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Review

Utilization of Biomass Waste Through Small-Scale Gasification Technology in the Eastern Cape Province in South Africa: Towards the Achievement of Sustainable Development Goal Number 7

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Abstract: Despite being resource-richly endowed with various energy sources, and despite the connection of 89.8% of the households to the grid in South Africa, the Eastern Cape province, as compared to other provinces, has the lowest level of grid connection of about 64.5%. Some of the rural poor households in the Eastern Cape province supplement their free basic electricity with unclean energy alternatives. Using unclean energy alternatives is not only detrimental to the environment and health of the people, but it is a sign of energy poverty and among the contributing factors to depesantization, deagrarianization, and deindustrialization which prolongs the underdevelopment in rural areas. Innovation in energy technologies is a key ingredient in meaningful rural development. The utilization of small-scale biomass gasification technologies can be a solution to the South African energy crisis in rural areas, and it is in line with sustainable development goal number 7, which is about ensuring access to affordable, reliable, sustainable, and modern energy for all. Alternative renewable energy sources cannot be ignored when dealing with the energy crises in South Africa. Renewable energy sources in the country include biomass, solar, wind, and hydropower. Despite its low utilization in the Eastern Cape province, small-scale biomass gasification technology remains pivotal in reducing energy crisis by producing electricity. However, the affordability of biomass gasification technology also plays a role in whether people will accept small-scale biomass gasification technology. The purpose of this paper is to determine the possibilities of using small-scale biomass gasification technology. This paper gives a comprehensive review of small-scale biomass gasification technology potential in the Eastern Cape province and the link between acceptance of small-scale gasification technology and affordability by evaluating the availability of biomass sources in the province and achievements with regards to small-scale biomass gasification. This paper also covers the impact of biomass gasification technology integration in the energy grid, what needs to be taken into consideration before its installation, its benefits and the barriers to its development in Eastern Cape province.

Keywords: waste management; small-scale biomass gasification; fluidized gasifier sustainable development goals; innovation

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1. Introduction

With the increasing costs of grid energy and the country's commitment towards the use of renewable energy sources [1] the application of small-scale biomass gasification technology in the Eastern Cape province can be a step in the right direction towards sustainable rural development and towards the respect to right to energy access as a human right and towards the achievement of sustainable development goal number 7, which is to

ensure access to affordable, reliable, sustainable, and modern energy for all [2]. Biomass waste have the potential to either substitute or augment fossil fuels for energy production, as well as in the development of a range of value-added products [3]. Alternative renewable energy technologies need to be taken into consideration in solving the energy crisis, if we are to achieve sustainable development goal number 7 by 2030. Small-scale biomass gasification technology allows for the conversion of different wastes such as plant waste and animal waste to a gaseous fuel such as syngas which can be used as an energy. Given the fact that, by nature, resources are scarce, there is a need for a deeper understanding of alternative renewable energy technologies in rural areas. Feedstock for small-scale biomass gasification technology is eco-friendly and available in rural areas and farms considering the availability of animal waste and crop waste in rural areas. Using plant and food waste for small-scale biomass gasification protects the water sources and the environment. In support of this, the National Energy Policy and Integrated Resource Plan of South Africa is in support of the use of biomass as a renewable resource [4]). In the same line, the South African Department of Science and Technology has indicated that biomass has the potential of contributing 1300 Megawatt (MW) of electricity to South Africa's energy mix [5]. The acceptance of two biomass energy projects, namely Mkuze 16 MW and the Ngodwana (25 MW), by the Department of Energy under the Renewable Energy Independent Power Producer Procurement Programme shows the potential of biomass energy source as a renewable alternative [6]. There is a need for further research in terms of the harvesting, transport, maintenance, and availability of affordable and small-scale biomass technology as well as the sustainability of biomass energy sources; moreover, biomass as compared to the current grid, which uses coal, has an advantage of using renewable feedstock.

The use of plants and animal and domestic waste will reduce environment and water pollution and assist in waste management while providing affordable energy to rural households [7]. As much as small-scale biomass gasification technology has many advantages environmentally and in terms of employment creation and energy crises solution, it is still lagging in terms of application in the Eastern Cape province. The Eastern Cape province was chosen because it has the lowest level of grid connection compared to other provinces in South Africa Opting for small-scale biomass gasification technology will reduce environmental degradation in the future. Energy is the key to sustainable development [8]. However, the use of non-renewable energy sources does not only impact energy access but also affects the livelihoods, health, and education access of the affected people [9].

About 43% of South African households spend more than 10% of their budget on domestic energy services [10]. Despite coverage of over 89.8% of the grid connection and the government efforts towards energy poverty reduction such as the free basic electricity policy, which offers 50 kWh to registered indigent households in the indigent program, some indigent households continue to use unclean energy alternatives because the free 50 kWt which they receive monthly is not enough [11]. Energy poverty is still a challenge in South Africa, especially in off-grid and rural areas as indicated by the approximately 3.5 million households not connected to the grid [12]). The Eastern Cape is the second province in South Africa, with the largest number of households receiving free basic electricity and the third province with a huge number of households using firewood for cooking [13]. Electricity cost is high, and for low-income households, such a scenario leaves them with limited energy choices. In most cases, low-income households resort to unclean sources of energy.

In the current power grid of South Africa, 78% of electricity is from coal, 5.9% from open cycle gas turbines (OCGTs), 5.7% from wind, 3.9% from hydro, 3.6% from solar and 3.2% from nuclear. More than 78% of electricity from South Africa is from fossil fuel which is non-renewable. In such a scenario, opting for improved biomass energy sources which are renewable and using readily available sources of energy such as leaves, grass, and dung in a manner which is eco-friendly will be a better option. However, biomass is not in the current power grid of South Africa. Further details of the current power grid are indicated in Figure 1.

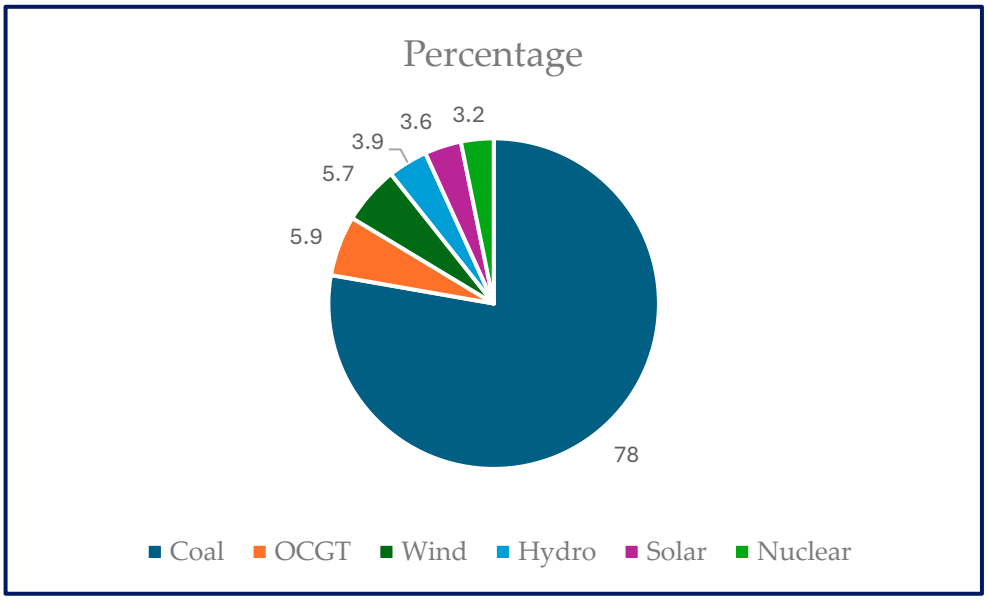


Figure 1. The current power grid of South Africa.

1.1. Significance of This Study

The significance of this study is that it focuses on small-scale biomass gasification technology in the Eastern Cape in South Africa, an area which still needs more research not only in South Africa but in Africa. The advantage of small-scale gasification technology especially in rural areas is that biomass gasification feedstock is available. Considering the country's high reliance on coal, biomass gasification technology which uses renewable energy sources can reduce the country's high reliance on coal, which is a non-renewable resource. Gasification technology is a promising sustainable technology of waste management because it converts waste into electricity. As much as gasification technology requires a lot of capital, small-scale biomass gasification technology, in the case of South Africa, reduces fossil fuel usage; it has a potential of creating scarce skill employment and contributing to the goal of the country—using 18% of the energy from renewable energy sources by 2030.

1.2. Research Questions

The study used the literature review methodology. The following research questions were formulated to guide the study on which this paper is based:

- Which biomass energy sources are available in the Eastern Cape province?
- Does Eastern Cape have a potential of small-scale biomass gasification?
- Which factors need to be taken into consideration before small scale biomass gasification technology?
- Which areas which need research and innovation to promote small scale biomass gasification technology?

1.3. Research Objectives

The research objectives were as follows:

- To identify different sources of biomass energy in the Eastern Cape province.
- To examine the potential of small-scale biomass gasification technology in the Eastern Cape province.
- To identify the factors which need to be taken into consideration before small-scale biomass gasification technology.
- To identify the areas which need research and innovation to promote small-scale biomass gasification technology.

1.4. Search Strategy and Literature Search Process

The information in this paper was searched from different databases. Some of them are as follows: DHET, DOAJ, Scopus, Google Scholar, google, and different relevant government websites and reports. The keywords which were used include, small-scale biomass gasification and biomass. The researchers screened the articles by evaluating article titles, and abstracts. The purpose for screening articles was to focus on the most relevant articles. The study focused mainly on articles published not more than 10 years ago and excluded articles that were irrelevant to the research questions, unpublished theses, articles written in other languages, and duplicates. Articles used were selected according to their relevance to the research questions and objectives of the paper.

2. Biomass Gasification

As shown in Table 1 there is a potential of using biomass energy in South Africa as indicated by the presence of biomass energy sources, namely agriculture residues, sugar cane bagasse, sugar cane field residues, plantation residue, pulp and paper mill residue, black liquor, sawmill waste, invasive species, fuel wood, organic solid waste, organic sewage sludge, and purposively cultivated crops. As much as there is potential for biomass energy in South Africa, the challenge of biomass is rainfall constraints which will also cause constraints in access to the sources of biomass thereby affecting the supply of biomass sources [5]. Despite the question of sustainability in the extraction of some of the biomass energy sources, small-scale biomass gasification technology energy can be used at small-scale level in areas with plenty of biomass sources such as Eastern Cape. Biomass can also be used as an alternative during load shedding. There is a need for more research on small-scale biomass gasification technology potential in the Eastern Cape province.

Biomass refers to carbon-based materials such as animal waste, human waste, food waste, algae, industrial waste like sawdust, cut-offs, bark, shavings, and reject timber from sawmills plant material, which when processed can produce organic fuels [14]. Biomass is renewable and available in rural areas. The advantage of biomass is that it can be converted into heat and electrical energy, methane gas, chemicals, and transportation fuel through thermochemical and biochemical processes. Examples of thermochemical conversation are gasification, pyrolysis, and combustion.

Biomass can be used directly for heating and combustion and indirectly as biofuels [15]). The utilization of biomass as an energy source is based on the heat energy released during the combustion of biomass waste [16]. The solar energy trapped by plants is given off in the form of heat energy during biomass combustion.

As indicated on the 2022 South African power grid, biomass energy is not part of the power grid. Despite not being considered part of the energy grid, there is a potential for biomass as a source of energy in South Africa, as evidenced by the availability of 42 million hectares of natural woodland; 1.2 million tons of woods fuel; 35 million hectares of plantation; several trees in rural areas [17]); 107 million tons of waste annually, with most of it being landfilled; 92.7 hazardous and 65% general waste [18]); plant and animal waste in rural areas; and domestic waste. Table 2 shows the number of biomass power plants in South Africa namely Umfolozi Sugar Mill, Tongaat Felixton, Komati Mill, Busby Renewables Biomass Project, George Biomass to Energy Project, Tongaat Amatikulu, Malelane Mill and Illovo Eston.

Table 1. The availability of feedstock for biomass gasification in South Africa.

Source	Potential (Dry Mass) Tg/a	Allocated Already (Dry Mass)			Estimates of Availability or Potential				Energy Density (PJ/Tg) (10)	Moisture Content Estimate (%) (11)	Energy Equivalent Available Now (PJ/a)
		Re-Use (Tg/a)	Unavailable (Tg/a)	Energy Use (Tg/a)	Not Available (Dry Mass) Tg/a	Available Now (Dry Mass) Tg/a	Potential Additional Availability (Dry Mass) Tg/a				
Agricultural residues	36.22		30.42		30.42	5.80	2.90	1	10.00	42%	57.95
Sugar cane field residues	5.06		5.06		5.06	0.00	2.53	2	10.00	42%	0.00
Sugar cane bagasse	5.35	0.2		4.54	4.74	0.60	2.34	3	10.00	42%	6.02
Plantation residue	6.70		5.20		5.20	1.50	0.00	4	12.50	30%	18.75
Pulp and paper mill residues	0.69			0.69	0.69	0.01	0.35	5	12.50	30%	0.09
Black liquor	1.50			1.49	1.49	0.00	0.77	6	6.30	59%	0.00
Sawmill waste (bark included)	3.10	0.15		2.00	2.15	0.95	1.03	7	10.40	40%	9.88
Invasive species	11.30		3.23		3.23	8.07	1.16	8	14.70	20%	118.63
Fuelwood	14.00			10.00	10.00	4.00	12.00	9	14.70	20%	58.80
Organic solid waste component	6.47			0.65	0.65	5.82	0.00	12	10.00	20%	58.23
Organic sewage sludge	2.53			0.25	0.25	2.28	0.00	13	10.00	20%	22.77
Purposely cultivated crops	9.26				0.00	9.26	0.00	14	14.70	42%	136.12
Total	**83.91**	**0.35**	**43.91**	**18.72**	**62.97**	**20.92**	**23.08**				**487.24**

(Hugo, 2016:14). [5].

Column description of Table 1.

Allocated	Unavailable to maintain soil productivity and condition, or not accessible
Energy Allocated	Used already for energy applications
Not available	Total not available = Sum (allocated Categories)
Available now	Available = Total potential—Not available
Potential additional availability	Additional biomass unlocked through various scenarios
Energy density	Specific energy content of biomass
Moisture content	Estimated moisture content of the biomass (air-dried, except in the case of black liquor)
Energy equivalent now	Total energy in dry biomass currently available

(Hugo, 2016:15) [5].

Table 2. Biomass plants in South Africa, a source of raw material for gasification.

Power Plant	Province	Installed Capacity MW	Annual Output GWh	Date Commissioned	Operator
		4.2	(32)	2007	PetroSA
Ngodwana Energy Project		25	(198)	Q3 2018	Sappi
Mkuze		(17.5)	(130)	2023–2024	
Umfolozi Sugar Mill	Kwazulu Natal	4.5			Umfolozi Sugar Mill Pty (Ltd.)
Tongaat Felixton	Kwazulu Natal	9			Tongaat Hulett Sugar SA Ltd.
Komati Mill	Mpumalanga	8			TSB Sugar International
Busby Renewables Biomass Project	Mpumalanga	5			
George Biomass to Energy Project	Western Cape	5			
Tongaat Amatikulu	Kwazulu Natal	5			Tongaat Hulett Sugar SA Ltd.
Malelane Mill	Mpumalanga	4			TSB Sugar International
Illovo Eston	Kwazulu Natal	2			Illovo Sugar (South Africa) Ltd.

Mkuze biomass plant: The success story of the potential of biomass energy as an alternative renewable energy in South Africa

The Mkuze biomass project in Kwazulu Natal, currently owned by Navosync, was accepted by the Department of Energy under the Renewable Energy Independent Power Producer Procurement Programme in 2013. The construction of Mkuze biomass plant project is expected start in 2026 and enter into commercial operation in 2027. The sources of energy which will be used for the Mkuze biomass plant will be agriculture (mainly sugar cane waste) and forest biomass (woody). Mkuze biomass project is expected to produce 132,000 MWh electricity and supply clean energy to around 40,000 households and is expected to offset 67,600 t of carbon dioxide emissions (CO_2) a year [19].

Biomass gasification is a thermochemical process which converts carbon-containing material into combustible gas through the supply of restricted amounts of oxygen. Compared to other conversion technologies such as combustion and pyrolysis, gasification has a higher energy efficiency recovery and higher heat capacity. The gas produced by biomass gasification, especially in the case of feedstock is known as producer gas, wood gas, or syngas [20]. Syngas is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide,

nitrogen, and water vapor [21]. It is important to note that gas specifications are different for various applications and the composition of gas is dependent on the gasification process, the gasification agent, and gasification temperature. Two main types of gasification gas are biosyngas and product gas [22]. Product gas is generated in a low-temperature gasification process of about 800 to 1000 °C, whereas biosyngas is produced at a higher temperature of around 1200 to 1400 °C. Product gas contains carbon monoxide, hydrogen, methane, and other hydrogen carbon components (CO, H_2, CH_4, CxHy), whilst Biosyngas contains carbon monoxide and hydrogen (CO and H_2). Syngas can also be produced from producer gas through heating, thermal cracking, or catalytic reforming. This is further indicated in Figure 2.

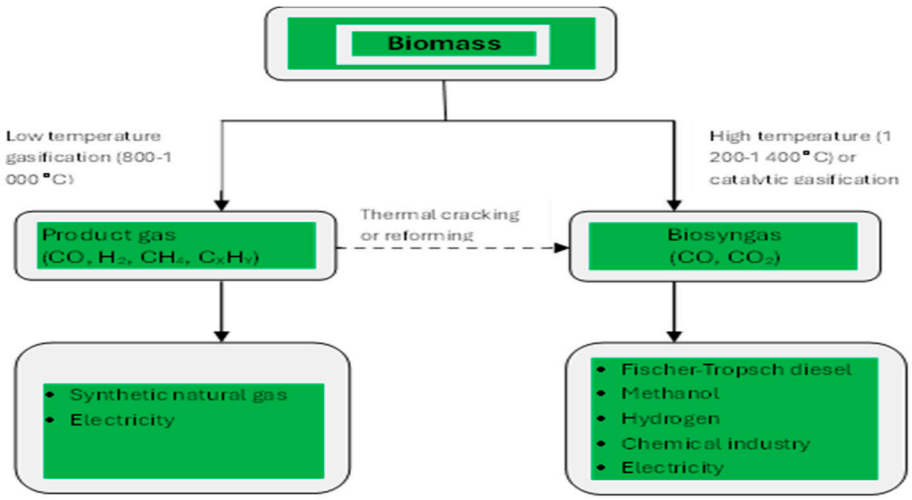


Figure 2. Differences between biosyngas and product gas and their typical utilization applications (Kilpimaa, 2013:1012) [23].

Uses of syngas

Syngas can be used for heating, steaming, electricity generation, chemicals, and fuel. It can be converted to methane, methanol, and ethanol. Methanol from syngas can further be processed into biodiesel. Table 3 further shows the uses of syngas.

Table 3. Uses of syngas.

Syngas	Syngas End Uses	Benefits to People
Syngas	Syngas	Generation of electricity Generation of liquid fuels
Syngas products	Methane	Electricity production Heating Lighting
		Fuel for vehicle
	Methanol	Used to make clothing Used as a chemical agent in pharmaceuticals and agrichemicals.
	Ethanol	Used as a high-octane fuel in vehicles Heating Pest control in agriculture Used as an antibacterial cleaner Used for removing grease and stains on clothes

The gasification of biomass can be a cheaper and better energy technology alternative to rural households as compared to the current energy grid which uses [12]. Gasification refers to the indirect combustion of solid and liquid biomass to convert them to combustive syngas [24]. The advantage of syngas is that it can be purified before use, thereby reducing air pollution [25]. Unlike the traditional combustion of biomass that produces gases such as carbon monoxide, which pollutes the air, gasification reduces carbon emissions while using the energy sources available to rural households [26]. A biomass gasification system generally comprises different parts that make up a unit, namely, a feeding system, a gasifier/reactor, cleaning systems such as cyclone, and syngas cooling systems such as a gas scrubber [27].

The thermochemical process occurs in a gasifier which is also known as a reactor. As indicated in Figure 3, the main types of gasifiers are 01: fixed bed, 02: fluidized bed, 03: entrained flows and 04: plasma gasifiers (Jančauskas et al., 2024 [22]). Examples of fixed bed gasifiers are downdraft, updraft, and cross draft gasifiers. Fixed bed gasifiers consist of four different zones, namely the drying zone, pyrolysis zone, reduction zone, and combustion zones, where different chemical and physical processes take place. In general, fixed bed gasifiers are cheap, simple and they produce low heat [28], whereas fluidized bed gasifiers are more expensive, complicated, and produce syngas of high heat value [29]. Examples of fluidized gasifiers are bubbling fluidized bed gasifiers and circulating fluidized gasifiers.

Entrained flow gasifiers are comparatively new, and they have a high efficiency. In most cases, entrained flow gasifiers are used for large-scale gasification of biomass and coal and refinery residues. Entrained flow gasifiers require highly pulverized articles which makes it problematic to use biomass as a feed stock [30]. Entrained flow gasifiers can be used as a substitute for natural gas heating which is an advantage of carbon reduction. It has the advantage of a calorific value of synthetic gas of about 10 MJ/m^3 [31].

Plasma gasifiers are the other types of gasifiers which are environmentally more friendly because they use waste, which is very helpful in terms of reducing landfills and in terms of waste management [32] presenting its alignment with SDG 7 especially in terms of sustainable energy access for all. Plasma gasifiers gasify the feedstock in plasma produced by a high-energy electric arc. Inert gas is passed through the arc, heating the process gas to 1500–5000 °C [33].

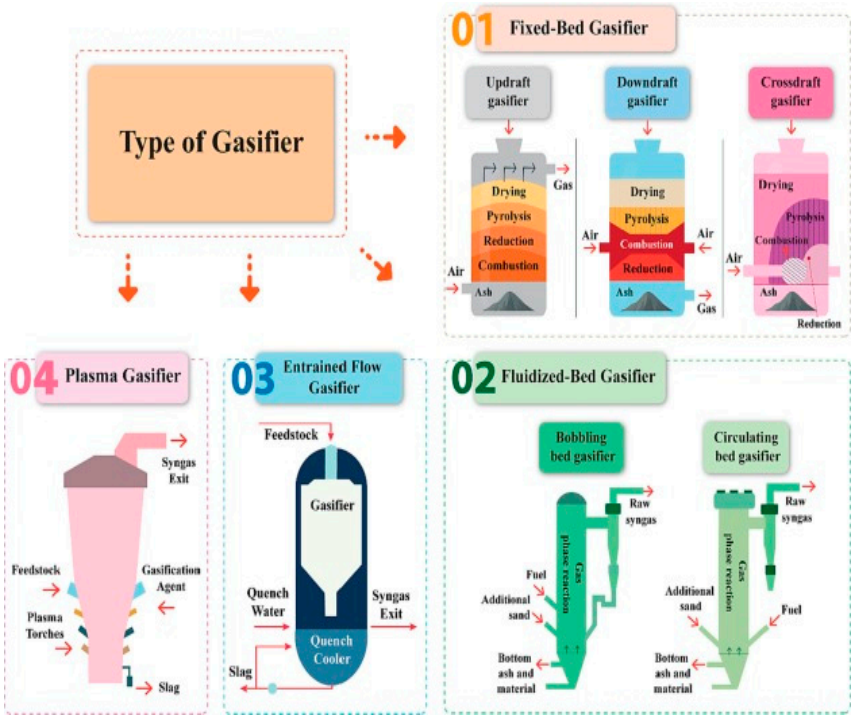


Figure 3. Types of gasifiers: (Akbarian et al.,2022: 4) [34].

3. Sawmills in Eastern Cape for Small-Scale Biomass Gasification

Sawmill waste can be used as a feedstock for biomass gasification. The sawmill's main waste materials are sawdust, cut-offs, bark, shavings, and reject timber. Table 4 shows some of the sawmills in the Eastern Cape, which shows the potential of biomass gasification technology in the province.

Table 4. Sawmills in Eastern Cape source gasification feedstock.

Sawmill	Location
Rance timber	Stutterheim
Mto Forestry (PTY) Ltd.	Uitenhage
E Lentz	King Williams Town
Schenk Enterprises (PTY) Ltd.	Alice
A C Whitcher (PTY) Ltd.	Tsitsikamma
Uitenhage Sawmills (PTY) Ltd.	Uitenhage
Pirie Sawmills (PTY) Ltd.	Stutterheim
Tekwani Sawmills	Mount Ayliff
A P Green's Sawmills Cc	Queenstown
Chestnut Grove Sawmills	Bedford
Longmore Sawmill	Humansdorp
Yonder Lea Timber (Pty) Ltd.	Stutterheim
Green's Sawmills	Komani

4. Forests in Eastern Cape

The Eastern Cape constitutes about 46% of South Africa's remaining indigenous forest cover. Forests constitute about 2.2% of the land cover of the Eastern Cape, and there seems to be an increase in the indigenous forest cover in the Eastern Cape due to revegetation of the previously cultivated fields since independence, owing to the increasing deagranisation in rural areas [35]. As much as the Eastern Cape has the potential of biomass energy, there is a need for sustainable ways of collecting biomass raw materials in the forests since the forest in the Eastern Cape constitutes 46% of South Africa's remaining indigenous cover [35]. The list of forests in the Eastern Cape include the following: Missippi, Lully, jhali Donkey, Hogsback, Inyarha Isidenge, Katberger, Kologha, Booman, Krishna River, Surbhi, Lamborguine, Lottering, Plaatbos, Robbe Hoek, Storms River, Welbedacht, Amatole, Dwesaa and Tsitsikamma. Table 5 shows the number of households with serviced and unserviced sewage sludge. Sewage sludge can be used as a source of biomass gasification.

Table 5. Potential of Sewage sludge as a source of biomass energy in the Eastern Cape province.

Category of Sewage Sludge	Number of Households
Serviced	584,140
Unserviced	1,092,176
Total	1,676,316

Hugo, 2016 [5].

Research conducted by [5] indicated the presence of both serviced (584,140) and unserviced sewage sludge (1,092,176) from 1,676,316 households. The availability of sludge which can be used as a source of small-scale biomass gasification shows that the Eastern Cape has the potential of using sewage sludge for biomass gasification. Using sewage sludge for small-scale biomass gasification reduces land pollution, which in turn has a

negative impact on the climate. Table 6 shows the potential of animal waste as a source of biomass gasification.

Table 6. Potential of animal waste as a source of biomass in the Eastern Cape province.

		Cattle	Goats	Pigs	Springbok	Impala	Wild Beast	Kudu Number	Zebra
Amathole	Great Kei (incl. Mnquma)	30,232	5859		750	4805	3898	350	2696
	Amahlathi	58,515			146	614	95	255	58
	Raymond Mhlaba	20,096	21,476	29,178	2530	1196	185	480	162
Alfred Nzo	Matatiele	37,515							
Buffalo City	Buffalo City	39,867	631	576	30	40	15	40	4
Chris Hani	Emalahleni	17,021			100				
	Enoch Mgijima (incl. Intsika Yethu)	72,270	8126	75,128	689	282	278	60	151
	Inxuba Yethemba	50,837	47,908	121	5543	1154	715	2526	393
	Sakhisizwe	153,092	3876						
Joe Gqabi	Sengu	31,075	4044	2					
	Elundini	169,232							
	Walter Sisulu	31,033	675	13,149	2234	615	494	171	131
Nelson Mandela Ba	Nelson Mandela Bay	20,791	2229	431	47	257	5	189	
Sarah Baartman	Blue Crane Route	28,256	22,524	40,125	133	210	21	227	7
	Dr Beyers Naude	34,641	269,260	2094	11,374	798	497	2993	2
	Kou-Kamma	26,651		30	32	24		41	
	Kouga	101,700		224	66	253	161	286	35
	Makana	21,453	7094		1920	4388	902	138	527
	Ndlambe	52,485	216		20	495	139	238	125
	Sundays River Valley	16,525	23,374	183		282	79	20	19
Total		**1,013,298**	**417,296**	**162,884**	**25,618**	**15,418**	**7469**	**9260**	**4314**

(Census of commercial agriculture—Eastern Cape, Report No. 11-02-03 2017:75-81).

There are plenty of animals in the Eastern Cape. Animals produce animal waste which can be used as a source of biomass energy. The Census of commercial agriculture—Eastern Cape Report of 2018 showed that there were plenty of animals in the Eastern Cape province as indicated by the availability of 1,013,298 cattle, 476,296 goats, 162,884 pigs 25,618 springbok; 15,418 impala; 7116 wild beast 9260 kudu, and 4314 zebras. In support of this, research performed by [36] indicated that there are a lot of energy sources for biomass energy in the Eastern Cape province. A rough estimation of cow dung produced by a cow per day is 15 kg, while a rough estimation of animal waste produced per day is 15,199,470 kg from cattle, 417,296 kg from goats, and 488,652 kg from pigs. Animal waste is rich in nitrogen, which is used for biomass gasification. Through biomass gasification technology, if all this animal waste is utilized for the energy production of the Eastern Cape province, it will go a long way in promoting economic opportunities for rural poor and in improving pass rates especially for the girl child. Energy poverty is a symptom of low income and, at times, a major challenge in households with gender-based violence. Promoting sustainable energy production through using energy alternatives such as the use of small-scale biomass gasification technology has the potential for creating sustainable employment, which in turn will promote stability in families and improve pass rates. Usually, violence and all forms of poverty including energy poverty affects the mortality rates of children. At the country level, small-scale biomass gasification may not be financially viable; however, in the Eastern Cape province, it may be a viable option for a mini grid, especially in areas with plenty of biomass energy sources. What is needed is biomass gasification technology which can harness biomass at the household level. From the rough

estimation of animal waste produced by animals in Eastern Cape per day, there is a need for biomass gasification technology. Table 7 indicates an estimation of waste produced by each animal per day.

Table 7. Rough estimation of animal waste produced per day.

	Number of Cows	Estimation of Quantity of Animal Waste Produced per Day	Estimation of Quantity of Animal Waste Produced per Day
Cattle	1,013,298	15 kg	15,199,470 kg
Goats	417,296	1 kg	417,296
Pigs	162,884	3 kg	488,652 kg

5. Culture and Biomass Gasification Technology in Eastern Cape

The Eastern Cape province is mostly rural [37]. The rural population constitutes mostly of women, children, old people and unemployed youths. In rural areas, especially in female-headed households, women are responsible for the collection of biomass feedstock for biomass gasification. In most cases, in African rural areas, men are supposed to carry timber because timber is heavy especially when sawmills are far away from the villages. In the case of female-headed households, even if biomass gasification uses available sources, culture will be a hindrance to such renewable energy technology.

6. Legislative Frameworks of Energy Linked to Biomass in South Africa

There are legislations which have been put in place by the government in the energy sector to protect the environment and the rights of the citizens such as the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004), the National Energy Act 34 of 2008, the National Water Act, 1998 Section 24, and the 2008 Energy Act. Further details of the acts are explained in Table 8.

Table 8. Legislative frameworks of energy linked to biomass in South Africa.

Act	Aim	Link between the Act and Biomass Gasification
National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004).	Aims at protecting the environment through measures for preventing environmental pollution by all spheres of government. This Act aims to prevent pollution and ecological degradation and ensure sustainable development by providing for air quality measures, norms and standards, management and control by all spheres of government.	Biomass gasification technology uses renewable sources such as animal waste and plant waste which reduce air, water, and land pollution because it uses animal and plant waste, which pollutes the air when not used.
National Energy Act 34 of 2008	This Act establishes the framework for the accelerated development and advancement of renewable energy resources as well as the development of a strategic program to increase its utilization.	
National Water Act, 1998 Section 24	It is about the rights of the people to an environment that is not harmful to their health.	

Table 8. *Cont.*

Act	Aim	Link between the Act and Biomass Gasification
The 2008 Energy Act	It is about the diversification of sustainable and affordable energy sources even to the poorest of the poor.	
Electricity Regulation Act section 34	The law (Electricity Regulation Act section 34) provides for the Minister for Energy to issue a determination for large-scale new electricity generating capacity to be built.	

7. Benefits of Considering the Use of Small-Scale Biomass Technology in Rural Areas

The advantage of small-scale biomass gasification technology is that it is more efficient compared to direct combustion of the original feedstock material. Using biomass sources of energy in a traditional way, for example, cooking using traditional stoves, produces carbon monoxide, which pollutes the air while having negative impacts on people's health, especially women, children, and old people, who constitute most of the rural population. About 2.4 billion people cook using polluting technologies, and about 6.7 million people die yearly because of household air pollution [38].

Biomass gasification technology is a cleaner process that converts most dry organic matter into clean fuel. The clean fuel can also be converted to ammonia which can be used for agriculture in rural areas. It has an advantage over coal, a non-renewable source of energy which is currently used in South Africa as the main source of electricity [39]. Small-scale biomass gasification technology can be used on farms. Increase in agriculture productivity to cater for the increasing population requires energy. Small-scale biomass gasification technology, especially at farms with available feed stock, is much more reliable and economical than using expensive sources of energy like petroleum. The use of biomass gasification in agriculture is not new, it has been used for transportation and biomass gasification on farm systems during World War II [40].

The other advantage of small-scale biomass gasification is that it allows for wider choices of electricity generation through biomass technology since it produces gaseous fuel that can power boilers, engines, and turbines. Synthesis gas from thermal gasification of biomass can also produce electricity and heat through fuel cells. Moreover, the gasification of biomass can produce synthetic diesel which can be used as transport fuel. The generation of electricity through products of gasification reduces pollution as compared to direct air combustion from solid fuels [41].

Biomass gasification is helpful in sustainable waste management because it uses waste which pollutes the air, water, and land when not used [42]. Gasification is economically friendly because it uses waste material, which is available and accessible in rural areas, which is an advantage over traditional biomass.

8. Factors to Consider Before Small-Scale Biomass Technology Installation

The following must be considered: Need for sampling before such technology is used in many areas to test consumer preferences.

9. Affordability of Gasification Technology

There is a need to compare the affordability of gasification technology to the existing technologies and whether it can be cheaper in rural areas. If the biomass gasification technologies are cheaper than the existing technology, there will be a need to adopt the technology. In order to solve the challenge of affordability and to encourage stability in the biomass market, there is a need for partnership between biomass producers and biomass

energy plant producers to promote the large-scale production of biomass energy, which will promote stability in biomass energy supply [43].

10. Biomass Sector Report

10.1. Environmental Friendliness

There is a need to check the environmental friendliness of biomass gasification technology. As much as there is a need for renewable energy technologies, there is also a need for balance between energy and the environment for the sake of future generations. For example, there is a need for conserving the trees, and the disadvantage of tree harvesting is that it can cause soil erosion and health problems if it is not properly monitored [44].

10.2. Culture

Culture needs to be considered when installing small-scale biomass gasifiers to find out if the technology does not go against culture. Installing technology which does not comply with people's beliefs and needs results in a loss in the long run.

10.3. An Area Not Connected to the Grid

There are some rural areas which are not connected to the grid. It will be a good idea to install off-grid renewable energy technologies such as small-scale biomass gasifiers, considering the availability and affordability of such an energy source. In rural areas, trees and sawmill waste are accessible and not costly as compared to grid connection.

10.4. Low-Income Households

Installation of affordable renewable energy technologies in low-income households will reduce energy poverty. Energy is a basic need, but most low-income households spend more than half of their monthly income on energy which strains food security. Money that is supposed to be used for buying food will be used for energy, resulting in food insecurity to low-income households. Therefore, the use of affordable renewable gasification technologies in rural areas will reduce budget constraints and food insecurity among low-income households.

10.5. Availability of Biomass Energy Sources

There is a need to consider the availability of biomass gasification technology energy sources. In the case of the Eastern Cape, there are many forests and sawmills, making it easier for low-income households to use sawmill waste and animal waste for energy production thereby reducing land, air, and water pollution.

10.6. Biomass Technology Awareness

Before the installation of renewable energy gasification technology in rural areas, there is a need to provide detailed information to rural households about how to use such technologies, how to maintain the technology, and the advantages and disadvantages of renewable energy technology to people through awareness campaigns. There is also a need to use the vernacular language during explanations for the sake of older people and the uneducated communities.

The Success Story of Small-Scale Biomass Gasification Technology in Other Countries

A small-scale biomass gasification plant called the Harbøre Plant, with a capacity of 650 kWe, was successfully implemented in Denmark. Countries like Sweden, Germany, India, Japan, and Thailand have successfully set up small-scale biomass gasification technologies. Small-scale biomass gasification technology has been a success story as well in China as indicated by the commercialization of the small-scale biomass gasification technologies by the following companies, namely Huairou Wood Equipment, Huantai Integrate Gas Supply System, Tianyan Ltd. (downdraft), Tianyan Ltd. (fluidized bed), GIE,

and GIEC [35]). Further details of the small-scale biomass gasification technology in China are indicated in Table 9.

Table 9. Small-scale biomass gasification systems commercialized in China.

Company/Organization	Gasifier Types	Capacity	Biomass
Huairou Wood Equipment	Downdraft	200 kW	Sawdust
Huantai Integrate Gas Supply System	Downdraft	300 kW	Crop residues
Tianyan Ltd.	Downdraft	200 kW	Agriculture and forestry waste
Tianyan Ltd.	Fluidized bed	1 MW	Agriculture and forestry waste
GIEC	Circulating fluidized bed	200–1200 kW	Agriculture and forestry waste
GIEC	Circulating fluidized bed	5.5 MW	Rice husk, straw, wood sawdust, peanut hull

Situmorang et al., 2020:9. [35].

10.7. Biomass Gasification Technology in South Africa

A small-scale, 300 Nm^3/h (150 kVA) biomass gasifier in the Melani Village in the Eastern Cape was installed in 2007 to assess the viability of biomass gasification potential in the Eastern Cape. It uses sawmill waste as feedstock for the gasification process. In addition, in 2010, a biomass gasification plant of a capacity of 120 kW at Honeydew in Johannesburg was launched by Eecofuels re-newable energy company in South Africa [45]. SystMB Johansson gas producer also developed a gasifier with a capacity of 30–500 Kw to utilize woody biomass waste [46]

It is important to note that there are some of the gasification plants in South Africa which use coal, namely Synfuels West which started in 1977, Sasol Synfuel East which started in 1982, and ESKOM Majuba Underground gasification project which started in 2007, and CISR pilot plant [47] These gasification plants use coal. However, this study focuses on biomass gasification technology that uses renewable energy feedstock.

10.8. Eastern Cape and Gasification Technology in Eastern Cape

Considering the availability of biomass energy sources in rural areas, the implementation of biomass gasification technology could increase; however, the implementation of biomass gasification technology is moving at a snail's pace.

Despite the availability of energy sources for small-scale biomass gasification technology, rural people continue to use firewood. Firewood is used with cook stoves or with open fire and is the most preferred over cow dung. Firewood is used because it makes the flavor of the food taste nice, for example, meat cooked in a three-leg pot using firewood tastes nicer than meat cooked on an electric stove. Firewood is accessible. It is readily available and free in rural areas. It can be used without any technology. However, in firewood scarce areas use of firewood becomes expensive in the long run. Firewood releases carbon dioxide, sulphur dioxide, and particles, which result in both indoor and outdoor air pollution. There has been a challenge of time and labor involved in collecting wood which has made it costly [48]. Nonetheless, the contribution of biomass collection to environmental degradation cannot be ignored. Small-scale biomass gasification technology reduces the extent of deforestation attributable to biomass sources by enhancing efficiency therefore reducing demand [49]. Therefore, there is a need to design and construct many small-scale biomass gasifiers in the Eastern Cape province of South Africa, for electricity generation for the benefit of rural communities and can reduce pollution from unutilized biomass waste. Hydrogen from the gasification process can be a fuel for hydrogen cells.

11. Innovative Strategies Employed in the Utilization of Sawmill Waste

Given the availability of biomass waste for gasification technology in the Eastern Cape, cheaper small-scale biomass gasification technologies can be used as supplements for the energy grid which is more costly. On the other hand, from an economic point of

view, biomass gasification technology should be relatively inexpensive for it to be used over the other energy alternatives used by rural people. Advantages in terms of costs and sustainability should be the drive from moving from other sources of energy used by rural people to biomass gasification technology.

Biomass Gasification and Sustainable Development Goals

The sustainable development goals superseded the MDGs from 2016 and articulate the aims of the second 15-year phase of the United Nations Millennium Declaration [50]. The SDGs are inclusive of the three bottom line approaches to human well-being, namely social inclusion, environmental sustainability, and economic development. The unique character of the SDGs, especially SDG 7, lies in their integration of sustainability into the processes of reducing energy poverty, which enables the three bottom line approaches to human well-being to be balanced, thereby reducing pressure on resources [2]. The use of cheaper and renewable biomass wastes for gasification as a supplement to the grid which is more expensive especially in Eastern Cape province will go a long way in reducing pressure on environmental resources and reducing energy poverty and high costs of the current grid. In South Africa, there are around 59.89 million people [51], which indicates a high population. As the population of the world stands, it is expected to reach 8 billion this year; therefore, ensuring the sustainability of resources has become an increasingly crucial imperative for the survival of people [51]. The SDGs provide a set of 17 universal goals upon which South Africa is also expected to base its developmental agendas and energy policies on.

Although meeting SDG 7, which articulates the aims to ensure access to affordable, reliable, sustainable, and modern energy for all, would almost certainly be accompanied by significantly reduced levels of energy poverty, reliable affordable and sustainable energy technologies require immense injections of capital, particularly in rural areas. For some rural areas in the Eastern Cape province, with some families struggling with food insecurity, obtaining the capital for renewable technologies, especially at the household level, without significant government and external assistance would render the use of biomass renewable energy technologies impossible.

Although SDG 7 represents a global necessity and a necessity in the Eastern Cape province, in the face of reality as represented by the households which still use unclean sources of energy as supplements to the grid, the question of the willingness of the people to use biomass gasification technologies need to be answered to avoid wastage of the resources. In the absence of the appropriate strategies and plans, to the use of reliable, sustainable, and renewable energy sources, SDG 7 will take on the character of little more than a wish list item.

12. Conclusions

As much as there are plenty of sources for small-scale gasification technology in rural areas, capital for small-scale biomass energy technology remains a stumbling block to access to renewable, affordable, sustainable, and reliable energy sources and to the achievement of SDG 7. The installation of small-scale biomass technology requires capital. It was indicated in this paper that the advantages of biomass over coal, which is currently the main source of electricity in South Africa, is that biomass gasification is environmentally friendly as compared to coal-powered plants, and biomass is readily available. As much as biomass gasification process can be part of energy mix in South Africa since it is more environmentally friendly than coal, there is a need for more research on biomass gasification technology in the Eastern Cape province. There is also a need for awareness campaigns on biomass gasification technology since most rural people need more information on the advantages of biomass gasification technology. For instance, in Eastern Cape, firewood still represents the most prominent source of power despite the increased electrification in rural areas from 24% in 1996 to currently 64.5%. This paper also discusses what needs to be taken into consideration before the installation of biomass gasification technology, its benefits, and the barriers.

13. Recommendations

Rather than the current small-scale biogas energy system, biomass gasification has to be carried out on a large scale to outcompete the existing expensive grid connection.

Since low-income households in the Eastern Cape find it challenging to buy electricity, it is necessary to quantify the recently available sources of gasification for electricity generation. There is a potential for using biomass energy as an alternative source of energy, for instance, when solar energy is affected by weather or during load shedding. In the Eastern Cape, in the Melani village, there is a gasification plant. It can be used as a starting point in Eastern Cape rural areas, regarding sizing and the actual quantity of waste needed for a gasification plant in rural areas.

Electricity generation through gasification is more efficient than direct combustion. However, production and transport costs should be reasonable and not be more than the cost of available sources of energy for it to be favorable to rural people. The use of biomass gasification plants is also likely to reduce energy poverty. The coupling of biomass gasification with gas and steam turbines can provide a modern, efficient, and clean biomass system for generating heat and electricity. There is a need for more research and innovation on the affordable and small-scale biomass gasification technologies suitable at household level.

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References

1. Shabestari, S.T.; Kasaeian, A.; Rad, M.A.V.; Fard, H.F.; Yan, W.-M.; Pourfayaz, F. Techno-financial evaluation of a hybrid renewable solution for supplying the predicted power outages by machine learning methods in rural areas. *Renew. Energy* **2022**, *194*, 1303–1325. [CrossRef]
2. Chivanga, S.Y.; Monyai, P.B. From Millennium Development Goals (MDGs) to Sustainable Development Goals (SDGs): Towards Overcoming Development Challenges. *Transylv. Rev.* **2021**, *29*, 1–15. Available online: https://transylvanianreviewjournal.com/index.php/TR/article/view/859 (accessed on 14 October 2024).
3. Nwabunwanne, N.; Vuyokazi, T.; Olagoke, A.; Mike, O.; Patrick, M.; Anthony, O. Improving the Solid Fuel Properties of Non-Lignocellulose and Lignocellulose Materials through Torrefaction. *Materials* **2021**, *14*, 2072. [CrossRef]
4. Akom, K.; Shongwe, T.; Joseph, M.K. South Africa's integrated energy planning framework, 2015–2050. *J. Energy South. Afr.* **2021**, *32*, 68–82. [CrossRef]
5. Hugo, W. (Ed.) *BioEnergy Atlas for South Africa: Synopsis Report*; Department of Science and Technology: Pretoria, South Africa, 2016. [CrossRef]
6. Visser, H.; Thopil, G.A.; Brent, A. Life cycle cost profitability of biomass power plants in South Africa within the international context. *Renew. Energy* **2019**, *139*, 9–21. [CrossRef]
7. Koul, B.; Yakoob, M.; Shah, M.P. Agricultural waste management strategies for environmental sustainability. *Environ. Res.* **2022**, *206*, 112285. [CrossRef]
8. Mukisa, N.; Zamora, R.; Lie, T.T. Multi criteria analysis of alternative energy technologies based on their predicted impact on community sustainable livelihoods capitals: A case of Uganda. *Renew. Energy* **2022**, *182*, 1103–1125. [CrossRef]
9. Zhao, X.; Ramzan, M.; Sengupta, T.; Sharma, G.D.; Shahzad, U.; Cui, L. Impacts of bilateral trade on energy affordability and accessibility across Europe: Does economic globalization reduce energy poverty? *Energy Build.* **2022**, *262*, 112023. [CrossRef]
10. Department of Energy Annual Report. Department of Energy. Pretoria. 2013. Available online: https://www.gov.za/sites/default/files/gcis_document/201409/departemntofenergyannualreport2012-13.pdf (accessed on 14 October 2024).

11. Ye, Y.; Koch, S.F. Measuring energy poverty in South Africa based on household required energy consumption. *Energy Econ.* **2021**, *103*, 105553. [CrossRef]
12. Statistics South Africa. *General Household Survey*; Statistics South Africa: Pretoria, South Africa, 2023.
13. Mukumba, P.; Chivanga, S.Y. An Overview of Renewable Energy Technologies in the Eastern Cape Province in South Africa and the Rural Households' Energy Poverty Coping Strategies. *Challenges* **2023**, *14*, 19. [CrossRef]
14. Liu, S.; Li, H.; Daigger, G.T.; Huang, J.; Song, G. Material biosynthesis, mechanism regulation and resource recycling of biomass and high-value substances from wastewater treatment by photosynthetic bacteria: A review. *Sci. Total Environ.* **2022**, *820*, 153200. [CrossRef]
15. Champagne, P. Biomass. In *Future Energy*; Elsevier: Amsterdam, The Netherlands, 2008; pp. 151–170. [CrossRef]
16. Malik, A.; Mohapatra, S.K. Biomass-based gasifiers for internal combustion (IC) engines—A review. *Sadhana* **2013**, *38*, 461–476. [CrossRef]
17. Petrie, B.; Macqueen, D. South African Biomass Energy: Little Heeded but Much Needed. 2013. Available online: https://www.iied.org/sites/default/files/pdfs/migrate/17165IIED.pdf (accessed on 14 October 2024).
18. Department of Forestry, Fisheries and Environment. 2022. Available online: https://pmg.org.za/committee-meeting/34318/ (accessed on 4 October 2024).
19. GlobalData. 2024. Available online: https://www.power-technology.com/data-insights/power-plant-profile-mkuze-biomass-power-plant-south-africa/?cf-view (accessed on 21 July 2024).
20. Thongkhao, V.; Sukpancharoen, S.; Prasartkaew, B. Efficiency improvement of biomass gasifier using porous media heat recuperator. *Case Stud. Therm. Eng.* **2023**, *48*, 103143. [CrossRef]
21. Tezer, T.; Akyuz, E.; Gul, M. Optimal and reliable design of stand-alone hybrid renewable energy systems: A multi-objective approach. *Energy Sources Part A Recovery Util. Environ. Eff.* **2024**, *46*, 10948–10963. [CrossRef]
22. Jančauskas, A.; Striūgas, N.; Zakarauskas, K.; Skvorčinskienė, R.; Eimontas, J.; Buinevičius, K. Experimental investigation of sorted municipal solid wastes producer gas composition in an updraft fixed bed gasifier. *Energy* **2024**, *289*, 130063. [CrossRef]
23. Kilpimaa, S.; Kuokkanen, T.; Lassi, U. Characterization and Utilization Potential of Wood Ash from Combustion Process and Carbon Residue from Gasification Process. *BioResources* **2013**, *8*, 1011–1027. [CrossRef]
24. Ghodke, P.K.; Sharma, A.K.; Jayaseelan, A.; Gopinath, K. Hydrogen-rich syngas production from the lignocellulosic biomass by catalytic gasification: A state of art review on advance technologies, economic challenges, and future prospectus. *Fuel* **2023**, *342*, 127800. [CrossRef]
25. Akhtar, A.; Krepl, V.; Ivanova, T. A combined overview of combustion, pyrolysis, and gasification of biomass. *Energy Fuels* **2018**, *32*, 7294–7318. [CrossRef]
26. Rawat, Y.S.; Singh, G.S.; Tekleyohannes, A.T. Optimizing the Benefits of Invasive Alien Plants Biomass in South Africa. *Sustainability* **2024**, *16*, 1876. [CrossRef]
27. Nwokolo, N.; Mukumba, P.; Obileke, K.C. Gasification of eucalyptus wood chips in a downdraft gasifier for syngas production in South Africa. *Int. J. Renew. Energy Res.* **2020**, *10*, 663–668.
28. Monteiro, E.; Ramos, A.; Rouboa, A. Fundamental designs of gasification plants for combined heat and power. *Renew. Sustain. Energy Rev.* **2024**, *196*, 114305. [CrossRef]
29. Arshad, M.Y.; Jaffer, H.; Tahir, M.W.; Mehmood, A.; Saeed, A. Maximizing hydrogen-rich syngas production from rubber wood biomass in an updraft fluidized bed gasifier: An advanced 3D simulation study. *J. Taiwan Inst. Chem. Eng.* **2024**, *156*, 105365. [CrossRef]
30. Sikarwar, V.S.; Zhao, M.; Fennell, P.S.; Shah, N.; Anthony, E.J. Progress in biofuel production from gasification. *Prog. Energy Combust. Sci.* **2017**, *61*, 189–248. [CrossRef]
31. Lu, H.; Bian, Y.; Guo, X.; Dai, Z.; Liu, H. Feasibility Analysis and Carbon Reduction Effect of Biomass Entrained Flow Gasification. *J. East China Univ. Sci. Technol.* **2024**, *50*, 328–334. [CrossRef]
32. Mallick, D.; Sharma, S.D.; Kushwaha, A.; Brahma, H.S.; Nath, R.; Bhowmik, R. Emerging commercial opportunities for conversion of waste to energy: Aspect of gasification technology. In *Waste-to-Energy Approaches Towards Zero Waste*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 105–127. [CrossRef]
33. Sanjaya, E.; Abbas, A. Plasma gasification as an alternative energy-from-waste (EFW) technology for the circular economy: An environmental review. *Resour. Conserv. Recycl.* **2023**, *189*, 106730. [CrossRef]
34. Akbarian, A.; Andooz, A.; Kowsari, E.; Ramakrishna, S.; Asgari, S.; Cheshmeh, Z.A. Challenges and opportunities of lignocellulosic biomass gasification in the path of circular bioeconomy. *Bioresour. Technol.* **2022**, *362*, 12777. [CrossRef]
35. Situmorang, Y.A.; Zhao, Z.; Yoshida, A.; Abudula, A.; Guan, G. Small-scale biomass gasification systems for power generation (<200 kW class): A review. *Renew. Sustain. Energy Rev.* **2020**, *117*, 109486. [CrossRef]
36. Mukumba, P.; Makaka, G.; Mamphweli, S.; Masukume, P.-M. Design, construction and mathematical modelling of the performance of a biogas digester for a family, Eastern Cape province, South Africa. *Afr. J. Sci. Technol. Innov. Dev.* **2019**, *11*, 391–398. [CrossRef]
37. Mahlalela, P.T.; Blamey, R.C.; Hart, N.C.G.; Reason, C.J.C. Drought in the Eastern Cape region of South Africa and trends in rainfall characteristics. *Clim. Dyn.* **2020**, *55*, 2743–2759. [CrossRef]
38. World Health Organisation 2022. Available online: https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants (accessed on 14 October 2024).

39. Ram, M.; Mondal, M.K. Biomass gasification: A step toward cleaner fuel and chemicals. In *Biofuels and Bioenergy*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 253–276. [CrossRef]
40. Sivabalan, K.; Hassan, S.; Ya, H.; Pasupuleti, J. A review on the characteristic of biomass and classification of bioenergy through direct combustion and gasification as an alternative power supply. *J. Phys. Conf. Ser.* **2021**, *1831*, 012033. [CrossRef]
41. Li, P.; Cheng, P.; Wang, G.; Wang, F.; Cheong, K.-P.; Liu, Z.; Mi, J. MILD Combustion of Solid Fuels: Its Definition, Establishment, Characteristics, and Emissions. *Energy Fuels* **2023**, *37*, 9998–10022. [CrossRef]
42. Quarshie, S.D.-G.; Xiao, X.; Zhang, L. Enhanced phytoremediation of soil heavy metal pollution and commercial utilization of harvested plant biomass: A review. *Water Air Soil Pollut.* **2021**, *232*, 475. [CrossRef]
43. Fikizolo, S. Biomass Sector Report. 07/12/2021. 2021. Available online: https://www.tikzn.co.za/resources/docs/research/Biomass%20Sector%20Report.pdf (accessed on 7 December 2021).
44. Awaafo, A.; Awafo, E.A.; Mahdavi, M.; Akolgo, G.; Jurado, F.; Vera, D.; Amankwah, E. Crops production and the contribution of agricultural biomass power generation to Africa's clean energy transition: Analysis of trends from 1990 to 2021. *Biomass Bioenergy* **2024**, *186*, 107244. [CrossRef]
45. EECO. Fuels Launches Biomass-Powered Gasification Plant. 2010. Available online: http://www.engineeringnews.co.za/print-version/eecofuels-unveils-africas-first-biomass-powered-gasification-plant-2010-11-23 (accessed on 16 September 2024).
46. Sansaniwal, S.; Pal, K.; Rosen, M.; Tyagi, S. Recent advances in the development of biomass gasification technology: A comprehensive review. *Renew. Sustain. Energy Rev.* **2017**, *72*, 363–384. [CrossRef]
47. Segakweng, T Gasification in South Africa. 2023. Available online: https://task33.ieabioenergy.com/wp-content/uploads/sites/33/2023/11/S_Africa.pdf (accessed on 25 September 2024).
48. Heltberg, R. Factors determining household fuel choice in Guatemala. *Environ. Dev. Econ.* **2005**, *10*, 337–361. [CrossRef]
49. Masera, O.R.; Saatkamp, B.D.; Kammen, D.M. From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model. *World Dev.* **2000**, *28*, 2083–2103. [CrossRef]
50. Greig, A.; Turner, M. Policy and hope: The millennium development goals. *Glob. Policy* **2024**, *15*, 66–77. [CrossRef]
51. World Bank. International Development Indicators. *Datacatalog.worldbank.org.* 2022. Available online: https://datacommons.org/place/country/ZAF?utm_medium=explore&mprop=count&popt=Person&hl=en (accessed on 9 August 2024).

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