Progress in Chemical and Biochemical Research 2021, 4(2), 109-133

Progress in Chemical and Biochemical Research

Journal homepage: www.pcbiochemres.com

Review Article

A Review of the Current Trends in the Production and Consumption of Bioenergy

Benjamin K. Korir, Joshua K. Kibet*, Bornes C. Mosonik

Department of Chemistry, Egerton University, P.O Box 536-20115, Egerton, Kenya

ARTICLE INFO

Article history

Submitted: 2020-09-29
Revised: 2020-11-25
Accepted: 2020-11-29
Available online: 2021-02-11
Manuscript ID: PCBR-2009-1131
DOI: 10.22034/pcbr.2021.126117

KEYWORDS

Bioenergy,
Carbon trade,
Climate change,
Corruption,
Energy poverty

ABSTRACT

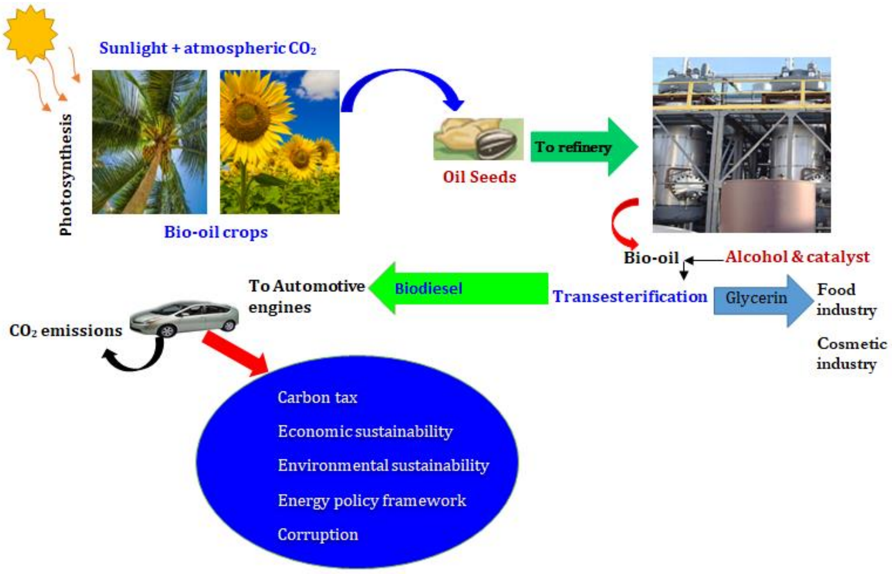
With the current traditional fossil fuels depleting at an alarming rate coupled with environmental degradation because of toxic emissions, there is a mounting desire in search of renewable and sustainable energy resources. In this regard, bioenergy is considered as one of the greatest potentials to address the global energy demands in order to foster confidence in energy security, economic sustainability, and environmental protection. Global use of biomass to generate electricity and enhanced green energy transport is expected to increase in the near future. Accordingly, the demand for renewable energy is aimed at minimizing energy poverty and mitigation against climate change. Bioenergy despite bioconversion challenges is one of the key solutions to the world's current energy demands. Model bioenergy plant sources – *Croton megalocarpus*, palm oil, Jatropha, and soybeans are briefly discussed in this review as major sources of bioenergy. The increased focus on bioenergy has been necessitated by high oil and gas prices, and the desire for sustainable energy resources. Nonetheless, corrupt practices and lack of political goodwill has hampered efforts towards achieving the full utilization of bioenergy. Corruption has been widely cited as a major setback to bioenergy development in a range of global jurisdictions. In order to minimize environmental damage, carbon trade has been projected as a necessary action by developing countries to reduce carbon emissions. Generally, the analysis of the use of fossil fuels across the world shows a strong interrelationship involving energy utilization, degradation of air quality, and environmental health concerns.

HIGHLIGHTS

- Renewable energy for clean energy combustion
- Model biomass components for development of bio-oil; *Croton megalocarpus*, Palm oil, Jatropha curcas and soybean
- The presence of environmental persistent free radicals (EFRs) in bio-oil
- Policy framework in the development of bioenergy
- Carbon trade and carbon emissions

* Corresponding author: Joshua K. Kibet
✉ E-mail: jkibet@egerton.ac.ke
☏ Tel number: +254 720 352 437

GRAPHICAL ABSTRACT



Introduction

Rural households face inadequacies associated with reliable and clean energy resources. This ultimately has forced rural communities, especially in developing countries to continue using low-grade fuels such as coal and solid biomass materials [1]. The condition where households are unable to afford and access clean energy for domestic applications is referred to as energy poverty. Women and mainly school-going children are the most affected because they are responsible for collecting biomass fuels [1]. The harnessing of firewood is time-consuming and deprives communities of time needed for diverse income-generating activities such as farming and small scale business activities [2]. Collection of firewood as a source of fuel in rural settings may prevent children from attending school and this is a precursor for child labour [3]. Energy poverty is assessed using different parameters; accessibility to modest energy resources – biofuels, liquefied petroleum, kerosene, charcoal, and conventional energy resources such as wood and animal waste. It is another parameter that has been used in evaluating the amount and quality of energy that households consume per year [4]. The inability of households to afford energy may be attributed to low incomes, unemployment, or the high cost of energy services provided [5]. Other challenges to clean energy resources include lack of education, corrupt practices in the energy sector, and energy pricing [6]. Ultimately, the scarcity of conventional fossil fuels has pushed up the prices lately and slowed down economies. Accordingly, the search for renewable energy resources – bioenergy, in particular, is increasingly necessary for the 21st century. Clearly, with an intensified focus on the energy supply and problems caused by fossil fuels, increased attention to tap renewable and clean energy from biomass materials has become progressively unstoppable [7-9]. Bioenergy is considered the greatest potential to address the global energy demands in various sectors of the economy; transport, power, energy security, manufacturing, and construction [10]. The compelling reasons underpinning the intense interest in renewable energy sources (RES) is motivated by the fast depletion of fossil fuels, the looming climate crisis, advancement in scientific technologies, energy security, and social acceptance among the energy consumers [11]. Owing to the aforementioned features of RES, bioenergy possesses elegant potentially attractive features in fulfilling the primary energy demands worldwide with industrialized nations – USA [12], Germany, Brazil, Japan, and China [13] marked the highest energy consumers. Opportunities, advantages, barriers, and technical issues that impede bioenergy systems have been widely reported in the literature [14]. Bioenergy is carbon neutral and does not result in emissions of GHGs. Nonetheless, its supply involves key players such as the general public, growers of biomass materials, production of biomass intermediaries, regulatory authorities, plant owners, and energy plant operators [15]. In order to assess these concerns, it is necessary to evaluate the bioenergy developments and the policy framework governing the economic viability, environmental concerns as well as social acceptability [15].

Generally, vegetable-based fuels for diesel engines are becoming popular alternatives to petroleum diesel based-fuels because they are considered green and environmentally friendly [16]. Biofuel platforms are modest and their use as transport fuels is expected to enhance energy security, energy sustainability, and boost economies [17]. Incorporating new technologies and promoting favourable investment policies will significantly encourage the growth and development of bioenergy resources [18, 19]. Besides, the utilization of high-yielding lignocellulosic feedstocks has sustainably provided bioenergy for use in transport and other uses without jeopardizing food supplies [20]. The sustainability of the first, second, third, and fourth-generation biofuels coupled with state-of-the-art production technologies has immensely increased the capacity of bioenergy production [21]. The first generation utilized edible feedstocks whereas the second-generation biofuels were extracted from non-edible biomass. On the other hand, third-generation biofuels are obtained from micro-organisms while the fourth generation biofuels are produced from modified micro-organisms [22]. Despite bioenergy maintaining low carbon emissions (LCE), sustainability in producing bio-based chemicals and biofuels via various bio-refinery technologies is still a major challenge [23]. Biomass feedstocks such as corn and sugarcane contain high levels of starch and glucose, respectively but their use as biofuel sources threaten food supply [24]. Lignocellulosic feedstocks on the other hand are still economically uncompetitive because their conversion to biofuels is not only laborious but energy-intensive [23]. It is therefore worth noting that, the availability of diverse varieties of biomass, biofuels, and bio-conversion technologies requires an adequate understanding of how bioenergy platforms can foster sustainable energy demands in the world today [25]. Biomass refinery technologies that are environmentally desirable [26, 27] as well as the ability to secure reliable feedstock [28] are still a major challenge towards the growth of bioenergy. Policymakers worldwide have designed strategic policies in line with millennium sustainable development goals [25]. Presently, energy policies worldwide are highly debated especially in the USA and mainly the European Union (EU) countries [29], with specific issues being energy sufficiency, decreased importation of fossil fuels, energy security, and volatile prices of natural gas and petroleum products [30-32]. Unsustainable bioenergy practices such as harvesting biomass feedstock from the forest, forest clearing for biofuel-crop cultivation, use of chemical fertilizers has led to considerable deterioration of natural ecosystems, emissions of GHGs due to declining carbon sequestration, degradation of agricultural lands, and loss of biodiversity [33, 34]. Bioenergy policies have been structured to encourage agricultural activities [35] as well as to protect the environment [36]. The bioenergy policy framework has been developed and implemented from environmental, economic, and political frameworks over the past decades [37]. These areas are often the driving forces for the production of biofuels at a commercial scale as well as other forms of renewable energy resources (RES) [38].

The main focus of this study is to provide an overview of widely explored biomass feedstocks – *Croton megalocarpus*, soya beans, *Jatropha curcas*, and palm seeds as well as bio-oil technological conversion procedures that have been employed to improve the quality of bio-oil. Bioenergy is important in accelerating energy demands for primary applications such as cooking and heating. However, four dimensions of sustainable energy development; energy security, environmental sustainability, social acceptance, and economic viability are important determinants of bioenergy development. In this review, we provide a comprehensive study on the development and implementation of strategic decisions by policymakers in selected countries to ensure bioenergy platforms are sustainable. Accordingly, corruption as well as carbon taxation and energy prices are discussed based on the future direction of bioenergy development.

Bio-oil from biomass materials

Biomass materials offer the largest inexpensive and renewable energy resource on earth but unfortunately, the potential of such biomass is generally underutilized since most of it is wasted in agricultural practices during harvesting and food processing [39, 40]. Bio-oils are the main volatile products from the pyrolysis of biomass materials considered potential fuels to run diesel engines, gas turbines, boilers, and cooking. Besides, it can be used as raw materials for the production of essential chemicals, such as resins, pharmaceutical products, and hydrocarbons, by appropriate treatment techniques [41, 42]. Cellulose bio-oil displays unique saccharides and higher furan levels [41]. The knowledge of the formation mechanism of bio-oils is highly important for the utilization of biomass resources [41]. Remarkably, there has been an increased shift to biodiesel globally owing to the abundance of raw materials and the fact that non-petroleum-based diesel is environmentally friendly and this has motivated increasing exploration efforts in search of a variety of potential biodiesel feedstock [43]. Some of the notable feedstock currently in use as sources of biodiesel includes soya beans, palm oil, Jatropha, and lately *Croton megalocarpus* plant [43]. Among these sources, the potential for Jatropha and palm oil as future sources of bio-oil is overwhelming.

Bio-oil from Croton megalocarpus as a model bio-oil plant

Croton megalocarpus plant is a relatively new potential source of biodiesel but it is yet to receive extensive attention – it is known to produce non-edible transparent liquid bio-oil [44]. Generally, bio-diesel can be prepared locally from non-edible oils which include *C. megalocarpus* oil, castor oil, or edible waste vegetable oils [7]. This presents an economical renewable fuel resource and has lower emissions than petroleum-based diesel as well as the fact that it can be used alone or in binary forms with commercial diesel [7, 45]. Figure 2 shows the *C. megalocarpus* plant and its seeds and has previously been considered a central source of biofuel. International Energy Agency's World Energy Outlook 2011, reports that 60% of the population in Africa, approximately 600 million people, and mostly in sub-Saharan Africa, did not have access to electricity by 2009 and proposed the native croton-based bio-oil be harnessed to electrify Africa [46].

Fig. 1 *Croton megalocarpus* plant (a) dried croton seeds and (b) is the dried croton seeds with pods – modified from [45]

Because studies have shown that *Croton megalocarpus* is an indigenous tree in East and South Africa which has recently attracted lots of interests as a biofuel source owing to its high oil yield; the potential solution to electrify Africa largely depends on biofuels, particularly because of the copious supply of biofuel resources in this continent and the affordable price for their application [16, 46]. Even though previous investigations have shown that *C. megalocarpus* bio-oil emits fine particulates and high levels of free radicals at elevated temperatures that can cause biological tissue damage [45], it is a better compromise and a promising solution to Africa's energy problems particularly with a little modification in engine design or on the introduction of an initiator in the *C. megalocarpus* biodiesel.

Bio-oil from palm oil

Although many Asian countries produce palm oil, Malaysia is the global leader in terms of production and its utilization of palm oil as a biodiesel source [43]. In terms of bio-oil yields, palm oil has a higher yield compared with the other common resources of bio-oil (Fig. 3) per hectare of farmland. Peak oil yields of 12 t $ha^{-1}yr^{-1}$ have been recorded in small scale palm plantations although maximum yields are predicted theoretically at 18.5 t oil $ha^{-1}yr^{-1}$, yet the average productivity worldwide has stagnated at about 3 t oil $ha^{-1}yr^{-1}$ [47]. Moreover, the cultivation of palm oil is cost-effective because it requires low application of fertilizer and other inputs such as pesticides. Palm oil has also been reported to have better oxidative stability compared with other bio-oil feedstock such as jatropha, even though its oil has negatively been associated with NO_X emission [48]. Nonetheless, such emissions can significantly be reduced by using catalytic converters in automobiles [49].

Jatropha curcas as a source of bio-oil

Jatropha plant has been identified as a major source of biodiesel owing to its high oil content of approximately 30% by weight, and it reportedly yields up to 5 tons of seed yearly Ha^{-1} [51]. Jatropha is believed to have originated in North America and later on introduced to South Africa, Mozambique, India, Indonesia, and the Philippines by colonialists. Besides holding the prospect of being a major bioenergy source, Jatropha is an extremely hardy plant grown in semi-arid areas and can withstand drought and survive in harsh temperature conditions where other plants cannot.

Fig. 2 Palm oil seeds - adapted from [50]

Jatropha yields higher biodiesel of 51.78% when compared to palm oil whose yield is approximately 23.44% [52]. Several studies have revealed that Jatropha has a significantly high potential to generate electricity effectively minimizing overreliance on petroleum diesel [53]. Furthermore, the cultivation of Jatropha is an income earner, contributing to economic growth among farmers and small-scale enterprises [54]. Nevertheless, some varieties of Jatropha are toxic to humans because of poisonous chemicals found in its seeds – phorbol esters, trypsin inhibitors, lectins, and phytates [52]. Extraction of bio-oil from Jatropha is via either a mechanical process or by a chemical-aided process [55]. Engine-driven screw press is a widely used method produces up to 80% of the available Jathropa seed oil [56], which is lower than that from the chemical extraction process (solvent extraction) that yields approximately 98 % of the available oil, although the chemical procedure is only economical in large scale production [52]. Transesterification is also useful in obtaining biodiesel from Jatropha oil, where lower molecular weight alcohol such as methanol displaces glycerol from triglycerides leaving methyl esters (biodiesel) [57]. This is an equilibrium process in which alcohol is added to the oil in the ration 6:1 to shift the equilibrium to the right thus favouring the production of biodiesel; in this case, NaOH or KOH is introduced as a catalyst to achieve the 98% yield within a reaction time of two hours at 60 ℃ [57].

Soybean as a biodiesel source

Soybean is a leguminous crop that has been utilized by many countries as a major biodiesel source and it is a major crop in Asia and the United States [58, 59]. The United States is the world's largest producer of this crop accounting for 32% of the world's production whereas South Africa is the largest producer in Africa [60]. Brazil produces 28 % of the world's soybean production [61]. The attractiveness of soya bean as biodiesel feedstock is attributed to the high oil content of its seeds which when crushed yields 18 - 20% oil [62]. In the last decade, biodiesel production from soybean has significantly increased into billions of gallons but the major challenge is that soybean oil has various competing uses; notably as cooking oil and its wide industrial applications [60]. Soya biodiesel is a fuel alternative obtained from soya bean oil through transesterification to yield methyl esters (biodiesel) and glycerine [61]. Soya biodiesel can be efficiently used in diesel engines without any form of modification because it is free from petroleum diesel although the two can be blended to produce better combustion characteristics [60]. Biodiesel from soybean has advantages over petroleum diesel in that it has been proven a better lubricant, and is associated with reduced emissions to the environment in the form of unburned hydrocarbons, carbon monoxide, soot, and the notorious greenhouse gas CO_2 [61].

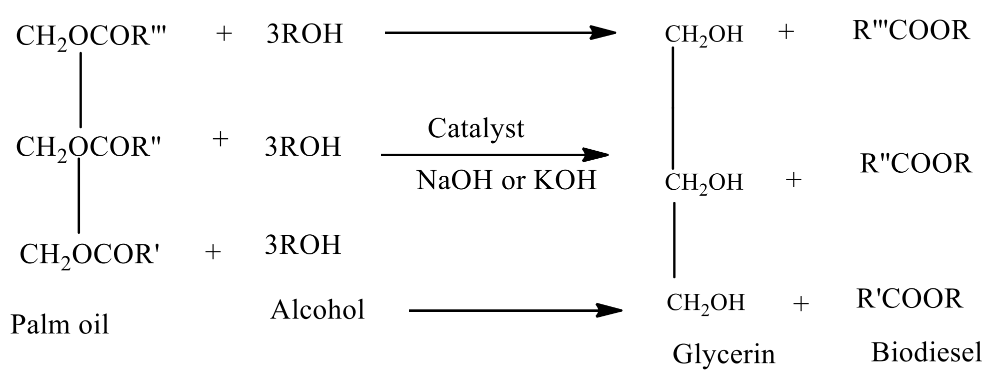
Transesterification of bio-oil to biodiesel

Plant-oil is transformed into biodiesel by transesterification (Scheme 1) of vegetable oils using short-chained alkanols, preferably methanol or ethanol – a process that involves catalysis by an alkaline solution or acids whereas other studies have proposed its conversion to fatty acids and ultimate transformation into biodiesel [63]. The attractive nature of bio-oil lies in its characteristics, for example, bio-oil from palm oil is currently quite attractive owing to its properties such as non-toxicity, easily biodegradable, absence of greenhouse gas emissions, and most importantly the fact is sulfur-free [64].

Parameters affecting the yield of bio-oil

Recent advances on biomass pyrolysis have focused on the yield and quality of bio-oil produced by numerous types of biomass materials [65]. The formation of bio-oils from various biomass components can be demonstrated by several mechanistic channels. The yield depends on biomass composition as well as reactor parameters such as temperature, reaction time, heating rate, feed rate, and the catalyst applied [65, 66]. Temperature besides having the highest influence on biomass pyrolysis is positively correlated with bio-oil yield [65]. Table 1 shows that other than temperature influence, the yield of bio-oil also depends on the nature of biomass and reactor type. Other factors such as the particulate size of the feedstock, elemental composition of the biomass, and its pre-treatment have been reported to significantly affect the bio-oil yield [67].

Biomass can also be converted into important carbon materials as well as essential chemicals [84] via physio-chemical [85], biochemical [86], and thermochemical processes. Wastes from biomass can be utilized in the generation of char which plays a significant role in wastewater treatment, soil amendment, and energy recovery [87-89]. Through various thermochemical technologies, biomass can be used to generate important products [90] such as formic acid and lactic acid [84]. Figure 3 illustrates various thermochemical processes and important products derived from biomass. Ideally, pyrolysis is not only the first stage of combustion but also an individual technique to form liquid products of high energy density and it is a promising thermochemical conversion route for biomass components in limited oxygen to produce bio-oil, gases, and bio-char which has found significant importance in water purification and soil improvement [91].



Scheme 1 Formation of biodiesel from palm oil via transesterification procedures

Table 1 Type of biomass and corresponding bio-oil yields

Biomass type	Type of reactor	Temp. (^{o}C)	Bio-oil yield (wt%)	Type of pyrolysis	Ref.
Grape bagasse	Stainless steel fixed-bed reactor	550	27.6	Fast pyrolysis	[68]
Hardwood and softwood from pine tree	Tubular vacuum pyrolysis reactor	450	55.0	Fast pyrolysis	[69]
Municipal, livestock, and wood waste	Internal circulating fluidized-bed (ICFB) reactor	500	39.7	Fast pyrolysis	[70]
Plant thistle, Onopordum acanthium L.	Fixed-bed reactor	550	27.0	Slow pyrolysis	[71]
Potato skin	Stainless steel fixed-bed reactor	550	24.8	Steam pyrolysis	[72]
Pinewood sawdust	Conical spouted bed reactor	500	75.0	Fast pyrolysis	[73]
Pinewood	Auger reactor	450	50.0	Fast pyrolysis	[74]
Waste furniture sawdust	Fluidized-bed reactor	450	65.0	Fast pyrolysis	[75]
Rice husks	Fluidized-bed reactor	450	60.0	Fast pyrolysis	[76]
Sugar cane waste	Fixed-bed fire-tube heating reactor	475	56.0	Fast pyrolysis	[77]
Corn cobs and stover	Bubbling fluidized bed reactor	650	61.9	Fast pyrolysis	[78]
Laurel (Laurus nobilis L.) extraction	Fixed-bed reactor	500	21.9	Fast pyrolysis	[79]
Corncob	Fluidized-bed reactor	550	56.8	Fast pyrolysis	[80]
June stick	Continuous feeding fluidized bed reactor	500	66.7	Fast pyrolysis	[81]
Apricot Pulp	Fixed-bed reactor	550	22.4	Fast pyrolysis	[82]
Wood sawdust	Cyclone	650	74.0	Fast pyrolysis	[83]

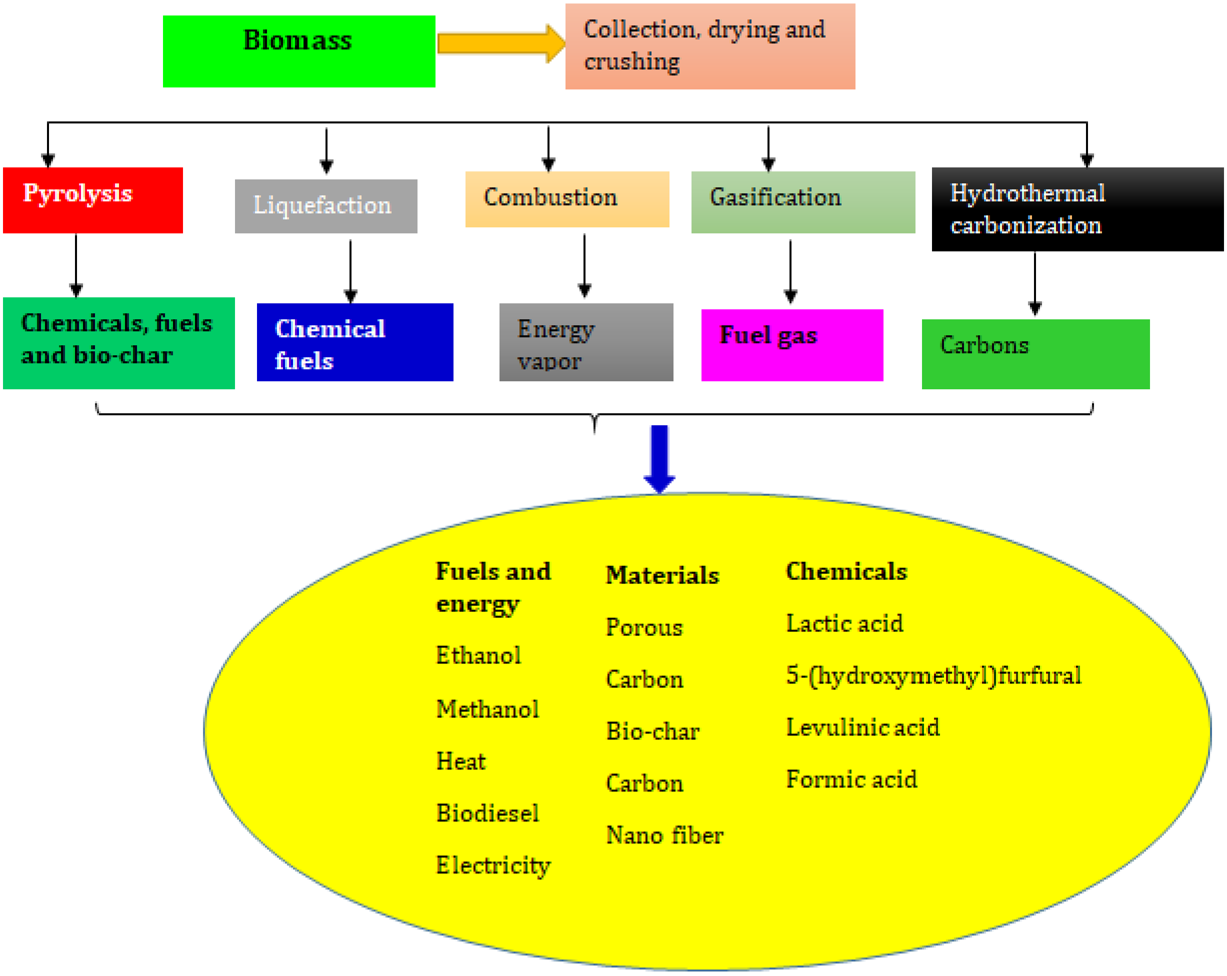
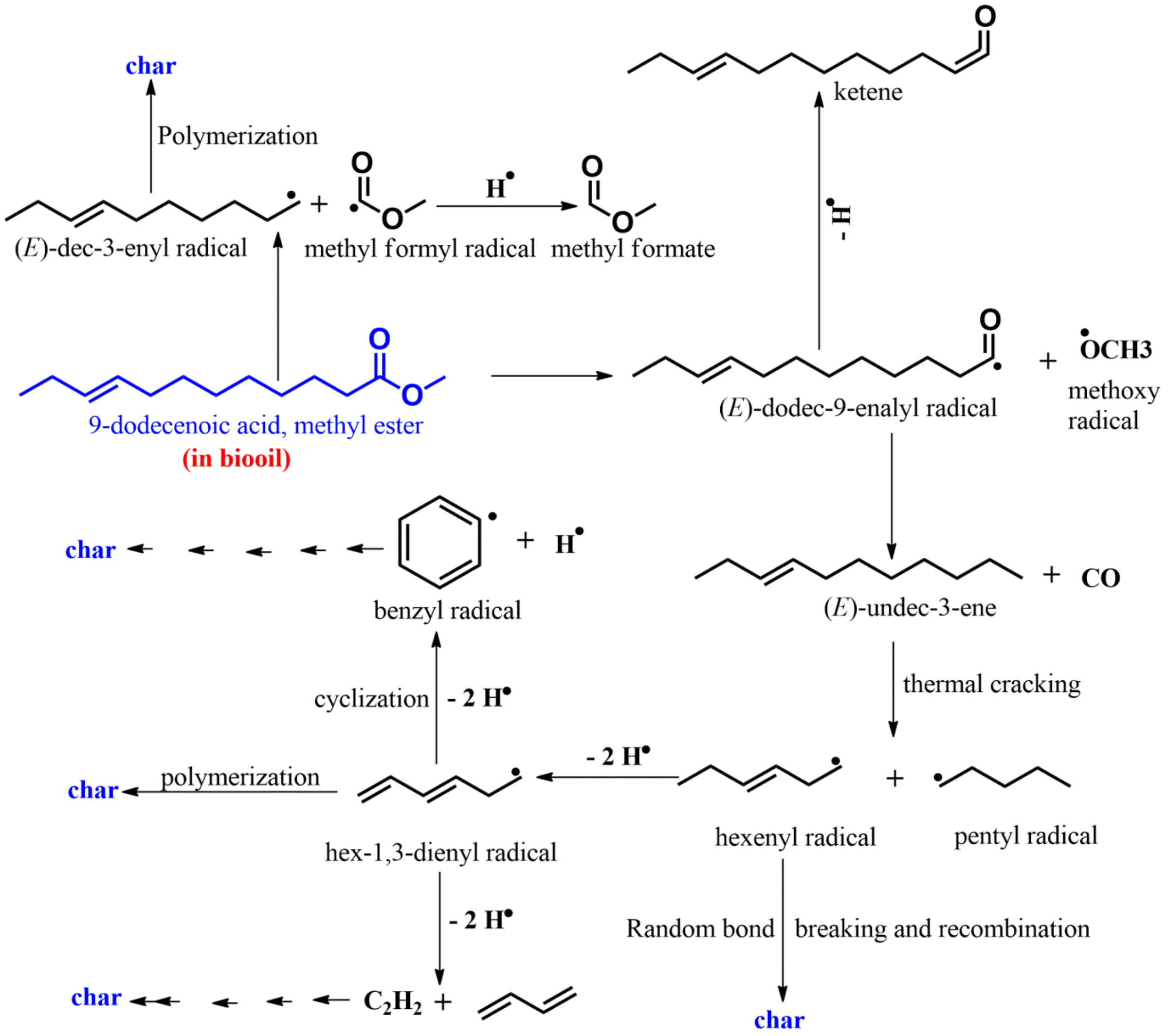


Fig. 3 Various thermochemical processes of biomass and their products [84]

The quality of bio-oils can be improved by hydrogenation [92], catalytic cracking [93, 94], and steam reforming [95, 96]. These methods transform oxygenated compounds in bio-oils to hydrocarbons, aromatics, hydrogen, and syngas [86]. From a chemical perspective, bio-oil is a multi-component mixture containing water and different types of organic compounds, including hydrocarbons and oxygenated compounds such as phenols, furans, aldehydes, and ketones, among other organics [97-99]. Despite its dark brown viscous appearance, elemental analysis of bio-oil indicates that it contains relatively little sulfur and nitrogen content, but has a high oxygen content, typically between 40 wt% and 50 wt% including water, implying that bio-oils are highly oxygenated, contains complex mixtures, viscous, relatively unstable, and susceptible to ageing and this is a major challenge towards its utilization [7, 41]. Therefore, although bio-oil is a promising alternative to crude oil for wide application in industries and internal combustion engines, its applications have been impeded by poor bio-oil quality as a result of expensive appropriate technologies to convert it into high-grade biodiesel [100]. Scheme 2 shows the mechanistic pathways through which bio-oil is converted to various reaction products.



Scheme 2 Conversion of bio-oil to char and other combustion by-products through various mechanistic processes – Adapted from [44]

The oxygenated compounds in bio-oil can be transformed into light chemical reaction products during the upgrading processes, which involve hydrogenation, hydrodeoxygenation, ketonization/aldol condensation, aromatization, and cracking [101]. For example, bio-oil cracking mainly comprises pyrolytic cracking of the C—C bond cleavage, hydrogen radical transfer, aromatic side-chain scission, isomerization, concerted reactions, rearrangements as well as deoxygenation reactions including decarboxylation, decarbonylation, and dehydration reactions as presented in scheme 2 [44, 100].

Environmentally persistent free radicals (EPFRs) in bio-oil

Electron paramagnetic resonance (EPR) spectroscopy is an analytical method to explore materials with unpaired electrons and therefore, it is an important technique to probe the presence of radicals in the bio-oil matrix [102, 103]. Conventionally, EPR measures energy absorption attributed to the transition of sub-atomic particles such as electrons between different energy levels caused by the interaction of free radicals with the magnetic field component of the microwave radiation in the presence of an external magnetic field applied to the sample [45, 102]. EPR has been used broadly to study free radicals in various condensed phases, such as biochar [44, 103] – Figure 4. Previous research [104] has established that levoglucosan (a major component of bio-oil) breaks down in what is referred to as ring opening to form radicals that can rapidly react to form a wide range of products. However, these radicals are transient and may not be responsible for the observed stability of free radicals in the bio-oil matrix. Nonetheless, bio-oil produced for use as a transport fuel is a burden to the environment and public health systems because of the reactive free radical species which can be emitted during combustion [44, 105]. Although biodiesel is an environmentally friendly alternative to fossil diesel, its degradation triggered by radical oxidative reactions produces free radical species capable of damaging the mechanics of combustion engines [106]. The rate of degradation of biodiesel is associated with the duration of producing the free radical species, implying that the longer the time of radical formation, the longer it takes the biofuel to complete the oxidative radical reaction cycle [107].

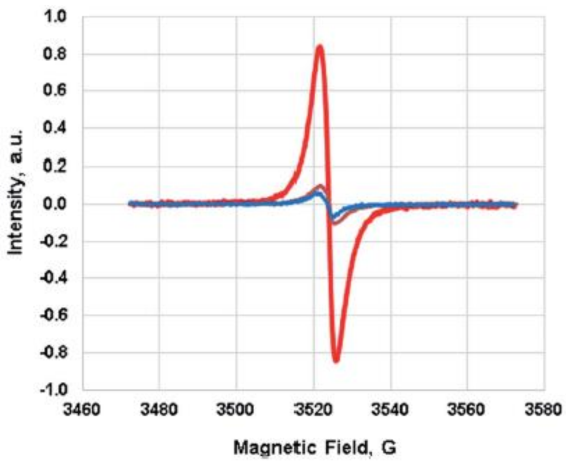


Fig. 4 EPR spectra of bio-oil extracted from pyrolytic lignin – adapted from [103]

From a public health perspective, environmentally persistent free radicals emitted from the combustion of biodiesel or bio-oil are candidate precursors for acute health problems including cancer, cardiac-related problems such as oxidative stress, respiratory diseases, and cell injury triggered by reactive oxygen species (ROS)[108, 109]. Because reactive free radical species from thermal emissions from the thermal degradation of bio-oil are very stable, then they are conventionally referred to as environmentally persistent free radicals (EPFRs). These persistent free radicals represent a class of reactive species that have longer lifetimes uniquely in ambient environments and have been the subject of grave scientific concern in various studies [110]. Generally, the term environmentally persistent free radicals (EPFR) implies radicals that have long lifetimes in the combustion reaction atmosphere; for example, the lifetime of HO_2 radicals are in the region of 1.0 ms [111]. From a biological health standpoint, evidence in the literature has proven that proteins are major targets for free radical attack in biological systems because of their abundance and high rate constants, which inevitably result in tissue and cell damage at various sites of protein components followed by protein unfolding and altered conformational interaction landscape [112].

The future trends in the use of biomass

Scientists and government authorities have in recent times focused on the search for alternative sources of energy that can be generated using locally available resources [113]. The global focus has therefore shifted to bioenergy [114]. The increased focus on bioenergy has been necessitated by high oil and gas prices, and the desire for sustainable energy resources [114]. In developed countries, a shrunken global market for surplus farm produce has been strongly linked to biomass energy and this justifies the proposition that 'biomass fuel can revive the aborted Doha round of agricultural trade negotiations' at the World Trade Organization [114, 115]. Low-cost biomass fuel has catalysed industrial activities – fetches good returns because it utilizes locally available resources [113]. Global use of biomass to generate electricity is expected to increase in the near future [116]. This trend is expected to be higher in developing countries where the current energy consumption from biomass stands at 35% whereas at the global stage the consumption stands at 14% [117]. It is estimated that global emissions of greenhouse gasses (GHGs) will drop with the increased use of renewable bioenergy considered cost-effective, clean, and sustainable [116]. The future use of biomass and biofuel use depends on the availability of cheap locally available resources and incentives to investors from government policies [113]. The world's projected energy usage is estimated to rise to 623 exajoules by 2035 with biofuels accounting for a quarter of the energy projection - only possible when biofuel technologies are enhanced [117]. It is also believed that by improving the efficiency of agriculture and forestry, biofuels generation will improve without jeopardizing food production. Additionally, the tendency of households and industries to switch to biofuels is largely dependent on the policymaker's introduction of subsidies, tax reduction, and provision of incentives [117]. Currently, green transport relies on biodiesel and ethanol as fuels are obtained from canola, corn, and sugarcane [117]. The current production of biodiesel stands at 20 billion litres [113]. Extensive use of agricultural land in the cultivation of biofuel producing crops such as canola, sugarcane, corn, oil palm, and soya beans will increase the generation of biofuels and ethanol significantly in the future to come [117].

Policymakers and researchers opine that besides generating electricity, the use of biomass materials can be largely cost-effective and may be applied in heating homes [118-120]. This study also reported that saving one ton of carbon dioxide (CO_2) will cost an estimated $149 when biomass replaces coal in a power plant [118]. Furthermore, the same study reported that by using biomass in boilers instead of fossil fuel oil, a significant amount of money more than $52 is saved for every ton of CO_2 decreased [118]. Therefore, owing to a myriad of factors involved, it is a challenge to predict the cost-cutting potential of biomass because of factors that determine the cost reduction capacity of biomass which is not limited to nature and supply of feedstock, land availability, industrial utilization, and deforestation related issues, reduction in the cost of feedstock and increased production at relatively low cost which will, in turn, make bioenergy prices very competitive [121, 122]. Nonetheless, the cost of storage and transportation of biomass pellets is significantly lower than those of fossil fuel oils although it is suggested that the incorporation of biomass with common agricultural activities such as crop rotation can enhance yields at lower costs [118]. The cost benefits of using biomass can therefore be summed up as: lowered energy cost, reduction in greenhouse gas emissions, guaranteed security of power supply, enhanced economic growth, increased employment opportunities, and better waste management [121, 123, 124].

Bioenergy development and the existing policy framework in a developing country – Kenya

Currently, the usage of biomass as a renewable energy resource in Kenya stands at 68% relative to other forms of energy, with 89% and 34% consumption of wood fuel and charcoal, respectively in rural Kenya according to 2009 statistics [125]. The development of biofuels in developing countries has not been robust because of the intense focus on poverty reduction, environmental health concerns, and lack of technologies to convert biomass to modest biofuel [126]. Kenya has enormous potential for the development of bioenergy mainly for power generation and in form of liquid biofuel such as ethanol whose annual production is estimated at 41 million litres [125]. The ever increasing global oil prices have pushed Kenya to focus on the development of alternative sources of energy in the form of biofuel and subsequently come up with a policy framework for the establishment of biofuel plants [125]. Recently, Kenya has come up with policy and legislation on energy, forest, and charcoal protocols that are intended to shape biomass energy development. The policy framework that encourages the utilization of biomass is contained in Sessional Paper No.4 of 2004 on Energy, Energy Act of 2006, and Feed-in Tariff Policy for Renewable Energy [127].

The report explored the possible ways in which biomass use or development of bioenergy can be supported or impeded by societal, fiscal, or environment-related issues [127]. The major bottlenecks in the development of bioenergy as a source of electricity and motor use are: (i) limitations related to unavailability of technical expertise, (ii) lack of confidence in sugar farmers, (iii) unclear mode of financing, (iv) imminent sale of existing sugar factories and (v) lack of feed-in tariffs [127, 128]. Nonetheless, the report highlighted the following as key policy recommendations;

- a reliable and sustainable supply of feedstock
- a clear way of financing farmers
- clear revenue sharing formula between farmers and the state
- modernization of boiler technology

The challenges faced by Kenya towards the development of bioenergy and the salient recommendations that the country has put in place can be replicated in many other developing as well as developed countries. Overcoming these teething problems will promise better energy security and a cleaner environment.

Bioenergy development and the existing policy framework in the eu and brazil

Due to the increase in demand for energy, various energy supplies have been diversified in various parts of the world to mitigate against climate change as well as provide an enabling environment for the development of European industries [129]. Currently, bioenergy in the EU is the most consumed and flexible energy with EU's biomass production higher than coal and domestic gas [130]. The consumption of energy in the EU member states aims at achieving a low carbon economy [131]. Moving towards a low-carbon economy, the EU, has been tasked to produce liquid biofuels that are economically, environmentally, and socially acceptable [132]. This aims at replacing conventional fossil fuels as transport fuels as well as reducing overdependence on imported energy resources. A range of energy sustainability development perspectives is environmental, social, economic, and politically motivated policies [133]. There have been legislative policies that promote the adoption of green energy and hence realizing low net GHGs emissions [131]. The Renewable Energy Directive (RED) 2009/28/EC that was proposed in 2012 aimed at replacing 20% of the total energy and 10% of the energy used in the transport sector with RES by the year 2015 [131]. The deployment of bioenergy in the region is tied to major policies of renewable energy as a whole [130]. Policies promoting bioenergy include, agricultural policies that promote the cultivation of energy crops, stimulated residue collection, and/or improving crop yields [130]. In 2014, the European Council targeted at least 40% domestic reductions of GHGs emissions by the year 2030 compared with 1990 in line with the 2030 Climate and Energy Framework [134]. Currently, the EU signed the Paris Agreement in 2016 that replaced the Kyoto Protocol [135, 136], and subsequently, the European council parliament adopted the 2030 climate and Energy

Framework in 2018 [130]. The key highlights of this legislative package were:

- The reduction of annual GHGs emissions by its member states from 2021 to 2030.
- The European Parliament and the European council included GHGs emissions and removal from the forestry, land use, and land-use change in the 2030 climate and energy framework. This policy aimed at removing CO_2 from the atmosphere in the period 2021 to 2030.

The European Commission also published a climate strategy proposal for the years up to 2050 with a major aim being to ensure a carbon neutral EU economy by the year 2050 [130]. Besides, it was proposed that at least 25% of the annual budget be injected into this strategic plan [130]. The severe acute respiratory syndrome coronavirus-2019 (SARS Covid-2019) has challenged the renewable energy policies by causing a financial burden worldwide and has immensely disrupted economies in Europe and across the world. It is more likely that the current policies in place will be tremendously challenged by the COVID-19 global pandemic.

Brazil has heavily invested in bioenergy, currently being the pioneer in the utilization of liquid biofuels such as unique ethanol and biodiesel blends as transport fuel [137]. Brazil's economy has attracted considerable attention mainly because of its ability to reduce overdependence on conventional fuels and foster energy security with clean bioenergy resources [138]. Sugarcane is the primary feedstock that is largely utilized in Brazil for bioenergy production [139]. Using biofuels has enhanced the decarbonization of transport fuels but has also had indirect and direct impacts on biodiversity [140]. These impacts include an increase in GHGs as a result of land use, land erosion, loss of soil fertility, and scarcity of freshwater [141]. The competing human needs such as adequate food supply and freshwater availability has triggered a serious debate on the production of bioenergy in the region. The efforts of Brazil to mitigate climate change according to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have been boosted by the availability of sugarcane considered suitable for ethanol production [142]. The current global pandemic (COVID-19) has stretched government budgets especially in putting in place containment measures against the pandemic [143]. The investment in clean energy is therefore challenged. The pandemic is a reminder to policymakers and the people to pay attention to scientific matters to reduce GHGs emissions including carbon taxation and energy pricing. The scientific community should be mandated to pursue potential strategic energy policies to ease natural disasters and possible future pandemics.

Bioenergy development, consumption, and corruption

Corruption has been widely cited as a major setback to energy development especially bioenergy development in a range of global jurisdictions [144]. The energy sector particularly the renewable energy system has become a target for corruption practices. This is motivated by huge revenues allocated to the sector, excessive oversight powers by public officials over energy resources, and the remoteness of major energy operations [144]. More importantly, both the oil and gas sectors have been criticized for condoning bribery according to the Bribe Payers Index commissioned by Transparency International – Kenya [145]. Besides slowing economic growth, corruption in the energy sector leads to severe consequences some of which include slowed rate in technological advancement, poor health, compromised living standards, loss of funds, and ultimately increased cost of energy which in turn has a negative ripple effect on other sectors of the economy [145, 146]. World Bank which has been a major financier of the energy sector in developing countries has emphasized strengthening governance as a mechanism to stem runaway corruption and bribery [145]. Data from developed and developing countries have revealed a strong relationship between institutional quality, corruption, and energy consumption [147]. Menegaki and Ozturk (2013) observed that political stability can either abate or hinder corruption [148]. In a related study, Sekrafi and Sghaier (2018) reported that corruption and energy consumption are positively correlated, and consequently, escalated corruption increases energy consumption [149]. Corruption being the use of public office for personal gain reportedly influences policy formulation and implementation especially those that concern bioenergy development but also provides immunity against adverse penalties arising from specific stringent energy-related policies [150]. Corruption retards the political will to support bioenergy development and in most cases plummets the subsidies directed to companies that deal with bioenergy production [150].

Carbon taxation and energy pricing

The challenge posed by global warming to humanity and the environment in the world today as a result of fossil fuel use cannot be underestimated [151]. The carbon tax is a tax imposed on carbon from fossil fuel consumption and has been proven to be the only mechanism that can encourage the transition from fossil-based fuels to biofuel besides increasing the cost of fossil fuels. Tax on carbon increases the competitiveness of biofuel energy [152]. The carbon tax is quite simple to compute and its computation is based on the carbon content of the fuel (Table 2) as the objectives of imposing carbon dioxide tax are aimed at impairing greenhouse gas (mainly CO_2) emissions and invest in cleaner alternatives [153]. Generally, the carbon tax (%) can be calculated using expression 1:

$$\text{Carbon tax rate } (\%) = CE \div P \times CT \times 100\% \quad (1)$$

where CE = the carbon equivalent of CO_2 emissions from combustion (Mg/GJ); P = price of fossil fuel ($/GJ); CT = carbon emission tax ($/Mg). Table 2 provides the amount of carbon in selected fossil fuels with the corresponding CO_2 emissions. Equation 1 does not apply to biofuels because combustion of biomass and biofuels releases an amount of carbon dioxide which is equivalent to the quantity utilized by the very plants used to generate bioenergy. The carbon tax has a direct effect on the pricing of fossil fuels since biofuel producers will heavily pay the levied tax, in turn, the prices of natural gas, coal, and oil will increase, and the chain continues to the consumers [153]. The nature gas commonly used by many households and other fossil fuels such as diesel used by power plants will be sold expensively [154].

Table 2 Fossil fuels and their carbon coefficients

Fossil fuel	Average low calorific value kJ/kg	Carbon content kgC/GJ	Rate of carbon oxidation	Carbon emission coefficients (tc/t)
Coal	20,908	25.8	0.913	0.4925
Coke	28,435	29.2	0.928	0.7705
Crude Oil	41,816	20.0	0.979	0.8187
Natural gas	38,931(kJ/m^3)	15.3	0.990	0.5896 tC/m^3
Fuel oil	41,816	21.2	0.985	0.8691
Gasoline	43,070	18.9	0.980	0.7977

This challenge can be surmounted by imposing carbon border taxes to get compliance with the use of clean energy systems [155]. Carbon taxation increases energy cost resulting in a depressed firm's profitability [156]

The current state of global carbon pricing

Putting a price on carbon to reduce greenhouse gas emissions and push investments into cleaner energy technologies has received positive momentum in many countries around the world [157]. It is estimated that 40 countries across the globe have embraced and implemented the two common types of carbon pricing: carbon tax or emission trading systems (ETS) as direct methods of pricing carbon [154]. The decision as to which to apply depends on the individual states and the prevailing fiscal situations [157]. Countries can also adopt indirect ways of pricing carbon such as payment of greenhouse gas emissions, removing subsidies on fossil fuels, and coming up with regulations that will adopt what is generally known as "social cost of carbon" [157]. Some of the countries that currently price carbon by imposing carbon tax include Sweden, Denmark, Finland, France, Ireland, Japan, Norway, and Slovenia with quite several other countries considering adopting carbon tax [154]. Interestingly, the carbon tax on fuels does not only mitigate greenhouse gas emissions but also promotes economic growth as reported in the case of Sweden which has been pricing carbon since 1990 (Fig. 5) and increasing its GDP by 60 % [152].

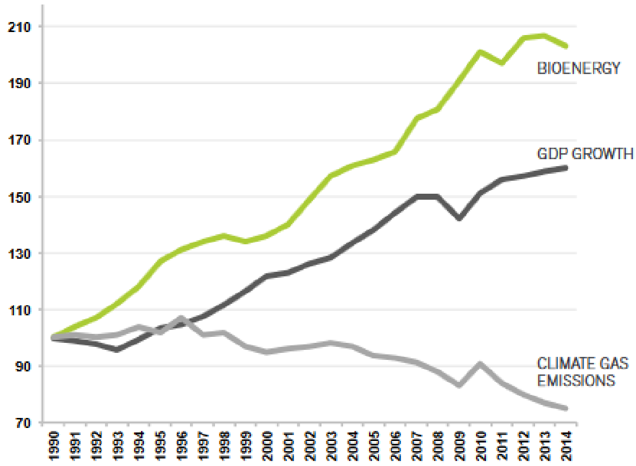


Fig. 5 Carbon pricing, economic growth, biofuel development of Sweden [145]

The price of carbon differs with jurisdictions, for example, France projects a carbon tax of 100 Euros per ton of CO_2 in the near future [154]. Reports indicate that Sweden heavily imposes a carbon tax on fossil fuels – arguably the highest carbon pricing for private consumers globally which currently stands at US$140 per tonne of CO_2 [152]. Some state organizations have tried to come up with a common minimum carbon tax imposed by its member states. Some of the directives have remained inactive. For example, European Union (EU) has given a directive to its member states to impose a common minimum carbon tax of 20 Euros per ton of CO_2 and like many others, this directive is yet to be processed for implementation [157].

CONCLUSION

There has been a remarkable shift to biodiesel worldwide because of the abundance of raw materials for the production of bio-based diesel which is considered environmentally friendly. This paper has shown that Jatropha seeds produce a high yield of bio-oil of 52% compared with most plants such as palm oil which produces 23% and soybean which generates about 18% bio-oil. This demonstrates that Jatropha produces bio-oil twice as much as that produced by palm oil and three times as much as that generated by soybean. This work, therefore, recommends the commercialization of Jatropha for large-scale biodiesel production especially in arid and semi-arid lands around the world. Although biodiesel is considered a green energy resource, its degradation to yield radical oxidative reactions produces free radical species capable of damaging the mechanics of combustion engines as well as impairing biological systems in humans. Nonetheless, biodiesel has excellent characteristics such as lowering the net greenhouse gas emission in the atmosphere. The by-product of biodiesel, glycerol, has also proven to be an alternative source of clean energy that can be used to produce hydrogen for clean energy combustion. Carbon trade has been projected as a necessary action by developing countries to reduce carbon emissions which ultimately are detrimental to the ecological environment. Nonetheless, implementation of a carbon tax regime has been cited to create uneven competition between companies that use taxed carbon and those in other jurisdictions that refuse to comply with carbon taxation protocols. It is also evident that the effort to develop bioenergy in most countries has been characterized by corrupt practices. The advancement strategy for clean energy resources will require not only better technological know-how but also political goodwill.

Declarations

Ethics approval and consent to participate
Not Applicable

Consent for publication
This article has the consent of all the authors

Availability of data and materials
N/A

Competing interests
The authors have no competing interests

REFERENCES

[1] R. Day,G. Walker and N. Simcock, Conceptualising energy use and energy poverty using a capabilities framework. Energy Policy, 93 (2016) 255-264.
[2] G.T. Tucho,H.C. Moll,A.J. Schoot Uiterkamp and S. Nonhebel, Problems with biogas implementation in developing countries from the perspective of labor requirements. Energies, 9 (2016) 750.
[3] D. Levison,D.S. DeGraff and E.W. Dungumaro, Implications of environmental chores for schooling: Children's time fetching water and firewood in Tanzania. The European journal of development research, 30 (2018) 217-234.
[4] M. Bersisa, Multidimensional measure of household energy poverty and its determinants in Ethiopia. Economic Transformation for Poverty Reduction in Africa. A Multidimensional Approach, (2019) 59-84.
[5] C. Liddell and C. Morris, Fuel poverty and human health: a review of recent evidence. Energy policy, 38 (2010) 2987-2997.
[6] H. Titheridge,R. Mackett,N. Christie,D. Oviedo Hernández and R. Ye, Transport and poverty: a review of the evidence. (2014)
[7] S.-Y. No, Bio-Oil and Pyrolytic Oil, in Application of Liquid Biofuels to Internal Combustion Engines. Springer, (2019) 181-219.
[8] A. Bridgwater and G. Peacocke, Fast pyrolysis processes for biomass. Renewable and sustainable energy reviews, 4 (2000) 1-73.
[9] M. Blander, Biomass gasification as a means for avoiding fouling and corrosion during

combustion. Journal of molecular liquids, 83 (1999) 323-328.
[10]J.P. Paredes-Sánchez,L.M. López-Ochoa,L.M. López-González,J. Las-Heras-Casas and J. Xiberta-Bernat, Evolution and perspectives of the bioenergy applications in Spain. Journal of Cleaner Production, 213 (2019) 553-568.
[11]P. Sadorsky, Some future scenarios for renewable energy. Futures, 43 (2011) 1091-1104.
[12]K. Bracmort, Biomass Feedstocks for Biopower: Background and Selected Issues. Congressional Research Service, (2010).
[13]O. IEA, Energy and climate change, world energy outlook special report. 2015, Paris, France: OECD, International Energy Agency, (2015).
[14]C.T. Smith,B. Lattimore,G. Berndes,N.S. Bentsen,I. Dimitriou,J. Langeveld and E. Thiffault, Opportunities to encourage mobilization of sustainable bioenergy supply chains. Wiley Interdisciplinary Reviews: Energy and Environment, 6 (2017) e237.
[15]L. Elghali,R. Clift,P. Sinclair,C. Panoutsou and A. Bauen, Developing a sustainability framework for the assessment of bioenergy systems. Energy Policy, 35 (2007) 6075-6083.
[16]F. Lujaji,A. Bereczky,L. Janosi,C. Novak and M. Mbarawa, Cetane number and thermal properties of vegetable oil, biodiesel, 1-butanol and diesel blends. Journal of thermal analysis and calorimetry, 102 (2010) 1175-1181.
[17]Y. Kim,J. Lee and J. Ahn, Innovation towards sustainable technologies: A socio-technical perspective on accelerating transition to aviation biofuel. Technological Forecasting and Social Change, 145 (2019) 317-329.
[18]D. So,F. Oo and Y. Eo, Bioenergy technologies adoption in Africa: A review of past and current status. Journal of Cleaner Production, (2020) 121683.
[19]D. Thrän,K. Schaubach,S. Majer and T. Horschig, Governance of sustainability in the German biogas sector—Adaptive management of the Renewable Energy Act between agriculture and the energy sector. Energy, Sustainability and Society, 10 (2020) 3.
[20]M. Bilal and H.M. Iqbal, Recent Advancements in the Life Cycle Analysis of Lignocellulosic Biomass. Current Sustainable/Renewable Energy Reports, (2020) 1-8.
[21]N.S. Mat Aron,K.S. Khoo,K.W. Chew,P.L. Show,W.H. Chen and T.H.P. Nguyen, Sustainability of the four generations of biofuels–A review. International Journal of Energy Research, (2020)
[22]H.A. Alalwan,A.H. Alminshid and H.A. Aljaafari, Promising evolution of biofuel generations. Subject review. Renewable Energy Focus, 28 (2019) 127-139.
[23]X.-H. Long,H.-B. Shao,L. Liu,L.-P. Liu and Z.-P. Liu, Jerusalem artichoke: a sustainable biomass feedstock for biorefinery. Renewable and Sustainable Energy Reviews, 54 (2016) 1382-1388.
[24]Y. Subramaniam,T.A. Masron and N.H.N. Azman, The impact of biofuels on food security. International Economics, 160 (2019) 72-83.
[25]S. Khishtandar,M. Zandieh and B. Dorri, A multi criteria decision making framework for sustainability assessment of bioenergy production technologies with hesitant fuzzy linguistic term sets: The case of Iran. Renewable and Sustainable Energy Reviews, 77 (2017) 1130-1145.
[26]C. Huang,H.J. Guo,H.R. Zhang,L. Xiong,H.L. Li and X.D. Chen, A new concept for total components conversion of lignocellulosic biomass: a promising direction for clean and sustainable production in its bio-refinery. Journal of Chemical Technology & Biotechnology, 94 (2019) 2416-2424.
[27]M.J. Stolarski,K. Warmiński,M. Krzyżaniak,E. Olba–Zięty and M. Akincza, Bioenergy technologies and biomass potential vary in Northern European countries. Renewable and Sustainable Energy Reviews, 133 (2020) 110238.
[28]J. Sadhukhan,E. Martinez-Hernandez,M.A. Amezcua-Allieri and J. Aburto, Economic and environmental impact evaluation of various biomass feedstock for bioethanol production and correlations to lignocellulosic composition. Bioresource Technology Reports, 7 (2019) 100230.

[29]F. Di Fulvio,N. Forsell,A. Korosuo,M. Obersteiner and S. Hellweg, Spatially explicit LCA analysis of biodiversity losses due to different bioenergy policies in the European Union. Science of the total environment, 651 (2019) 1505-1516.
[30]T. Aized,M. Shahid,A.A. Bhatti,M. Saleem and G. Anandarajah, Energy security and renewable energy policy analysis of Pakistan. Renewable and Sustainable Energy Reviews, 84 (2018) 155-169.
[31]V. Troster,M. Shahbaz and G.S. Uddin, Renewable energy, oil prices, and economic activity: A Granger-causality in quantiles analysis. Energy Economics, 70 (2018) 440-452.
[32]A. Bluszcz, European economies in terms of energy dependence. Quality & Quantity, 51 (2017) 1531-1548.
[33]S. Singh,D.K. Jaiswal,R. Krishna,A. Mukherjee and J.P. Verma, Restoration of degraded lands through bioenergy plantations. Restoration Ecology, 28 (2020) 263-266.
[34]P. Turner,K. Mach,D. Lobell,S. Benson,E. Baik,D. Sanchez and C. Field, The global overlap of bioenergy and carbon sequestration potential. Climatic Change, 148 (2018) 1-10.
[35]C.-C. Kung, A dynamic framework of sustainable development in agriculture and bioenergy. Agricultural Economics, 64 (2018) 445-455.
[36]A. Baumber, Enhancing ecosystem services through targeted bioenergy support policies. Ecosystem Services, 26 (2017) 98-110.
[37]Š.P. Malovrh,M. Kurttila,T. Hujala,L. Kärkkäinen,V. Leban,B.H. Lindstad,D.M. Peters,R. Rhodius,B. Solberg and K. Wirth, Decision support framework for evaluating the operational environment of forest bioenergy production and use: Case of four European countries. Journal of Environmental Management, 180 (2016) 68-81.
[38]S. Mittlefehldt, From appropriate technology to the clean energy economy: renewable energy and environmental politics since the 1970s. Journal of Environmental Studies and Sciences, 8 (2018) 212-219.
[39]G. Mtui and Y. Nakamura, Bioconversion of lignocellulosic waste from selected dumping sites in Dar es Salaam, Tanzania. Biodegradation, 16 (2005) 493.
[40]A.L. Demain,M. Newcomb and J.H.D. Wu, Cellulase, clostridia, and ethanol. Microbiology and molecular biology reviews : MMBR, 69 (2005) 124-154.
[41]C. Zhao,E. Jiang and A. Chen, Volatile production from pyrolysis of cellulose, hemicellulose and lignin. Journal of the Energy Institute, 90 (2017) 902-913.
[42]L. Mao,Y. Li and Z.C. Zhang, Upgrading of derived pyrolysis vapors for the production of biofuels from corncobs. Frontiers of Chemical Science and Engineering, 12 (2018) 50-58.
[43]N.A. Ludin,M.A.M. Bakri,N. Kamaruddin,K. Sopian,M.S. Deraman,N.H. Hamid,N. Asim and M.Y. Othman, Malaysian oil palm plantation sector: Exploiting renewable energy toward sustainability production. Journal of cleaner production, 65 (2014) 9-15.
[44]B.C. Mosonik,J.K. Kibet,S.M. Ngari and V.O. Nyamori, Environmentally persistent free radicals and particulate emissions from the thermal degradation of Croton megalocarpus biodiesel. Environmental Science and Pollution Research, 25 (2018) 24807-24817.
[45]J.K. Kibet,B.C. Mosonik,V.O. Nyamori and S.M. Ngari, Free radicals and ultrafine particulate emissions from the co-pyrolysis of Croton megalocarpus biodiesel and fossil diesel. Chemistry Central Journal, 12 (2018) 1-9.
[46]D. Wu,A.P. Roskilly and H. Yu, Croton megalocarpus oil-fired micro-trigeneration prototype for remote and self-contained applications: experimental assessment of its performance and gaseous and particulate emissions. Interface focus, 3 (2013) 20120041.
[47]L.S. Woittiez,M.T. van Wijk,M. Slingerland,M. van Noordwijk and K.E. Giller, Yield gaps in oil palm: A quantitative review of contributing factors. European Journal of Agronomy, 83 (2017) 57-77.
[48]S. Lim and L.K. Teong, Recent trends, opportunities and challenges of biodiesel in Malaysia: an overview. Renewable and

Sustainable Energy Reviews, 14 (2010) 938-954.
[49]I. Lozada,J. Islas and G. Grande, Environmental and economic feasibility of palm oil biodiesel in the Mexican transportation sector. Renewable and Sustainable Energy Reviews, 14 (2010) 486-492.
[50]C. McFadden, Seven Cool Biofuel Crops That We Use for Fuel Production. https://interestingengineering.com/seven-biofuel-crops-use-fuel-production#:~:text=Energy%20crops%2C%20so%2Dcalled%2C,companies%20mix%20them%20with%20gasoline, 2017 (accessed 26 September 2020).
[51]M.R. Giraldi-Díaz,D. Medina-Salas,E. Castillo-González and D. la Cruz-Benavides, Environmental Impact Associated with the Supply Chain and Production of Biodiesel from Jatropha curcas L. through Life Cycle Analysis. Sustainability, 10 (2018) 1451.
[52]K. Siregar,A.H. Tambunan,A.K. Irwanto,S.S. Wirawan and T. Araki, A comparison of life cycle assessment on Oil Palm (Elaeis guineensis Jacq.) and Physic Nut (Jatropha curcas Linn.) as feedstock for Biodiesel production in Indonesia. Energy Procedia, 65 (2015) 170-179.
[53]M.M. Mayorga,I.H. Orozco,Y.L. Pérez,N.C. Gomez and E.I. Martínez, Environmental assessment of electricity based on straight Jatropha oil on Floreana Island, Ecuador. BioEnergy Research, 11 (2018) 123-138.
[54]J.C. Sacramento Rivero,A. Eastmond-Spencer,J. Becerril García and F.S. Navarro-Pineda, A three-dimensional sustainability evaluation of jatropha plantations in Yucatan, Mexico. Sustainability, 8 (2016) 1316.
[55]A. Aderibigbe,C. Johnson,H. Makkar,K. Becker and N. Foidl, Chemical composition and effect of heat on organic matter-and nitrogen-degradability and some antinutritional components of Jatropha meal. Animal feed science and technology, 67 (1997) 223-243.
[56]W. Achten,B. Muys,E. Mathijs,V. Singh and L. Verchot, Life-cycle assessment of Bio-diesel from Jatropha curcas L. energy balance, impact on global warming, land use impact. in Book of Proceedings: the 5th International Conference LCA in Foods 25-26 April 2007, Gothenburg, Sweden. 2007.
[57]P. Chitra,P. Venkatachalam and A. Sampathrajan, Optimisation of experimental conditions for biodiesel production from alkali-catalysed transesterification of Jatropha curcus oil. Energy for sustainable development, 9 (2005) 13-18.
[58]F.G. Santeramo and S. Searle, Linking soy oil demand from the US Renewable Fuel Standard to palm oil expansion through an analysis on vegetable oil price elasticities. Energy Policy, 127 (2019) 19-23.
[59]A. Syafiuddin,C.J. Hao,A. Yuniarto and T. Hadibarata, The current scenario and challenges of biodiesel production in Asian countries: A review. Bioresource Technology Reports, (2020) 100608.
[60]M.L. Savaliya and B.Z. Dholakiya, A notice on newly synthesized silica-induced boron trisulfonic acid catalyst towards biodiesel synthesis from refined soybean oil. Research on Chemical Intermediates, 41 (2015) 8199-8210.
[61]O. Cavalett and E. Ortega, Integrated environmental assessment of biodiesel production from soybean in Brazil. Journal of Cleaner Production, 18 (2010) 55-70.
[62]D.R. Moses, Performance evaluation of continuous screw press for extraction soybean oil. American journal of science and technology, 1 (2014) 238-242.
[63]S. Mekhilef,S. Siga and R. Saidur, A review on palm oil biodiesel as a source of renewable fuel. Renewable and Sustainable Energy Reviews, 15 (2011) 1937-1949.
[64]B.H. Hameed,L. Lai and L. Chin, Production of biodiesel from palm oil (Elaeis guineensis) using heterogeneous catalyst: an optimized process. Fuel Processing Technology, 90 (2009) 606-610.
[65]R.E. Guedes,A.S. Luna and A.R. Torres, Operating parameters for bio-oil production in biomass pyrolysis: A review. Journal of analytical and applied pyrolysis, 129 (2018) 134-149.
[66]W.N.R.W. Isahak,M.W. Hisham,M.A. Yarmo and T.-y.Y. Hin, A review on bio-oil production from biomass by using pyrolysis

method. Renewable and sustainable energy reviews, 16 (2012) 5910-5923.
[67]J.A. Cunha,M.M. Pereira,L.M. Valente,P.R. De la Piscina,N. Homs and M.R.L. Santos, Waste biomass to liquids: Low temperature conversion of sugarcane bagasse to bio-oil. The effect of combined hydrolysis treatments. Biomass and bioenergy, 35 (2011) 2106-2116.
[68]I. Demiral and E.A. Ayan, Pyrolysis of grape bagasse: effect of pyrolysis conditions on the product yields and characterization of the liquid product. Bioresource technology, 102 (2011) 3946-3951.
[69]J.V. Ortega,A.M. Renehan,M.W. Liberatore and A.M. Herring, Physical and chemical characteristics of aging pyrolysis oils produced from hardwood and softwood feedstocks. Journal of Analytical and Applied Pyrolysis, 91 (2011) 190-198.
[70]J.-P. Cao,X.-B. Xiao,S.-Y. Zhang,X.-Y. Zhao,K. Sato,Y. Ogawa,X.-Y. Wei and T. Takarada, Preparation and characterization of bio-oils from internally circulating fluidized-bed pyrolyses of municipal, livestock, and wood waste. Bioresource technology, 102 (2011) 2009-2015.
[71]H.F. Gerçel, Bio-oil production from Onopordum acanthium L. by slow pyrolysis. Journal of Analytical and Applied Pyrolysis, 92 (2011) 233-238.
[72]E.P. Önal,B.B. Uzun and A.E. Pütün, Steam pyrolysis of an industrial waste for bio-oil production. Fuel Processing Technology, 92 (2011) 879-885.
[73]M. Amutio,G. Lopez,M. Artetxe,G. Elordi,M. Olazar and J. Bilbao, Influence of temperature on biomass pyrolysis in a conical spouted bed reactor. Resources, Conservation and Recycling, 59 (2012) 23-31.
[74]S. Thangalazhy-Gopakumar,S. Adhikari,H. Ravindran,R.B. Gupta,O. Fasina,M. Tu and S.D. Fernando, Physiochemical properties of bio-oil produced at various temperatures from pine wood using an auger reactor. Bioresource technology, 101 (2010) 8389-8395.
[75]H.S. Heo,H.J. Park,Y.-K. Park,C. Ryu,D.J. Suh,Y.-W. Suh,J.-H. Yim and S.-S. Kim, Bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed. Bioresource technology, 101 (2010) S91-S96.
[76]H.S. Heo,H.J. Park,J.-I. Dong,S.H. Park,S. Kim,D.J. Suh,Y.-W. Suh,S.-S. Kim and Y.-K. Park, Fast pyrolysis of rice husk under different reaction conditions. Journal of Industrial and Engineering Chemistry, 16 (2010) 27-31.
[77]M.R. Islam,M. Parveen and H. Haniu, Properties of sugarcane waste-derived bio-oils obtained by fixed-bed fire-tube heating pyrolysis. Bioresource Technology, 101 (2010) 4162-4168.
[78]C.A. Mullen,A.A. Boateng,N.M. Goldberg,I.M. Lima,D.A. Laird and K.B. Hicks, Bio-oil and bio-char production from corn cobs and stover by fast pyrolysis. Biomass and bioenergy, 34 (2010) 67-74.
[79]M. Ertaş and M.H. Alma, Pyrolysis of laurel (Laurus nobilis L.) extraction residues in a fixed-bed reactor: Characterization of bio-oil and bio-char. Journal of Analytical and Applied Pyrolysis, 88 (2010) 22-29.
[80]H. Zhang,R. Xiao,H. Huang and G. Xiao, Comparison of non-catalytic and catalytic fast pyrolysis of corncob in a fluidized bed reactor. Bioresource Technology, 100 (2009) 1428-1434.
[81]M. Asadullah,M.A. Rahman,M.M. Ali,M.A. Motin,M.B. Sultan,M.R. Alam and M.S. Rahman, Jute stick pyrolysis for bio-oil production in fluidized bed reactor. Bioresource Technology, 99 (2008) 44-50.
[82]N. Özbay,E. Apaydın-Varol,B.B. Uzun and A.E. Pütün, Characterization of bio-oil obtained from fruit pulp pyrolysis. Energy, 33 (2008) 1233-1240.
[83]J. Lédé,F. Broust,F.-T. Ndiaye and M. Ferrer, Properties of bio-oils produced by biomass fast pyrolysis in a cyclone reactor. Fuel, 86 (2007) 1800-1810.
[84]F. Shen,X. Xiong,J. Fu,J. Yang,M. Qiu,X. Qi and D.C. Tsang, Recent advances in mechanochemical production of chemicals and carbon materials from sustainable biomass resources. Renewable and Sustainable Energy Reviews, 130 (2020) 109944.
[85]P. Adams,T. Bridgwater,A. Lea-Langton,A. Ross and I. Watson, Biomass conversion

technologies, in Greenhouse Gas Balances of Bioenergy Systems. Elsevier, (2018) 107-139.
[86]X. Zhang,A. Athmanathan and N.S. Mosier, Biochemical conversion of biomass to biofuels. Valorization of lignocellulosic biomass in a biorefinery: from logistics to environmental and performance impact. Nova Science Publishers, New York, (2016) 79-141.
[87]B. Singh,B.P. Singh and A.L. Cowie, Characterisation and evaluation of biochars for their application as a soil amendment. Soil Research, 48 (2010) 516-525.
[88]K.A. Thompson,K.K. Shimabuku,J.P. Kearns,D.R. Knappe,R.S. Summers and S.M. Cook, Environmental comparison of biochar and activated carbon for tertiary wastewater treatment. Environmental science & technology, 50 (2016) 11253-11262.
[89]G. Wang,Y. Li,L. Sheng,Y. Xing,G. Liu,G. Yao,H.H. Ngo,Q. Li,X.C. Wang and Y.-Y. Li, A review on facilitating bio-wastes degradation and energy recovery efficiencies in anaerobic digestion systems with biochar amendment. Bioresource technology, (2020) 123777.
[90]T. Mathimani,A. Baldinelli,K. Rajendran,D. Prabakar,M. Matheswaran,R.P. van Leeuwen and A. Pugazhendhi, Review on cultivation and thermochemical conversion of microalgae to fuels and chemicals: process evaluation and knowledge gaps. Journal of cleaner production, 208 (2019) 1053-1064.
[91]A.V. Bridgwater, Review of fast pyrolysis of biomass and product upgrading. Biomass and bioenergy, 38 (2012) 68-94.
[92]H. Wang,S.-J. Lee,M.V. Olarte and A.H. Zacher, Bio-oil stabilization by hydrogenation over reduced metal catalysts at low temperatures. ACS Sustainable Chemistry & Engineering, 4 (2016) 5533-5545.
[93]F. Gong,Z. Yang,C. Hong,W. Huang,S. Ning,Z. Zhang,Y. Xu and Q. Li, Selective conversion of bio-oil to light olefins: controlling catalytic cracking for maximum olefins. Bioresource technology, 102 (2011) 9247-9254.
[94]Á. Ibarra,A. Veloso,J. Bilbao,J.M. Arandes and P. Castano, Dual coke deactivation pathways during the catalytic cracking of raw bio-oil and vacuum gasoil in FCC conditions. Applied Catalysis B: Environmental, 182 (2016) 336-346.
[95]P. Fu,W. Yi,Z. Li,X. Bai,A. Zhang,Y. Li and Z. Li, Investigation on hydrogen production by catalytic steam reforming of maize stalk fast pyrolysis bio-oil. International journal of hydrogen energy, 39 (2014) 13962-13971.
[96]M.V. Gil,J. Fermoso,F. Rubiera and D. Chen, H2 production by sorption enhanced steam reforming of biomass-derived bio-oil in a fluidized bed reactor: An assessment of the effect of operation variables using response surface methodology. Catalysis Today, 242 (2015) 19-34.
[97]S. Black and J.R. Ferrell III, Determination of carbonyl groups in pyrolysis bio-oils using potentiometric titration: review and comparison of methods. Energy & Fuels, 30 (2016) 1071-1077.
[98]D. Mohan,C.U. Pittman Jr and P.H. Steele, Pyrolysis of wood/biomass for bio-oil: a critical review. Energy & fuels, 20 (2006) 848-889.
[99]C.A. Mullen,G.D. Strahan and A.A. Boateng, Characterization of various fast-pyrolysis bio-oils by NMR spectroscopy. Energy & Fuels, 23 (2009) 2707-2718.
[100]X. Lian,Y. Xue,Z. Zhao,G. Xu,S. Han and H. Yu, Progress on upgrading methods of bio-oil: a review. International Journal of Energy Research, 41 (2017) 1798-1816.
[101]A.M. Smith,S. Singh and A.B. Ross, Fate of inorganic material during hydrothermal carbonisation of biomass: Influence of feedstock on combustion behaviour of hydrochar. Fuel, 169 (2016) 135-145.
[102]K.H. Kim,X. Bai,S. Cady,P. Gable and R.C. Brown, Quantitative investigation of free radicals in bio-oil and their potential role in condensed-phase polymerization. ChemSusChem, 8 (2015) 894-900.
[103]J. Meng,T.I. Smirnova,X. Song,A. Moore,X. Ren,S. Kelley,S. Park and D. Tilotta, Identification of free radicals in pyrolysis oil and their impact on bio-oil stability. RSC advances, 4 (2014) 29840-29846.
[104]R. Lanza,D. Dalle Nogare and P. Canu, Gas phase chemistry in cellulose fast pyrolysis. Industrial & Engineering Chemistry Research, 48 (2009) 1391-1399.

[105]Z. Sun,J. Yi,D. Feng,C. Kasbergen,A. Scarpas and Y. Zhu, Preparation of bio-bitumen by bio-oil based on free radical polymerization and production process optimization. Journal of Cleaner Production, 189 (2018) 21-29.
[106]A.C.G. Mantovani,L.T. Chendynski,A. Salviato,D. Borsato,V.T. Santana and E. Di Mauro, Monitoring free radicals formation in the biodiesel oxidation reaction via electronic paramagnetic resonance. Fuel, 224 (2018) 255-260.
[107]L. Chendynski,A. Mantovani,F. Savada,G. Messias,V. Santana,A. Salviato,E. Di Mauro and D. Borsato, Analysis of the formation of radicals in biodiesel in contact with copper and metallic alloys via electronic paramagnetic resonance (EPR). Fuel, 242 (2019) 316-322.
[108]S.J. Forrester,D.S. Kikuchi,M.S. Hernandes,Q. Xu and K.K. Griendling, Reactive oxygen species in metabolic and inflammatory signaling. Circulation research, 122 (2018) 877-902.
[109]M. Sitorus and D.R. Anggraini, Decreasing Free Radicals Level on High Risk Person After Vitamin C and E Supplement Treatment. (2017).
[110]N.W. Assaf,M. Altarawneh,I. Oluwoye,M. Radny,S.M. Lomnicki and B.Z. Dlugogorski, Formation of environmentally persistent free radicals on α-Al2O3. Environmental science & technology, 50 (2016) 11094-11102.
[111]M. Altarawneh and B.Z. Dlugogorski, Reactions of HO2 with n-propylbenzene and its phenylpropyl radicals. Combustion and Flame, 162 (2015) 1406-1416.
[112]M.J. Davies, Protein oxidation and peroxidation. Biochemical Journal, 473 (2016) 805-825.
[113]S. Ladanai and J. Vinterbäck, Global potential of sustainable biomass for energy. Swedish University of Agricultural Sciences, (2009).
[114]J. Caldwell, Fueling a New Farm EconomyCreating incentives for Biofuels in Agriculture and Trade Policy. Center for American Progress, (2007).
[115]K. Ericsson,S. Huttunen,L.J. Nilsson and P. Svenningsson, Bioenergy policy and market development in Finland and Sweden. Energy policy, 32 (2004) 1707-1721.
[116]M. Balat and G. Ayar, Biomass energy in the world, use of biomass and potential trends. Energy sources, 27 (2005) 931-940.
[117]H. Kopetz, Build a biomass energy market. Nature, 494 (2013) 29-31.
[118]T.O. Wilson,F.M. McNeal,S. Spatari,D. G. Abler and P.R. Adler, Densified biomass can cost-effectively mitigate greenhouse gas emissions and address energy security in thermal applications. Environmental science & technology, 46 (2012) 1270-1277.
[119]T. Ranta,M. Laihanen and A. Karhunen, Development of the bioenergy as a part of renewable energy in the Nordic Countries: A comparative analysis. Journal of Sustainable Bioenergy Systems, 10 (2020) 92-112.
[120]M. Ozturk,N. Saba,V. Altay,R. Iqbal,K.R. Hakeem,M. Jawaid and F.H. Ibrahim, Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia. Renewable and Sustainable Energy Reviews, 79 (2017) 1285-1302.
[121]D. Gielen, Renewable energy technologies: cost analysis series. Sol photovolt, 1 (2012) 52.
[122]H.M. Junginger,T. Mai-Moulin,V. Daioglou,U. Fritsche,R. Guisson,C. Hennig,D. Thrän,J. Heinimö,J.R. Hess and P. Lamers, The future of biomass and bioenergy deployment and trade: a synthesis of 15 years IEA Bioenergy Task 40 on sustainable bioenergy trade. Biofuels, Bioproducts and Biorefining, 13 (2019) 247-266.
[123]K.L. Kline,S. Msangi,V.H. Dale,J. Woods,G.M. Souza,P. Osseweijer,J.S. Clancy,J.A. Hilbert,F.X. Johnson and P.C. McDonnell, Reconciling food security and bioenergy: priorities for action. Gcb Bioenergy, 9 (2017) 557-576.
[124]T. Baležentis,D. Streimikiene,T. Zhang and G. Liobikiene, The role of bioenergy in greenhouse gas emission reduction in EU countries: An Environmental Kuznets Curve modelling. Resources, Conservation and Recycling, 142 (2019) 225-231.
[125]S. Karekezi and J. Kimani, Status of Bioenergy Development in Kenya: The Case of Bagasse-based Cogeneration. Nairobi. August, (2010).

[126]A. Pradhan and C. Mbohwa, Development of biofuels in South Africa: Challenges and opportunities. Renewable and Sustainable Energy Reviews, 39 (2014) 1089-1100.
[127]K. Murungi, Kenya's Energy Sector Bubbling with Opportunities. Business Daily, 10 (2009).
[128]R.L. Carvalho,P. Yadav,N. García-López,R. Lindgren,G. Nyberg,R. Diaz-Chavez,V. Krishna Kumar Upadhyayula,C. Boman and D. Athanassiadis, Environmental Sustainability of Bioenergy Strategies in Western Kenya to Address Household Air Pollution. Energies, 13 (2020) 719.
[129]L. Pelkmans,M. Van Dael,M. Junginger,U.R. Fritsche,R. Diaz-Chavez,G.J. Nabuurs,I. Del Campo Colmenar,D.S. Gonzalez,D. Rutz and R. Janssen, Long-term strategies for sustainable biomass imports in European bioenergy markets. Biofuels, Bioproducts and Biorefining, 13 (2019) 388-404.
[130]S. Mandley,V. Daioglou,H. Junginger,D. van Vuuren and B. Wicke, EU bioenergy development to 2050. Renewable and sustainable energy reviews, 127 (2020) 109858.
[131] S.S.H. Davarani, Z. Rezayati-zad, A. Taheri, N. Rahmatian, Highly selective solid phase extraction and preconcentration of Azathioprine with nano-sized imprinted polymer based on multivariate optimization and its trace determination in biological and pharmaceutical samples, Materials science & engineering. C, Materials for biological applications, 71 (2017) 572-583.
[132]F. Meng and J. McKechnie, Challenges in Quantifying Greenhouse Gas Impacts of Waste-Based Biofuels in EU and US Biofuel Policies: Case Study of Butanol and Ethanol Production from Municipal Solid Waste. Environmental Science & Technology, 53 (2019) 12141-12149.
[133]A. Razmjoo,A. Sumper,M. Marzband,A. Davarpanah,A. Shahhoseini and S. Sarlak, Energy sustainability analyses using feasible indicators for urban areas. International Journal of Energy and Water Resources, 3 (2019) 127-140.
[134]B. Knopf,P. Nahmmacher and E. Schmid, The European renewable energy target for 2030–An impact assessment of the electricity sector. Energy policy, 85 (2015) 50-60.
[135]S.C. Jagers,F. Nilsson and T. Sterner, EU Climate Policy in a Changing World Order, in The European Union in a Changing World Order. Springer, (2020) 145-165.
[136]E. Brosset and S. Maljean-Dubois, The Paris Agreement, EU Climate Law and the Energy Union, in Research Handbook on EU Environmental Law. Edward Elgar Publishing, (2020).
[137]A.P. Saravanan,A. Pugazhendhi and T. Mathimani, A comprehensive assessment of biofuel policies in the BRICS nations: Implementation, blending target and gaps. Fuel, 272 (2020) 117635.
[138]P. Sakai,S. Afionis,N. Favretto,L.C. Stringer,C. Ward,M. Sakai,P.H. Weirich Neto,C.H. Rocha,J. Alberti Gomes and N.M. de Souza, Understanding the Implications of Alternative Bioenergy Crops to Support Smallholder Farmers in Brazil. Sustainability, 12 (2020) 2146.
[139] Z. Rezayati-zad, S.S.H. Davarani, A. Taheri, Y. Bide, Highly selective determination of amitriptyline using Nafion-AuNPs@branched polyethyleneimine-derived carbon hollow spheres in pharmaceutical drugs and biological fluids, Biosens Bioelectron, 86 (2016) 616-622.
[140] A. Taheri, R. faramarzi, M. Roushani, Determination of Paraquat in Fruits and Natural Water using Ni(OH)2 Nanoparticles-Carbon Nanotubes Composite Modified Carbon Ionic liquid Electrode, Anal. Bioanal. Electrochem., 7 (2015) 666-683.
[141]M.R. Cherubin,I.P. Lisboa,A.G. Silva,L.L. Varanda,R.O. Bordonal,J.L. Carvalho,R. Otto,P.S. Pavinato,A. Soltangheisi and C.E. Cerri, Sugarcane straw removal: Implications to soil fertility and fertilizer demand in Brazil. Bioenergy Research, 12 (2019) 888-900.
[142]E.C. Pischke,B. Solomon,A. Wellstead,A. Acevedo,A. Eastmond,F. De Oliveira,S. Coelho and O. Lucon, From Kyoto to Paris: measuring renewable energy policy regimes in Argentina, Brazil, Canada, Mexico and the United States. Energy Research & Social Science, 50 (2019) 82-91.

[143]K.T. Gillingham,C.R. Knittel,J. Li,M. Ovaere and M. Reguant, The Short-run and Long-run Effects of Covid-19 on Energy and the Environment. Joule, 4 (2020) 1337-1341.
[144]A. Williams and K. Dupuy, Deciding over nature: Corruption and environmental impact assessments. Environmental Impact Assessment Review, 65 (2017) 118-124.
[145] D. Mehrabi Nasab, A. Taheri, S.S. Athari, Design and Fabrication of Gold Nanoparticles for Anti-Asthma Drug Delivery, Archives of Medical Laboratory Sciences, 6 (2020) e4.
[146] R. Jalilian, M. Shahmari, A. Taheri, K. Gholami, Ultrasonic-assisted micro solid phase extraction of arsenic on a new ion-imprinted polymer synthesized from chitosan-stabilized pickering emulsion in water, rice and vegetable samples, Ultrasonics Sonochemistry, 61 (2020) 104802.
[147] F. Abdollahi, A. Taheri, M. Shahmari, Application of selective solid-phase extraction using a new core-shell-shell magnetic ion-imprinted polymer for the analysis of ultra-trace mercury in serum of gallstone patients, Separation Science and Technology, (2019) 1-14.
[148] Z.R. Zad, S.S.H. Davarani, A. Taheri, Y. Bide, A yolk shell Fe3O4@PA-Ni@Pd/Chitosan nanocomposite -modified carbon ionic liquid electrode as a new sensor for the sensitive determination of fluconazole in pharmaceutical preparations and biological fluids, Journal of Molecular Liquids, 253 (2018) 233-240.
[149] K. Kamari, A. Taheri, Preparation and evaluation of magnetic core–shell mesoporous molecularly imprinted polymers for selective adsorption of amitriptyline in biological samples, Journal of the Taiwan Institute of Chemical Engineers, 86 (2018) 230-239.
[150] R. Jalilian, A. Taheri, Synthesis and application of a novel core-shell-shell magnetic ion imprinted polymer as a selective adsorbent of trace amounts of silver ions, e-Polymers, 18 (2018) 123-134.
[151]R. York and S.E. Bell, Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. Energy Research & Social Science, 51 (2019) 40-43.
[152] Z. Rezayati zad, B. Moosavi, A. Taheri, Synthesis of monodisperse magnetic hydroxyapatite/Fe3O4 nanospheres for removal of Brilliant Green (BG) and Coomassie Brilliant Blue (CBB) in the single and binary systems, Advanced Journal of Chemistry-Section B, 2 (2020) 159-171.
[153]E. Tvinnereim and M. Mehling, Carbon pricing and deep decarbonisation. Energy Policy, 121 (2018) 185-189.
[154]G.E. Metcalf and D. Weisbach, The design of a carbon tax. Harv. Envtl. L. Rev., 33 (2009) 499.
[155]R. Dorsey-Palmateer and B. Niu, The effect of carbon taxation on cross-border competition and energy efficiency investments. Energy Economics, 85 (2020) 104602.
[156]M. Hoel, Should a carbon tax be differentiated across sectors? Journal of public economics, 59 (1996) 17-32.
[157]V. Smil, Examining energy transitions: A dozen insights based on performance. Energy Research & Social Science, 22 (2016) 194-197.

HOW TO CITE THIS ARTICLE

Benjamin K. Korir, Joshua K. Kibet, Bornes C. Mosonik, A Review of the Current Trends in the Production and Consumption of Bioenergy, Prog. Chem. Biochem. Res., 4(2) (2021) 109-133.

DOI: 10.22034/pcbr.2021.126117

URL: http://www.pcbiochemres.com/article_126117.html