# Jatropha Curcas Biodiesel

Subjects: Green & Sustainable Science & Technology | Chemistry, Organic | Engineering, Chemical
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J. Curcas is a small and medium sized fern tree, rising to around 5–7 m tall, belonging to the Euphorbiaceae genus, consisting of approximately 800 species, around 321 genera. Jatropha is an herb immune to famine, with a lifespan of around fifty years. It is also called physic nut and Ratanjayot. J. Curcas will generate 2000 L/ha of oil annually. JCL oil is transesterified primarily into (m)ethyl esters (biofuels) and glycerol. One of the greatest challenges of the 21st century is to fulfill the growing energy needs sustainably and cost-effectively. Among the different sources of energy, biodiesel is one of the alternative energy sources that has tremendous potential to become a major mainstream renewable energy mix. Jatropha is an important raw input for biodiesel that provides an ecological and sustainable solution for emerging greenhouse gas emissions over the other biomass feedstock.

Keywords: renewable energy ; alternative fuel ; biodiesel ; Jatropha Curcas ; biomass ; emissions and carbon footprints ; green fuels

## 1. Renewable Energy: Biodiesel

Liquid biofuels are being supported by environmental and economic factors in the global energy matrix [1]. The European Union (EU) set the scientific arrangements and technical requirements for biodiesel as EN 14214, and by the United States of America as ASTM 6751-02. Biodiesel consists of fatty acids and long-chain monoalkyl esters extracted through livestock fats or plant oils (maybe non-edible or edible) [2][3]. Particularly, in comparison with fossil fuel, it is non-toxic, ecofriendly, and biodegradable. The various processing techniques of biodiesel are emulsification, cracking, transesterification, and dilution of the mixing of hydrocarbons [4][5][6][7][8]. Transesterification among the above techniques is the best technique. This method allows the oil to convert into esters, and in this method, glycerin is separated out. The biodiesel rests on the surface, from where it can be taken out, and the glycerin settles down on the floor. Ten pounds of alcohol interact in one hundred pounds of oil or fat along with a catalyst to create ten pounds of glycerin and one hundred pounds of biodiesels.

This process requires oil to react with three mol of methanol. Catalytic transesterification is the most widely used process. Three methods can be used for catalytic transesterification: catalysts of alkaline such as KOH or NaOH, enzymes such as $CH_2N_2$, and catalysts of acid such as sulfonic, sulfuric, and hydrochloric acids. Several studies found that catalytic alkali methods are more prudent and rapid from all the reactions of catalytic alkali methods [5][9][10][11], although the method catalyzed by acids provides quite high esters production. Glycerol is a critical by-product of this process used for fuel or used in the superficial industry as just a raw material [12]. Biodiesel is now widely used in the European countries and the United States to reduce environmental contaminants and eliminate reliance on the production of fossil fuels found across various areas in the globe and rising crude petroleum prices [13]. Biodiesel does not include petroleum additives, so it is consistent with traditional fuel and is mixed in any fossil-based gas ratio and from a natural bio-diesel combination. Therefore, biodiesel is now one of the world's most famous forms of biofuels [14].

### 1.1. Feedstocks for Biodiesel

One of the most significant benefits of developing biodiesel as a sustainable power option is the wide variety of feedstocks available for biodiesel processing [15]. More than 350 oil-bearing plants are classified as a possible source for renewable oils, such as soybean, sunflower, palm, cottonseed, safflower oil, peanut oil, and oilseed rape [13][16]. Many other un-edible oils such as neem, Karanja, and Jatropha are also gaining interest [17]. The abundance of fuel sources for producing biodiesel depends on both the country's geographical position and farming activities. The usage of the right raw material is thus critical in maintaining nominal manufacturing costs for biodiesel. Studies have shown that only raw material accounts for more than 75% of the total cost of manufacturing biodiesel. The feedstock for biodiesel can usually be classified into four major groups [18]:

- Fats of animals: black butter, seaweed, and animal fat.

- Recycled or surplus crude.
- Non-edible vegetable oil: halophytes, Karanja, coral, Jatropha, and ocean plum.
- Edible vegetable oil: rape, sunflower, soybean, coconut oil, and hemp oil.

## 1.2. Standards and Policies of Biodiesel

Worldwide, there are several policies for biodiesel, which have been set out by several countries. These policies have been encouraging biodiesel within the energy mix and raised the goal for the planned utilization of biodiesel. A list of certain biodiesel goals in chosen countries across the world is displayed in **Table 1**.

**Table 1.** Some countries' policies about biofuel.

| Country | Biodiesel Policy | Reference |
| --- | --- | --- |
| USA | By 2006, the Energy Policy Act 2005 imposed a commitment of 400 million gallons of biofuels in the transport industry. The Energy Independence and Security Act 2007 set a goal of 18% renewable energy use in transport fuel by 2022. Oregon also has an established fuel regulation, whereby 5% biodiesel is required to be blended into diesel transport. | [19][20][21] |
| EU | The EU has approved a 20% and 10% renewable fuel standard as the domestic product consumption in the transport sector by 2020. The EU also set out a Sustainable Low-Carbon Economic roadmap for 2011, in which greenhouse gas emissions would be reduced to 40%, 60%, and 80% by 2030, 2040, and 2050, respectively. | [22][23][24][25] |
| Canada | Under the Environmental Protection Act 1999 (BillC-33), 2% and 5% of biodiesel blends in traditional diesel were set as targets. | [19] |
| Thailand | Thailand also planned to achieve 5% diesel blending with palm oil and 10% ethanol blending with cassava. | [26] |
| Malaysia | The policy anticipated that diesel of the whole country blended with 5% of palm oil would generate a demand of 500,000 tons for palm oil, which is similar to replacing 40–50% of the country's supply of palm oil. The increase in the mixing rate occurred from 1.3% in 2011 to 7% in 2015. The B15 mixing rate will be discussed by 2020. | [21][27] |
| Indonesia | In 2006, the Indonesian government developed the first policy of biofuel for the country, in which they set a plan of covering 10% of transportation fuel with biofuel by 2010. By 2025, the contribution of biodiesel in the transport sector will be 20%. | [14] |
| Philippines | The Biofuels Act 2006 (RA 9367) states that under three months of the act, effectivity at least 1% of biodiesel will be blended by quantity across all diesel engines offered for sale in that region, which rises to 2% after two years. This act set out the biofuel policy to accomplish energy independence by decreasing imported oil, fulfilling environmental problems, and growing rural jobs and wages. | [28][29] |
| China | The focus of China's policy is the farming of energy plants and the advancement of matured technology to produce biofuel. The target of the production of biodiesel by 2020 is 2 million tons. | [24] |
| India | The suggested goal is to blend 20% ethanol and 5% biodiesel by 2030. | [30] |

The Mid-Term Policy (MTP) was subordinated to upgrades in 2006. Thus, the MTP would excel in this year's latest short-term Renewable Energy (REP) strategy. Given that such a program's instruments would continue to boost the growth of the sustainable energy market in the household by 2014 and beyond, the approach path is then decided. The MTP seems to be the culmination of several years of change, involving experts, advisors, and members from across Pakistan and other nations in exchanging protocols and lessons learned [31][32]. In early 2006, this approach was a successful one [33][34]. In increasing the MTP, renewable energy facilities were aimed at assisting the work of various departments of government. Due to this, the power shortage has increased Pakistan's usage of sustainable technology. The key aims were to promote trade and encourage investment from the private sector by offering opportunities and expenditure and supporting the efficient usage of energy capital and revenue-generating behavior. It aimed to aid in developing specific scientific, organizational, and prepared competencies [31][35].

The Mid-Term Policy was developed in the short term, utilizing an extended summary of alternative options and renewables, to contend with participant interests, decide on policy disagreements, including the knowledge gained, and to establish that sustainable and renewable technologies are being supported. It also proposes a biodiesel strategy that extended opportunities through innovative funding, i.e., alternate energy production funds [36][37]. Intending to develop and use biofuel as an alternative fuel in Pakistan, the AEDB (Alternate Energy Production Board) has provided strategic guidelines for reducing import fuel bills, meeting the need for biofuel raw materials, and promoting a pollution-free environment. Additionally, as of 14 February 2008, the National Cabinet's ECC (Economic Coordination Committee) approved the plan to use biofuel as an alternative fuel in its hearing. The canon's critical ends will be as follows:

- The Petroleum and Natural Resources Ministry can establish fuel standards of quality for B-100 (spiffy biofuel) and mix up to B-20 (20% biodiesel/80% diesel mixture).
- AEDB is perhaps the main preparation and support agency for the nationwide biofuel scheme.
- Oil Marketing Companies (OMCs) will be sourcing biofuel (B-100) from biodiesel manufacturers and, at the time of selling, providing this processed diesel-mixed biodiesel (getting started with B-5).
- The gradual introduction of biofuel combined with petroleum fuel will reach a minimum of 5% by volume of a state's total diesel use by 2015, and 10% by 2025.

Pakistan State Oil (PSO) arranged the biodiesel pilot scheme in 2010, with the involvement of the AEDB and the Pak Agricultural Research Council. The progress of the 2012 pilot plant led to an oil marketing firm's blend of biofuel in 2013 [38]. Pakistan's long-term comprehensive energy strategy accounts for four core values: availability, affordability, sustainability, and responsibility (use). As part of the overall strategy, the alternate and renewable energy) (ARE) 2019 Strategy aims to create an effective, reliable, safe, accessible, productive, and environmentally safe power grid, while encouraging the indigenization of sources of energy and the growth of local production potential in these technologies.

ARET's key goals for 2019 are as follows:

- ARET energy projects guarantee quick routes and open growth.
- To protect the atmosphere by raising the proportion of "carbon" resources in the global energy mixture.
- Encouraging and ensuring local capital is exploited.
- Providing the minimum expense of producing energy while considering certain restrictions.
- Encouraging private industry expenditure, thus maintaining reasonable return rates.

Different goals are established under this Framework which can be changed occasionally through administrative intervention instead of legislative reform. Currently, the GOP also set goals of at minimum 20% renewable power capacity generation by 2025, as well as at least 30% by 2030 (20 by 25 and 30 by 30). To accomplish such goals, the GOP must obtain a higher proportion of additional power through the alternate and renewable energy (ARE) Policy 2019, considering the limitations of baseload, variance production criteria, and alternate and renewable energy technologies (ARET's) alternative options that are like baseload power variables [39].

### 1.3. Policy Suggestions on Biodiesel

Pakistan seems to have a huge potential for generating biodiesel if the resources are being used in a sustainable manner and action is taken in the right direction. As per a report focused on evaluating the Environmental Kuznets Curve (EKC) assumption to evaluate the ability of renewables in Pakistan data collected spanning the duration from 1970 to 2012, militant enthusiasm for EKC has been identified. Renewable electricity plays a major role in lowering $CO_2$ pollution, and current non-renewable activities are the key contributors to $CO_2$ pollution, as per previous research. The policy will also promote the extension of investment in renewable energy initiatives to offset and alleviate the effects of climate change and global warming [40]. The major economic dependency on agriculture in Pakistan affects 70% of the country's citizens. People's living conditions may be improved by planting oil seed plants. Less expenditure is expected in a mini-scale production facility which can aid in biofuel development [41]. The barren land areas that can solve water scarcity problems and soil salinity are being used for the development of oil plants. Expanding energy plants can be advantageous for the welfare of farmworkers and the state's economy. The use of specific technology rather than several technologies is needed for effective commercially and mainstream biomass energy production settlements in Pakistan's rural locations [42]. Pakistan has been one of the fast-growing power economies in the world during the last 20 years due to the increasing population and rising per capita energy use, rapid urbanization, and sound economic development [43].

Pakistan's main contributors to a power crisis are strong electricity demand, poor energy source expertise, rising oil import prices, increasing manufacturing requirements, and accelerated demographic development. Electrical power requirements for homes and factories have risen due to fast demographic development. The world's rural sector, which accounts for around 62% of an overall world demographic, is largely reliant on non-commercial assets [44]. The world's economic recession has arisen over the last five years due to an unforeseen energy crisis. Lower output along with higher losses stems from a lack of modern knowledge when using energy sources [41]. The long-term energy problems confronted can be resolved by leveraging alternative energy sources in developed countries. Expanding the resources available and finding new outlets is necessary to keep those assets competitive. The environmental effect is indirect due to poor productivity in extra carbon emissions [45].

In February 2008, the Ministry for Water and Power in Pakistan issued guidelines which the Cabinet's Economic Coordinating Committee considers helpful for the use of biofuels as an alternate fuel. The plan is accepted and as per this overview, the Water and Power Ministry and Alternative Energy Development Board (AEDB) will organize the National Biodiesel System to include the services. To fulfill the criteria for consistency in fuel in accordance with the Ministry of Petroleum and Natural Resources, up to 5% of the total quantity should be mixed with biofuel by 2015 and 10% by 2025 [32][46]. To guarantee biodiesel's price competitiveness with Petroleum Diesel OGRA, the price process of different biodiesel variants (B-5, B-10, etc.) should be liable. In addition to making the usage of biodiesel mandatory for public-sector automobiles operating on diesel at such a cost decided by OGRA, the government must provide biodiesel manufacturers with incentives for buying back. Manufactured plants, supplies, machines, and similar products are excluded from customs duties and taxes used in biofuel development [47].

As with the ramifications of solar energy, the bioenergy industry still suffers from a shortage of financing, adequate policymaking, and execution. Similarly, AEDB, Pakistan's Higher Education Commission (HEC), Pakistan's Ministry of Climate Change (MOCC), Pakistan's Environmental protection Agency (Pak-EPA), and PSO will take steps to cooperate with universities and institutes and distribute funding for bioenergy development and research. They need to evaluate and update the Mid-Term Policy (MTP), identify the inefficiencies in meeting the standards set in 2015, and create a detailed plan to accomplish 10% (B-10) to 20% (B-20) biofuel blends in diesel in 2025 at PSO station in Pakistan, with biofuel that will conform with ASTM requirements [40][48]. For meeting energy needs and discovering sustainable and anti-conventional power options, numerous problems such as analysis, growth, promotion, network creation, decentralized model of the power distribution system, business development, education, outreach initiatives, public perception, incentives, policy involvement, technology transition, acceptance, tracking, and assessment should be recognized, and there also needs to be a clear framework for consistently tracking and incorporating them at the state level [49].

### 1.4. Biodiesel Benefits and Drawbacks

Biodiesel has certain benefits and deficiencies that are summarized in **Table 2** as follows.

**Table 2.** Review of benefits and deficiencies of biodiesel [50][51].

| No. | Benefits | Deficiencies |
|---|---|---|
| 1 | Biodiesel could boost the efficiency of an engine because it has a Cetane amount of above 100. | Injection smelting on the piston and motor side. |
| 2 | Biodiesel seems to be more cost-effective than gasoline since it is locally sourced. | Biodiesel is not compatible with diesel or gasoline. |
| 3 | It could be used without requiring extra lubricant, except for diesel motors, due to biodiesel's consistency and pureness. | During cold conditions, greater pouring and clouds stage and oil freezing, triggering a cool weather launch. |
| 4 | Biodiesel releases fewer toxins than fossil fuels, such as CO, HC, $CO_2$, PM, and $SO_2$. | It produces more NOx than diesel fuel. |
| 5 | Biodiesel has a tremendous capacity to promote effective rural growth and an electricity protection approach. | The higher viscosity during long-term service induces clogging growth, injector deposition forming, filter plugging, rows and injectors, loop clinging, and inconsistency with traditional moisturizing oils. |
| 6 | No motor alteration is needed until B-20. | Biodiesel reduces strength and motor rpm. Biodiesels drop about 5% on average relative to oil at level load. |
| 7 | Being less harmful, more degradable, and possessing a low spark level, it is easier to treat. | Carbon sits on pistons and engine heads. |
| 8 | Biodiesel production is better than fossil fuels, and requires little time. | Biodiesel has had an acidic quality to the brass and copper. |
| 9 | Greater performance in combustion. | Biodiesel induces unnecessary damage to engines. |

| No. | Benefits | Deficiencies |
|---|---|---|
| 10 | **It is inflammable and non-poisonous, decreasing the exhaust pipe, noticeable fumes, toxic vapors, and bad smells.** | **Biodiesel depletion during preservation for longer periods.** |
| 11 | **Despite the sulfur level, flame stage, aromatic quality, and biodegradability of biodiesel are higher than diesel fuel.** | **Because of the chemical composition and massive molecular mass of plant oils, the large viscosity (around 12 times higher than diesel fuel) creates issues in the atomization, pumping, and combustion of a diesel engine's injector structures.** |

### 1.5. Biodiesel Sustainability

The idea of sustainable development has been included in the United Nations Commission on the Environment's 1987 study entitled Our Shared Future, organized by Gro Harlem Brundtland. In this study, sustainability was described as addressing the needs of today's generation without undermining future generations' needs. The growing concern in spreading biofuel output on a worldwide scale, in addition to the shortage of traditional fossil fuels, their increasing pollutant pollution, their growing costs, and the need to develop biodiesel sustainability and qualification requirements, has been established globally [52][53]. Biodiesel is used as a way out of misery for developed countries. Besides, biodiesel will offer new opportunities for innovation in agriculture research and production, and provide farmers with an income stream [54] and promote connections to already non-existing food stores [55]. Biodiesel usage will render any country self-dependent to a certain degree, but it is still far behind in making a substantial change in crude oil imports, which is required nowadays.

The biodiesel sustainability standards were drawn mainly from current standards established by the Sustainable Biofuels Roundtable (RSB). The following are some principles of these concepts [56][57]:

- Biodiesel output shall lead to the growth of local communities in economic and social terms.
- Biodiesel development shall prevent adverse impacts of higher ecological importance on habitats, communities, and regions.
- Biodiesel shall lead to climate change mitigation by substantially reducing greenhouse gas pollution from the lifecycle relative to fossil fuels. Producers will continue to work to boost the use of biodiesels.
- The biodiesel sector shall incorporate management processes in the supply chain that preserve and aim to enhance habitats, areas with high ecological value, and the efficiency of natural resources, including land, climate, and water.
- The development of biodiesel would aim to enhance food protection.
- The development of biodiesel shall own the rights to natural resources, including water and land.
- Biodiesel's development shall foster human and civil rights and maintain healthy and fair work conditions.

Achten et al. [58] conducted a qualitative assessment of Jatropha production's future feasibility, focused on the environmental, economic, and social aspects, and decided that the agriculture is viable when conducted in barren or depleted fields but not where productive regions are used that could be used to plant more lucrative grain or other crops.

## 2. Jatropha Curcas

### 2.1. Horticultural Details of Jatropha Curcas

J. Curcas is a small and medium sized fern tree, rising to around 5–7 m tall, belonging to the Euphorbiaceae genus [6][11][59][60][61][62][63][64][65][66], consisting of approximately 800 species, around 321 genera. Many plants of global economic importance come from this family, as follows [67]:

- Physic nut
- Roots: esculenta Manihot (cassava)
- Chinese sebiferum (Sapium sebiferum); J. Linn Curcas
- Hydrocarbon: spp euphorbia

- H. brasiliensis: Rubber
- Oils: linn ricinus communis (castor bean); spp aleurites (Tung Tree)
- Nuts: The orinocense caryodendron tacay nut
- Medical: croton spp.; jatropha spp
- Vegetables: Sauropus androgynus (katuk)

Jatropha is an herb immune to famine, with a lifespan of around fifty years [6][66][68][69]. It is also called physic nut and Ratanjayot [7][11][62][68]. It may grow within the forest, parched and semi-parched [69][70]. The plants grow a large flower stalk and initially four deep, superficial roots. The tapering root can strengthen the ground toward mudslides, while the deeper roots are believed to avoid and monitor air or water-borne soil degradation, but this ability is not being scientifically examined. The leaf is flat, with 4–6 lobes, and is about 10–15 cm long, and wide. The plant is polygamous, so there are bisexual plants in the marginal leaf buds. The proportion of female to male plants varies between 1:13 and 1:29 and reduces with plant age. Usually, JCL flowers in the rainy season once per year. JCL grows almost year-round in chronically moist areas or under deluge conditions. The black seeds with certain authenticity produce contaminants, such as phytates, phorbol esters, lectins, trypsin agonists, and curcin, to prevent detoxification of seeds, oil, and seed cake [60][71][72].

J. Curcas may grow from 250 to above 1200 mm per year under a wide variety of rainfall climates [61][73]. The growing temperature is 20–26 °C, and these plants can also adjust between 5.0 to 6.5 pH, fertile soil, not stagnant, and decent drainage [74]. The J. Curcas plant grows in well-drained fields with good air circulation and is well-suited to little land with a lower nutritional quality, and it sheds its leaves during the hot season [59][61]. Planting spaces of 2 by 2 m, 2.5 by 2.5 m, and 3 by 3 m have been stated to be enough and to produce greater fruit outputs [65]. It grows fruit from the second year of creation, and from the fourth or fifth year onwards, the growth stabilizes economic production. The plant is a kernel, with 3 seeds in each. It yields approximately 2–4 kg/seed/plant/annually. The yields in bad soils were stated to be 1 kg/sow/plant/annually [75]. J. Curcas oil outputs are estimated at 1590 kg/ha [7][64][76][77].

### 2.2. Jatropha Curcas Growth and Applications

J. Curcas will generate 2000 L/ha of oil annually [78]. JCL oil is transesterified primarily into (m)ethyl esters (biofuels) and glycerol [12]. Currently, J. Curcas fuel development and use are no longer restricted to a geographical area or just a small range of final products, and significant amounts of J. Curcas fuel are used worldwide, as components in various goods produced by a broad number of sectors. J. Curcas was discovered to have been ideal in the oleochemical industries as a non-edible vegetable oil raw material (biofuels, cosmetics, soap, fatty acids, kerosene, fat nitrogen compounds, and cleaning products, etc.) [11][78][79]. The J. Curcas oil industry was developed over the years to provide J. Curcas oil as well as its associated products [67]. **Figure 1** illustrates several major J. Curcas usages.

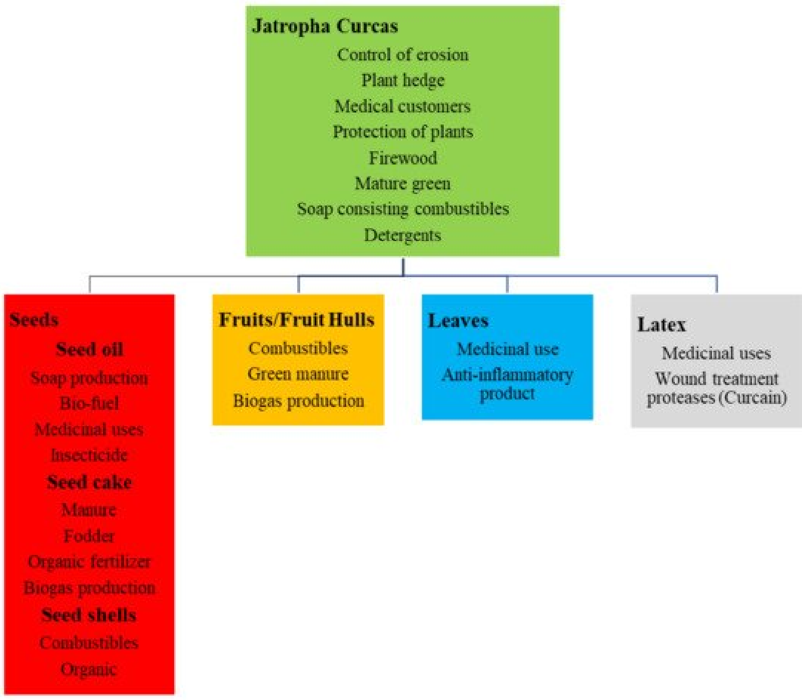

**Figure 1.** A few essential Jatropha Curcas usages [66][67][80].

The J. Curcas plant was noticed to be ideal in several cultures for usage in different facets. It is typically grown across Indonesia's farm fields as a live fence, as cows or goats do not consume it. It can also be sliced or clipped to the required size. Aside from the use of J. Curcas oil as a biofuel, biocides (herbicide, molluscicide, nematicide, and pesticide) and soap may also be generated using the oil [80].

## 2.3. Jatropha Curcas Qualities and Properties

The properties of raw J. Curcas oil (CJCO) differ according to the area in which it was produced. The actual quantity of fuel collected from a provided seed sample relies on the nature of the raw material and the extracting process. J. Curcas kernel oil content was observed to have been greater than sunflower oil, soya, and palm kernels, 33.33%, 18.35%, and 44.6% respectively [81], while in several other sources, the oil content of the J. Curcas kernels was 63.16% and 66.4% [79][82]. The specifications that are chosen and set to determine biodiesel efficiency can be split into two classes. Each class includes basic criteria that are often used for mineral oil-based fuel, such as physical and chemical characteristics. The other category defines the chemical structure and cleanliness of methyl esters of fatty acids [83]. **Table 3** describes the physicochemical characteristics of boorish J. Curcas fuel. Moreover, some properties of J. Curcas in Pakistan is shown in **Table 4**.

**Table 3.** Physicochemical characteristics of crude Jatropha Curcas oil [80][84][85].

| Parameters | Jatropha Curcas Oil |
|---|---|
| **Density at 15 °C (g/cm$^3$)** | **0.920** |
| **Flashpoint (°C)** | **240** |
| **Cloud point (°C)** | **9 ± 1** |
| **Cetane number** | **38** |
| **Viscosity at 30 °C (cSt)** | **52 cSt** |
| **Pour point (°C)** | **4 ± 1** |
| **Fire point (°C)** | **274 ± 3** |
| **Caloric value (MJ/kg)** | **38.20** |
| **Conradson carbon residue (%*w/w*)** | **0.8 ± 0.1** |
| **Oxygen (%*w/w*)** | **11.06** |
| **Carbon (%*w/w*)** | **76.11** |
| **Sulfur (%*w/w*)** | **0** |
| **Nitrogen (%*w/w*)** | **0** |
| **Hydrogen (%*w/w*)** | **10.52** |
| **Neutralization number (mg KOHg$^{-1}$)** | **0.92** |
| **Iodine No.** | **94 ± 0.0** |
| **Ash content (%*w/w*)** | **0.03** |
| **Saponification value** | **198.00** |
| **Monoglycerides** | **Not distinguished** |
| **Triglycerides (m/m)** | **97.3%** |
| **Diglycerides** | **2.7%** |
| **Calcium (mg/kg)** | **56** |
| **Iron (mg/kg)** | **2.4** |
| **Water (m/m)** | **0.07%** |
| **Magnesium (mg/kg)** | **103** |

| Parameters | Jatropha Curcas Oil |
| --- | --- |
| **Phosphorus (mg/kg)** | **290** |

**Table 4.** Tested by Faisalabad [86] and PSO [42], domestic biodiesel's important characteristics from Jatropha and high-speed diesel.

| Parameters | High-Speed Diesel (PSO) | B-10 (PSO) | B-100 (PSO) | B-100 (Faisalabad) | Test Method |
| --- | --- | --- | --- | --- | --- |
| **Density at 20 °C (g/cm$^3$)** | **0.83** | **0.8522** | **0.8816** | **0.88** | **ASTM D 1298** |
| **Kinematic Viscosity (cSt)** | **2.73** | **4.19** | **4.38** | **4.8** | **ASTM D 445** |
| **Cetane index** | **46** | **53** | **47** | **-** | **ASTM D 976** |
| **Flash point (°C)** | **37** | **90** | **140** | **188** | **ASTM D 93** |
| **Calorific value (Btu/lb)** | **19,528** | **19,233** | **17,162** | **-** | **ASTM D 240** |

The main fatty acids in JCL seed oil are linoleic, oleic, stearic, and palmitic acids. Oleic acid recorded the largest compositional proportion, followed by linoleic acid [6][60][62][68][70][79][87][88]. Fatty acids' formation of J. Curcas oil is provided in **Table 5**.

**Table 5.** Fatty acid's formation of J. Curcas oil [74][80][87][89].

| Fatty Acid | Structure [a] | Formula | Composition (wt.%) |
| --- | --- | --- | --- |
| **Myristic** | **(14:0)** | $C_{14}H_{28}O_2$ | **0–0.1** |
| **Palmitoleic** | **(16:1)** | $C_{16}H_{16}O_2$ | **0–1.3** |
| **Oleic** | **(18:1)** | $C_{18}H_{34}O_2$ | **34.3–45.8** |
| **Linolenic** | **(18:3)** | $C_{18}H_{32}O_2$ | **0–0.3** |
| **Behenatic** | **(22:0)** | $C_{22}H_{44}O_2$ | **0–0.2** |
| **Palmitic** | **(16:0)** | $C_{16}H_{32}O_2$ | **14.1–15.3** |
| **Stearic** | **(18:0)** | $C_{18}H_{36}O_2$ | **3.7–9.8** |
| **Linoleic** | **(18:2)** | $C_{18}H_{32}O_2$ | **29.0–44.2** |
| **Arachidic** | **(20:0)** | $C_{20}H_{40}O_2$ | **0–0.3** |

[a] Carbon in the chain: double bonds.

Since the mechanical stickiness of J. Curcas oil is quite strong, the friction coefficient of J. Curcas oil for use in biodiesel must be decreased [56]. The large viscosity of J. Curcas oil frequently contributes to compliance issues, including carbon accumulation, fuel ring trapping, oil thickening, and gelatinizing due to vegetable oils. The smoother flow of oil in the motor can also be influenced by the increased viscosity of J. Curcas oil. Varied methods such as preheating, drying, transesterification of ultrasonic methanol, and supercooled methanol are being used to reduce viscosity to render it suitable for motor operations [90][91][92]. After transesterification, the kinematic viscosity of raw J. Curcas fuel could be reduced by around 82% and corresponds to 4.8 $mm^2/s$ [58][93]. J. Curcas fuel's flashpoint is higher relative to fossil fuels. Jatropha fuel has many benefits over diesel, including increased protection in preparation, processing, and transportation, due to its increased ignition point. The high flashpoint may, therefore, affect the motor's initial start issue [92].

Like biodiesel derived from plant oils, including palm oil, J. Curcas fuel has a low pouring level. Therefore, it can be utilized in countries with four certain seasons [94]. The iodine content is an indicator of oils' and fats' unsaturation. High iodine content indicates a greater unsaturation of oils and fats [95]. The iodine quality of JCL fuel reached 101 $gI_2$/100 g, where the normal iodine quality for diesel is less than 120 for European standard 14214 EN. The restriction of fatty acids is also important since the heat of highly unsaturated fatty acids resulted in glyceride polymerizing. It may contribute to development of deposit accounts, oil decay, and the creation of dense effluent in the motor tank [79]. **Table 6** describes the characteristics of JCL fuel and JCL methyl esters with all the requirements of ASTM D6751 and EN 14214. **Table 7** demonstrates the physicochemical characteristics of JCL fuel in comparison to diesel as well as its variants.

**Table 6.** Characteristic comparison of diesel, Jatropha methyl esters, Jatropha oil, ASTM D 6751, and EN 14214 specifications [4][11][80].

| Properties | Diesel | JME | Jatropha Oil | ASTM D6751 | EN 14214 |
|---|---|---|---|---|---|
| Density at 15 °C (kg/m3) | 850 | 879 | 918 | 875–900 | 860–900 |
| Acid value (mg KOH/g) | 0.35 | 0.24 | 11 | 0.5 (Maximum) | 0.5 (Maximum) |
| Sulfated ash (wt%) | - | 0.014 | - | 0.02 | 0.02 |
| Kinematic viscosity at 40 °C (cSt) | 2.6 | 4.84 | 35.4 | 1.9–6.0 | 3.5–5.0 |
| Cetane number | 46 | 51 | 23 | 47 (Minimum) | 51 (Maximum) |
| Flashpoint °C | 70 | 191 | 186 | 130 (Maximum) | >101 (Minimum) |
| Iodine number (g/100 g) | - | 86.5 | 101 | - | <120 |
| Water (mg/kg) | 0.02 | 0.16 | 0.05 | 0.05 | 0.05 |
| Calcium (ppm) | - | 6.1 | - | 5 (Maximum) | 5 (Maximum) |
| Conradson carbon residue | 0.17 | 0.025 | 0.3 | <0.050 wt.% | <0.30% m/m |
| Free glycerol (wt.%) | - | 0.015 | - | 0.02 | 0.02 |
| Total glycerol (wt.%) | - | 0.088 | - | 0.25 | 0.24 |
| Magnesium (ppm) | - | 1.4 | - | 5 (Maximum) | 5 (Maximum) |

**Table 7.** Physico-chemical characteristics of JCL fuel and its blends compared to diesel [96].

| Properties | Fuel Blends | | | | |
|---|---|---|---|---|---|
| | 100/0 | 80/20 | 50/50 | 97.4/2.6 | 0/100 |
| Density at 15 °C (kg/m$^3$) | 866.9 | 876.9 | 891.7 | 868.4 | 917.7 |
| Pour point (°C) | 15 | 12 | 6 | 15 | −3 |
| Kinematic viscosity at 40 °C (cSt) | 5.7 | 8.2 | 14.6 | 5.9 | 36.9 |
| Caloric value (MJ/kg) | 45.90 | 44.15 | 43.099 | 45.202 | 42.048 |
| Flashpoint (°C) | 86 | 90 | 94 | 88 | 99 |

### 2.4. The Efficiency of Diesel Engines Using Diesel and Jatropha Methyl Esters

JCL methyl esters and diesel scientists in several countries worldwide have been studying Jatropha in engines, and have contrasted the engine output tests with those of conventional fuels in identical circumstances. Due to Jatropha's peculiar characteristics, ingestion, alienation, and burning features continue to vary. All such differences in the usage of Jatropha methyl esters in engines may create other problems. The research indicates a major difference in results from the states listed. Many engine output specifications were gathered in this analysis, such as braking strength, fuel usage, brake capacity, torque, thermal brake efficiency, emissions, etc.

## 3. Jatropha Curcas Oil Effect as Biodiesel

Biodiesel use in the agriculture sector faces multiple obstacles and prospects. Various analysis reports suggest that the biodiesel sector would affect food output. Jatropha is, therefore, one of Indonesia's strong options for the biodiesel sector. The following section discusses JCL's environmental, emissions, social, and economic impacts. Furthermore, the political, economic, social, and tech (PEST) analysis is shown in **Figure 2**.

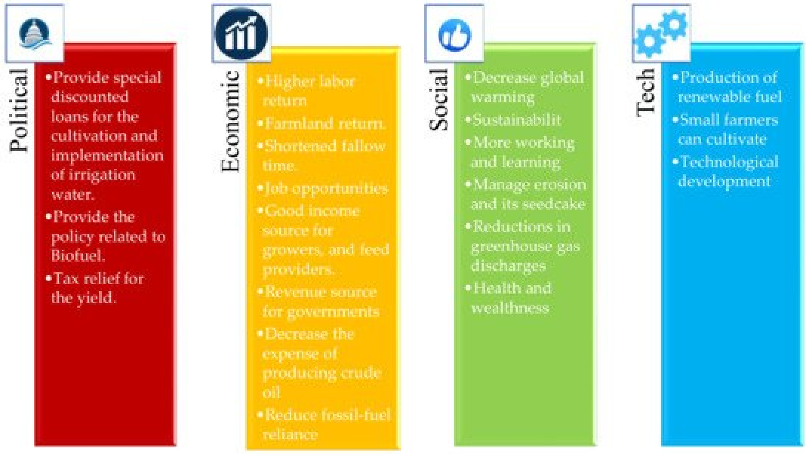


**Figure 2.** Political, economic, social, and tech (PEST) analysis.

### 3.1. Emission Impacts

Biodiesel releases fewer pollutants as opposed to fossil fuels, such as HC, CO, and PM. It therefore produces higher NOx pollution than diesel [97][98][99][100][101][102][103]. **Table 8** describes the cumulative emissions adjustments for B-20 and B-100 reported by the EPA. Reports often display slightly lower emission rates of different harmful substances, such as nitro-polyaromatic hydrocarbons, PAH, and aldehydes, for biodiesel and biodiesel mixes [6][104][105]. **Table 9** reveals diesel and biodiesel $CO_2$ pollution levels, accordingly. Additionally, the possible mitigation of mid- and long-term $CO_2$ emissions generated from biodiesel substitutes can be seen in **Table 10**.

**Table 8.** The average effect of 20% and 100% biodiesel on heavy-duty emissions compared to average typical diesel [6][104][105].

| Air Pollutant | Change for B-20 (%) | Change for B-100 (%) |
|---|---|---|
| Nox | +2.0 to −2 | +10 |
| PM | −10.1 | −47 |
| CO | −11.0 | −48 |
| Hydrocarbon | −21.1 | −67 |
| Sulfates | −20 | −100 |
| PAH (polycyclic aromatic hydrocarbons) | −13 | −80 |
| nPAH (nitrated PAH's) | −50 | −90 |

**Table 9.** Aspects of emissions of Co2 from biodiesel and diesel [106].

| Fuel Type | Emissions $CO_2$ (kg/TJ) |
|---|---|
| Biodiesel | 70,800 |
| Diesel | 74,100 |

**Table 10.** The possible Co2 emissions' mitigation generated from biodiesel [106].

| Parameter | Unit | Middle Term (2010–2015) | Long Term (2015–2025) |
|---|---|---|---|
| Substitution | Ton oil | 6,000,000 | 16,000,000 |
| Mitigation of $CO_2$ emission | Million ton | 19.12 | 50.98 |

### 3.2. Environmental Impacts

The evaluation of the long-term environmental effects of the development of biodiesel raw material is a dynamic activity. Reductions in the lifespan of carbon dioxide emissions rely on the raw material sources, the processing processes, and the assumptions about the new uses of the lands from which the feedstock was generated, particularly if the field had been wooded before [107]. One of the most desirable qualities of Jatropha is its capacity to survive scarcity and to develop in droughty and semiarid regions with poor rainwater and poor land quality [61][68]. In semiarid regions, Jatropha could be used to manage erosion and its seedcake could be used to boost soil [69][108]. The JCL plant is nitrogen-fixing and developed as among the finest methods to draw additional oxygen back into the ozone layer. Jatropha may help farmers avoid collisions with protected species as a natural barrier. The significance chain of Jatropha biofuels may result in important reductions in greenhouse gas discharges.

At the same time, additional studies are needed to determine such effects throughout the growth, power generation, and then use lifecycle. Current work suggests that Jatropha biofuel output is expected to be relatively positive relative to fossil fuel use, but the importance of such an energy balance depends on the ways of developing, transportation, and processing that appear to be unique to the plant. Nonetheless, land-use adjustments related to new farms may involve years of new plant growth to re-sequester the lost carbon through land clearing, particularly on land not initially used for agriculture. The toxicity of Jatropha will pose possible problems for the atmosphere and the health of the public. One scientist has cautioned that the curcanoleic acid present in the fuel can encourage cancer of the skin, and that field staff may be annoyed by the oil. In other areas of the country, Jatropha is often deemed invasive, such as Australia, Hawaii, and South Africa [109].

### 3.3. Socio-Economic Impacts

Jatropha oil provides higher labor and farmland returns and other advantages such as shortened fallow times. Kumar and Sharma [60] underscored some of Jatropha's cultural significances. The establishment of JTC oil conversion factories will generate job opportunities, offer a good income source for growers and feed providers, and finally, provide a significant revenue source for governments. It would also reduce fossil-fuel reliance and decrease the expense of producing crude oil [110].

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## References


1. Cutz, L.; Tomei, J.; Nogueira, L.A.H. Understanding the failures in developing domestic ethanol markets: Unpacking the ethanol paradox in Guatemala. Energy Policy 2020, 145, 111769.
2. Knothe, G. Analyzing Biodiesel: Standards and Other Methods. J. Am. Oil Chem. Soc. 2006, 83, 823–833.
3. Nakpong, P.; Wootthikanokkhan, S. High free fatty acid coconut oil as a potential feedstock for biodiesel production in Thailand. Renew. Energy 2010, 35, 1682–1687.
4. Pandey, A. Handbook of Plant-Based Biofuels, 1st ed.; Taylor & Francis Group: Abingdon, UK, 2008.
5. Biodiesel from Triglycerides via Transesterification. In Biodiesel; Springer: London, UK, 2008.
6. Koh, M.Y.; Idaty, T.; Ghazi, M. A review of biodiesel production from Jatropha curcas L. oil. Renew. Sustain. Energy Rev. 2011, 15, 2240–2251.
7. Yusuf, N.N.A.N.; Kamarudin, S.K.; Yaakub, Z. Overview on the current trends in biodiesel production. Energy Convers. Manag. 2011, 52, 2741–2751.
8. Leung, D.Y.C.; Wu, X.; Leung, M.K.H. A review on biodiesel production using catalyzed transesterification. Appl. Energy 2010, 87, 1083–1095.
9. Khan, N.A.; Dessouky, H. Prospect of biodiesel in Pakistan. Renew. Sustain. Energy Rev. 2009, 13, 1576–1583.
10. Marchetti, J.M.Ã.; Miguel, V.U.; Errazu, A.F. Possible methods for biodiesel production. Renew. Sustain. Energy Rev. 2007, 11, 1300–1311.
11. Balat, M. Potential alternatives to edible oils for biodiesel production—A review of current work. Energy Convers. Manag. 2011, 52, 1479–1492.
12. Achten, W.M.M.J.; Verchot, L.; Franken, Y.J.; Mathijs, E.; Singh, V.P.; Aerts, R.; Muys, B. Jatropha bio-diesel production and use. Biomass Bioenergy 2008, 32, 1063–1084.
13. Parawira, W. Biodiesel production from Jatropha curcas: A review. Sci. Res. Essays 2010, 5, 1796–1808.

14. Dillon, H.S.; Laan, T.; Dillon, H.S. BIOFUELS—AT WHAT COST? Government Support for Ethanol and Biodiesel in Indonesia; Global Subsidies Initiative: Geneva, Switzerland, 2008.

15. Atadashi, I.M.; Aroua, M.K.; Aziz, A.A. High quality biodiesel and its diesel engine application: A review. Renew. Sustain. Energy Rev. 2010, 14, 1999–2008.

16. Demirbas, A. Importance of biodiesel as transportation fuel. Energy Policy 2007, 35, 4661–4670.

17. Hassan, M.H.; Kalam, A. An overview of biofuel as a renewable energy source: Development and challenges. Procedia Eng. 2013, 56, 39–53.

18. Lim, S.; Teong, L.K. Recent trends, opportunities and challenges of biodiesel in Malaysia: An overview. Renew. Sustain. Energy Rev. 2010, 14, 938–954.

19. Sorda, G.; Banse, M.; Kemfert, C. An overview of biofuel policies across the world. Energy Policy 2010, 38, 6977–6988.

20. Yacobucci, B.D.; Bracmort, K.S. Calculation of Lifecycle Greenhouse Gas. Emissions for the Renewable Fuel Standard (RFS); Congressional Research Service: Washington, DC, USA, 2009.

21. The Digests Biofuels Mandates around the World. Available online: (accessed on 16 June 2021).

22. Czyrnek-delêtre, M.; Smyth, B.M.; Murphy, J.D. Beyond carbon and energy: The challenge in setting guidelines for life cycle assessment of biofuel systems. Renew. Energy 2017, 105, 436–448.

23. Smyth, B.M.; Gallachóir, B.P.Ó.; Korres, N.E.; Murphy, J.D. Can we meet targets for biofuels and renewable energy in transport given the constraints imposed by policy in agriculture and energy? J. Clean. Prod. 2020, 18, 1671–1685.

24. Su, Y.; Zhang, P.; Su, Y. An overview of biofuels policies and industrialization in the major biofuel producing countries. Renew. Sustain. Energy Rev. 2015, 50, 991–1003.

25. Lima, M.G.B.; Gupta, J. The extraterritorial dimensions of biofuel policies and the politics of scale: Live and let die? Third World Q. 2014, 35, 392–410.

26. Kumar, S.; Shrestha, P.; Salam, P.A. A review of biofuel policies in the major biofuel producing countries of ASEAN: Production, targets, policy drivers and impacts. Renew. Sustain. Energy Rev. 2013, 26, 822–836.

27. Jayed, M.H.; Masjuki, H.H.; Kalam, M.A.; Mahlia, T.M.I.; Husnawan, M.; Liaquat, A.M. Prospects of dedicated biodiesel engine vehicles in Malaysia and Indonesia. Renew. Sustain. Energy Rev. 2011, 15, 220–235.

28. Republic of the Philippines. Republic Act no. 9367. An Act to Direct the Use of Biofuels. Biofuels Act of 2006, Manila, Philippines. Available online: (accessed on 6 June 2020).

29. Labios, A.E.M.G. The Philippine Biofuels Program: The Social & Economic Impacts. Available online: (accessed on 10 May 2021).

30. Economic Times. Make Ethanol from Surplus Food Grains: Draft Policy. 2017. Available online: (accessed on 14 June 2020).

31. Koljonen, T.; Flyktman, M.; Lehtilä, A.; Pahkala, K.; Peltola, E. The role of CCS and renewables in tackling climate change. Energy Procedia 2009, 1, 4323–4330.

32. Government of Pakistan. Alternative and Renewable Energy Policy 2011; Government of Pakistan: Islamabad, Pakistan, 2011.

33. Solangi, K.H.; Islam, M.R.; Saidur, R.; Rahim, N.A.; Fayaz, H. A review on global solar energy policy. Renew. Sustain. Energy Rev. 2011, 15, 2149–2163.

34. Islam, M.T.; Shahir, S.A.; Uddin, T.M.I.; Saifullah, A.Z.A. Current energy scenario and future prospect of renewable energy in Bangladesh. Renew. Sustain. Energy Rev. 2014, 39, 1074–1088.

35. Bazmi, A.A.; Zahedi, G. Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review. Renew. Sustain. Energy Rev. 2011, 15, 3480–3500.

36. Mukherjee, I.; Sovacool, B.K. Sustainability principles of the Asian Development Bank's (ADB's) energy policy: An opportunity for greater future synergies. Renew. Energy 2012, 48, 173–182.

37. Braadbaart, F.; Poole, I.; Huisman, H.D.J.; van Os, B. Fuel, Fire and Heat: An experimental approach to highlight the potential of studying ash and char remains from archaeological contexts. J. Archaeol. Sci. 2012, 39, 836–847.

38. Ali, S.I. City District Government of Karachi (CDGK) to Grow Jatropha Plants. Available online: (accessed on 10 May 2020).

39. Government of Pakistan. Alternative and Renewable Energy Policy 2019; Government of Pakistan: Islamabad, Pakistan, 2019.

40. Danish; Zhang, B.; Wang, B.; Wang, Z. Role of renewable energy and non-renewable energy consumption on EKC: Evidence from Pakistan. J. Clean. Prod. 2017, 156, 855–864.

41. Zaman, K.; Mushtaq, M.; Ahmad, M.; Rustam, R. The relationship between agricultural technology and energy demand in Pakistan. Energy Policy 2012, 44, 268–279.

42. Pakistan State Oil. Bio-Diesel Initiative: A Step towards a Cleaner and Self Sufficient Pakistan; Pakistan State Oil: Islamabad, Pakistan, 2008; pp. 1–4.

43. Asif, M. Sustainable energy options for Pakistan. Renew. Sustain. Energy Rev. 2009, 13, 903–909.

44. Mahmood, A.; Javaid, N.; Zafar, A.; Ali, R.; Ahmed, S.; Razzaq, S. Pakistan's overall energy potential assessment, comparison of LNG, TAPI and IPI gas projects. Renew. Sustain. Energy Rev. 2014, 31, 182–193.

45. Tahir, S.N.A.; Rafique, M.; Alaamer, A.S. Biomass fuel burning and its implications: Deforestation and greenhouse gases emissions in Pakistan. Environ. Pollut. 2010, 158, 2490–2495.

46. Khalid, M.; Kumar, S.; Shrestha, R.M. Energy, environmental and economic effects of Renewable Portfolio Standards (RPS) in a Developing Country. Energy Policy 2013, 62, 989–1001.

47. Zaman, K.; Mushtaq, M.; Ahmad, M. Factors affecting commercial energy consumption in Pakistan: Progress in energy. Renew. Sustain. Energy Rev. 2013, 19, 107–135.

48. Harun, M.; Ali, M.; Nazir, J.; Ahmed, N.; Hasan, B.; Islam, S.; Aziz, A.; Raman, A.; Yusoff, R.; Faisal, M. Status of biodiesel research and development in Pakistan. Renew. Sustain. Energy Rev. 2012, 16, 4396–4405.

49. Rafique, M.M.; Rehman, S. National energy scenario of Pakistan—Current status, future alternatives, and institutional infrastructure: An overview. Renew. Sustain. Energy Rev. 2017, 69, 156–167.

50. Silitonga, A.S.; Atabani, A.E.; Mahlia, T.M.I.; Masjuki, H.H.; Badruddin, I.A.; Mekhilef, S. A review on prospect of Jatropha curcas for biodiesel in Indonesia. Renew. Sustain. Energy Rev. 2011, 15, 3733–3756.

51. Mofijur, M.; Masjuki, H.H.; Kalam, M.A.; Hazrat, M.A.; Liaquat, A.M.; Shahabuddin, M.; Varman, M. Prospects of biodiesel from Jatropha in Malaysia. Renew. Sustain. Energy Rev. 2012, 16, 5007–5020.

52. Demirbas, A. Progress and recent trends in biodiesel fuels. Energy Convers. Manag. 2009, 50, 14–34.

53. Vianna, D.S.; Aliana, C.; Garcez, G. Brazilian Biodiesel Policy: Social and environmental considerations of sustainability. Energy 2011, 34, 645–654.

54. Smeets, E.M.W.; Faaij, A.P.C.; Lewandowski, I.M.; Turkenburg, W.C. A bottom-up assessment and review of global bio-energy potentials to 2050. Prog. Energy Combust. Sci. 2007, 33, 56–106.

55. Peters, C.J.; Bills, N.L.; Wilkins, J.L.; Fick, G.W. Foodshed analysis and its relevance to sustainability. Renew. Agric. Food Syst. 2008, 24, 1–7.

56. Biodiesel. National Biodiesel Board (NBB). Biodiesel Sustainability Symposium. Available online: (accessed on 10 May 2020).

57. Biodiesel. National Biodiesel Board. Guiding Principles for Biodiesel Sustainability. Available online: (accessed on 10 May 2020).

58. Achten, W.M.M.J.; Mathijs, E.; Leuven, K.U. Jatropha biodiesel fueling sustainability? Biofuels Bioprod. Biorefining 2007, 1, 283–291.

59. Openshaw, K. A review of Jatropha curcas: An oil plant of unfulfilled promise. Biomass Bioenergy 2000, 19, 1–15.

60. Kumar, A.; Sharma, S. An evaluation of multipurpose oil seed crop for industrial uses (Jatropha curcas L.): A review. Ind. Crop. Prod. 2008, 28, 1–10.

61. Divakara, B.N.; Upadhyaya, H.D.; Wani, S.P.; Gowda, C.L.L. Biology and genetic improvement of Jatropha curcas L.: A review. Appl. Energy 2010, 87, 732–742.

62. Garnayak, D.K.; Pradhan, R.C.; Naik, S.N.; Bhatnagar, N. Moisture-dependent physical properties of jatropha seed (Jatropha curcas L.). Ind. Crop. Prod. 2008, 27, 123–129.

63. Misra, R.D.; Murthy, M.S. Jatropa—The future fuel of India. Renew. Sustain. Energy Rev. 2011, 15, 1350–1359.

64. Vyas, D.K.; Singh, R.N. Feasibility study of Jatropha seed husk as an open core gasifier feedstock. Renew. Energy 2007, 32, 512–517.

65. Heller, J. Physic Nut. Jatropha curcas L. Promoting the Conservation and Use of Underutilized and Neglected Crops. Available online: (accessed on 10 May 2020).

66. Wirawan, S.S. Potential of Jatropha curcas L. Joint Task 40. In Proceedings of the ERIA Workshop, Tsukuba, Japan, 28 October 2009.

67. Capstick, R. Assessment of the Bio-Fuels Value Chain in Indonesia. Available online: (accessed on 2 May 2020).
68. Kumar, A.; Sharma, S. Potential non-edible oil resources as biodiesel feedstock: An Indian perspective. Renew. Sustain. Energy Rev. 2011, 15, 1791–1800.
69. Pradhan, R.C.; Mishra, S.; Naik, S.N.; Bhatnagar, N.; Vijay, V.K. Oil expression from Jatropha seeds using a screw press expeller. Biosyst. Eng. 2011, 109, 158–166.
70. Lu, H.; Liu, Y.; Zhou, H.; Yang, Y.; Chen, M.; Liang, B. Production of biodiesel from Jatropha curcas L. oil. Comput. Chem. Eng. 2009, 33, 1091–1096.
71. Henning, R.K. The Jatropha System. Available online: (accessed on 2 May 2020).
72. Raju, A.J.S.; Ezradanam, V. Pollination ecology and fruiting behavior in a monoecious species Jatropha curcas L. (Euphorbiaceae). Curr. Sci. 2002, 83, 1395–1398.
73. Katwal, R.P.S.; Soni, P.L. Biofuels: An opportunity for socioeconomic development and cleaner environment. Indian For. 2003, 129, 939–949.
74. Hambali, D.I.E. Prospek Pengembangan Tanaman Jarak Pagar untuk Biodiesel dan Produk Turunan Lainnya. In Proceedings of the Workshop Pendirian Kebun Bibit Sumber, Demplot dan Feasibility Study untuk Perkebunan Jarak Pagar, Bogor, Indonesia, 16–17 May 2006.
75. Pradesh, I.U.; Farm, C. Synergistic cropping of summer groundnut with Jatropha curcas—A new two-tier cropping system for Uttar Pradesh. Growth 2007, 5, 1–2.
76. Gui, M.M.; Lee, K.T.; Bhatia, S. Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. Energy 2008, 33, 1646–1653.
77. Janaun, J.; Ellis, N. Perspectives on biodiesel as a sustainable fuel. Renew. Sustain. Energy Rev. 2010, 14, 1312–1320.
78. Azam, M.M.; Waris, A.; Nahar, N.M. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. Biomass Bioenergy 2005, 29, 293–302.
79. Akbar, E.; Yaakob, Z.; Kamarudin, S.K.; Ismail, M.S. Characteristic and Composition of Jatropha curcas Oil Seed from Malaysia and its Potential as Biodiesel Feedstock. Eur. J. Sci. Res. 2009, 29, 396–403.
80. Gübitz, G.M.; Mittelbach, M.; Trabi, M. Exploitation of the tropical oil seed plant Jatropha curcas L. Bioresour. Technol. 1999, 67, 73–82.
81. Gunstone, F. The Chemistry of Oils and Fats: Sources, Composition, Properties and Uses; John Wiley & Sons: Hoboken, NJ, USA, 2004; ISBN 1405116269.
82. Length, F. Chemical composition and insecticidal properties of the underutilized Jatropha curcas seed oil. Afr. J. Biotechnol. 2006, 5, 901–906.
83. Mittelbach, M. Diesel fuel derived from vegetable oils, VI: Specifications and quality control of biodiesel. Bioresour. Technol. 1996, 56, 7–11.
84. Pramanik, K. Properties and use of Jatropha Curcas oil and diesel fuel blends in compression ignition engine. Renew. Energy 2003, 28, 239–248.
85. Agarwal, D.; Agarwal, A.K. Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Appl. Therm. Eng. 2007, 27, 2314–2323.
86. Rashid, U.; Anwar, F.; Jamil, A.; Bhatti, H. Jatropha curcas Seed Oil as a Viable Source for Biodiesel. Pak. J. Bot. 2010, 42, 575–582.
87. Sarin, R.; Kumar, R.; Srivastav, B.; Puri, S.K.; Tuli, D.K.; Malhotra, R.K.; Kumar, A. Biodiesel surrogates: Achieving performance demands. Bioresour. Technol. 2009, 100, 3022–3028.
88. Odetoye, T.E.; Ogunniyi, D.S.; Olatunji, G.A. Preparation and evaluation of Jatropha curcas Linneaus seed oil alkyd resins. Ind. Crop. Prod. 2010, 32, 225–230.
89. Johanes, H.; Hirata, S. Biodiesel production from crude Jatropha curcas L. seed oil with a high content of free fatty acids. Bioresour. Technol. 2008, 99, 1716–1721.
90. Thepkhun, P. Biofuels Standard & Regulations in Thailand; Thailand Institute of Scientific and Technological Research: Pathum, Thailand, 2007.
91. Widodo, T.W.; Rahmarestia, E. Current Status of Bioenergy Development in Indonesia. In Proceedings of the Regional Forum on Bioenergy Sector Development: Challenges, Opportunies, and the Way Forward, Bangkok, Thailand, 23–25 January 2008; pp. 1–41.

92. Parajuli, R. Jatropha curcas and Its Potential Applications; A Compilation Paper on Plantation and Application of Jatropha curcas. Renew. Sustain. Energy Rev. 2009, 15, 3733–3756.
93. Traore, S. Characterisation of a Biodiesel from an Alkali Transesterification of Jatropha curcas oil. Available online: (accessed on 2 May 2020).
94. Sarin, R.; Sharma, M.; Sinharay, S.; Malhotra, R.K. Jatropha–Palm biodiesel blends: An optimum mix for Asia. Fuel 2007, 86, 1365–1371.
95. Knothe, G. Structure Indices in FA Chemistry. How Relevant Is the Iodine Value? J. Am. Oil Chem. Soc. 2002, 79, 847–854.
96. Forson, F.K.; Oduro, E.K.; Hammond-Donkoh, E. Performance of jatropha oil blends in a diesel engine. Renew. Energy 2004, 29, 1135–1145.
97. Jayed, M.H.; Masjuki, H.H.; Saidur, R.; Kalam, M.A.; Jahirul, M.I. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. Renew. Sustain. Energy Rev. 2009, 13, 2452–2462.
98. Murugesan, A.; Umarani, C.; Chinnusamy, T.R.; Krishnan, M.; Subramanian, R.; Neduzchezhain, N. Production and analysis of bio-diesel from non-edible oils—A review. Renew. Sustain. Energy Rev. 2009, 13, 825–834.
99. Patil, P.D.; Deng, S. Optimization of biodiesel production from edible and non-edible vegetable oils. Fuel 2009, 88, 1302–1306.
100. Xue, J.; Grift, T.E.; Hansen, A.C. Effect of biodiesel on engine performances and emissions. Renew. Sustain. Energy Rev. 2011, 15, 1098–1116.
101. Wassell, C.S.; Dittmer, T.P. Are subsidies for biodiesel economically efficient? Energy Policy 2006, 34, 3993–4001.
102. Szulczyk, K.R.; Mccarl, B.A. Market penetration of biodiesel. Renew. Sustain. Energy Rev. 2010, 14, 2426–2433.
103. Lapuerta, M.; Armas, O.; Rodríguez-Fernández, J. Effect of biodiesel fuels on diesel engine emissions. Prog. Energy Combust. Sci. 2008, 34, 198–223.
104. Environmental Protection Agency (EPA). A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions; EPA: Washington, DC, USA.
105. McCormick, R.L.; Allerman, T.L.; Yanowitz, J. Impact of Biodiesel Fuel on Pollutant Emissions from Diesel Engines; National Renewable Energy Laboratory: Golden, CO, USA.
106. Sugiyono, A. Pengembangan Bahan Bakar Nabati untuk Mengurangi Dampak Pemanasan Global. Development of Vegetable oils to Reduce Global Warming Effect. Seminar Nasional Kebijakan Pemanfaatan Lahan dalam Menanggulangi Dampak Pemenasan Global, Keluarga Mahasiswa Ilmu Tanah, Fakultas Pertanian, UGM. 2008. Available online: (accessed on 3 February 2011).
107. Knowgenix Sustainable Biodiesel Feedstock. Jatropha: A Strategic Option. 2007. Available online: (accessed on 12 June 2020).
108. Reubens, B.; Achten, W.M.M.J.; Maes, W.H.; Danjon, F.; Aerts, R.; Poesen, J.; Muys, B. More than biofuel? Jatropha curcas root system symmetry and potential for soil erosion control. J. Arid Environ. 2011, 75, 201–205.
109. German Technical Cooperation. Jatropha Reality Check: A Field Assessment of the Agronomic and Economic Viability of Jatropha and Other Oilseed Crops in Kenya 2010. Available online: (accessed on 12 June 2020).
110. Baroi, C.; Yanful, E.K.; Rahman, M.F.; Bergougnou, M. Environment Friendly Biodiesel from Jatropha Curcas: Possibilities and Challenges; Springer: Dordrecht, Germany, 2010.