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Review
Pregledni rad

THE COMPREHENSIVE REVIEW ON BIOMASS POTENTIAL FOR AGRICULTURAL BIOGAS PRODUCTION IN SRI LANKA
SVEUBOHVATNI PREGLED POTENCIJALA PROIZVODNJE BIOGASA OD BIOMASE U ŠRI LANCI

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ABSTRACT

Biogas has emerged as a renewable energy option that offers a wide range of advantages. This study assesses the appropriateness of a range of biomass feedstock choices, encompassing energy crops, bio-waste, materials derived from both animals and plants, as well as organic residues produced within the food production sector. The aim is to determine their potential as viable substrates for agricultural biogas plants in Sri Lanka. Nevertheless, administrative obstacles and inefficiencies within the existing facilities impede the complete utilization of this potential. In parallel, it is of paramount importance to develop and enhance cost-effective technologies for converting agricultural biomass into energy, all while avoiding conflicts with the food and animal feed industries. Consideration should be given to judiciously utilizing disputed resources like fresh fruits and vegetables as raw materials. When employing biomass for energy generation, factors like economic viability, resource availability, and storage need to be meticulously assessed. Additionally, this review proposes that conducting a life cycle assessment within Sri Lanka's energy sector is both feasible and essential for comparing the energy potential of biomass-based sources with conventional fossil fuels. Such an evaluation can offer invaluable insights into sustainable energy choices for the nation's future.
Keywords: *biomass, renewable energy, biogas, food waste, agricultural residues.*

REZIME

Biogas se pojavljuje kao obnovljiva opcija energije koja pruža širok spektar prednosti. Ovo istraživanje procenjuje prikladnost različitih izbora biomase, uključujući energetske useve, bio-otpade, materijale dobijene od životinja i biljaka, kao i organske ostatke proizvedene u sektoru proizvodnje hrane. Cilj je utvrditi njihov potencijal kao održivi supstrati za poljoprivredne biogasne postrojenja u Šri Lanki. Ipak, administrativne prepreke i neefikasnosti unutar postojećih objekata ometaju potpunu iskorišćenost ovog potencijala. Istovremeno, od suštinskog je značaja razvijati i poboljšavati ekonomične tehnologije za pretvaranje poljoprivredne biomase u energiju, sve uz izbegavanje sukoba sa industrijama hrane i stočne hrane. Trebalo bi razmotriti pažljivo korišćenje spornih resursa poput svežeg voća i povrća kao sirovina. Prilikom korišćenja biomase za proizvodnju energije, faktori poput ekonomske održivosti, dostupnosti resursa i skladištenja trebaju se pažljivo procenjivati. Osim toga, ova recenzija predlaže da je sprovođenje procene životnog ciklusa unutar energetskog sektora Šri Lanke izvodljivo i esencijalno radi upoređivanja energetskog potencijala izvora baziranih na biomasi sa konvencionalnim fosilnim gorivima. Takva evaluacija može pružiti dragocene uvide u održive energetske izbore za budućnost nacije.
Ključne reči: *biomasa, obnovljiva energija, biogas, otpad hrane, poljoprivredni ostaci.*

INTRODUCTION

Due to the adverse effects of climate change and the rapid depletion of fossil fuel reserves, the world is deliberately focusing on renewable energy resources and their applications *(Muhamad et al, 2023)*. The swift pace of industrialization, global urbanization, and the relentless growth of economics have propelled the surge in solid waste production (*Suocheng et al, 2011*).

The world population is predicted to increase up to 9.7 billion by 2050 and providing food continuously from existing resources will be a huge challenge *(UN, 2023).* However, inappropriate use of waste has contributed tremendously to the serious issues of human and environmental well-being. Hence, the utilization of waste in an efficient and appropriate way is vital to optimize the waste management processes *(Jambeck et al, 2015).*

To address this challenge, a multitude of scientific endeavours have been initiated, aiming to harness the potential of organic residues by exploring novel applications and avenues for their utilization *(Rodriguez and Latawiec, 2018).* An effective method for managing organic waste is to harness its potential through anaerobic digestion, which enables the production of biogas as a valuable outcome (*Surmen, 2002).* Anaerobic digestion is a simple technology that requires low energy input and is used to convert organic materials from various sources, including wastewater, solid waste, and biomass, into methane gas. The ultimate result is biogas, consisting of a combination of methane and carbon dioxide, and it represents a valuable and environmentally- friendly energy source (*Mes de et al, 2003*).

Diverse forms of biomass can be categorized into several groups, such as Agricultural waste and crop residues, wood and woody biomass, aquatic biomass (algae, seaweeds, water hyacinth etc), animal and human biomass waste (cattle dung, goat, sheep and pig manure, slaughterhouse waste) and semi-biomass, which includes contaminated biomass and industrial waste like municipal solid waste, refuse-derived fuel, sewage sludge and other industrial organic materials. These various biomass sources, when combined, offer potential opportunities for the production of biofuels and biochemicals *(Deepanraj et al, 2014; Stanislav et al, 2015)*.

When evaluating the advantages of biomass, it becomes apparent that it offers several notable benefits. During the combustion process of biomass, carbon dioxide is emitted into the atmosphere. However, it is important to note that the carbon dioxide released originated from the carbon present in the biomass itself, resulting in a balanced carbon cycle with no net increase in carbon dioxide emissions. However, the carbon neutrality of biomass hinges on its origin and the practices involved in its gathering and transportation to the point of use. It can only be considered carbon neutral when employed in a sustainable fashion. It exhibits superior economic viability in comparison to other energy forms, as it offers a higher energy output per unit of production.

Biomass energy, a time-honoured energy source, has been utilized since ancient times to fulfil diverse energy requirements. It serves as a versatile resource for generating electricity, space heating, powering vehicles, and supplying industrial facilities with process heat *(Balat and Ayar, 2005)*. Hence, scientific investigation of the potential of biomass is a crucial factor for the success of any kind of its applications in any climatological region. Fewer researchers have been done on biomass potential for biogas production in tropical regions including Sri Lanka. This review article aims to reduce this knowledge gap by evaluating the different biomass-generating sources that can be utilized for biogas production.

The focal point of this paper revolves around exploring the prospective utilization of residual biomass within the energy sector specifically in Sri Lanka. The primary emphasis lies in evaluating the viability of utilizing biomass derived from agricultural activities, as well as the by-products and residues originating from the agriculture-food industry, as a valuable feedstock for the production of biogas.

Nomenclature:

IEA – International Energy Authority
USD – United States Dollars
EJ – Exa Joule
MW – Mega Watt
CGIAR – Consultative Group on International Agricultural Research
WLE – Water, Land and Ecosystems
TWh – TeraWatt hour
MSW – Municipal Solid Waste

MATERIAL

This study conducted a comprehensive analysis of the available worldwide literature encompassing diverse sources such as reputable journals, conference papers, literature reviews, books, project proposals, PhD thesis and more, addressing the topics of biomass, biomass energy and its versatile applications.

The search for relevant literature was conducted utilizing prominent online databases, including Google Scholar, Science Direct, Scopus, and Web of Science based on suitable keywords (Ex: Biomass, Biogas, Biomass energy). All-encompassing compilation of scholarly resources and maximize access to a diverse range of academic materials.

RESULTS AND DISCUSSION

Global energy scenario

The current population of the world up to the date is nearly 8,037,765,625 *(Worldometer, 2023)*. Addressing the energy needs of such a sizable population poses a significant challenge. Figure 1 depicts the annual primary energy consumption pattern on a global scale, encompassing a period of 12 consecutive years from 2010 to 2021 *(Our World in Data, 2023)*.

Hence, the demand for energy has been steadily increasing in parallel with the global population growth. In response to this demand, researchers and decision-makers across the globe have directed increased attention towards scaling up the deployment of renewable energy sources *(Ang et al., 2022)*. Moreover, in recent decades, numerous countries have developed an increasing awareness of the detrimental effects of global warming. Consequently, there is a collective global desire among nations to mitigate environmental pollution and minimize the harmful consequences of greenhouse gas emissions. As a result, there is a widespread eagerness across nations to harness renewable energy sources as a viable solution *(Adib et al, 2015)*. Furthermore, the economic rebound following the downturn caused by the Covid-19 pandemic coupled with the response to the global energy crisis, has generated a notable upswing in clean energy investment.

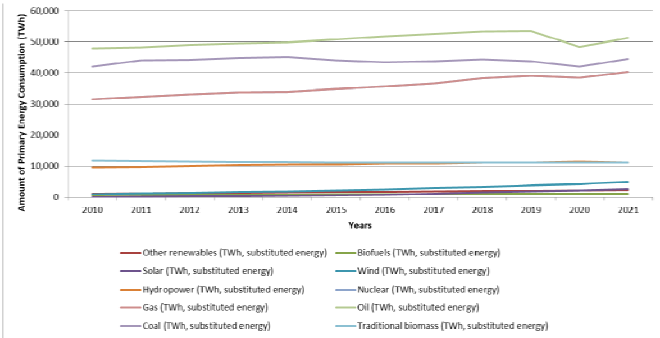

Fig. 1. Global Primary Energy Consumption by using Different Sources

Figure 2 illustrates the global energy investment trends in clean energy and fossil fuels from 2015 to 2023 based on the data on IEA, 2023.

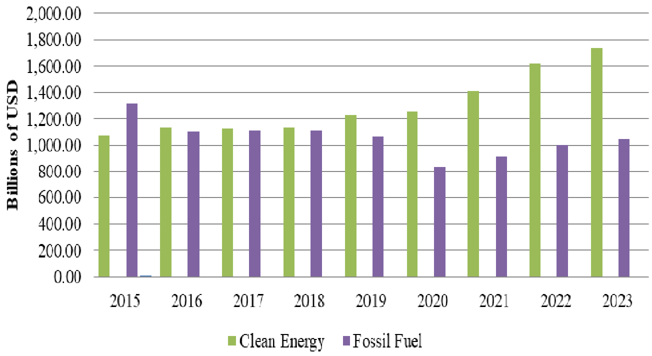

Fig. 2: World Energy Investment for Clean Energy and Fossil Fuels

A comparison between projections for 2023 and the data from 2021 reveals that annual investment in clean energy has experienced a more rapid growth rate compared to investment in fossil fuels during this period. Specifically, clean energy investment has surged by 24%, while investment in fossil fuels has increased by 15%.

Approximately USD 2.8 trillion is projected to be invested in the energy sector in 2023. Out of this, more than USD 1.7 trillion will be allocated to clean energy initiatives, encompassing renewable power, nuclear energy, grid infrastructure, energy storage, low-emission fuels, efficiency enhancements, and the expansion of renewable energy sources and electrification.

The remaining portion, slightly exceeding USD 1 trillion, will be directed towards unabated fossil fuel supply and power. Among these fossil fuels, around 15% will be allocated to coal, while the remainder will be invested in oil and gas. Notably, the ratio of investment in clean energy to fossil fuels has significantly shifted, with every USD 1 now spent on fossil fuels being accompanied by USD 1.7 invested in clean energy. This ratio marks a substantial change from the 1:1 ratio observed five years ago *(IEA, 2023)*.

Status of the global bioenergy production

The energy stored in biomass can be described as "bioenergy," which belongs to the category of potential chemical energy *(Haase, 1971)*. Bioenergy derives from the conversion of solar energy by plants, algae, and cyanobacteria. These organisms utilize sunlight, primarily within the range of 400 to 700 nm, to carry out photosynthesis. During this photosynthesis process, they transform CO_2 into organic matter *(Klass, 1998)*. Moreover, Biomass encompasses all organic materials of biomass resources that possess an immense capacity of non-fossil origin, characterized by their inherent chemical energy content.

Biomass consists of a wide range of resources, including vegetation, trees, and various types of organic waste. These sources can be categorized into two main groups: virgin biomass, consisting of water- and terrestrial-based plants, and waste biomass, which comprises materials like municipal solid waste and bio-solids from sewage (Figure 3). One notable advantage of biomass over fossil fuels is its renewable nature. Biomass can be replenished relatively quickly, allowing for the replacement of used resources within a relatively short period. This renewable aspect sets biomass apart from finite fossil fuel reserves *(Garg and Datta, 1998)*. The combined biomass resources found in aquatic and terrestrial environments worldwide are estimated to be around 4 billion tons and 1.8 trillion tons, respectively.

These vast biomass reservoirs have the potential to generate an astounding 33,000 EJ of energy. To put this into perspective, this amount of energy is more than 50 times the global annual energy consumption. In other words, the available biomass resources possess an immense capacity to contribute significantly to meeting the world's energy demands, surpassing the current consumption levels by a substantial margin *(Kalak, 2023)*.

In the year 2020, the global domestic supply of biomass amounted to a substantial 57.5 EJ *(WBA, 2023)*. Within this supply, a significant proportion of approximately 86% was sourced from solid biomass, encompassing materials such as wood chips, wood pellets, and traditional biomass sources. Liquid biofuels, on the other hand, contributed around 7% to the domestic supply, signifying a growing presence in the energy mix. The municipal and industrial waste sectors together accounted for approximately 2-3% of the biomass supply, indicating their modest but noteworthy role. Lastly, biogas, although relatively smaller in proportion, still made a meaningful contribution, representing around 2% of the global biomass supply *(WBA, 2023)*. Following Figure 3 shows the global energy biomass supply sources and their contribution.

The table below (Table 1) illustrates the worldwide production of three distinct primary biomass energy types in the years 2020 and 2021. Furthermore, the table highlights the contribution of the Asian region to this overall global production. In the years 2020 and 2021, the global production of wood fuel reached a volume of 1.9 billion m^3. Asia emerged as one of the leading contributors to this production, accounting for the considerable shares of 37%. Nevertheless, wood pellets and wood charcoal production in Asia make a relatively smaller contribution to the global production scale.

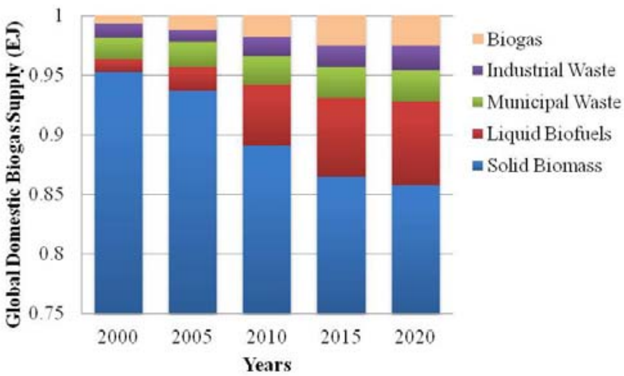

Fig. 3. Global Energy Biomass Supply Sources and its Contribution

Table 1: Production of Primary Biomass Energy

Type of Bioenergy	Global Production		Production in Asia		Asian Contribution to the Global Production as a Percentage	
	Year 2020	Year 2021	Year 2020	Year 2021	Year 2020	Year 2021
Wood fuel	1928 million m^3	1948 million m^3	708 million m^3	705 million m^3	36.72%	36.19%
Wood Pellets	43.2 million tonnes	44.3 million tonnes	5.67 million tonnes	5.97 million tonnes	13.13%	13.48%
Wood Charcoal	52.9 million tonnes	54 million tonnes	8.02 million tonnes	8.04 million tonnes	15.16%	14.89%

Sri Lanka is a country situated in the Indian Ocean, positioned near the southern coastline of the Indian subcontinent, making it an island country. The economy of Sri Lanka witnessed a decline of 7.8 per cent in 2022 *(ADB, 2023)*. Moreover, Sri Lanka's economy experienced a sharp decline in the first quarter of 2023, contracting by 11.5% compared to the previous year. This marked the fifth consecutive quarter of decline, indicating the country's most severe financial crisis in decades *(TE, 2023)*. Sri Lanka currently relies on a combination of energy sources to meet its energy needs, which includes a mix of locally sourced non-fossil fuels and imported fossil fuels. Biomass, an indigenous fuel source, along with imported fossil fuels such as petroleum and coal, constitute the main contributors to the country's energy supply. The remaining share of energy comes from other locally available sources, including large-scale hydroelectric power, as well as renewable sources like solar, small-scale hydro, and wind energy (Figure 4).

The country's heavy dependence on imported fossil fuels has exposed it to multiple disruptions in the past year, leading to an energy crisis. As a consequence of the energy crisis, long queues of vehicles have formed, and there has been a surge in the demand for cooking gas. Moreover, the crisis has disrupted the routines of individuals and entrepreneurs, exerting a significant impact on the country's economy.

To ensure a secure energy future, Sri Lanka, with its limited indigenous fossil fuel reserves, must prioritize the development and adoption of locally available renewable energy sources. By shifting its focus towards these indigenous renewables, Sri Lanka can effectively meet its ever-growing energy demand. This shift will not only reduce the country's dependence on imported fossil fuels but also yield significant cost savings that can be allocated to other developmental initiatives. Moreover, embracing renewable energy will establish a foundation for sustainable development and economic growth, emphasizing the importance of long-term, low-carbon sustainability *(ADB,2023).* Figure 4 below shows the primary energy supply by various sources for local use in the year 2020.

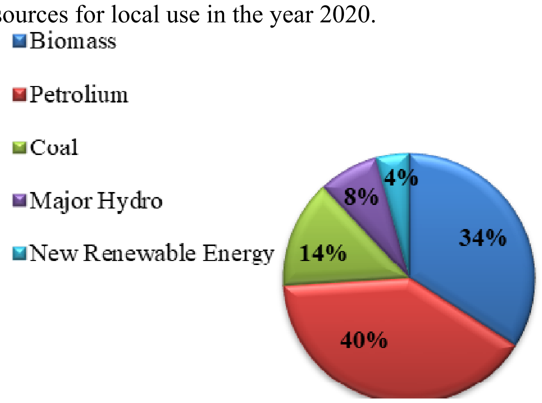

Fig. 4. Primary Energy Supply by Various Sources

Biomass resources in Sri Lanka

In Sri Lanka, biomass remains the primary source of energy, particularly in rural households where substantial amounts of firewood and other biomass resources are utilized for cooking *(SEA, 2023)*. In addition to fuel wood, the country has abundant agricultural residues such as rice husk and rice straw, sugarcane bagasse, coconut wastes, residues released from tea and rubber plantations, fruits and animal waste etc *(Kumaradasa, 1999).*

Common sources of biomass in Sri Lanka and their applications are shown in the table below (Table 2).

While the rural population heavily relies on firewood, there exists untapped potential to expand the use of biomass for energy purposes across the country, particularly in meeting the thermal energy requirements of the industrial sector *(SEA, 2023).*

Table 2. Primary biomasses in the country and their major applications

Primary Source of Energy	Major Application
Firewood	The utilization of thermal energy is essential in powering boilers for steam generation in industrial applications and electricity generation. Furthermore, combustible gases derived from thermal sources are employed to drive internal combustion engines, specifically for the purpose of electricity generation.
Sugarcane bagasse	Thermal energy to produce steam, which is subsequently employed in steam turbine units to generate electricity.
Wood	Charcoal production
Municipal waste	There exists a single power plant that is operational, boasting a capacity of 10 MW
Coconut shell	The primary focus of charcoal and activated carbon production in the country is geared towards export as non-energy commodities.

Exploring the Viability of Biogas Production from Agricultural Residues in Sri Lanka

The increasing need for renewable heat and electricity and the emerging energy crisis in Sri Lanka create a favourable environment for the expansion of agricultural biogas production.

Furthermore, the abundance of feedstock offers intriguing prospects for potential investors, particularly farmers due to its continuous provision of raw materials is essential for the production of agricultural biogas *(Sikora and Tomal, 2016), (Jędrejek, and Jarosz, 2016).*

Nevertheless, the quality and capacity of biogas derived from biomass are influenced by various factors, such as the moisture content and physical condition of the feedstock, the utilized technology, temperature and pressure conditions and so on.

In the context of agricultural power plants, a wide range of substrates from both animal and plant sources, as well as waste from the agri-food industry can be utilized as inputs *(Piwowar et al, 2016).*

Agricultural residue serves as a viable source for the production of biogas. The utilization of agricultural residue for energy production through anaerobic digestion is a highly encouraging and environmentally sustainable alternative for generating renewable energy *(Raja, 2021).* The vast potential of renewable energy makes it a practical and sustainable approach to effectively mitigate local energy deficits.

Biogas production through solid waste

Solid waste is any waste or waste resulting from industrial, commercial, mining, and agricultural activities and community activities, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility, and other waste materials, people leave behind some kind of waste. Moreover, the definition of solid waste is not restricted to waste in solid form. Even, liquid, semi-solid or gaseous forms of the waste are considered as solid waste *(USEPA, 2023).*

Any organic material in waste can be broken down into carbon dioxide, water, methane or simple organic molecules by microbes and other organisms using composting, aerobic digestion, anaerobic digestion or similar processes is called bio-degradable waste. In waste management, it also includes some inorganic materials that can be decomposed by bacteria *(HELPO, 2023).* Following Figure 5 shows the Municipal Solid Waste composition of Sri Lanka.

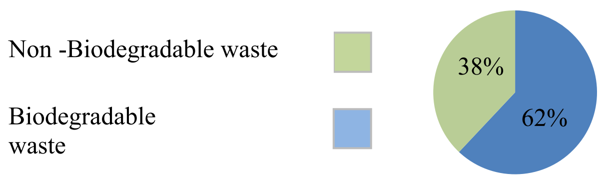

Fig. 2. MSW Composition in Sri Lanka

As this pie chart shows that biodegradable waste constitutes more than half of the total MSW produced in Sri Lanka, there is a huge potential to produce biogas in order to manage biodegradable waste. Further, Biogas units offer benefits beyond composting such as energy production, 100% burning of Methane.

Food waste as a resource for biogas production

Food waste makes up between 50% and 76% of the total municipal solid waste in Sri Lanka's Local Authority regions, with an average of about 56% *(IWMI, 2023)*. On a daily basis, it is estimated that the total amount of food waste generated in Local Authority areas of Sri Lanka is nearly 4,000 tons *(Arachchige, 2019)*. Food waste is present at various stages of the food supply chain, encompassing manufacturing, households, catering, and other food services *(Reitemeier et al, 2021)*. CGIAR Research Program on Water, Land and Ecosystems (WLE) 2021 has conducted a study on the topic of food waste measurement as a tool for prevention and reduction: A case study from a hotel in Colombo, Sri Lanka. They have selected a hotel in Colombo to understand current practices driving Food Waste generation while aiming to facilitate the development and prioritization of reduction strategies.

The selected hotel has 11 banquet halls and 11 restaurants with the capacity for catering to over 4,000 guests under the assistance of more than 400 employees. Figure 6 shows the commodity-wise analysis of the food waste in their research and it reveals that 38% of the edible waste is in the form of cooked rice, 27% is composed of starchy foods such as bread, pasta, and wheat-based noodles.

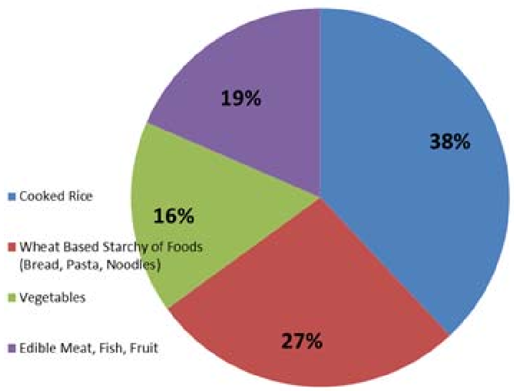

Fig. 3. Commodity-wise analysis of food waste

Further, the following table (Table 3) shows the summary of their findings in the first phase of their study.

Table 3. Summary of the findings

Total food waste production/week	2,442 kg
Total food waste production as a percentage of total food prepared	21 % Buffet surplus (46%) Customer plate (33%) Waste occurring during the process of Food preparation in the kitchen (21%)

In accordance with their findings, the following calculations show the potential of producing methane as a cooking fuel from the total food waste generated in the hotel within one day with several assumptions (Table 4).

Table 1. Potential of producing methane as a cooking fuel

Description	Quantity/ties	Reference
Amount of food waste generated in the hotel/week	2,442 kg (2.442 ton)	*(CGIAR,2023)*
The amount of waste needed to treat the biogas plant for conversion of 100 m^3 of biogas (but this value varies with the condition of the feedstocks, conditions of the digesters, climatic factors, etc)	1 ton	*(Lokuliyana et al, 2016)*
The average amount of biogas converted in biogas plants due to 2.442 tons of food waste	244 m^3	
The approximate amount of methane contained in biogas	50 -70 % (average 60%)	
The approximate methane production through hotel food waste	146.4 m^3	
Approximate methane requirement for cooking meals per person in one day	0.25 m^3	*(Alwis, 2002)*
The number of people who can complete their meals in a day	585	

Hence, this amount can be utilized for 585 people (Guests, Employees, etc) in a hotel to fulfil his/her daily requirement. Following the initial investment required for establishing a biogas unit, there is now, a favourable opportunity to significantly decrease the expenses associated with procuring cooking gas for the hotel.

Livestock waste as a source for biogas production

Livestock wastes have a significant contribution to the biogas production. 5.3% of methane has been produced by the management of manure in Sri Lanka *(Chathumini et al, 2021)*. According to the data released by the Department of Animal Production and Health in Sri Lanka, there were 296,111 of cattle-based registered livestock farms in the year 2020. Out of the total, a significant portion was located in the Eastern Province of Sri Lanka *(DAPH, 2023)*. Hence, the viability of tapping into the significant energy potential of this

resource becomes achievable through the establishment of an ample number of biogas production stations in animal husbandries and rural areas.

Limitations of biogas production through agricultural crop residues

Agricultural residues, including crop residues, manure, and other organic waste materials, serve as a significant source of biogas through anaerobic digestion. Anaerobic digestion is a biological process that involves the breakdown of organic matter by microorganisms in the absence of oxygen, resulting in the production of biogas. However, the high lignin content present in some lignocellulose biomass, such as corn stover, wheat straw, and rice husks, presents challenges for anaerobic digestion. Lignin is a complex compound that provides structural support to plant cells and is resistant to degradation.

Consequently, the anaerobic digestion of lignocellulose biomass with high lignin content can be slow and incomplete.

Several factors contribute to the slow and incomplete digestion of lingo-cellulosic biomass with high lignin content:

- Resistance to lignin degradation: The intricate structure of lignin makes it difficult for anaerobic microorganisms to break it down, leading to a slower digestion process.
- Inadequate microbial communities: Successful anaerobic digestion relies on a diverse array of microorganisms working together to break down organic matter. The absence or insufficient presence of lignin-degrading microorganisms further hampers the degradation of lignocellulosic biomass.
- Limited substrate accessibility: Lignin forms a protective barrier around the cellulose and hemicellulose components of biomass, reducing their accessibility to microbial enzymes. This limited accessibility slows down the degradation process.

To address these challenges and improve the anaerobic digestion of lingo-cellulosic biomass with high lignin content, several strategies can be employed:

1. Pretreatment techniques: Physical, chemical or biological pretreatment methods can be utilized to break down or modify the lignin structure, thereby increasing its susceptibility to microbial degradation. Common pretreatment methods include steam explosion, acid hydrolysis, and enzymatic treatments.
2. Co-digestion with other waste streams: Blending lignocellulosic biomass with waste streams that have higher organic matter content and better biodegradability can enhance overall digestion performance. Co-digestion provides a more balanced nutrient composition and a diverse microbial community, facilitating the breakdown of lignin-rich materials.
3. Optimization of operating conditions: Adjusting factors such as temperature, pH, and hydraulic retention time can promote the growth and activity of lignin-degrading microorganisms. By optimizing operating conditions, an environment conducive to the breakdown of lingo-cellulosic biomass can be created.
4. Microbial augmentation: Introducing specific lignin-degrading microorganisms or microbial consortia into the anaerobic digestion system can enhance lignin degradation and overall performance. This approach involves selecting and introducing microorganisms with effective lignin degradation capabilities.
5. Research and development: Ongoing research and development efforts focus on improving the understanding of lingo-cellulosic biomass degradation and identifying novel techniques or microbial strains that can enhance anaerobic digestion efficiency.

By employing these strategies, it is possible to overcome the challenges associated with the slow and incomplete anaerobic digestion of lignocellulose biomass with high lignin content. This can lead to increased biogas production and the utilization of agricultural residues as a renewable energy source *(Yan et al., 2019)*, *(Abbasi et al., 2012)*.

CONCLUSION

In summary, this comprehensive review has highlighted the substantial potential of biomass resources, particularly in the realm of agricultural biogas production in Sri Lanka. The evaluation encompassed a diverse array of biomass feedstock options, ranging from energy crops to organic residues, illustrating their suitability for powering agricultural biogas facilities. While the prospects are positive, challenges arising from administrative issues and operational inefficiencies in existing facilities are impeding the full realization of this potential. Moreover, this underscores the pressing need for the development of cost-effective technologies to convert agricultural biomass into energy, all while ensuring compatibility with the food and animal feed industries. Thoughtful utilization of resources like food waste, livestock waste, and crop residues further strengthens the viability of biogas production.

This review also emphasizes the critical importance of conducting a life cycle assessment within Sri Lanka's energy sector. Such an assessment is not only feasible but also essential for making well-informed comparisons between the energy potential of biomass-based sources and traditional fossil fuels. This invaluable insight can serve as a guide for the nation to make sustainable energy choices in the future.

In a world, that increasingly prioritizes renewable energy sources due to concerns about climate change and the depletion of fossil fuels, the role of biomass in meeting energy needs is of paramount significance. Biomass offers a carbon-neutral, economically viable, and sustainable alternative. As Sri Lanka grapples with its energy challenges, prioritizing the development and efficient utilization of locally available biomass resources represents a crucial step toward a more secure, sustainable and environmentally friendly energy future.

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