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Circular Economy Use of Biomass Residues to Alleviate Poverty, Environment, and Health Constraints

Sammy N. Aso [a, #], Chijioke M. Osuji [b], Madu O. Iwe [c], Simeon C. Achinewhu [d]

[a] Rivers State University, Food Engineering Laboratory, Port Harcourt, Nigeria (Present address: Brookings, South Dakota, USA)
[b] Federal University of Technology, Department of Food Science and Technology, Owerri, Nigeria
[c] Michael Okpara University of Agriculture, Department of Food Science and Technology, Umudike, Nigeria
[d] Rivers State University, Department of Food Science and Technology, Port Harcourt, Nigeria

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ABSTRACT

Inadequate energy and water resources supply are major constraints contributing to poverty and poor health outcomes in developing economies. Low-income countries lack ready access to modern necessities such as electricity and potable water. On one hand, the scarcity of electricity and other clean energies compel reliance on traditional biomass for domestic fuels. On the other hand, harvesting firewood to meet energy needs leads to deforestation and environmental degradation. Furthermore, burning the wood for heat creates ecosystem perturbators such as toxicants, greenhouse gasses, and particulate matter. These pollutants portend adverse health concerns, including premature mortality. Globally, fine particulate matter air pollution alone causes about 3.3 million deaths annually. The contribution of this paper is to offer how circular economy targeted technologies could come to the rescue. In particular, utilizing biomass residues and wastes for briquette and pellet creation is highlighted. These densified fuel products could serve as green energies in domestic and industrial applications; and thus, help to attenuate poverty, and the adverse environmental and health consequences of traditional biomass.

1. Introduction

Most of the energy consumed on planet earth today is still fossil fuels based. As of 2018, fossil fuels account for 85 % of the global primary energy supply. In 2020, renewable energies accounted for only 22.1 % of the total ultimate energy consumed in Europe (EurObserv'ER, 2021). This circumstance imposes energy insecurity because, fossil fuels are finite, depleted, nonrenewable and therefore unsustainable. Also, fossil fuels exert unwanted external costs to the environment such as the contamination of air, soil, and water resources. Perhaps one of the most ominous effect of fossil energy is the potential to perturb the global climate with the emission of greenhouse gases (GHGs). To preserve humanity and natural resources, a more environmentally friendly energy source is needed.

Renewable energy could play a role and stand proxy for fossil fuels. Among renewable energy sources, traditional biomass (such as agricultural residues, dung, and firewood) is used extensively in low-income countries. In 2020, approximately 1.93 billion m^3 of wood fuel were produced in the world. Africa and Asia accounted for 74 % (each contributing 37 %), followed by Americas (17

[#] Corresponding author: sammyasso@yahoo.com

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%). In the same year, about 53.6 million tons of wood charcoal were also produced globally. Africa accounted for 65 %; and the Americas and Asia each accounted for about 17 % (WBA, 2021). However, traditional biomass is encumbered by some of the limitations of fossil fuels, for instance, GHGs and particulate matter emissions. In the contribution made with this paper, some unwanted external costs associated with traditional biomass are highlighted, and solutions to mitigate them are presented.

2. Traditional biomass

The oldest of all fuels is arguably biomass. When primordial Homosapien invented fire, the spark was likely nurtured into flame and sustained with traditional biomass (dry grass, leaves, and twigs). These biomasses, as well as others like charcoal, firewood, husks, stalks, cobs, shells, and animal dung, are routinely used as biofuel today. About 2.5 to 3 billion people worldwide depend on traditional biomass for energy (IEA, 2017; Lello, 2022; Rakos, 2022). This population relies on biomass as the primary energy source to boil water, cook food, and warm homes. In Sub-Saharan Africa (SSA), traditional biomass supplies over 80 % of primary energy for more than 90 % of the population. In Kenya, charcoal provides 34 % and 82 % of energy needs respectively for rural and urban dwellers (Njenga et al., 2014). In Turkey, 60 % of energy for the paper industry comes from wood wastes, and about 6.5 million households use wood for heating (Baris and Kucukali, 2012). Types of biomass utilized as fuel have been enumerated in published literature (Demirbas, 2004; Tumuluru et al., 2011; Bajwa et al., 2018; Pradhan et al., 2018; Hao, 2020; Coad, 2021; Kedia, 2021; Rakos, 2022). In 2018 about 85 % of the 55.6 EJ global domestic energy supply originated from solid biofuels (WBA, 2020). However, there are costs associated with the use of traditional biomass.

3. Unwanted external costs

The unwanted external costs of traditional biomass pervade a broad range of areas and resources. The burden impact crucial sectors essential for human existence such as the ecosystem, food, housing, health, soil, and agricultural productivity. Perhaps the most visible route that represents a burden in many developing countries is the degradation of air quality.

4. Air pollution

Air pollution is a prominent level 2 risk factor. This is within the level 1 risk factor of environmental and occupational risks that constitute a lion's share of the global burden of disease and premature mortality. Environmental and occupational risks registered the highest exposure values in the past three decades, with mean summary exposure values (SEVs) of 52.55, 48.50, and 45.36, respectively, for the year 1990, 2010, and 2019. In comparison to another level 1 risk factors, behavioral risks had mean SEVs of 16.80, 15.38, and 15.09, respectively, for the said time frame, while those for metabolic risks were 14.90, 19.40, and 22.14. The SEVs are measured on a 0 to 100 scale. A 0 is when the entire population is exposed to a minimum risk, and a 100 is when the population is exposed to a maximum risk (Murray et al., 2020).

Air quality may be degraded by suspended matter and particulates. Air-borne particulates of public health interest are usually defined as particles with an aerodynamic diameter less than 10 µm (PM_{10}), with those with diameters less than 2.5 µm ($PM_{2.5}$) further categorized as fine particles. Particulates include black carbon/soot, dust, nitrates, sulfates, and ozone. Ammonia (NH_3) is a particulate matter precursor. The abundance of NH_3 is often considered the limiting criterion in the formation of, and pollution by $PM_{2.5}$. Although chemical fertilizers and animal husbandry are the main sources of anthropogenic NH_3 emissions, the burning of biomass contributes to the problem (Dentener and Crutzen, 1994; Galloway et al., 2004). Over the 14-year period (2002 - 2016), significant increments in atmospheric ammonia were observed around the world, e.g. in Africa (Egypt, Ghana, Guinea, Nigeria, Sierra Leone), Asia (Bangladesh, Cambodia, China, India, Pakistan, Uzbekistan, Vietnam), Europe (Denmark, Germany, Italy, Netherlands), and the Americas (Brazil, Colombia, Ecuador, Peru, USA). Increasing trends in mean yearly NH_3 concentrations of about 1.83, 2.27, and 2.61 percentage points for the EU, China, and the USA were reported, respectively (Warner et al., 2017).

Particulate matter air pollution may occur from combustion processes via wild, domestic/ residential and industrial actions, and from vehicular traffic/ transportation functions. Examples include forest fires, burning of traditional biomass for domestic reasons, and combustion of fossil fuels for air, land, and sea transportation (Pennise et al., 2001; Edwards et al., 2003; IEA, 2017). Between 1983 and 1984, about 3.7 million hectares of forest were burned around Kalimantan and neighboring Sabah in Indonesia (Repetto et al., 1989). Citing the European Forest Fire Information System (EFFIS), Horton and Palumbo (2022), reported that for the first 197 days of the year 2022 (as of 16 July 2022), almost 346,000 hectares of land were burned by wild fires in the European Union. Other authors have reported on the combustion characteristics of different types of biomass (Haykiri-Acma, 2003; Demirbas, 2004; Hao, 2020; Suman et al., 2021), and on the emission factors for biomass and fossil fuel-fired stoves (Gaegauf et al., 2001; Bhattacharya et al., 2002; Johansson, 2002; Edwards et al., 2003; Boman et al., 2004; Sippula et al., 2007; Bäfver et al., 2011; Njenga et al., 2014; Obaidullah and De Ruyck, 2021).

Combustion operations create unwanted external costs. Annually, about 2 Mt of carbonaceous aerosol pollutants are pumped into the Asian atmosphere, forming the

"Asian dark cloud" (Laghari, 2013). Carbonaceous aerosols can absorb solar energy and heat the atmosphere (Teng et al., 2012), resulting in the melting of ice and glaciers. During the period 2003 - 2009, about 174 Gt of water were estimated to have been lost by the Himalayan glaciers; and contributed to floods that affected human life, water supplies, and hydroelectric power across the region. In 2010, for example, seasonal melt and excessive monsoon rains caused the loss of 2000 lives and billions of dollars in economic damage in Pakistan (Laghari, 2013). In July 2022, forest and wild fires raged across the world, in Europe (France, Greece, Italy, Portugal, Spain, etc.), and in several states in the USA (e.g., California, Oregon, New Mexico, Texas, and Washington); spewing to the atmosphere, huge amounts of heat energy, particulate matter, smoke, and other pollutants with environmental and health consequences. Pollutants released by the combustion of traditional biomass pose adverse health implications. Each year, over 4 million premature deaths globally are associated with air pollution from cooking on open fireplaces (Lello, 2022; Rakos, 2022). About 2.5 to 2.8 million of these deaths are thought to emanate from indoor air pollution (IEA, 2017; Ohlson, 2022). In India, 25 % of black carbon emissions come from household energy use, and about 25 % of deaths due to $PM_{2.5}$ is attributed to residential biomass burning (Kokil, 2022a). Implications of combustion particulate matter air pollution have been reported for Jakarta, Indonesia (Ostro, 1994), Cairo, Egypt (Raufer, 1997), Santiago, Chile (Eskeland, 1997; Zegras and Litman, 1997), and Oslo, Norway, (Rosendahl, 1998). Table 1 lists more burdens that may emanate from burning processes and traditional biomass exploitation.

Table 1
Unwanted external costs attributable to traditional biomass and combustion operations

S/N	Cost description	Reference
1	Annually, 17 million hectares of rain forest are destroyed globally due to wood harvesting, animal husbandry, etc.	Baroni et al., 2007
2	From 1980 to 2000, about 100 million hectares of tropical forest (≈ 50 % intact ecosystems) were lost to agricultural expansion (plantations, ranching, etc.)	IPBES, 2020
3	Across the 21 countries with detailed records, the expansion of invasive alien species has risen by about 70 % since 1970; and global terrestrial habitat integrity reduced by 30 % due to habitat loss and deterioration	IPBES, 2020
4	In 1983-1984, biomass combustion (3.7 million hectares of forest fires burned around Kalimantan and neighboring Sabah) in Indonesia was conservatively estimated to cost about US$ 3.5 billion in timber assets.	Repetto et al., 1989
5	Each year, costs of public and environmental health losses related to soil erosion in USA exceed US$ 44 billion	Pimentel et al., 1995
6	In Oslo, Norway, particulate matter air pollution due to transportation reduced life expectancy by about 0.9 years, with the social costs estimated at Nkr 3,600 (US$ 481.19) per capita	Rosendahl, 1998
7	Unwanted external costs of agriculture in USA per annum were estimated at US$ 5.7-16.9 billion. The damages incurred by sub-categories were (in million US$): water resources, 419.4; soil resources, 2,242.7-13,394.7; air resources, 450.5; wildlife and ecosystem biodiversity, 1,144.9-1,174.1; and human health, 1,425.4-1,450.5	Tegtmeier and Duffy, 2004
8	Adverse health effects account for over 95 % of external costs associated with particulate matter, nitrogen and sulfur dioxides	Eshet et al., 2006
9	Fine particulate matter ($PM_{2.5}$) is a significant risk factor in low birth weight	Tu et al., 2016
10	A minimum of 42 % of all lower respiratory infections is attributable to environmental pollution in developing countries. Solid fuel uses alone account for 36 %	Prüss-Üstün and Corvalán, 2006
11	Health losses associated with airborne particulate matter in the EU is estimated at € 90-190 (US$ 105.758-223.266) billion per year	Van Grinsven et al., 2006
12	In the USA, the cost of premature mortality from fine particulate matter ($PM_{2.5}$) associated with food export was reported to be US$ 36 billion per year (in 2006 US$). The mean mortality rate ratio from lung cancer and cardiopulmonary disease associated with these fine particulates was estimated to be 1.26	Paulot and Jacob, 2014; Dockery et al., 1993
13	One report estimated global economic losses of food crops due to ozone pollution at US$ 11-26 billion per annum. Ozone is formed by precursors such as nitrogen oxides and carbon monoxide. The precursor gasses are however generated by the burning of fossil fuels and biomass	Mills and Harmens, 2011; Wallack and Ramanathan, 2009
14	Global impact of fine particulate matter ($PM_{2.5}$) pollution has been estimated at 3.3 million deaths annually	Lelieveld et al., 2015
15	In 2002, the global death burden from environmental, diarrheal and respiratory diseases was over 16.5 million persons. In 2015, the impact of diseases caused by all pollutions was estimated at 9 million premature deaths (16 % of all deaths worldwide). The global impact of all pollution on welfare was reported to inflict a loss of 6·2 % of world economic output (≈ US$ 4·6 trillion) per year	Prüss-Üstün and Corvalán, 2006; Landrigan et al., 2017

5. Mitigation technologies

As Table 1 highlights, burdens associated with anthropogenic exploitation of traditional biomass are tremendous. With the increasing global population, these problems will accentuate in the future unless measures to attenuate them are implemented. A number of technologies such as anaerobic digestion (Aso et al., 2019; Aso, 2022); hydropower (IHA, 2022); solar, wind, and other renewable energy sources (EurObserv'ER, 2020; 2022), could be employed as mitigation interventions. In the next section, two related technologies (briquettes and pellets) that could be used are presented.

6. Briquettes and pellets

The efficiency of biomass in open fire combustion is low (≈ 5-15 %). With charcoal, energy is wasted in the carbonization process. Yet, > 36 Mt of charcoal valued at $US 11 billion were produced in SSA in 2012 (Lello, 2022); while globally, 53.6 Mt of wood charcoal were produced in 2020 (WBA, 2021). Also, traditional biomasses have low bulk density; a characteristic that reduces energy content per unit volume, and exacerbates handling, storage and transportation costs. Densification circumvents these limitations. Briquetting and pelleting are two methods used to densify solid biomass, and could serve as vehicles for fuel in domestic and industrial applications. Briquettes and pellets could be used to fire boilers, cook stoves and gasifiers, and as feedstock to generate heat, or power, or combined heat and power (CHP). The worldwide production of densified biofuel increased from < 7 Mt in 2006 to > 26 Mt in 2015 (Kang et al., 2019). In the year 2018, solid biofuels accounted for 60 % of the 226 TWh of biopower produced as CHP (WBA, 2020).

Briquettes and pellets may differ in size, shape and moisture content. Pellets are generally produced from finely ground ingredients, and are usually of smooth cylindrical configuration with a length of 18-24 mm; diameter 6-8 mm; unit density 560-1,190 kg/m^3; and moisture content 8-18 %. On the other hand, briquettes could be densified from larger-sized ingredient particles with a wider range of moisture contents; and produced as cylinders, cuboids, hexagons, logs, sticks, and other shapes. Briquettes can range in length from 60-200 mm, diameter 50-100 mm, unit density 320-1,000 kg/m^3, and moisture content 10-30 % (Tumuluru et al., 2011; Balan et al., 2013; Bajwa et al., 2018; Brunerová et al., 2018). Figure 1 is a pictorial representation of sample briquettes and pellets.

7. Briquettes and pellets production machinery

Briquettes and pellets may be produced from many kinds of biomass. Perhaps the availability and versatility of biomass feedstocks enabled the application of densification technology all over the world. Examples include reports from Brazil (Rousset et al., 2011), Chile (Hernández et al., 2019), China (Hao, 2020), Congo (Fodor, 2022), Gabon (Fodor, 2022), India (Kedia, 2021; Kokil, 2022 b), Indonesia (Susastriawan and Sidharta, 2014), Malaysia (Chin and Saddiqui, 2000), Nigeria (Olorunnisola, 2007; Onuegbu et al., 2012; Zubairu and Gana, 2014; Onukak et al., 2017), Poland (Stolarski et al., 2016), Tanzania (Sjølie, 2012), and Zambia (Ohlson, 2022; Peterson and Klingenberg, 2022; Stahl, 2022). A review of the briquette value chain in some African countries (including Kenya, Rwanda, and Uganda) was reported in 2016 (Asamoah et al., 2016). A systematic review and life cycle assessment of biomass pellets and briquettes production in some Latin American countries (including Colombia, Costa Rica, and Mexico) was reported in 2022 (Silva et al., 2022).

In order to manufacture briquettes and pellets, several production systems may be deployed. The machinery may range from rudimentary, laborious, and drudgery-intensive operations: wood is harvested and transported on wheelbarrows manually (Njenga et al., 2014), and recycled containers are used to manually mold the briquettes into shapes (Asamoah et al., 2016); the use of manually operated piston and die presses that could generate pressures of 1.2-7.0 MPa (Chin and Saddiqui, 2000; Olorunnisola, 2007; Onuegbu et al., 2012); the use of small scale briquette extruder powered by 4.103 kW gasoline internal combustion engine (Susastriawan and Sidharta, 2014); and the use of large scale industrial machines with capacities of 2,000-5,000 kg/h (Tumuluru et al., 2011; Madsen, 2021; Pesliakas, 2021). Commercial and industrial scale machinery systems may include: agglomerators, baggers, boilers, coolers, grinders, shredders and many others. Design features, operating principles and typical applications of some technologies and mechanical systems have been reported by Bajwa et al., 2018; Pradhan et al., 2018; Zhang et al., 2018; Kang et al., 2019; and Šooš, 2021. Machinery for the production of forest chips in Finland has also been reported (Kärhä, 2011). One biomass processing equipment manufacturer claimed to have installations in over sixty countries (Morillas, 2021). Figure 2 presents some devices that are used in briquettes and pellets production.

8. Financial implications

Machinery for briquettes and pellets can appear in various sizes, shapes, and mode of operation (Figure 2). Depending on capacity and level of sophistication (e.g., manual, small scale, automated), equipment costs may range from a few to many thousand dollars. While a recycled container used to manually mold a briquette into the desired shape may cost zero dollars, a shredder could cost € 20,000 (US$ 21,666.67), and a packing or briquetting unit over € 50,000 (US$ 54,166.67) (Pesliakas, 2021). However, the production costs of briquettes and pellets are influenced by feedstock type and pre-processing requirements.

One study in Poland evaluated the quality and cost of small-scale production of briquettes from various biomass feedstocks. The authors reported production cost to range from € 66.55 (US$ 72.10) per tonne for briquetts produced from rape straw, to € 137.87 (US$ 149.36) per tonne for briquettes produced from a 50:50 mixture of rape straw and rapeseed oilcake (Stolarski et al., 2013). In Argentina, the costs of pellet production from sawmill residues were estimated at € 35-47 (US$ 37.92-50.92) per tonne (Uasuf and Becker, 2011).

[A]: Briquette Samples [B]: Pellet Samples

Figure 1. Densified biomasses for green energy production: ([a]. Briquettes; [b]. Pellets) (Bajwa et al., 2018; Hao, 2020; Coad, 2021; Madsen, 2021; Naehrig, 2021; Pesliakas, 2021; Smaliukas, 2021; Šooš, 2021; Ohlson, 2022)

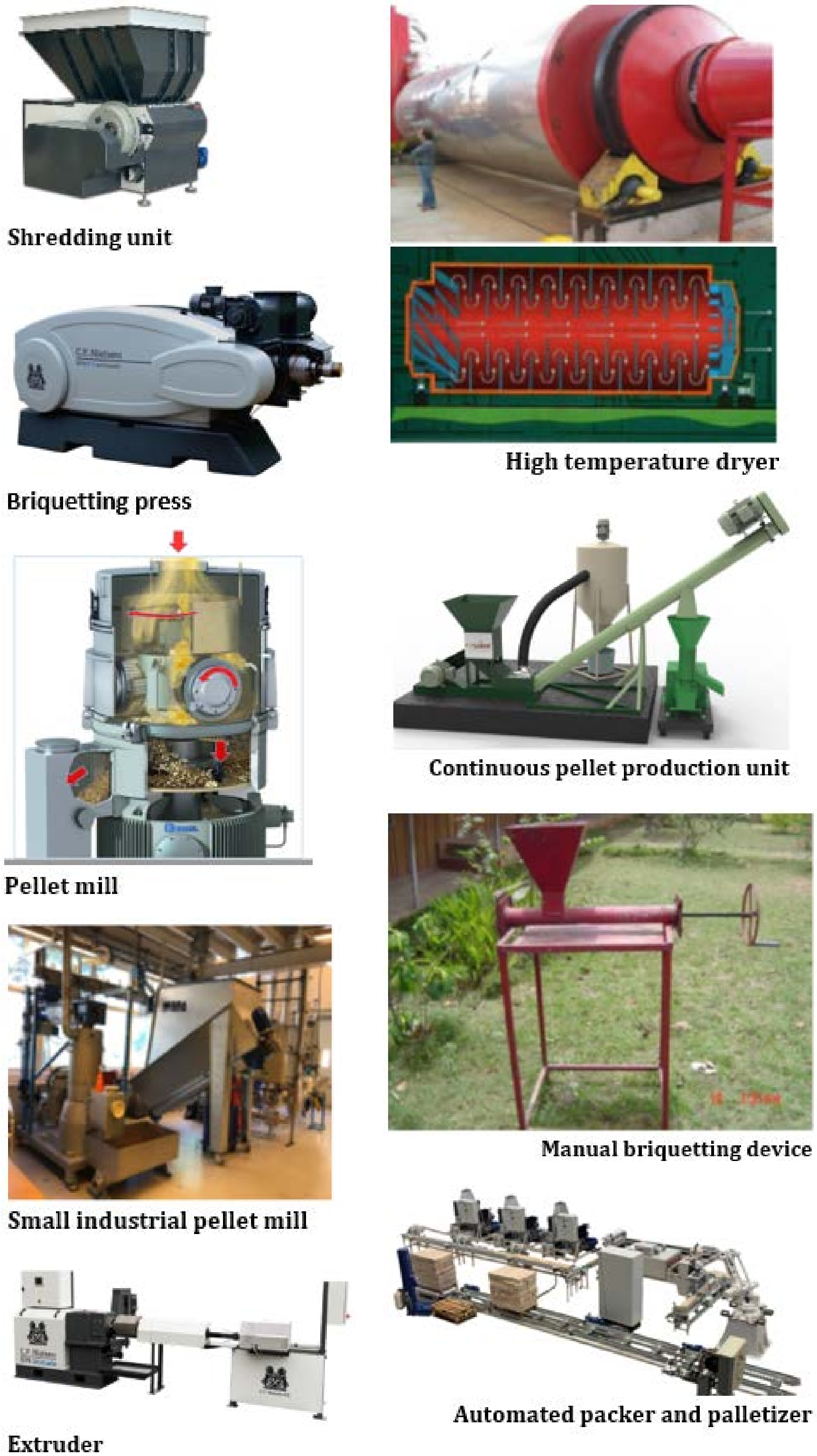

Figure 2. Sample briquette and pellet production machinery systems (Olorunnisola, 2007; Coad, 2021; Madsen, 2021; Naehrig, 2021; Pesliakas, 2021; Kokil, 2022b; Stahl, 2022)

A study in Chile showed that pellet profitability increased by 11.0 % when producing the pellets from olive oil processing wastes and residues (Hernández et al., 2019). In Africa, one study reported that investment cost for large-scale briquette plants vary from US$ 108-350 per tonne, while production costs vary from US$ 61-

237 per tonne. The input cost was estimated to account for 46-54 % of total production cost for large-scale briquette businesses (Asamoah et al., 2016). In the case of Gabon, the investment cost for a 2,000 kg/h pellet equipment operating with the power of 125 kW could range € 50,000-300,000 (US$ 54,166.67-325,000). The production cost for the pellets was estimated at € 65.05 (US$ 70.47) per tonne. For a briquette unit with production capacity of 300-900 kg/h, and energy usage of 25 kW, the investment for equipment was reported at € 5,000-50,000 (US$ 5,416.67-54,166.67) per tonne (Fodor, 2022).

In India, pellets are reported to be sold in local markets at INR (₹) 10 (US$ 0.13) per kilogram (Kokil, 2022b). In Kenya, the cost of kerosene fuel for cooking the traditional meal for a family of five was estimated at Ksh 45 (US$ 0.6). The cost of charcoal briquettes for cooking the same meal was reported to be Ksh 3 (US$ 0.04) (Njenga et al., 2013).

9. Advantages and benefits of briquettes and pellets

Briquettes and pellets exhibit characteristics that enable circumvention of the noted unwanted external costs. Advantages/benefits include convenience, availability, and affordability; mitigation of air pollution, deforestation, soil erosion, health maladies, and global warming occasioned by the harvesting process and combustion products of fossil fuels and traditional biomass. Burning fossil fuels and traditional biomass release air and health-impairing pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons, smoke and other particulate matter. These pollutants may contribute to climate change and premature mortality, as well as cause nausea, sneezing, eye and respiratory irritations, asthma attacks, hospital admissions, and reduced birth weight (Tu et al., 2016).

Production of briquettes and pellets from biomass waste streams minimizes the harvesting of wood (deforestation mitigation), and prevents firewood burning and exposure to combustion products and inherent health maladies. Unlike traditional biomass, briquettes and pellets have a higher energy density, better burning efficiency, maintain consistent quality, and exhibit fewer polluting effects (Pennise et al., 2001; Raymer, 2006; Sjølie, 2012; Muazu et al., 2017; Kokil, 2022a). Unlike fossil fuels, briquettes and pellets feedstocks are available, diverse, renewable, sustainable and environmentally friendly. Briquettes and pellets are regarded as green energy fuels because they could be carbon neutral. There may be no net addition of CO_2 to the environment when the feedstocks are residues and wastes. Replacing charcoal from wood with sawmill residues charcoal briquettes reduced net GHG emissions by 42-84 % (Sjølie, 2012). Pellets produced from olive oil processing wastes (alperujo and orujo) decreased emissions by 78,780 tonnes of CO_2 per year (Hernández et al., 2019). Briquettes and pellets emit less than 20 % of the GHGs typically emitted by fossil fuels (Raymer, 2006). Compared to kerosene fossil fuel, briquette generated lower indoor concentrations of CO_2, CO, and $PM_{2.5}$. The $PM_{2.5}$ emission factor for briquette was also lower than that for kerosene (Njenga et al., 2014). In addition, the net energy savings from densification technologies have been reported in the range: 200-1,000 kJ MJ^{-1}, while GHG emissions savings were reported in the range: 9-50 CO_2-eq (g MJ^{-1}) (Muazu et al., 2017). Table 2 provides more quantitative data on the advantages and benefits of briquettes and pellets.

Table 2

Statistics, advantages and benefits of briquettes and pellets as viable bioenergy technologies to mitigate the adverse effects of traditional biomass and fossil fuels

S/N	Statistics, advantages, benefits	Reference
1	In 2019, about 40.5 million tonnes of wood pellets were produced globally. Europe's share: 55 %; Americas': 30 %; and Asia: 14 %.	WBA, 2021
2	In 2020, approximately (A): 1.93 billion m^3 of wood fuel were produced in the world. Africa and Asia each accounted for 37 %; Americas, 17 %. (B): 53.6 million tonnes of wood charcoal were produced in the world. Africa accounted for 65 %; Americas, 17 %; and Asia, 16.9 %.	WBA, 2021
3	In the USA, the benefit of avoiding health care costs from lead exposure in children was estimated at US$ 110 - 319 billion per year. The impact of reduced particulate matter air pollution was reported to increase overall life expectancy by as much as 15 %	Grosse et al., 2002; Pope et al., 2009
4	In the South Coast Air Basin region of California, USA, the annual economic value of avoiding ozone and PM_{10} pollution effects was estimated at nearly $10 billion	Hall et al., 1992
5	In Grande Porto, Portugal, particulate matter air pollution abatement measures improved air quality by 1 %; reduced PM_{10} emissions by 8 %; and yielded economic benefit of € 8.8 (US$ 10.341) million per year	Silveira et al., 2016
6	In 2011, fossil fuels accounted for 76 % of the energy required for district heating in Lithuania. In 2018, only 31 % of the energy used in district heating emanated from fossil fuels; biomass energy for district heating increased proportionately during this time frame. In 2020, biomass energy accounted for 70 % of the energy required for district heating, and 80 % of requirements for private households. In addition, the price of heating was ≈ 45 % lower due to biomass energy use	Kummamuru, 2021; Gaubyte, 2021

Table 2 continued
Statistics, advantages and benefits of briquettes and pellets as viable bioenergy technologies to mitigate the adverse effects of traditional biomass and fossil fuels

S/N	Statistics, advantages, benefits	Reference
7	The annual cost of production of heat from briquettes for a house in Poland ranged from € 772-986 (US$ 825.104-1053.824). This cost was much lower compared to the cost for the production of equivalent energy from fuel oil, or natural gas, or coal	Stolarski et al., 2016
8	In 2019, about 11.5 million people were employed in the renewable energy sector with bioenergy accounting for ≈ 31 % (3.58 million people)	WBA, 2020; WBA, 2021

10. Conclusion

Because briquettes and pellets could be produced from biomass wastes and residues, they serve as a convenient waste management tool. This also precludes the consumption of fuel wood and associated repercussions (e.g. deforestation). Briquettes and pellets are stable in quality, and have improved energy density and burning efficiency. With their engagement, handling, storage and transport propensity of traditional biomass fuels are dramatically improved. Briquettes and pellets could serve as fuel to produce heat for warmth, boiling water, and cooking food to satisfy domestic needs; generate electricity for small-scale processing operations; fire industrial boilers, gasifiers, and commercial systems to generate heat, or power, or combined heat and power (CHP). However, to improve adoption and market diffusion in low-income economies, public support and interventions (regulatory frameworks, institutional arrangement, technical assistance, resources mobilization, business-friendly policies, credit facilities, investment grants, soft loans, tax incentives, and subsidy schemes) would be needed to offset investment costs and other barriers to their deployment. Utilization devices and systems like cookstoves for low-income rural residents, boilers and gasifiers for small-scale operators and entrepreneurs should be made available, accessible, and affordable. Unlike traditional biomass and fossil fuels, burning briquettes and pellets minimizes harmful combustion products that degrade air quality and impair human health. Since stove type influences emissions of pollutants that degrade indoor air quality, interventions that enable affordable ownership of efficient, safe, and durable cookstoves would alleviate adverse health outcomes. Perhaps the Indian approach (Kokil, 2022a; 2022b) could be modeled.

Traditional biomass is the main source of energy for billions of people in rural communities around the world. And fossil fuels continue to be the predominant energy engine of modern industrial economy. Production of briquettes and pellets from renewable biomass residues and wastes would mitigate hazards associated with traditional biomass and fossil fuels (e.g., climate change, particulate matter air pollution, premature mortality); provide energy security; facilitate rural development; create employment opportunities; boost incomes; and progress poverty alleviation and economic empowerment. Therefore, in the context of circular economy, briquettes and pellets technologies can utilize biomass residues to alleviate poverty, and environment and health constraints; to the benefit of humanity and planet earth.

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Kružna ekonomija primenjena na korišćenje ostataka biomase za smanjivanje siromaštva, očuvanje životne sredine i očuvanje zdravlja

Sammy N. Aso [a, #], Chijioke M. Osuji [b], Madu O. Iwe [c], Simeon C. Achinewhu [d]

[a] Državni univerzitet Rivers, Laboratorija za prehrambeno inženjerstvo, Port Harcourt, Nigerija (Sadašnja adresa: Brukings, Južna Dakota, SAD)
[b] Federalni tehnološki univerzitet, Odsek za prehrambene nauke i tehnologiju, Owerri, Nigerija
[c] Poljoprivredni univerzitet Michael Okpara, Odsek za prehrambene nauke i tehnologiju, Umudike, Nigerija
[d] Državni univerzitet Rivers, Odsek za prehrambene nauke i tehnologiju, Port Harcourt, Nigerija

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Tradicionalna biomasa

I Z V O D

Neadekvatno snabdevanje energijom i resursima vode predstavlja ključno ograničenje koje doprinosi siromaštvu i lošim zdravstvenim ishodima u zemljama u razvoju. Zemlje sa niskim prihodima nemaju lak pristup savremenim potrepštinama koa što su struja i voda za piće. S jedne strane, nedostatak električne energije uslovljava oslanjanje na korišćenje tradicionalne biomase kao domaćeg goriva. S druge strane, seča šume za ogrev dovodi do krčenja šuma i degradacije životne sredine. Pored toga, sagorevanje drveta radi toplote prouzrokuje poremećaje ekosistema, tako što se stvaraju toksikanti, nastaje efekat staklene bašte i pojavljuju se štetne čestice. Ovi zagađivači mogu da izazovu zdravstvene probleme, uključujući preranu smrt. Na globalnom nivou, samo zagađenje finim česticama uzrokuje oko 3,3 miliona smrtnih slučajeva godišnje. Ovaj rad pruža uvid u načine na koje bi tehnologije koje primenjuju cirkularnu ekonomiju mogle da pomognu. Posebno je istaknuto korišćenje ostataka biomase i otpada za pravljenje briketa i peleta. Ovi zgusnuti proizvodi od goriva se mogu koristiti kao vid zelene energije u domaćoj i industrijskoj aplikaciji, a samim tim i doprineti smanjenju siromaštva i negativnih ekoloških i zdravstvenih posledica prouzrokovanih korišćenjem tradicionalne biomase.