity of setting system boundaries and assuming data limitations. The investigation's scope is also influenced by the selection of environmental impacts to be analysed and the level of scientific evidence required to classify a substance as hazardous. Weighing, or comparing the values of different impacts, typically forms the final stage of the LCA. This facet of evaluation is also quite arbitrary, as individuals may assign varying importance to specific categories based on their differing beliefs. Given these factors, offering a comprehensive and transparent overview of the study is crucial.

An LCA requires a significant amount of time for completion, potentially impeding the pace of change. Moreover, the outcomes are confined to predetermined parameters, rendering them inapplicable if any element of the process is modified.

The information encompassed in the study mirrors the technological and environmental state at the time. If disposal takes place a decade after production, the product's ecological impact may be inaccurate, as emission regulations for waste management could have undergone substantial changes.

The investigation is also constrained by the available data. Result quality hinges on the accuracy of assumptions due to data gaps requiring assumptions. While data collection is time-consuming, LCA databases expedite the process. These databases encompass diverse data types concerning materials, processes, transportation, and more. Frequently, datasets constitute an average compilation of data or a singular process example. The dataset is also geographically confined, such as to Switzerland or Europe, where the data was sourced. Given the perpetual availability of more detailed data, time stands as a significant limiting factor during LCA execution.

The analysis has the drawback of lacking site-specificity, which hinders a complete understanding of environmental implications. An LCA might not disclose, for instance, that certain locations are more vulnerable to emissions than others. The study's defined system boundaries also impose limitations. Environmental consequences may arise beyond the established timeframe. For instance, a landfill could continue emitting pollutants long after the study's specified period ends. Another drawback of the life cycle assessment lies in scientific research.

This applies to all environmental systems analysis tools, not just LCA. If there's no scientific evidence of a chemical's carcinogenic effect, it cannot be incorporated into a process. LCA focuses solely on the environmental facet of sustainability, omitting social and economic factors. Hence, a product's overall sustainability cannot be fully assessed with only an LCA. To offer a comprehensive view of impacts, the consideration of other factors is necessary.

Life cycle assessment is a potent method for examining measurable system elements. However, not all factors can be quantified and incorporated into a model. Accounting for system changes is complex due to rigid system boundaries. This is sometimes termed the systems thinking border critique. Inaccuracy can also stem from data reliability and accessibility.

2. Literature Survey

2.1 General

Numerous studies have been conducted by various researchers on the subject of life cycle assessment of perishable waste from the CMBT market. These investigations aim to discern the environmental aspects associated with different types of perishable wastes.

2.2 Review

Guerrini *et al.,* [1] employed conditional order-m estimation to analyze waste collection service efficiency in 40 municipalities within Verona province. Exogenous factors including customer data, household characteristics, and service operations were considered. They found these factors significantly influenced efficiency. Sarra *et al.,* [2] conducted research from 2011 to 2013, using a modified DEA-based model to assess MSW service efficiency in 289 Abruzzo municipalities.

Environmental and economic aspects were considered, with the unsorted waste percentage as an undesirable output. Geographical characteristics were evaluated using bit and probit regressions.

Agovino *et al.,* [3] investigated MSW management efficiency in Italian provinces (2004-2011) using DEA. They employed three output-focused DEA models, evaluating effectiveness from municipal and citizen perspectives. Geographical dependencies were also studied. Hage *et al.,* [4] found Sweden's high recycling rates were due to curbside pickup and widespread recycling drop-off locations. Complexity of the waste collection system might negatively affect recycling rates. Fusco and Allegrini [5] analyzed 4250 Italian municipalities in 2020. They used stochastic frontier analysis to assess spatial interdependence's impact on waste service efficiency, discovering nearby municipalities influenced each other significantly.

Romano and Molinos-Senante [6] calculated MSW service eco-efficiency in Tuscany using a multi-stage non-parametric approach. Meta-frontier analysis categorized municipalities based on ownership, revealing higher eco-efficiency when services were publicly managed. Life Cycle Assessment (LCA) was frequently used globally to evaluate and compare solid waste management options, assessing traditional methods like landfilling and incineration against alternatives like AD and composting.

Rana *et al.,* [7] had studied that Improper waste disposal harms the environment. Swift action is vital. Economic growth drives waste generation, posing challenges for many municipalities. This study used LCA to assess waste management scenarios in the Tricity area. The recycling, composting, and landfill combo had the least impact. Energy recovery from current methods benefited the environment. A sensitivity analysis varied recycling rate.

Khandelwal *et al.,* [8] had utilised Life Cycle Assessment (LCA) to assess the environmental impact of Municipal Solid Waste Management (MSWM) in Nagpur, India, across four scenarios. Through LCA, it compares the scenarios, finding that MRF and composting combined with landfilling (S2) has the least environmental impact. Sensitivity analysis reveals a connection between recycling rate and environmental burdens.

Wang *et al.,* [9] had evaluated Nottingham's MSW management historical GWP from 2001 to 2017 using LCA. Findings indicated ongoing reduction in GHG emissions due to enhanced waste practices, lowering emissions from 1,076.0 to 211.3 kg CO_2–eq./t of MSW. Further enhancements such as food waste separation and improved treatment could result in more substantial reductions.

Istrate *et al.,* [10] had studied in waste-to-energy (WtE) solutions for municipal solid waste (MSW) is growing globally due to environmental concerns. Evaluating WtE's environmental impacts employs LCA. We reviewed LCA studies on MSW systems to identify WtE's influence on environmental performance. Consensus exists on positive effects of diverting organic waste to anaerobic digestion and using landfill gas for power. Shifting from landfilling to incineration often reduces global warming impact, but health effects vary. This review aids decision-makers in identifying sustainable WtE solutions, while tailored LCAs remain crucial.

Ferronato *et al.,* [11] had utilized LCA software with an academic licence to evaluate MSWM scenarios in La Paz, Bolivia. It explores energy recovery and recycling as pivotal methods for reducing environmental impact, emphasising potential for collaborative projects. The research advances technical knowledge in developing regions for sustainable MSWM strategies through cooperation between universities and local governments.

Bartolozzi *et al.,* [12] had addressed a research gap by utilizing life cycle assessment (LCA) to compare environmental impacts of various street sweeping services in two medium-sized Italian cities. The analysis identifies fuel consumption as the primary contributor to environmental impact, followed by equipment material consumption. The study offers insights for managerial decisions and policy-making, aiding in reducing sweeping service's environmental footprint and guiding Green Public Procurement practices.

Di Maria *et al.,* [13] had used life cycle assessment (LCA), the environmental and health effects of MSWI were studied. LCA offers a cost-effective approach, although its results are based on average emissions and exposure models. LCA indicated both positive and negative impacts on various indicators, aligning with epidemiologic studies and biomonitoring. LCA's role in health impact assessment alongside epidemiology was highlighted.

Erkisi-Arici *et al.,* [14] had proposed analyzing products based on functional and physical architecture, yielding new assembly-oriented product families. This aids both assembly line optimization and reconfigurable systems creation. The method's application to a nail-clipper example is illustrated, with an industrial case study evaluating steering column product families from ThyssenKrupp Presta France.

Haupt *et al.,* [15] had introduced a comprehensive approach using LCA and MFA to evaluate waste management systems. It links detailed waste flow data with LCA for more accurate assessments. The method is applied to Switzerland's waste management system, revealing the influence of dominant waste fractions, energy efficiency, and material substitution on environmental impacts. The research suggests focusing on efficient material use and energy recovery in waste-to-energy plants for advanced waste management systems.

Iqbal *et al.,* [16] had reviewed that explores LCA's application in MSW management, identifying best practices. After categorizing study results, appropriate MSW management scenarios are ranked. Study objectives impact procedures. Variances exist in boundaries, impact categories, data, and analysis methods. Sensitivity analysis is vital, but lacking in 38% of cases. Integrated recycling, treatment, and disposal are found to be effective. Technology choice depends on regional context.

Khandelwal *et al.,* [17] had analyzed LCA's evolution, methodology, and findings in MSWM. It summarized functional units, models, LCIA methods, and critical results of selected LCAs. Income groups were considered, highlighting technology and geographic trends. Integrated waste management was favored, but life cycle costing and social aspects were limited. Most studies were in Europe and Asia, with many countries lacking LCA research. GDP's impact on LCA publication was insignificant due to data and time constraints. Government policies and training might enhance LCA's MSWM application.

Viau *et al.,* [18] had critically evaluated the substitution modeling in LCAs of recovered materials from MSWMS. It analyzes 51 LCA studies and finds 22% lacking transparent documentation of substitution ratios. Additionally, 65% of ratios lack justification, and the remaining 35% don't represent realistic replacements. The study calls for increased rigor and transparency and proposes guidance for documenting substitution ratios to enhance credibility and robustness. To be deemed physically realistic, justifications should include information about quality loss, substitutable materials' function, and the sector of use.

Paes *et al.,* [19] had introduced a method that combines Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) to analyze municipal solid waste management systems (MSWMS) in Sorocaba, Brazil. The study shows that scenarios emphasizing higher dry waste recycling rates lead to significant reductions in environmental impacts. Moreover, combining recycling goals, transport efficiency, and composting yields the best economic results, reducing social costs by 31% to 33%. Overall, integrating environmental and economic analyses suggests optimal strategies for enhancing waste management systems.

Wang *et al.,* [20] had studied the environmental impacts of two integrated pathways were compared to single AD and Py processes for organic fraction of municipal solid waste (OFMSW) treatment. Results indicate that the environmental impacts are influenced by energy inputs and outputs. AD-Py emerges as the most environmentally friendly option surpassing single AD and Py. Py-AD demonstrates the highest environmental burden. Thus, AD-Py is recommended as the preferred OFMSW treatment pathway for its lower environmental impact. This study offers theoretical support for OFMSW utilization.

3. Methodology

The Life Cycle assessment of vegetable and fruit wastes from Koyambedu market is analysed from birth to cradle using Open LCA. The flow for the entire analysis is represented in the Figure 2.

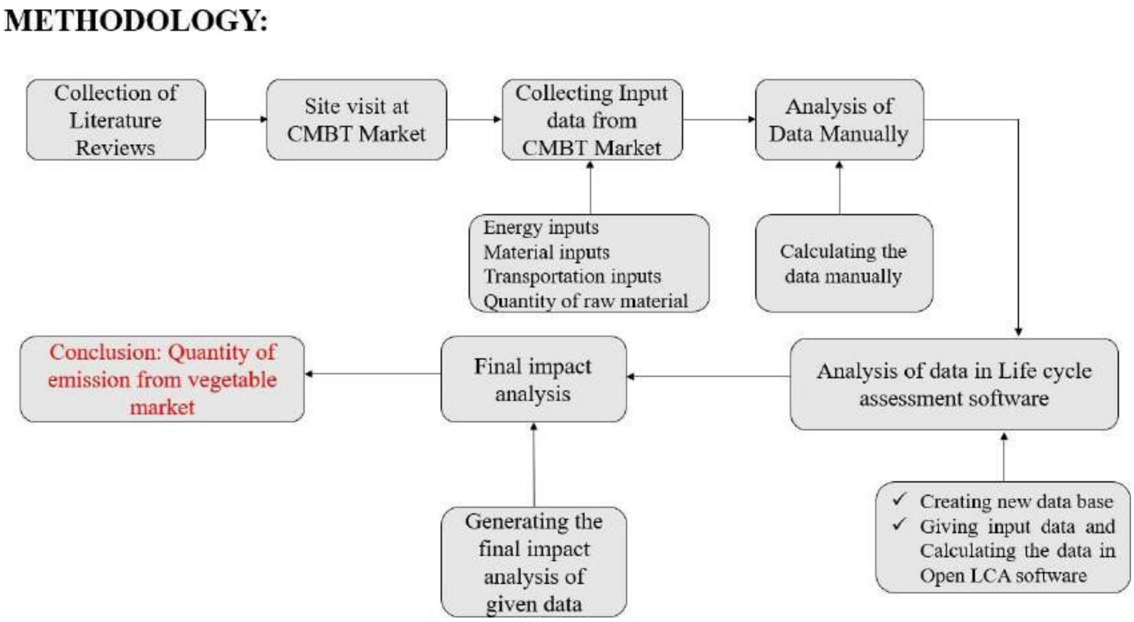


Fig. 2. Flowchart refers to the collection of vegetable waste.

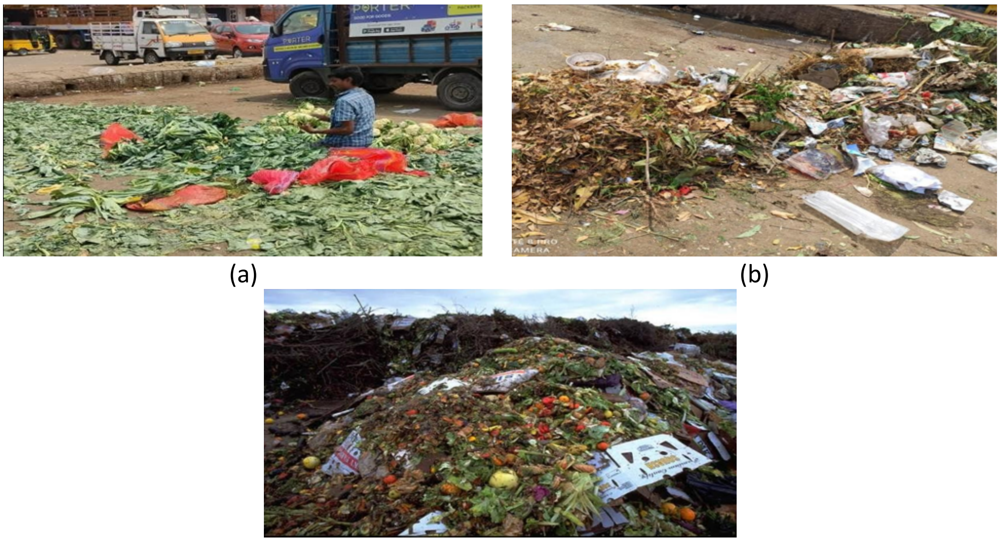
3.1 Energy Inputs

Energy input labelling, also known as EIL, involves determining the energy required for manufacturing a product or providing a service and displaying this information on the product and its packaging. This enables consumers to understand the energy expended in producing the item. However, EIL does not indicate the energy consumption of the product during its usage phase.

(i) Bio-gas
(ii) Methane

3.2 Material Inputs

All the different types of vegetables and quantities of materials are inputted into the material entry field. Discovering innovative methods to make use of by-products from fruit and vegetable processing is of global significance. Industrial fermentation applications have been developed to increase nutritional value or produce biologically active compounds from these by-products. In this context, Figure 3 illustrates the fermentation of various by-products, such vegetable wastes, decaying wastes and fruit wastes that are produced in Koyambedu market.



(a) (b) (c)

Fig. 3. (a) Vegetable waste; (b) Decaying Waste; (c) Vegetable and Fruit wastes

3.3 Transportation Inputs

To avoid the overflow of garbage cans and containers, as well as the scattering of trash on streets, it's essential to schedule regular transportation of waste from temporary storage depots. Ensuring the timely removal of garbage from these bins is crucial for maintaining clean and hygienic urban environments. The transportation system's design must prioritize both efficiency and cost-effectiveness. This involves collecting garbage from the market and utilizing trucks to transport the waste to disposal sites.

(i) Trucks
(ii) Cost of the diesel/petrol

4. Result and Discussion

Research carries out a life cycle assessment (LCA) to gain a comprehensive understanding of the environmental impact of a product, process, or service. Additionally, it offers a projection of the emissions that will be released into the atmosphere. LCA assesses the total effects on the world as a result. Information gathering is intended to improve the environmental profile of the product.

4.1 Inputs of the Data

Energy input labelling, often abbreviated as EIL, is the practice in which producers of goods and services determine the amount of energy needed for the production of their products and subsequently include this information on the product and its packaging. This approach enables consumers to be informed about the energy expended in the manufacturing process. However, it's important to note that energy input labelling doesn't provide insight into the energy consumption of a product during its usage phase. Figure 4 represents the model graph that is derived from the analysis.

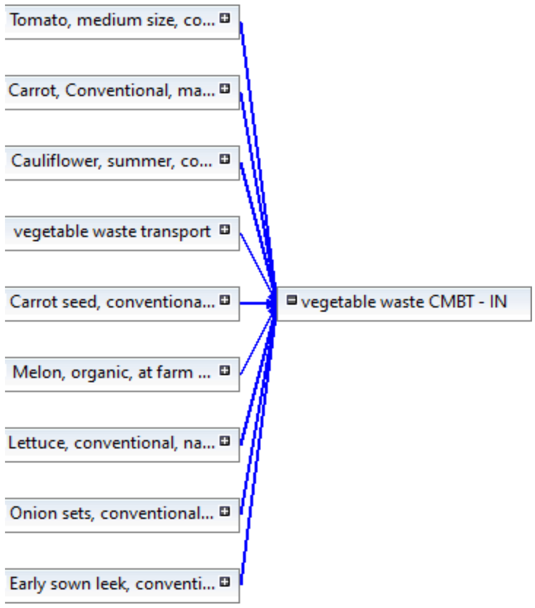


Fig. 4. Model graph

4.2 Comparative Life Cycle Assessment: Utilizing Vegetable Waste for Biogas vs. Landfill Disposal

An LCA study was conducted to compare the environmental impacts of utilizing fruit waste for biogas production versus disposing of it in a landfill. This assessment considered various operations involved in collecting, transporting, and converting decaying fruit into biogas and subsequent energy. Each process involves input and output flows that influence the environment. The research centred on the complete emissions and global warming potential (GWP) linked to the production of biogas and the disposal of waste in landfills, aiming to ascertain their individual ecological effects. The biogas plant, designed to handle 4 tonnes of rotten fruit daily, served as the basis for evaluation.

Both the landfill and biogas plant emitted a total of 237 kg and 565 kg of emissions, respectively. Carbon dioxide (CO_2) comprised the majority of emissions from both options. Specifically, the biogas plant emitted 232 kg of CO_2, while the landfill process resulted in 561 kg of CO_2 emissions. Notably, the biogas plant consumed more energy (258 kWh) due to the use of equipment for biogas feed preparation, compared to the landfill's energy consumption when processing 4 tonnes of fruit waste daily.

The concept of GWP was employed to quantify how much a given quantity of greenhouse gases contributes to global warming. The impact that is produced from the wastes that is analysed is tabulated in detail in Table 1.

Table 1
Impact Categories Obtained from LCA Study

Impact Category	Gases	Biogas Plant	Landfill
Acidification	NO_2	1.13×10^{-2}	3.94×10^{-1}
	Sulphur	1.88×10^{-5}	
Human health	CO_2	3.24×10^{-4}	7.86×10^{-4}
	NO_2	6.18×10^{-6}	2.16×10^{-4}
	CH_4	1.59×10^{-4}	1.02×10^{-4}
Climate change	CO_2	1.8×10^{-6}	4.5×10^{-6}
	NO_2	3.5×10^{-8}	1.2×10^{-6}
	CH_4	9.0×10^{-7}	5.8×10^{-7}
	Sulphur	1.59×10^{-2}	

The biogas plant exhibits a significantly lower acidification threshold (1.1×10^{-2}) compared to landfills (3.94×10^{-1}), indicating a lesser impact on environmental acidity. To assess the impact of climate change on human health, the disability-adjusted life year (DALY) metric is utilized. The biogas plant's overall effect on human health is measured at 4.9×10^{-4} DALY, whereas the landfill's impact on human health is 2.2 times higher, indicating a more substantial negative effect.

Furthermore, in terms of climate change/terrestrial impact, the landfill presents a 6.3×10^{-6} potentially vanished fraction (PDF), whereas the biogas facility exhibits a 2.8×10^{-6} PDF. This aligns with the previous findings, illustrating that the biogas plant has a lower impact than landfill disposal across these various criteria.

4.3 Percentages of Gases Releasing from Vegetable Waste

When the analyses are carried out for the given data it was also analysed to check the amount of gases that are produced from the wastes that are disposed in Koyambedu market. The gases produced are showed in Figure 5.

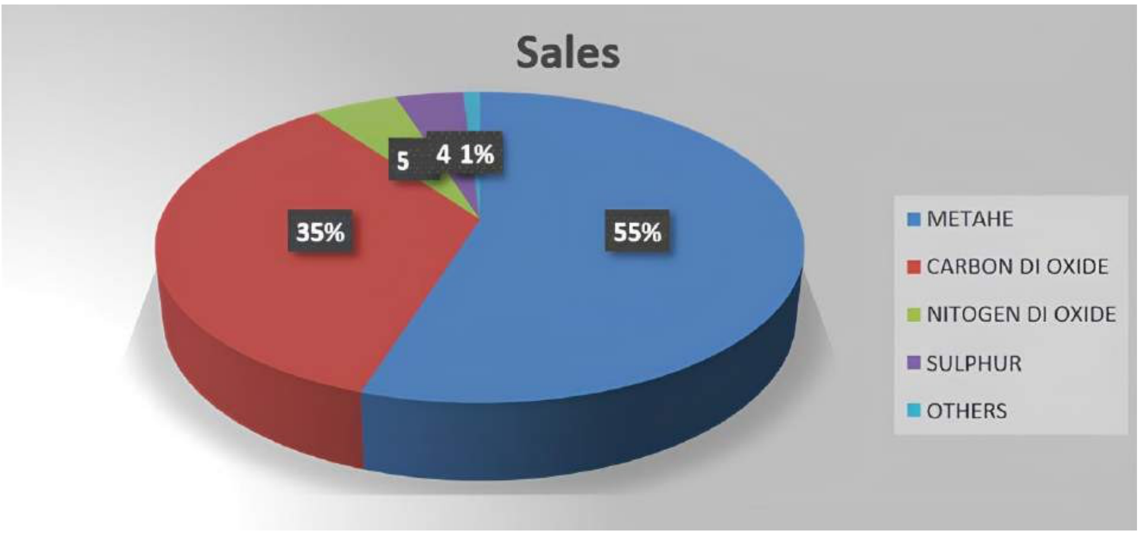


Fig. 5. Gases releasing from vegetable waste.

Following the analysis, it was determined that 55% of the generated gas from the daily collected waste at CMBT market is methane. The second most prevalent gas in the collection is carbon dioxide (CO_2), constituting 35%. A combination of nitrogen dioxide, sulfur, and other gases accounts for 1 to 5% of the collected gases.

4.4 Impact Categories Obtained from LCA Results

In comparison to other waste items, vegetable waste contributes significantly more to global warming. Notably, carbon dioxide (CO_2) ranks as the second most significant contributor to this phenomenon as shown in Figure 6.

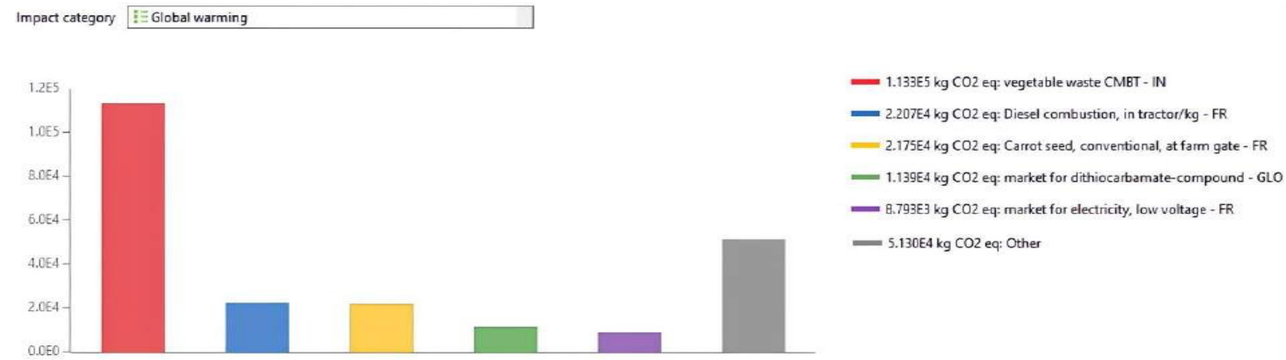


Fig. 6. Effects on global warming

Similarly, Figure 7 shows the effect of waste on the ozone layer. On-renewable energy resources encompass coal, natural gas, oil, and nuclear energy. These resources have a finite supply and cannot be regenerated once depleted. This poses a significant challenge for humanity, given our heavy reliance on them to fulfil the majority of our energy requirements. Increased electricity consumption directly impacts the dynamics of non-renewable energy, as depicted in Figure 8.

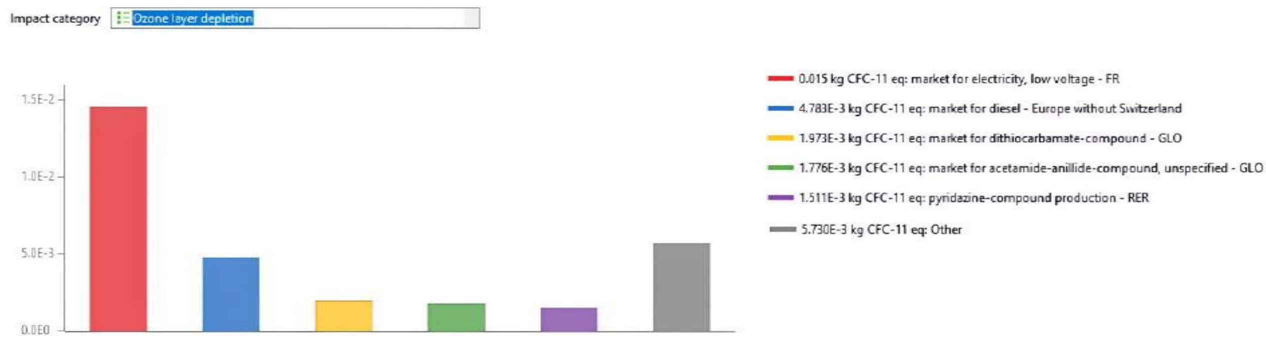


Fig. 7. Effects on ozone layer

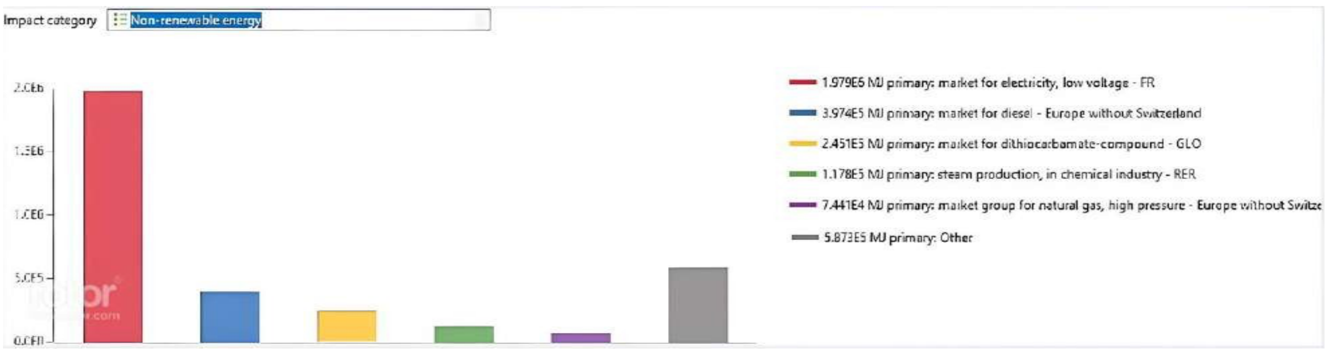


Fig. 8. Effects on Non-renewable energy

5. Conclusions

The acidification threshold of the biogas plant ($1.1x10^{-2}$) is notably lower than that of landfills ($3.94x10^{-1}$), signifying a lesser impact on environmental acidity. The measurement of disability-adjusted life years (DALY) is employed in the human health domain to illustrate climate change's influence on human well-being. The biogas plant's overall impact on human health is $4.9x10^{-4}$ DALY, while the landfill's impact is 2.2 times greater, indicating a significantly higher effect. The landfill exhibits a potentially vanished fraction (PDF) of $6.3x10^{-6}$, whereas the biogas facility displays a $2.8x10^{-6}$ PDF in terms of climate change and terrestrial impact. This bolsters the preceding criteria by highlighting the biogas plant's reduced impact compared to landfill disposal. The LCA study suggests that the biogas plant extracts a greater variety of gases compared to the landfill, and while the biogas plant consumes more electricity, it's advised to establish small biogas plants near major markets to harness methane gases generated predominantly from vegetable waste and mitigate degradable waste dumping in open areas.

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