

Experimental investigation of thermal properties of Lignocellulosic biomass: A review

¹Olatunji Obafemi, ²Akinlabi Stephen, ³Oluseyi Ajayi, ²Peter Mashinini and ¹Madushele Nkosinathi

¹Mechanical Engineering Science, University of Johannesburg, South Africa

²Mechanical & Industrial Engineering Technology, University of Johannesburg, South Africa

³Mechanical Engineering, Covenant University, Ota, Nigeria

Email address-tunjifemi@gmail.com

Abstract. Most recently, there is a renewed interest in the generation of energy from biomass given its abundance and its perceived ability as an alternative to a fossil fuel, which significantly contributes to greenhouse gas emission. Given this, lignocellulosic biomass has been acknowledged as the most abundant biomass stock for renewable energy generation across the globe. The socio-economic significance is also very overwhelming. This review article takes stock of different sources of lignocellulosic biomass and also different experimental procedure, which has been applied in the determination of the heating value and elemental composition. The review concluded that most of the research paper often echoed the enormous energy potential of biomass without thoroughly highlighting their contribution to greenhouse gas emission. It was also observed that it is only a few papers that have analyzed the effect of mixing on the heating value and elemental composition, while there are few direct comparisons of the biomass by geographical location. In overall the authors advocate for a more harmonized database for biomass.

Keywords: Lignocellulosic, proximate analysis, ultimate analysis, mixing, biomass.

1. Introduction

Among all the renewable energy options, biomass can be considered as the most abundant with the most significant potential, which can meet energy requirements of the globe and could provide energy supply in the future just as the world is earnestly seeking a way out of the consumption of fossil fuel. Also, sustainable development of a country decisively depends on the energy sustainability[1-3]. Biomass can be defined as an organic material which originates from plants and animals via a spontaneous or induced biological process. It is usually referred to certain types of wood, energy crops, marine algae, agricultural and silvicultural waste, and certain animal, industrial and human wastes[4, 5]. The phytomass and zoomass are often generally referred to as biomass.

Biomass exploration has the potential to employ thousands of people along the entire value chain. The growth of biomass power market has been supported by the gradual use of biomass in electricity generation. Based on political considerations, interest in bioenergy is driven by some major factors: increasing energy prices, energy security, rural development, in addition to the effect of climate change[6]. In the developing countries bioenergy may represent real time opportunities for domestic and industrial revolution towards economic growth given its abundance from various sources [7]. In a year, the production of biomass is around eight times the summation of other types of renewable energy sources [8] and it the only renewable resources which can be converted directly to liquid fuel [9].

Achieving sustainable fuel production means: developing fuels from raw materials that are locally sourced to avoid transportation over a long distance; that the production process does not encumber the land and take up so much water; and in overall, drastically reduce the Green House Gas (GHG) missions[10]. This is exactly where the biomass comes into play. Energy from biomass supplies 10% of global energy demands [7]. Biomass can be used in its natural state as fuel and can be refined to different kinds of biofuels, which are solid, liquid and gaseous fuels. These fuels can be applied in electricity production,



transportation, heating and cooling across all the economic sectors of the society, considering criteria such as energy efficiency, applicability, environmental impact, and flexibility[11-13]. Therefore, bioenergy is now a global energy commodity.

As at 2011, European Commission (EU) had set a long-term goal to develop a competitive, resource efficient and low carbon economy by 2050 which is significantly built on bio-economy [13]. From different scenarios that were analysed by EU, it was indicated that a cost effective economic pathway demands a 40% household decrease in Green House Gas (GHG) emissions for 2030 compared to 1990 levels, and 80% for 2050. The energy sector was identified as an important contributor to attaining cost effective economy[13]. Bioenergy production is expected to account for about 57 % of the renewable energy use in 2020, of which 45 % will consist in heat and electricity production from biomass, and 12 % will be provided by biofuels[14, 15]. Such was an audacious move intended to eradicate all non-bio-based material in European countries economy.

The aim of this present survey is to review the classification, availability and utilization of biomass, to review the properties, application and classification of lignocellulosic biomass; to describe the current trends in the experimental analysis of lignocellulosic biomass, to collect the most recent experimental results for the structural, elemental composition and heating value, and to identify the possible gaps in the experimental analysis of lignocellulosic biomass.

2. Biomass energy availability and utilization

The utilization of biomass has proven to be tremendously advantageous. The vast uncultivated land in most developing countries can be used to plant energy crops which can serve as a source of income and water retention of the soil under controlled conditions. The use of agricultural biomass residue can reduce the risk of forest burning and insect invasion while establishing a new market, but that has not been the case. For instance, billions of tonnes of straw and similar plant residues are annually available across the globe, but the utilization is very dismal. In each year, below 100 million tonnes are converted to energy while the remaining are usually burnt or left to decompose[7]. The consequent of this practice is the emission of greenhouse gases. This practice is the same, be it rice residue in Asia, sugar cane residue in Brazil, wheat stalk in Australia, soybean residue in Argentina, cotton in Egypt or palm oil in Indonesia and also the vast amount of higher moisture content biomass around the world, such as manures, abattoir wastes, and green leafy material[7]. As shown in Figure 1, the global consumption of biofuel sourced from biomass has been on the increase, and this trend promises to continue provided all issues surrounding the exploration of bioenergy is frontally addressed.

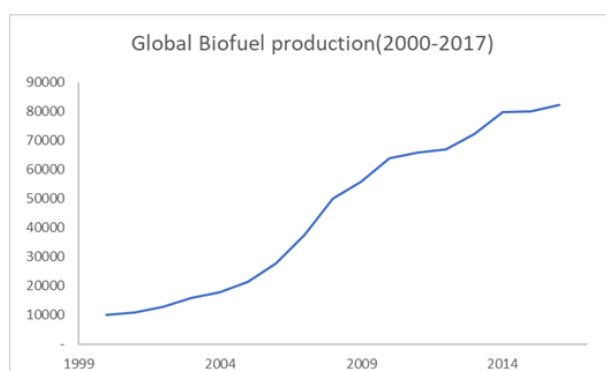


Figure 1: World biofuel production over sixteen years [16]

The growth of renewable energy applied across the globe in electricity generation since 1990 at the rate of 3.6 % per annum is slightly faster than total electricity generation growth rate, which stands at 2.9%. There has been a steady increase from 19.4 % in 1990 to 22.8 % in 2015. The contribution of the renewable energy used in the production of electricity increased from 1.3% in 1990 to 6.8% in 2015[16-18]. As shown in Figure 2, in 2015, renewable energy was the third largest contributor to global electricity production. They

contributed 22.8% of world electricity generation, after coal (39.3%) and gas (22.9%) and ahead of nuclear (10.6%) and oil (4.1%)[16]. Apart from hydro which contributed 16% of renewable energy, biofuel and waste accounted for 1.9% of the total renewable energy contribution while others (solar, wind, geothermal, tidal) jointly accounted for 4.8%.

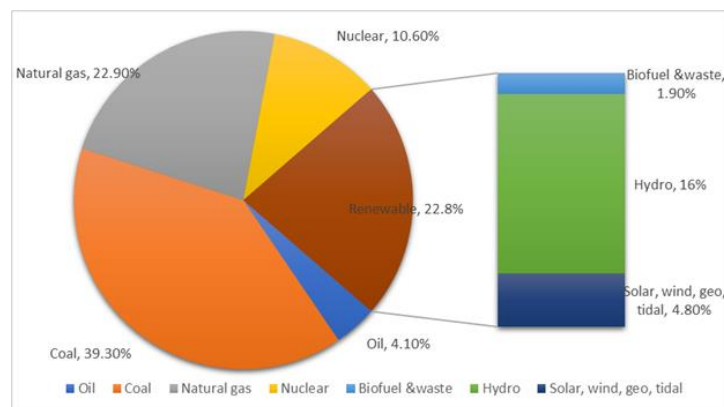


Figure 2: Fuel shares in global electricity production, 2015[16]

Globally, bioenergy which includes waste accounts for 14% of the world's energy consumption in 2012 with roughly 2.6 billion people dependent on traditional biomass to meet their energy needs[17]. The consumption and production pattern of bioenergy varies geographically. USA and Brazil lead the world in production and consumption of liquid biofuels for transportation (accounting for almost 80% of production). Figure 3, shows the biofuel production across the globe in the last sixteen years. The use of biomass for electricity which is predominantly sourced from forestry products and residues is common in Europe and North America [16]. The Europe and America contribute more than 70% of all consumption of biomass for electricity[19]. Although there has been some improvement in biomass to biofuel generation in Africa, it is interesting to note that Africa has not performed up to global expectation despite her enormous biomass resources. Africa has great potential to play a leading role regarding the biomass energy exploration given her large bio-resources, land mass and human capital. This implies that there is still so much to be done to improve the fortune of this continent in term of bioenergy.

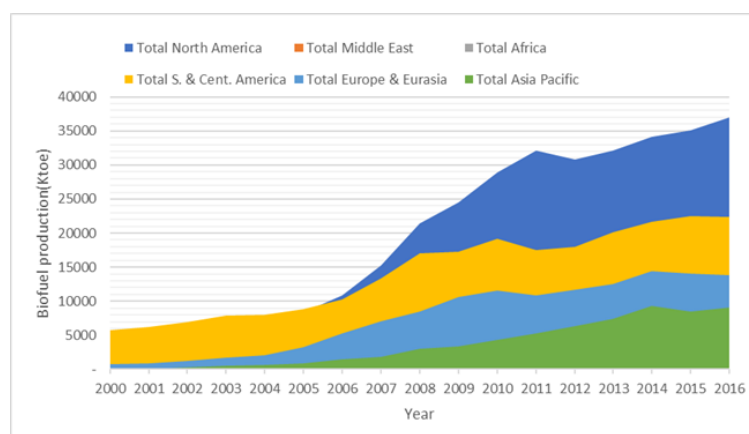


Figure 3: Biofuel Production in the last sixteen years for different regions in the world[18]

In the transport sector, the production of corn ethanol in USA and sugarcane ethanol in Brazil has increased significantly. The production of all biofuels in America increased from about 16 billion litres in 2000 to 79 billion litres in 2012[16]. A significant sector for future use of biofuels is the aviation sector. Liquid biofuels are the only sustainable and viable option for replacing aviation fuel and efforts are underway where airlines, airports, finance institutions, and universities are coming together to explore sustainable aviation pathways. Commercial airlines using biofuels have already flown transatlantic routes. Other important sectors include heavy road and maritime where biofuels can play a big role. In 2013, 462 TWh of electricity was produced globally from biomass[19]. In the past few years, biomass uptake in developing countries such as Asia and Africa where significant population lacks access to electricity has increased. Biogas and decentralized bioenergy systems are becoming more cost competitive. Already co-generation plants using agricultural residues like Bagasse in India, Mauritius, Kenya, and Ethiopia are successful. Currently, the major use of biomass is in the form of heat in rural and developing countries[20].

The usability of these biomasses has been a subject of intense investigation. Several researchers have attempted to investigate different properties of biomass using various approaches. They include the elemental composition, the heating value, physical composition, chemical composition and little about the environmental impact of the exploration of these biomasses for energy production[21-38].

3. Classification of Biomass Resource

In view of the diversity of the sources of biomass, a classification which eases the process of prediction of the properties of biomass is very vital. Khan *et al.*[39]proposed two classifications of biomass; based on origin and properties. These have been discussed in[11] and it is outlined here as follows;

Table 1:Classification of biomass

Based on Origin	Based on properties
Primary waste, e.g. grain waste, wood waste	Wood and woody fuel (newly harvested soft and hardwood)
Secondary waste, e.g. food processing residue and sawdust.	Agricultural biomass (Straw, stalk, grass, Stover)
Tertiary waste, e.g. wood used in construction	Aquatic biomass (Algae)
Energy crop, e.g. cassava tuber	Animal and human waste (bones, manure, etc.)
	Municipal biomass (solid waste, organic waste, sludges, refuse.
	Biomass mixtures

3.1 Factors affecting the composition of biomass.

The composition and thermal properties of the biomass is determined by an interplay of several factors. These factors affect the characteristics of biomass to a different extent. While some play very significant roles, the effect of others is negligible. These factors have been outlined as follows[28];

- Types of biomass
- Parts of biomass plant and the species
- Growth process and growing conditions
- Geographical location
- Climate and seasons
- Soil types

- Water and nutrients and soil pH
- Age of plant
- Presence of pollutants and contaminants and the proximity to the pollutants
- Harvesting time and technique
- Transport and storage condition
- Mixing of biomass from multiple sources

The wood species grown in different geographical location showed slight differences in their elemental composition. Also, contaminants are introduced during transportation and industrial processing of natural biomass. This contaminant maybe dust particles and various left over from construction material, plastic rubbers, metals, chemicals, char, detergent, paints, coloured paper and so on[27, 40]. With regards to the mixing of biomass and presence of contaminants, combination of biomass from diverse sources maybe an advantage when it concerns the generation of sufficient fuel which can be applied on an industrial scale. Since a single source and the cost of sorting of biomass from multiple sources may not be sustainable in the long run, the effect of mixing and contamination should be a subject of more scientific investigations.

From the above and other related factors Vassilev *et al.*[28]identified some issues concerning the investigation on biomass. These can be summarized as follows: there is incomplete information in regards of life cycle assessment of most biomass which has been reported in the literature; in most cases, investigations do not detail the environmental impact of the selected biomass. However, there has been deliberate attempt to standardize the testing procedure so as to ensure uniformity in testing procedure and reportage[25, 41, 42]. Also, there is insufficient information on the biomass processing technique and ambiguous definition of resources potential. For instance, the location of the biomass, the manner in which they are collected, the storage process, and the exact condition of the biomass before analysis not often clearly outlined. This information is very vital in the analysis and application of a particular class of biomass on the industrial scale.

4. Lignocellulosic Biomass

Lignocellulosic materials are abundantly available and usually not expensive. From the literature survey, global annual production of Lignocellulosic biomass stands at around 181.5 billion tonnes[43]. About 50 % of the global biomass resources are made of Lignocellulosic biomass which is estimated at 3×10^{14} kg[44]. Several studies have confirmed that Lignocellulosic biomass holds great potential for sustainable energy generation and it is globally available, be it in the developing countries or developed countries[45]. Also, cellulose which is a vital component of Lignocellulosic biomass has a real potential to displace petroleum based fuel products[46]. Lignocellulose is a generic term for describing the main constituents in most plants, namely cellulose, hemicellulose, and lignin. It is a complex matrix, comprising many different polysaccharides, phenolic polymers, and proteins. Cellulose, the major component of cell walls of land plants, is a glucan polysaccharide containing large reservoirs of energy that provide real potential for conversion into biofuels. Lignocellulosic biomass consists of a variety of materials with distinctive physical and chemical characteristics. It is the non-starch based fibrous part of plant material.

First-generation biofuels (produced primarily from food crops such as grains, sugar beet, and oilseeds) are limited in their ability to achieve targets for oil-product substitution, climate change mitigation, and economic growth. Their sustainable production is under the scanner since it has the possibility of creating undue competition for land and water used for food and fibre production.

These concerns have increased the interest in developing biofuels produced from non-food biomass feedstock from lignocellulosic materials which includes cereal straw, bagasse, forest residues, and purposely grown energy crops such as vegetative grasses and short rotation forests [28]. These second-

generation biofuels could avoid many of the concerns facing first-generation biofuels and potentially offer greater cost reduction potential in the longer term.

Lignocellulosic materials consist mainly of three polymers: cellulose, hemicellulose, and lignin. These polymers are associated with each other in a hetero-matrix to different degrees and varying relative composition depending on the type, species, and even source of the biomass. The relative abundance of cellulose, hemicellulose, and lignin are key factors in determining the optimum energy. Extensive discussion has been done on lignocellulosic biomass by several researchers.[34, 37, 43, 47, 48]. Therefore, a brief description of the classes is sufficient in this survey.

4.1 Brief description of the major components of lignocellulosic biomass

4.1.1 Cellulose

Cellulose is the most abundant member of the trio, followed by hemicellulose and lignin[43]. Its structure is made of tightly knitted hydrogen bond due to complex inter and intramolecular relationship. Since about half of the organic carbon in the biosphere is present in the form of cellulose, the conversion of cellulose into fuels and valuable chemicals is a vital process in energy generation from biomass[49].

4.1.2 Hemicellulose

Hemicellulose is the second most abundant polymer. Unlike cellulose, hemicellulose has a random and amorphous structure, which is composed of several heteropolymers including xylan, galactomannan, glucuronoxylan, arabinoxylan, glucomannan and xyloglucan. It is a heterogeneous group of branched polysaccharides which serve as a connecting medium between the lignin and cellulose[34]

4.1.3 Lignin

Lignin is a complex, large molecular structure with a cross-linked phenolic polymer which is linear with no regular repeating units. Lignin serves as a binder between hemicellulose and cellulose in the cell wall [37]. Softwoods have a greater lignin content than hardwoods[37].

In energy generation from biomass, especially biochemical conversion process, the relative amount of cellulose and lignin are major determining factors for their suitability[50].

Table 2 shows the structural composition of some Lignocellulosic biomass. For most of these biomasses, the biodegradation of cellulose is greater than lignin and Hemicellulose. It should be noted that the conversion of cellulose is higher than lignin due to its biodegradation[51].

Table 2: Lignocellulosic biomass and their structural composition[37, 52-54]

Lignocellulose biomass class	Source	Lignin	Hemicellulose	Cellulose
Wood biomass	Oak	35.4	21.9	43.2
	Eucalyptus	21.5	18.4	54.1
	Pine	26.8	24.0	45.6
	Spruce	27.5	21.2	50.8
	Poplar	15.5-16.3	26.2-28.7	58.8-53.3
	Douglas Fir	27.0	11.0	44.0
	Ailanthus wood	22.2	22.6	46.7

	Albizia	33.8	6.7	59.5
	Birchwood	15.7	40.0	25.7
	Beechwood	21.9	31.8	45.8
	Furniture sawdust	22.16	32.63	37.23
	Subabul wood	24.7	24.0	39.8
	Oak	35.4	21.9	43.2
	Pine	26.8	24.0	45.6
	Spruce	27.5	21.2	50.8
	Wood chips	19.0	31.8	31.8
	Wood bark	31.0	47	22
Agricultural residue	Corn cob	15-16.6	28.7-35	40.3-45
	Cornstalk	15.59	43.01	22.82
	Corn Stover	14.4	30.7	51.2
	Bagasse	18.3	22.6	41.3
	Cashew nutshell	40.1	18.6	41.3
	Banana waste	14.0	14.8	13.2
	Barley straw	27.7	29.7	48.6
	Tea waste	40.0	19.9	30.2
	Rice Husk	14.3	24.3	31.3
	Rice straw	13.6	22.7	37.0
	Millet husk	14.0	26.9	33.3
	Sorghum bagasse	10.0	24.0	41.0
	Hazelnut shell	51.5	15.7	22.9
	Hazelnut seed coat	53.0	15.7	29.6
	Groundnut shell	30.2	18.7	35.7
	Coconut shell	28.7	25.1	36.3
	Nuts shell	30-40	25-30	25-30
	Flax straw	28.9	34.40	36.70
	grape residue	12.1	34.40	36.30
	Tobacco leaf	27.0	28.2	42.4
	Tobacco stalk			

	Bast fibre seed flax	23	25	47
	Bast fibre jute	21-26	18-21	45-53
	Bast fibre kenaf	15-19	22-23	31-39
	Coffee pulp	18.8	46.3	35
	Leaf fiber Abaca	8.8	17.3	60.8
	Leaf fiber Sisal	7-9	21-24	43-56
Energy grasses	Giant reed	19.0-17.6	30.0-29.5	37.0-36.1
	Switchgrass	19.1-17.8	27.2-27.8	38.2-36.5
	Pennisetum	18.5-16.5	22.53-21.93	41.8-40.9
	Silver grass	17.5-17.1	26.2-25.6	44.1-43.3
	Cat grass(orchard)	4.70	32	40
	Phalaris arundinacea	7.6 17-19	42.6 27-32	29.70 33-38
	Alfa grass	20	49.3	14.1
	Willow copies	4.7	40	32
	Orchard grass	3.5-3.55	48.7-49.2	18.2-18.4
	Water hyacinth			
Energy crop	Bamboo	21-31	15-26	26-43
	Sugarcane	22.9	31.3	45.8
	Jerusalem artichoke (October)	5.70 5.05	25.99 20.95	4.50 5.48
	Jerusalem artichoke (September)	8.76	53.86	5.18
	Hemp	9.02	39.27	25.96
	Silage			
Municipal Waste	Urban wood	-	-	-
	Urban greening	22.73	22.96	6.86
	Municipal biomass	-	-	-
	Sewage sludge	-	-	-
	Waste material	24.7	29.2	50.6

Newspaper	18-30	25-40	40-55
Kraft paper	20.8	9.9	57.3
General MSW	10-14	9-16	33-49
Food waste	11.4	7.2	55.4
Sorted refuse	20	20	60

4.2 Main Lignocellulosic biomass conversion route

Figure 4 shows the main conversion route for lignocellulose biomass. Three main processes through which energy can be generated from Lignocellulosic biomass were identified. Combustion is mostly used since it accounts for almost 97% of the bioenergy which is harnessed across the world[55]. It is particularly important in developing countries [56]. Combustion can be divided into three stages, which are drying, pyrolysis, and reduction. The last stage can generate up to 70% of the total heat of all the stages[37]. It is advised that only true end wastes should be applied in energy production in order to ensure that fixed CO₂ is not returned early into the atmosphere[57].

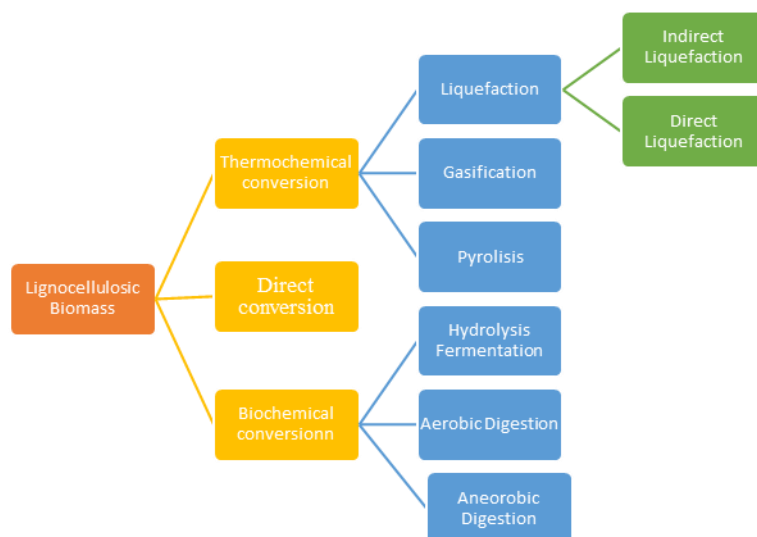


Figure 4: Main Lignocellulosic biomass conversion route [37, 57]

5. Environmental impact assessment of Lignocellulosic biomass

While researchers often focus on the thermal properties, elemental composition and chemical composition of Lignocellulosic biomass, little emphasis is laid on the environmental impacts about their contribution to greenhouse gas emission. Performance analysis of any biomass source must include a detailed life cycle assessment[42], which should include its environmental impact. It should be noted that greenhouse gas (GHG) is present in biomass even if it is in traces. The multiple effects of these maybe very significant when considering biomass for industrial energy generation.

One important factor which is often overlooked when considering the use of biomass to reduce global warming is the time lag between the instantaneous release of CO₂ from burning fossil fuels and its eventual uptake as biomass, which can take many years[25]. One of the dilemmas facing the developed world is the need to recognize this time delay and take appropriate action to mitigate against this lag period. An equal dilemma faces the developing world as it consumes its biomass resources for fuel but does not implement a programme to ensure replacement planting.

The advocates of biomass energy based their argument on the “carbon neutrality” of biomass. This means there is no net contribution of carbon dioxide to global warming [25, 58]. As much as this argument may be valid, biomass is not just a lump of carbon; it contains sulphur, nitrogen and several other vital nutrients in different ratios. An intensive cultivation of biomass and usage of such for energy generation has other implications apart from carbon capture. As at 1999, agricultural activities have been reported to generate more than 75 % of emitted reactive nitrogen compounds[59].The significance of this value will be appreciated more if it is understood that each molecule of nitrogen oxide has 300 times global warming potential when compared with carbon dioxide[60]. Therefore, the contribution of each potential GHG elemental component of biomass must be accounted for because of the cumulative effect for industrial-scale biomass energy plant.

The combustion of biomass produces significantly fewer nitrogen oxides and sulphur dioxide than the burning of fossil fuels. But, if a forest region is indiscriminately cleared for fuel, the CO₂ level will increase because its released into the atmosphere is not recycled for new growth[61].On the basis of Table 3, an attempt was made to review the research articles on the experimental investigation of the heating value and elemental composition of lignocellulosic biomass and to identify the geographical locations from where the biomasses were sourced. Also, the review considers the extent to which emphasis was placed on the GHG emission potential from biomass utilization for energy generation.

Table 3: Review of the contribution on geographical location and GHG

Author	Lignocellulosic Biomass samples group and variety	Geographical Location of biomass samples	Contribution to GHG emission	Comment
Wood and woody biomass				
[62]	Downy Birch bark	South Norway	Not highlighted	The information supplied on the location of biomass is insufficient.
[63]	Olive husk	Turkey	Not highlighted	
[23]	Hazelnut husk	Baghchung reserve forest, Assam, India	Not highlighted	
[64][12]	Hazelnut seed coat			
	Spruce wood			
	Beechwood			
	Ailanthus wood			
[64]	Albizia	Baghchung reserve forest, Assam, India	Not highlighted	
[65]	Furniture sawdust	Not stated	Not highlighted	
[66, 67]	Oak	Not stated		
[17]	Pinewood	Saskatchewan forest, Canada	Not in the objective.	The study site was clearly described
	Pine sawdust	Huazhong University, China	Not in the objective.	
[68]	Eucalyptus bark	Undonthani, Thailand		
[26]	Eucalyptus wood			
	Subabul wood			
Agricultural residue				
	Banana waste			
[48]	Paddy straw	Indonesia		

[37, 48, 69, 70]	Bagasse	Wakiso District, Uganda, Ombo forest, Kakamega forest, Alosa forest,		
[71, 72]	Sugarcane leaves Sugarcane tops Cassava stalk Cassava rhizome	North east, Thailand		
[37, 73]	Corn cob	Rosenberg, Germany and Ado Ekiti, Nigeria		
	Tea waste	Turkey		
[23, 69]	Corn Stover Corn stalk Tobacco leaf	Turkey		
[23, 66]	Tobacco stalk Wheat straw	Turkey and Saskatchewan forest, Canada	Not in the objective.	The study site, Test procedure and the equipment were clearly discussed.
[66]	Barley straw	Saskatchewan forest, Canada	Not in the objective.	The study site was clearly described
[66]	Flax straw	Saskatchewan forest, Canada		
[69]	Coconut coir Coconut shell Millet husk Rice husk Rice straw Groundnut shell	Bombay, India	Not in the objective.	The study site was not clearly described
[28]	Oat straw			
[74]	Cotton waste Soybean waste	Maharashtra, India	Not in the objective	The information supplied on the location of biomass is insufficient.
[75]	Kernel olive Eucalyptus sawdust	Morocco	Not in the objective	The information supplied on the location of biomass is insufficient.
[76]	Energy grasses Willow coppice Switchgrass Elephant grass Orchard grass Esparto grass Wild reed	Not state	Not in the objective	The study site was not clearly described
[77]	Timothy grass Hemp Straw Reed Reed canary grass	Latvian	Not in the objective	The information supplied on the location of biomass is insufficient.
[48]	Imperata cylindrical Eragrostisairoides	Assam and Manipur, North -East India	Not in the objective	The study site was clearly described.

	Typha angustifolia Arundinella khasiana Echinochiastagnina Municipal waste Newspaper	Not stated	Not in the objective	The information supplied on the location of biomass is insufficient
[78]	Sewage sludge Physical chemical sludge Biochemical sludge Cardboard Plastic Synthetic rubber	Nanjing, China Morocco	Not in the objective Not stated	 The information supplied on the location of biomass is insufficient.
[77]	Biomass Mixture Hemp and peat (15%,30%,50%) Reed and peat (15%,20%,30%) Reed canary grass (15%,30%,50%)	Latvian	Not stated	The information supplied on the location of biomass is insufficient.
[79]	Wood-agricultural residue Wood-almond residue Wood and straw residue	Not known	Not stated	The study site was not clearly described
[75]	Biochar and kernel olive (25%/75%:50%/50%:75%/25%) Biochar and manure (25%/75%:50%/50%:75%/25%) Biochar and Eucalyptus sawdust (25%/75%:50%/50%:75%/25%) Biochar and sugar cane (25%/75%:50%/50%:75%/25%) Biochar and wood sawdust (25%/75%:50%/50%:75%/25%) Activated Biochar and Kernel oil (25%/75%:50%/50%:75%/25%) Activated biochar and cattle manure (25%/75%:50%/50%:75%/25%) Activated biochar and eucalyptus sawdust (25%/75%:50%/50%:75%/25%) Activated biochar and sugar cane (25%/75%:50%/50%:75%/25%) Activated biochar and wood sawdust (25%/75%:50%/50%:75%/25%) Activated biochar and alfa (25%/75%:50%/50%:75%/25%) Contaminated biomass	Morocco	Not stated	The information supplied on the location of biomass is insufficient.
[79-82]	Shredded currency Mixed waste paper Demolition wood Greenhouse-plastic waste Refuse derived fuel.	Not stated	Not stated	

5.1 Proximate and Ultimate analysis of Lignocellulosic biomass

The proximate analysis, ultimate analysis and High temperature composition of biomass have been detailed in [28, 37]. It is briefly reviewed in this article;

5.1.1 Proximate analysis

Proximate analysis can give an extensive array of information on the characteristics of biomass samples. It classifies the biomass in term of moisture, fixed carbon, volatile matter, and ash content. The moisture content (M) is an indication of the amount of water present in a biomass sample. It is frequently used in the proximate analysis to show that the water content of biomass is a mineralized aqueous solution containing cation, anion or non-charged species. Moisture content determines the conversion factor between the different bases of analysis of biomass data. This can be expressed as a percentage of the biomass weight which are as received, air dried, oven dried and dry ash free basis[34, 83]. As received basis is determined from the gross weight of the sample as it arrived at the laboratory and prior to any pre-treatment. Air dried basis is based on the equilibrium condition between the sample and atmospheric humidity with only consideration been the inherent biomass moisture. Dry basis does not consider all the moisture component of biomass, be it external or inherent. Dry ash free basis is on the condition that there is neither moistures nor ash. Figure 4, shows the transformation principle between the different bases of biomass moisture content analysis.

Ash (A) content is the leftover of a complete combustion of biomass with the primary components which includes; oxides of silica, aluminium, iron, calcium, titanium, sodium, potassium. Ash content is among the most investigated properties of biomass[28].However, the researchers have not gained full understanding due to its complex behaviour. Ash content can be used to determine the bulk inorganic matter, prevailing affinity of elements and compound of organic and inorganic matter, and the probability of contamination[28]. The understanding of the physicochemical characteristics of ashes is helpful in determining the propensity of a biomass source to form a deposit in the boiler[84].

Table 4: Transformation between different basis of biomass moisture content analysis [34]

Wanted	As received (AR)	Air dried (AD)	Dry (DB)	Dry ash free (DAF)
Given				
As received	1	$\frac{1 - m_{AD}}{1 - m_{AR}}$	$\frac{1}{1 - m_{AR}}$	$\frac{1}{1 - m_{AR} - A_{AR}}$
Air dried	$\frac{1 - m_{AR}}{1 - m_{AD}}$	1	$\frac{1}{1 - m_{AD}}$	$\frac{1}{1 - m_{AD} - A_{AD}}$
Dry basis	$1 - m_{AR}$	$1 - m_{AD}$	1	$\frac{1}{1 - A_{AD}}$
Dry ash free	$1 - m_{AR} - A_{AR}$	$1 - m_{AR} - A_{AR}$	$1 - m_{DB}$	1

5.1.2 Ultimate analysis

The ultimate analysis is the determination of elemental composition of biomass. The result from the ultimate analysis is more detailed than proximate analysis. The result of this analysis can be used to determine the heating value of biomass [85].The aim of ultimate analysis of biomass is to determine the organic components which are C, H,N,S, Cl and O and inorganic constituents which are Si, Al, Ti, Fe, Ca, Mg, Na, K, S and P [37, 38, 48].The amount of N, S, Cl can give a clue on the environmental impact of biomass consumption. Different models of the elemental analyser can be used in the ultimate analysis of biomass [86]. However, this procedure is more expensive in comparison with proximate analysis.

The Table 5 shows the heating value and elemental composition of various kinds of biomass. The mixing ratios were described in [75, 76]. However, [75] results show that mixing of several biomass materials has some positive effect on the energy content and the heating value but nothing was reported on the elemental composition and proximate values. Meanwhile [76], only reported the elemental composition of the biomass blends which was selected without making mention of the heating value.

Table 5: Literature review of Experimental analysis of biomass

Author	Lignocellulosic Biomass group	Heating value(M J/kg)	Proximate Analysis (%)				Elemental composition (%)				
			M	VM	FC	Ash	C	H	N	S	O
	Wood and woody biomass										
[62]	Downy Birch bark	18.50-18.72	11.13	78.7	20.9	0.3	48.4	5.6	0.2	-	-
[63]											
[23]	Olive husk	19.2	9.2	70.3	26.1	3.6	50.0	6.2	1.6	-	42.2
[64][12]	Hazel nut husk		9.0	69.3	28,3	1.4	52.9	5.6	1.4		42.7
	Hazelnut seed coat	19.4	6.8	71.2	27.0	1.8	51.0	5.4	1.3	-	42.3
	Spruce wood	19.7	7.6	70.2	28.3	1.5	51.9	6.1	0.3		40.9
	Beech wood	17.4-18.9	7.4-9.7	74.0	24.6	0.4	49.5	6.2	0.4	-	40.9
	Ailanthus wood	19.0	8.1	73.5	24.8	1.7	49.5	6.2	0.3	-	41.0
[64]	Albizia	17.4	9.7	72.7	25.5	1.8	46.4	5.8	0.6	1.7	45.5
[65]	Furniture sawdust	15.79	7.1	79.43	12.69	0.78	47.42	5.67	0.2	-	46.71
[67]	Oak		0.6	89.7	9.5	0.2	-	-	-	-	-
[66]	Pinewood	19.6	5.8	82.4	10.3	1.5	49.0	6.4	0.14	0.01	44.4
	Pine sawdust	20.54	13.58	70.23	15.06	1.12	50.54	7.08	0.15	0.57	41.11
[68]	Eucalyptus bark	15.7	10.7	76.1	19.7	10.7	38.7	4.5	0.3	<1.8	54.9
[26]	Eucalyptus wood	18.6	7.7	82.6	16.4	1.0	48.7	6.2	0.3	-	44.8
	Subabul wood	19.78	-	85.6	-	0.9	48.2	5.9	0	-	45.1
	Agricultural residue										
	Banana waste										
[48]	Paddy straw	-	7.3	56.4	15.4	20.9	48.75	5.98	1.99	-	43.28
[37, 48, 69]	Bagasse	14.67-16.29	13.2	71.0-84.2	13.8	2.1-2.9	43.8-51.71	5.32-5.8	0.33-0.4		42.64-47.1
[71, 72]	Sugarcane leaves	18.4	6.7	79.0	8.6	5.7	48.9	6.5	0.2	-	44.4
	Sugarcane tops	18.3	6.6	74.9	12.5	6.0	49.0	6.6	0.6	-	43.8
	Cassava stalk	18.1	8.5	69.7	14.7	7.1	48.8	6.7	1.1	-	43.4
	Cassava rhizome	21.7	8.8	65.0	15.0	11.2	49.5	6.5	1.1		42.9
[37]	Corncob	16.6	12.1	86.5	12.5	1.0	49.0	5.4	0.3	-	44.6

	Tea waste	16.8	6.5	85.0	13.6	1.4	48.6	5.5	0.5	<0.1	40.9
[23, 69]	Corn Stover	17.6	10.6	78.7	17.6	3.7	42.6	5.06	0.83	0.09	36.52
	Corn stalk	16.54		80.1	-	6.8	41.9	5.3	0	-	46.0
	Tobacco leaf	16.3	8.4	72.6	11.2	17.2	-	-	-	-	-
							-	-	-	-	-
	Tobacco stalk	17.6	8.9	79.6	18.0	2.4	-	-	-	-	-
[23, 66]	Wheat straw	18.7-20.3	6.0-8.5	63.0-78.3	14.4-23.5	1.3-13.5	41.6-45.5	5.1-6.1	0.14-1.8	0.06	34.1-52.115.7
[66]	Barley straw	15.7	6.9	78.5	4.8	9.8	41.4	6.2	0.63	0.01	51.7
[66]	Flax straw	17.0	7.9	80.3	8.8	3.0	43.1	6.2	0.68	0.09	49.9
[69]	Coconut coir	14.67	-	82.8	-	0.9	47.6	5.7	0.2	-	45.6
	Coconut shell	20.50	-	80.2	-	0.7	50.2	5.7	0.2	-	45.6
	Millet husk	17.48	-	80.7	-	18.1	42.7	6.0	0.1	-	33.0
	Rice husk	15.29	-	81.6	-	23.5	38.9	5.1	0.6	-	32.0
	Rice straw	16.78	-	80.2	-	19.8	36.9	5.0	0.4	-	37.9
	Groundnut shell	18.65	-	83.0	-	5.9	48.3	5.7	0.8	-	39.4
[28]	Oat straw		8.2	73.9	12.5	5.4	48.8	6.0	0.08	0.5	44.6
[74]	Cotton waste	16.65	4.8	72.05	20.05	3.1	40.6	6.0	0.19	0.9	53.2
	Soybean waste	18.77	5.8	70.5	19.0	4.7	43.8	6.3	1.4	0.8	48.5
[75]	Kernel olive	20.54	-	-	-	-	47.63	6.41	0.97	0.08	44.92
	Eucalyptus sawdust	16.30	-	-	-	-	44.80	6.03	0.84	0.03	48.30
Energy grasses											
	Willow coppice	20	2.8	87.6	17.3	6.3	49.9	6.5	0.2	-	39.9
[76]	Switch grass	16.3	9.84	69.14	12.93	8.09	42	5.24	0.60	0.17	33.97
	Elephant grass	15.61	10.04	65.0	14.66	6.0	44.50	5.4	1.4	-	31.8
	Orchard grass	-	-	-	-	-	56.1	5.9	0.4	0.03	37.6
	Esparto grass	19.1	5.2	80.5	16.8	2.2-8	46.94	6.44	0.86	0.0	43.56
	Wild reed	24.98	4.34	78.57	12.54	4.54	48.7	6.96	0.36	-	42.96
[77]	Timothy grass	16.7	5.0	77.9	16.0	1.1	42.4	6.0	1.03	0.15	50.4
	Hemp	15.54	8.75	-	-	-	2.97	-	-	-	-
	Straw	16.02	8.40	-	-	-	2.10	-	-	-	-
	Reed	15.94	9.16	-	-	-	2.76	-	-	-	-
	Reed canary grass	15.12	15.68	-	-	-	5.13	-	-	-	-
[48]	Imperata cylindrical	-	8.55	84.14	0.36	6.95	50.04	5.92	1.15	-	42.9
	Eragrostis airoides	-	8.275	86.84	1.23	3.6	41.02	6.72	1.14	-	51.12
	Typha angustifolia	-	13.95	80.06	2.18	3.81	52.90	5.84	1.22	-	40.04

	Arundinella khasiana	-	10.37	80.06	2.18	8.12	41.26	5.40	1.25	-	52.10
	Echinochia stagnina	-	10.27	83.19	0.41	6.13	44.98	5.66	1.86	-	45/50
	Municipal waste										
	Newspaper	-	-	-	-	-	-	-	-	-	
[78]	Sewage sludge	6.56	-	29.01	3.49	67.50	12.79	1.74	1.20	0.55	16.22
	Physical chemical sludge	19.10	-	69.1	0.5	30.4	32.78	5.81	0.04	0.91	60.09
	Biochemical sludge	17.60	-	65.53	6.6-1	27.86	31,75	5.76	1.54	1.88	59.08
	Cardboard	13.81	-	-	-	-	38.49	5.68	0.82	0.09	54.92
	Plastic	44.81	-	-	-	-	82.61	14.01	0.74	0.00	2.64
	Synthetic rubber	37.82	-	-	-	-	83.96	7.93	0.97	1.14	6.00
	Biomass Mixture										
[77]	Hemp and peat (15%,30%,50%)	15.52,15.79,16.25	9.08,10.30,11.53	-	-	2.60,2.92,2.88	-	-	-	-	--
	Reed and peat (15%,20%,30%)	15.84,15.68,14.89	10.33,10.53,14.10	-	-	3.20,2.83,2.50	-	--	-	-	-
	Reed canary grass (15%,30%,50%)	15.16	16.13	-	-	4.33	-	-	--	-	--
[79]	Wood-agricultural residue	-	30.3	54.7	12.7	2.3	56.7	6.6	2.7	0.87	33.1
	Wood-almond residue	-	22.7	59.7	12.3	5.3	50.9	5.9	0.6	0.08	50.9
	Wood and straw residue	-	7.3	69.6	15.5	7.6	51.7	6.3	0.4	0.13	41.5
[75]	Biochar and kernel olive (25%/75%:50%/50%:75%/25%)	23.0/25.0/26.0	-	-	--	-	-	-	-	-	-
	Biochar and manure (25%/75%:50%/50%:75%/25%)	16.5/19.0/23.5	-	-	--	-	-	-	-	-	-
	Biochar and Eucalyptus sawdust (25%/75%:50%/50%:75%/25%)	17.0/21.0/24.0	-	-	--	-	-	-	-	-	-
	Biochar and sugar cane (25%/75%:50%/50%:75%/25%)	17.5/21.0/23.5	-	-	--	-	-	-	-	-	-
	Biochar and wood sawdust (25%/75%:50%/50%:75%/25%)	21/22/26.5	-	-	--	-	-	-	-	-	-
	Activated Biochar and Kernel	25.0/28.0/31.5	-	-	--	-	-	-	-	-	-

oil(25%/75%:50%/50%:75%/25%)										
Activated biochar and cattle manure (25%/75%:50%/50%:75%/25%)	17.0/24.0/28.0	-	-	--	-	-	-	-	-	-
Activated biochar and eucalyptus sawdust (25%/75%:50%/50%:75%/25%)	21.0/26.0/30.0	-	-	--	-	-	-	-	-	-
Activated biochar and sugar cane (25%/75%:50%/50%:75%/25%)	21.0/25.0/30.0	-	-	--	-	-	-	-	-	-
Activated biochar and wood sawdust (25%/75%:50%/50%:75%/25%)	23.0/26.0/32.0	-	-	--	-	-	-	-	-	-
Activated biochar and alfa (25%/75%:50%/50%:75%/25%)	23.0/26.0/31.0	-	-	--	-	-	-	-	-	-
[79-82] Contaminated biomass										
Shredded currency	-	4.7	79.0	11.1	5.2	45.4	6.3	1.9	0.32	46.1
Mixed waste paper	-	8.8	76.8	6.8	7.6	52.3	7.2	0.2	0.08	40.2
Demolition wood	-	16.3	63.4	14.5	5.8	51.7	6.4	1.1	0.09	40.7
Greenhouse-plastic waste	-	2.5	61.0	5.5	31.0	70.9	11.2	1.5	0.01	16.4
Refuse derived fuel.	-	4.2	70.3	0.5	25.0	53.8	7.8	1.1	0.47	36.8

5.2 Outlook for further research

Most of the research findings from 78 articles that were reviewed did not give information on the season, time of storage and the geographical location of the biomass samples. Approximately 5 % of the article reviewed described the geographical location from where the biomass was sourced. This may pose a difficulty on the reproducibility of data and may hinder future research that may want to compare the effect of location on the biomass properties. Developing a robust software for prediction means that all the variables which could affect the heating value and elemental composition have been properly investigated experimentally. Therefore, it may be necessary to properly describe the season, time of storage and geographical location from where the biomass is harvested.

Estimation of greenhouse gas (GHG) emission potential of biomass sources should be included in the assessment of the energy potential of biomass sources, most researchers did not account for this valuable parameter in the same context of biomass properties. Although this may not be significant at the experimental level, the cumulative impact of this may be so large in the case of industrial energy generation.

It is impossible to sustain the intensive and continued generation of biomass per unit land area envisaged in the biomass-based energy production programmes on the basis of the native nitrogen stocks in the soil as they are inadequate to provide sufficient nutrients to sustain non-nitrogen-fixing crops. It is expected

that more researchers should be conducted on the effect of mixing and contamination on the thermal properties and elemental composition of biomass.

Combination of biomass from diverse sources would be required to generate sufficient fuel which can be applied on an industrial scale. There are two implications of this;

- 1) The researchers may need to understand the extent to which the presence of contamination and biomass mixing would possibly affect the thermal properties, proximate value, and elemental composition. The understanding of this scope may eventually eliminate the need for sorting of some biomass while alleviating the fear of contamination. This will lead to the reduction in the sorting cost of biomass for energy generation.
- 2) Greenhouse gas emission as a result of this large-scale biomass mixing must be investigated. Under the normal condition biomass is not expected to contribute substantially to GHG, but in a scenario where the rate of harvesting of biomass resources does not correspond to the rate of cultivating, then there would be carbon deficit which will eventually culminate in greenhouse gas. Therefore, possible magnitude of this eventual deficit must be understood. This would provide information to the users and ensure sustainable use of biomass resources.

6. Conclusion

A drive towards sustainable and renewable energy generation triggered researchers to look into the potential of biomass as an alternative to fossil fuel. Lignocellulosic biomass has been identified due to its abundance across the globe. However, the environmental issues surrounding the exploration should be thoroughly investigated, knowing fully well that these may be magnified when the biomass is applied on a large scale. Also, the effect of biomass blending and contamination as related to the production of energy from Lignocellulosic biomass should be investigated for thorough understanding. In the long run, biomass would provide an efficient, cost-effective and sustainable alternative energy, which would assist the global community in reducing greenhouse gas emission. However, a complete understanding of different dynamics in biomass thermal and elemental composition must be well understood.

References

- [1] M. Ozturk *et al.*, "Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia," *Renewable and Sustainable Energy Reviews*, vol. 79, pp. 1285-1302, 2017.
- [2] M. A. Rosen, "Energy sustainability: a pragmatic approach and illustrations," *Sustainability*, vol. 1, no. 1, pp. 55-80, 2009.
- [3] E. Toklu, M. Güney, M. Işık, O. Comaklı, and K. Kaygusuz, "Energy production, consumption, policies and recent developments in Turkey," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 4, pp. 1172-1186, 2010.
- [4] R. Saidur, G. BoroumandJazi, S. Mekhilef, and H. A. Mohammed, "A review on exergy analysis of biomass based fuels," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 2, pp. 1217-1222, 2012.
- [5] A. Callejón-Ferre and J. López-Martínez, "Briquettes of plant remains from the greenhouses of Almería (Spain)," *Spanish journal of agricultural research*, vol. 7, no. 3, pp. 525-534, 2009.
- [6] F. GBEP, "A review of the current state of bioenergy development in G8 p5 Countries," *Rome: FAO*, 2007.
- [7] World Energy Council (WEC), "Waste to Energy." https://www.worldenergy.org/wpcontent/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf (Accessed on 16th January,2018)," 2016.
- [8] S. Tewfik, "Biomass utilization facilities and biomass processing technologies," *Energy Education Science and Technology*, vol. 14, pp. 1-19, 2004.
- [9] Y. Yanli, Z. Peidong, Z. Wenlong, T. Yongsheng, Z. Yonghong, and W. Lisheng, "Quantitative appraisal and potential analysis for primary biomass resources for energy utilization in China," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 9, pp. 3050-3058, 2010.

- [10] P. S. Nigam and A. Singh, "Production of liquid biofuels from renewable resources," *Progress in energy and combustion science*, vol. 37, no. 1, pp. 52-68, 2011.
- [11] J. M. Vargas-Moreno, A. J. Callejón-Ferre, J. Pérez-Alonso, and B. Velázquez-Martí, "A review of the mathematical models for predicting the heating value of biomass materials," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 3065-3083, 2012.
- [12] C. Sheng and J. L. T. Azevedo, "Estimating the higher heating value of biomass fuels from basic analysis data," *Biomass and Bioenergy*, vol. 28, no. 5, pp. 499-507, 2005.
- [13] N. Scarlat, J.-F. Dallemand, F. Monforti-Ferrario, and V. Nita, "The role of biomass and bioenergy in a future bioeconomy: Policies and facts," *Environmental Development*, vol. 15, pp. 3-34, 2015.
- [14] C. Hamelinck, I. De Lovinfosse, M. Koper, C. Beestermoele, C. Nabe, and M. Kimmel, "Renewable energy progress and biofuels sustainability. Report for the European Commission," *Ecofys, Utrecht, Netherlands, Tech. Rep. ENER/C1/463-2011-Lot2*, 2012.
- [15] M. Banja, N. Scarlat, F. Monforti-Ferrario, and J.-F. Dallemand, "Renewable energy progress in EU 27 (2005–2020)," *Ispira, Italy: Joint Research Centre*, 2013.
- [16] U. S. E. I. A. (USEIA), "Renewable energy explained. https://www.eia.gov/energyexplained/?page=renewable_home (accessed on 27th March 2018)," 2017.
- [17] I. D. w. o. r. e. e. W. (2013), "Global Bioenergy Statistics. (Accessed on 26th December,2017)," 2013.
- [18] BP, "Statistical review of world energy 2016.<https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html> (Accessed on 26th March 2018)," 2016.
- [19] T. Kar and S. Keles, "Environmental impacts of biomass combustion for heating and electricity generation," *Journal of Engineering Research and Applied Science*, vol. 5, no. 2, pp. 458-465, 2016.
- [20] S. Karekezi, W. Kithyoma, and M. Kamoche, "9. EVALUATING BIOMASS ENERGY COGENERATION OPPORTUNITIES AND BARRIERS IN AFRICA: THE CASE OF BAGASSE COGENERATION IN THE SUGAR INDUSTRY," *BIO-CARBON OPPORTUNITIES IN EASTERN & SOUTHERN AFRICA*, p. 179, 2009.
- [21] M. F. Askew and C. A. Holmes, "The potential for biomass and energy crops in agriculture in Europe, in land use, policy and rural economy terms," (in English), *Aspects of Applied Biology*, no. No.65, pp. 365-374, 2001.
- [22] M. K. Bahng, C. Mukarakate, D. J. Robichaud, and M. R. Nimlos, "Current technologies for analysis of biomass thermochemical processing: a review," *Anal Chim Acta*, vol. 651, no. 2, pp. 117-38, Oct 5 2009.
- [23] A. Demirbaş, "Calculation of higher heating values of biomass fuels," *Fuel*, vol. 76, no. 5, pp. 431-434, 1997.
- [24] M. F. Demirbas, M. Balat, and H. Balat, "Potential contribution of biomass to the sustainable energy development," *Energy Conversion and Management*, vol. 50, no. 7, pp. 1746-1760, 2009.
- [25] T. Abbasi and S. A. Abbasi, "Biomass energy and the environmental impacts associated with its production and utilization," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 3, pp. 919-937, 2010.
- [26] M. Guerrero, M. P. Ruiz, Á. Millera, M. U. Alzueta, and R. Bilbao, "Characterization of biomass chars formed under different devolatilization conditions: differences between rice husk and eucalyptus," *Energy & Fuels*, vol. 22, no. 2, pp. 1275-1284, 2008.
- [27] S. Vassilev, C. Braekman-Danheux, P. Laurent, T. Thiemann, and A. Fontana, "Behaviour, capture and inertization of some trace elements during combustion of refuse-derived char from municipal solid waste," *Fuel*, vol. 78, no. 10, pp. 1131-1145, 1999.
- [28] S. V. Vassilev, D. Baxter, L. K. Andersen, and C. G. Vassileva, "An overview of the chemical composition of biomass," *Fuel*, vol. 89, no. 5, pp. 913-933, 2010/05/01/ 2010.
- [29] S. V. Vassilev and C. Braekman-Danheux, "Characterization of refuse-derived char from municipal solid waste: 2. Occurrence, abundance and source of trace elements," *Fuel processing technology*, vol. 59, no. 2-3, pp. 135-161, 1999.

- [30] D. R. Nhuchhen, "Prediction of carbon, hydrogen, and oxygen compositions of raw and torrefied biomass using proximate analysis," *Fuel*, vol. 180, pp. 348-356, 2016.
- [31] D. R. Nhuchhen and M. T. Afzal, "HHV Predicting Correlations for Torrefied Biomass Using Proximate and Ultimate Analyses," *Bioengineering (Basel)*, vol. 4, no. 1, Jan 24 2017.
- [32] E. Akkaya, "ANFIS based prediction model for biomass heating value using proximate analysis components," *Fuel*, vol. 180, pp. 687-693, 2016.
- [33] G. E. Acquah, B. K. Via, O. O. Fasina, S. Adhikari, N. Billor, and L. G. Eckhardt, "Chemometric modeling of thermogravimetric data for the compositional analysis of forest biomass," *PLoS One*, vol. 12, no. 3, p. e0172999, 2017.
- [34] J. Cai *et al.*, "Review of physicochemical properties and analytical characterization of lignocellulosic biomass," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 309-322, 2017.
- [35] J. Cai *et al.*, "Processing thermogravimetric analysis data for isoconversional kinetic analysis of lignocellulosic biomass pyrolysis: Case study of corn stalk," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 2705-2715, 2018.
- [36] C. Huang, L. Han, Z. Yang, and X. Liu, "Ultimate analysis and heating value prediction of straw by near infrared spectroscopy," *Waste Manag*, vol. 29, no. 6, pp. 1793-7, Jun 2009.
- [37] V. Dhyani and T. Bhaskar, "A comprehensive review on the pyrolysis of lignocellulosic biomass," *Renewable Energy*, 2017.
- [38] S. K. Sansaniwal, K. Pal, M. A. Rosen, and S. K. Tyagi, "Recent advances in the development of biomass gasification technology: A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 363-384, 2017.
- [39] A. Khan, W. De Jong, P. Jansens, and H. Spliethoff, "Biomass combustion in fluidized bed boilers: potential problems and remedies," *Fuel processing technology*, vol. 90, no. 1, pp. 21-50, 2009.
- [40] J. Koppejan and S. Van Loo, *The handbook of biomass combustion and co-firing*. Routledge, 2012.
- [41] E. Gidarakos, G. Havas, and P. Ntzamilis, "Municipal solid waste composition determination supporting the integrated solid waste management system in the island of Crete," *Waste Manag*, vol. 26, no. 6, pp. 668-79, 2006.
- [42] A. L. Borrión, M. C. McManus, and G. P. Hammond, "Environmental life cycle assessment of lignocellulosic conversion to ethanol: a review," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 7, pp. 4638-4650, 2012.
- [43] S. Paul and A. Dutta, "Challenges and opportunities of lignocellulosic biomass for anaerobic digestion," *Resources, Conservation and Recycling*, vol. 130, pp. 164-174, 2018/03/01/ 2018.
- [44] J. Lynch, "Utilization of lignocellulosic wastes," *Journal of Applied Microbiology*, vol. 63, no. s16, 1987.
- [45] C. Somerville, H. Youngs, C. Taylor, S. C. Davis, and S. P. Long, "Feedstocks for lignocellulosic biofuels," *science*, vol. 329, no. 5993, pp. 790-792, 2010.
- [46] Y. Ahn *et al.*, "Electrospinning of lignocellulosic biomass using ionic liquid," *Carbohydrate polymers*, vol. 88, no. 1, pp. 395-398, 2012.
- [47] J. B. Sluiter, R. O. Ruiz, C. J. Scarlata, A. D. Sluiter, and D. W. Templeton, "Compositional analysis of lignocellulosic feedstocks. 1. Review and description of methods," *J Agric Food Chem*, vol. 58, no. 16, pp. 9043-53, Aug 25 2010.
- [48] Y. D. Singh, P. Mahanta, and U. Bora, "Comprehensive characterization of lignocellulosic biomass through proximate, ultimate and compositional analysis for bioenergy production," *Renewable Energy*, vol. 103, pp. 490-500, 2017.
- [49] C.-H. Zhou, X. Xia, C.-X. Lin, D.-S. Tong, and J. Beltramini, "Catalytic conversion of lignocellulosic biomass to fine chemicals and fuels," *Chemical Society Reviews*, vol. 40, no. 11, pp. 5588-5617, 2011.
- [50] P. McKendry, "Energy production from biomass (part 1): overview of biomass," *Bioresource technology*, vol. 83, no. 1, pp. 37-46, 2002.
- [51] S. Mahalaxmi and C. Williford, "Biochemical conversion of biomass to fuels," in *Handbook of Climate Change Mitigation*: Springer, 2012, pp. 965-999.

- [52] M. Raud, M. Tutt, J. Olt, and T. Kikas, "Effect of lignin content of lignocellulosic material on hydrolysis efficiency," *Agronomy Research*, vol. 13, no. 2, pp. 405-412, 2015.
- [53] H. Zabed, J. Sahu, A. Boyce, and G. Faruq, "Fuel ethanol production from lignocellulosic biomass: an overview on feedstocks and technological approaches," *Renewable and Sustainable Energy Reviews*, vol. 66, pp. 751-774, 2016.
- [54] L. Kou, Y. Song, X. Zhang, and T. Tan, "Comparison of four types of energy grasses as lignocellulosic feedstock for the production of bio-ethanol," *Bioresource Technology*, vol. 241, pp. 424-429, 2017/10/01/ 2017.
- [55] A. V. Bridgwater, "Renewable fuels and chemicals by thermal processing of biomass," *Chemical Engineering Journal*, vol. 91, no. 2-3, pp. 87-102, 2003.
- [56] L. Zhang, C. C. Xu, and P. Champagne, "Overview of recent advances in thermo-chemical conversion of biomass," *Energy Conversion and Management*, vol. 51, no. 5, pp. 969-982, 2010.
- [57] V. Menon and M. Rao, "Trends in bioconversion of lignocellulose: biofuels, platform chemicals & biorefinery concept," *Progress in Energy and Combustion Science*, vol. 38, no. 4, pp. 522-550, 2012.
- [58] A. Demirbaş, "Biomass resource facilities and biomass conversion processing for fuels and chemicals," *Energy conversion and Management*, vol. 42, no. 11, pp. 1357-1378, 2001.
- [59] V. Smil, "Nitrogen in crop production: An account of global flows," *Global biogeochemical cycles*, vol. 13, no. 2, pp. 647-662, 1999.
- [60] H. Gitay, A. Suárez, R. T. Watson, and D. J. Dokken, "Climate change and biodiversity," 2002.
- [61] Y. Sürmen, "The necessity of biomass energy for the Turkish economy," *Energy Sources*, vol. 25, no. 2, pp. 83-92, 2003.
- [62] J. Dibdiakova, L. Wang, and H. Li, "Heating Value and Ash Content of Downy Birch Forest Biomass," *Energy Procedia*, vol. 105, pp. 1302-1308, 2017.
- [63] R. Zanzi, K. Sjöström, and E. Björnbom, "Rapid high-temperature pyrolysis of biomass in a free-fall reactor," *Fuel*, vol. 75, no. 5, pp. 545-550, 1996/04/01/ 1996.
- [64] R. Kataki and D. Konwer, "Fuelwood characteristics of some indigenous woody species of north-east India," *Biomass and Bioenergy*, vol. 20, no. 1, pp. 17-23, 2001.
- [65] M. Jindal and M. Jha, "Catalytic hydrothermal liquefaction of waste furniture sawdust to bio-oil," *Indian Chemical Engineer*, vol. 58, no. 2, pp. 157-171, 2016.
- [66] S. Naik, V. V. Goud, P. K. Rout, K. Jacobson, and A. K. Dalai, "Characterization of Canadian biomass for alternative renewable biofuel," *Renewable energy*, vol. 35, no. 8, pp. 1624-1631, 2010.
- [67] J. Yu, N. Paterson, J. Blamey, and M. Millan, "Cellulose, xylan and lignin interactions during pyrolysis of lignocellulosic biomass," *Fuel*, vol. 191, pp. 140-149, 2017/03/01/ 2017.
- [68] B. Pidtasang, P. Udomsap, S. Sukkasi, N. Chollacoop, and A. Pattiya, "Influence of alcohol addition on properties of bio-oil produced from fast pyrolysis of eucalyptus bark in a free-fall reactor," *Journal of Industrial and Engineering Chemistry*, vol. 19, no. 6, pp. 1851-1857, 2013.
- [69] K. Raveendran, A. Ganesh, and K. C. Khilar, "Influence of mineral matter on biomass pyrolysis characteristics," *Fuel*, vol. 74, no. 12, pp. 1812-1822, 1995.
- [70] G. O. Mosiori, C. O. Onindo, P. Mugabi, S. B. Tumwebaze, S. Bagabo, and R. B. Johnson, "Characteristics of potential gasifier fuels in selected regions of the Lake Victoria Basin," *South African Journal of Science*, vol. 111, no. 5-6, pp. 1-6, 2015.
- [71] A. Pattiya, S. Sukkasi, and V. Goodwin, "Fast pyrolysis of sugarcane and cassava residues in a free-fall reactor," *Energy*, vol. 44, no. 1, pp. 1067-1077, 2012.
- [72] S. Sirijanusorn, K. Sriprateep, and A. Pattiya, "Pyrolysis of cassava rhizome in a counter-rotating twin screw reactor unit," *Bioresource technology*, vol. 139, pp. 343-348, 2013.
- [73] A. M. Azeez, D. Meier, J. r. Odermatt, and T. Willner, "Fast pyrolysis of African and European lignocellulosic biomasses using Py-GC/MS and fluidized bed reactor," *Energy & Fuels*, vol. 24, no. 3, pp. 2078-2085, 2010.
- [74] K. A. Motghare, A. P. Rathod, K. L. Wasewar, and N. K. Labhsetwar, "Comparative study of different waste biomass for energy application," *Waste Manag*, vol. 47, no. Pt A, pp. 40-5, Jan 2016.

- [75] I. Boumanchar *et al.*, "Effect of materials mixture on the higher heating value: Case of biomass, biochar and municipal solid waste," *Waste Manag.*, vol. 61, pp. 78-86, Mar 2017.
- [76] J. S. Tumuluru, C. T. Wright, R. D. Boardman, N. A. Yancey, and S. Sokhansanj, "A review on biomass classification and composition, co-firing issues and pretreatment methods," in *2011 Louisville, Kentucky, August 7-10, 2011*, 2011, p. 1: American Society of Agricultural and Biological Engineers.
- [77] A. Kakitis, I. Nulle, M. Ozollapins, and J. Kjakste, "ASSESSMENT OF COMBUSTION PARAMETERS OF BIOMASS MIXTURES," in *14th International Scientific Conference Engineering for Rural Development, Jelgava, Latvia, 20-22 May, 2015*, 2015, pp. 133-139: Latvia University of Agriculture.
- [78] Y. Li, L. W. Zhou, and R. Z. Wang, "Urban biomass and methods of estimating municipal biomass resources," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1017-1030, 2017.
- [79] T. R. Miles, T. Miles Jr, L. Baxter, R. Bryers, B. Jenkins, and L. Oden, "Alkali deposits found in biomass power plants: A preliminary investigation of their extent and nature. Volume 1," National Renewable Energy Lab., Golden, CO (United States); Miles (Thomas R.), Portland, OR (United States); Sandia National Labs., Livermore, CA (United States); Foster Wheeler Development Corp., Livingston, NJ (United States); California Univ., Davis, CA (United States); Bureau of Mines, Albany, OR (United States). Albany Research Center 1995.
- [80] A. T. Masiá, B. Buhre, R. Gupta, and T. Wall, "Characterising ash of biomass and waste," *Fuel Processing Technology*, vol. 88, no. 11-12, pp. 1071-1081, 2007.
- [81] D. A. Tillman, "Biomass cofiring: the technology, the experience, the combustion consequences," *Biomass and Bioenergy*, vol. 19, no. 6, pp. 365-384, 2000.
- [82] A. Pettersson, M. Zevenhoven, B.-M. Steenari, and L.-E. Åmand, "Application of chemical fractionation methods for characterisation of biofuels, waste derived fuels and CFB co-combustion fly ashes," *Fuel*, vol. 87, no. 15-16, pp. 3183-3193, 2008.
- [83] E. Dahlquist, *Technologies for converting biomass to useful energy: combustion, gasification, pyrolysis, torrefaction and fermentation*. CRC Press, 2013.
- [84] L. Nunes, J. Matias, and J. Catalão, "Biomass combustion systems: A review on the physical and chemical properties of the ashes," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 235-242, 2016.
- [85] S. Channiwala and P. Parikh, "A unified correlation for estimating HHV of solid, liquid and gaseous fuels," *Fuel*, vol. 81, no. 8, pp. 1051-1063, 2002.
- [86] W. Kirmse, *Organic elemental analysis: Ultramicro, micro, and trace methods*. Elsevier, 2012.