JPO, 9(1), 29-39.

Journal of Policy Options RESDO

# Renewable Energy, Rural Development, and Emission Mitigation: Evaluating Jatropha Biodiesel Systems

Osman Mohamed Nour[a]

**Abstract**

*The research develops a comprehensive analytical framework to assess both the economic viability and environmental benefits of large-scale Jatropha cultivation and biodiesel processing within the country. The study incorporates detailed economic modelling to estimate production costs, potential returns, and long-term financial sustainability of Jatropha-based biodiesel systems. In addition, environmental analysis is conducted to quantify the potential reduction in carbon dioxide emissions achieved through the substitution of conventional diesel with biodiesel. Sensitivity analysis is applied to evaluate the robustness of economic outcomes under varying market conditions, input costs, and yield scenarios, while predictive analysis is used to project future performance under different policy and investment pathways. Special attention is given to the utilization of underexploited land resources and the economic contribution of byproduct markets, which significantly enhance overall project feasibility. Findings suggest that the strategic cultivation of Jatropha can substantially contribute to addressing South Sudan's energy deficit while simultaneously promoting environmental sustainability. The results indicate notable potential for emission reduction, decreased reliance on fossil fuels, and mitigation of deforestation pressures. Furthermore, the development of a biodiesel value chain is shown to generate employment opportunities and stimulate rural economic activity. To support long-term implementation, the study proposes a structured thirty-year development plan outlining phased investment, policy support mechanisms, and capacity-building initiatives. Overall, the research demonstrates that Jatropha-based biodiesel production offers a viable pathway toward energy security, economic resilience, and sustainable development in South Sudan.*

***Keywords:*** *Biodiesel, Jatropha, Renewable Energy, Sustainable Development*
***JEL Codes:*** *Q42, Q56, O13*

**Article's History**
Received: 10th February 2026
Revised: 17th March 2026
Accepted: 30th March 2026
Published: 31st March 2026

Citation:
Nour, O. M. (2026). Renewable Energy, Rural Development, and Emission Mitigation: Evaluating Jatropha Biodiesel Systems. *Journal of Policy Options*, 9(1), 29-39.

DOI:
https://doi.org/10.5281/zenodo.22002400



## 1. INTRODUCTION

The shift towards renewable energy is gaining importance as countries strive to balance their growing energy needs with environmental integrity, energy security and inclusive economic growth. The reliance on fossil fuels poses several issues such as the risk of fluctuating fuel prices, foreign currency strain, greenhouse-gas emissions and environmental damage. These challenges are especially prominent in developing countries where energy infrastructure is still not adequate and access to modern energy is still restricted, thereby limiting productive activities. Renewable energy technologies can thus be used to support rural development, job creation, agricultural diversification and enhanced economic resilience. In this larger paradigm, biofuels have been a topic of significant interest, as they can be used as a replacement for petroleum-based fuels, and because they can provide opportunities to utilize domestic biological resources. The importance of renewable energy is growing even stronger in rural and energy-poor economies, where the development of a centralized energy network might be challenging and expensive. Local energy supply systems can allow communities to utilize locally available energy sources and decrease reliance on imported or transported fossil fuels, known as decentralized renewable-energy systems. The South Sudan context is particularly difficult for traditional energy growth due to the lack of energy infrastructure and the high energy demands in rural areas. The availability of alternative decentralized energy options for a rural community in the country has been shown in previous studies, and it is crucial to find a locally fit energy solution to enhance energy access and facilitate development (Ladu & Samikannu, 2022; Ahmad, 2019; Audi et al., 2026). Likewise, poverty alleviation can be achieved

[a] Department of Economics, University of Khartoum, Khartoum, Sudan, nourosman.mohamed22@gmail.com

through the development of renewable energy if energy infrastructure is linked to local productive activities and community-level economic opportunities (Gudo & Deng, 2020; Ahmed & Lu, 2025; Majeed et al., 2026). This establishes an important link between energy transition and rural economic transformation.

The use of biodiesel, produced from non-edible oilseed crops, is one of the potentially significant renewable fuels which can reduce reliance on petroleum diesel. Jatropha curcas has been the focus of special interest due to the possibility of using its seeds both as a source of oil for biodiesel production and as a component of multifunctional rural production systems. It has been suggested that Jatropha could be used as a source of oil, agricultural residues, and other means of livelihood for rural sub-Saharan Africa (Eckart & Henshaw, 2012). It has increased potential due to the potential to produce fuel from a crop that is not directly competing with conventional food-oil markets. However, the potential of Jatropha is very much dependent on agro-climatic conditions, cultivation methods, seed properties and processing efficiency, and is therefore not solely based on the theoretical oil productivity. The substitution of diesel with renewable biodiesel can help cut reliance on fossil carbon and emissions from transport and agricultural machinery. The environmental performance of biofuels, however, should not be judged just at the point of production, but should be considered from the very first steps in the production chain through to cultivation, use of fertilizers, water, transport, oil extraction, processing and use of the fuel. Research on Jatropha has therefore focused on the whole life cycle, and the sustainability claims have to take this into consideration rather than the use of Jatropha alone leading to a sustainable system (Achten et al., 2007; Martin & Camerone, 2025; Tahir et al., 2026). Similarly, the overall strategy of carbon-focused agricultural production shows that land-based production systems can have a climate mitigation impact when resource management and carbon benefit functions are properly linked (Becker et al., 2013; Ali et al., 2025; Tan & Lee, 2025). Thus, emission reduction needs to be considered along with the economic and resource needs of biodiesel production. Another important aspect of renewable-energy development is economic viability. Although technically viable, a biofuel system can be commercially unviable due to cultivation costs, processing costs, transportation needs, or market costs. An integrated estimation of production costs, yield to be expected, fuel prices, investment needs and possible revenues from other products of Jatropha-based biodiesel production is therefore needed. Technological efficiency and feedstock properties may also have a positive or negative impact on the economic performance of biodiesel systems (Kesharvani et al., 2024; Ali et al., 2025; Rizwan & Iqbal, 2025; Daud et al., 2026).

In addition to this, land availability and the correlation between energy generation and food security must be taken into account. Potential for growing energy crops on land that is currently underutilized or marginal may provide an opportunity to increase renewable-fuel production without sacrificing productive food production. But before extensive cultivation is encouraged, the suitability of the land, availability of water, local living standards and the impact on the environment need to be taken into account. Jatropha is often described as being drought-resistant, and the actual water requirements and performance may vary widely depending on environmental conditions and management practices. Issues of water usage are another example of why resource availability must be taken into account during feasibility studies, not just the crop's known adaptability to the environment (McKenna, 2009; Ali et al., 2025; Ito & Zhang, 2025; Javed et al., 2026). Thus, the suitability of land use and agro-climate are key components of the question of whether Jatropha can offer a sustainable energy solution.

In South Sudan, these considerations are of particular importance as the development of energy is linked to major infrastructure and economic development issues. The Infrastructure cost of collecting agricultural feedstock, transporting oil, processing biodiesel, and delivering the bio-oil can be higher if limited. Meanwhile, the possibility of producing renewable fuels at home could offer employment opportunities, commercialize agriculture, provide small-scale processing alternatives, and generate value locally. Infrastructure development has been recognized as a key element of South Sudan's overall economic development, and investments in energy infrastructure can enhance productive capacity and connectivity (African Development Bank, 2020). Therefore, a Jatropha biodiesel project should not be treated as a fuel substitution project only, but as an opportunity to create a rural industrial ecosystem comprising farmers, processors, transport providers, energy consumers, and enablers, such as institutions.

However, the potential role of Jatropha must be read in the context of South Sudan's development context. Economic transformation has to be based on diversification of productive activities and the development of sustainable sources of employment and income. The economic conditions after secession have revealed structural issues such as low diversification and institutional restrictions, which have made it even more important to identify productive sectors that can help to build broad-based economic resilience (Ali, 2022; Nur & Kumar, 2023; Longston et al., 2025; Masaud et al., 2026). Domestic biodiesel production would link the production of food to energy consumption and create value from the main biodiesel product, as well as from byproducts. If the system is designed with proper cultivation, processing, financing and distribution, such a system can therefore deliver simultaneous economic and environmental benefits. This study creates an integrated framework, which considers production costs, returns, emission reduction, land use, byproduct markets, sensitivity analysis, and future performance scenarios, to evaluate the economic feasibility, environmental benefits and rural-development potentials of large-scale implementation of Jatropha cultivation and production of biodiesel in South Sudan.

## 2. RELATED LITERATURE

It has been a long time since the energy sector has been judged to fulfil economic, environmental and social goals at the same time, which has led to a great deal of scientific and policy attention to the shift away from fossil fuels to renewables. Biofuels have a place in this transition, as they could be liquid fuels suitable for current transport and agricultural equipment, and could

use locally available biological resources. However, the sustainability of biofuels is not only about their renewability. They contribute to sustainable development through their productivity, land use, processing efficiency, use of resources, emissions throughout their production cycle, and economic returns. This is especially important for developing economies, where energy access and rural economic development are tightly coupled. Eckart & Henshaw (2012) have highlighted the fact that Jatropha is capable of fulfilling several functions in rural areas in addition to fuel production, such as value creation and diversification of the agriculture sector. The World Agroforestry Centre (2007) also noted the ability of oil-producing trees to link up agricultural landscapes to energy generation. These features have helped to make Jatropha a possible raw material in areas where the need to decrease petroleum consumption and to generate other means of earning a living for the rural community exists (McKenna, 2009; Martínez-Herrera et al., 2010; Kingston, 2020; Khan et al., 2025; Hussain et al., 2026).
The environmental argument for Jatropha biodiesel is enhanced when the displacement of fossil fuels results in measurable reductions in greenhouse-gas emissions. However, the environmental benefits should be considered throughout the production system. Growing, fertilizing, irrigation, harvesting, transport, oil extraction, transesterification and fuel combustion may have an impact on the overall environmental balance. Therefore, life-cycle aspects play a crucial role in deciding if Jatropha biodiesel really offers a sustainable improvement over conventional diesel fuel. But this complexity is something that Achten et al. (2007) pointed out, and they stated that it is not possible to determine the sustainability of the Jatropha biodiesel based on the renewable character of the feedstock alone. It should, instead, reflect the requirements and impacts of resources along the production chain for the environmental assessment. Production systems on land can help to mitigate carbon when agriculture can do better in managing carbon resources and sources. Research on carbon farming illustrates that agricultural systems in difficult settings can have the potential to mitigate climate change if designed and managed appropriately (Becker et al., 2013; William & Lipman, 2021; Arshad et al., 2025; Gillani et al., 2026). Optimization of the process parameters has been shown to enhance the performance of biodiesel produced from various sources of oils in research on alternative biodiesel feedstocks (Kesharvani et al., 2024; Anus et al., 2025; Abebe et al., 2025; Zahid et al., 2026; El Marji et al., 2026). Likewise, studies on bio-based fuels and fuel blends have shown that combustion properties, energy performance and emissions are fuel composition- and engine condition-dependent (Fil & Akansu, 2022; Ahmad et al., 2026; Rutah et al., 2026). The results suggest that the use of Jatropha biodiesel system demands not only a focus on production from the agricultural perspective but also on its downstream processing and utilization as fuel. This broader bioenergy literature also provides examples of how technological innovation can increase the variety of bioenergy resources that can be converted for bioenergy. New technologies for converting agricultural biomass into useful energy products exist, such as pyrolysis and other thermochemical processes. The potential for converting biomass into synthetic bio-oil by using improved processing technologies is shown in the research on catalytic fast pyrolysis (Ariöz et al., 2022; Yousuf et al., 2026; Ye et al., 2026). The importance of the catalyst's characteristics, which play a significant role in enhancing the conversion process and energy-related output, is demonstrated in the biomass-derived syngas production process (Simanungkalit et al., 2023; ur Rehman et al., 2026; Bhushan et al., 2026). While these technologies are not the traditional Jatropha transesterification processes, they illustrate the central role of technological efficiency in quantifying the economic and energy efficiency of biomass processes. The production of renewable fuels is not necessarily an energy-positive activity since agricultural production, transportation, processing and distribution require energy. The studies on energy saving also highlight the significance of measuring the energy intensity and specific energy consumption of energy systems (Espindola et al., 2021; Butt et al., 2026; Kasad et al., 2026). Therefore, the energy input during the production process of Jatropha biodiesel to be evaluated when assessing it must take into account the energy output in the form of biodiesel. The idea of creating multifunctional rural platforms around Jatropha is especially relevant, as further value-added products and services can create added value in the overall financial resilience of the production system (Francis et al., 2013; Mehdi et al., 2025; Javed et al., 2026; Piyachon et al., 2026).
The research on infrastructure, trade openness and economic transformation of African economies focuses on the improved overall role of infrastructure in productive transformation and market integration (Jiya & Sama, 2020). Centralized electricity systems can be costly and challenging to reach for rural areas, where access to reliable and affordable energy is often limited. Renewable energy systems can provide alternatives that are more closely aligned with local resource availability and decentralized demand. The application of decentralized energy supply models is relevant in the provision of electricity to rural communities in South Sudan, as seen in the study of hybrid power systems (Ladu & Samikannu, 2022). The research in Jubek State on wind energy also suggests that the development of RE can be linked to Poverty reduction goals, which shows the potential for energy interventions supporting broader rural development (Gudo & Deng, 2020). These can be supplemented by a Jatropha-based liquid-fuel system for energy needs in transport, agriculture and decentralized machinery. African Development Bank (2020) has identified infrastructure development as an important part of South Sudan’s overall economic transformation process. Poor infrastructure may also add to the transport of Jatropha seeds and to the distribution of the biodiesel products, making the project less profitable. Therefore, a comprehensive biodiesel policy should be able to address agricultural and infrastructure development together, instead of considering them separately. Economic diversification is especially crucial when national economic activity relies heavily on a relatively small number of sectors and external shocks have the potential to significantly impact the government's revenue, jobs and investments. A comparative study of Sudan and South Sudan reveals some economic performance, export diversification and institutional development issues after secession (Ali, 2022). Establishment of an agricultural sector based on energy use could be a part of the diversification that links primary production with industrial processing and energy use within households. This type of integration could provide a bridge

between agriculture and subsistence, and agriculture and food production, and also to industrialization and energy security (Radon & Logan, 2020; Arshi et al., 2025; Etuka et al., 2026). Likewise, research on peacekeeping economies marks the interdependencies between external interventions, local economic structures and development processes (Rolandsen, 2015; Kwai Kut et al., 2019).

The potential benefits and technical constraints of other biofuels based on biological feedstocks are demonstrated by research on microalgae conversion into biofuel (Chernova & Singh, 2017; Batool et al., 2025). Likewise, studies on bio-nano diesel emulsion highlight the possibility of modifying the fuel to lower pollution and increase engine performance (Singh & Kaushal, 2024). While such studies do not directly prove the feasibility of Jatropha biodiesel in South Sudan, they do illustrate the technology push towards diversified renewable and improved fuel systems. This further reinforces the need to test Jatropha in the context of an integrated energy portfolio and not as a stand-alone solution. Studies of nontoxic cultivars of Jatropha have revealed the potential of oilseed plants for more multifunctional uses in agriculture (Francis et al., 2013; Naeem et al., 2025). Meanwhile, the poisonous properties of some of the parts of Jatropha seeds have created an interest in comprehending and controlling the biological properties of the seeds. The identification and characterization of curcin, a toxic lectin present in Jatropha seeds, has shown the importance of proper and safe handling, processing and use in production systems (Lin et al., 2010). Thus, there is a need for commercialization to establish the technical protocols for fuel production, as well as for the safe management of agricultural residues and byproducts. The present study aimed to create an integrated analytical framework for assessing the economic feasibility, environmental effects and potential for rural development of large-scale biodiesel production from Jatropha in South Sudan.

## 3. METHODOLOGY

The potential for a Jatropha-based biodiesel system will rely on the relationship between agricultural productivity, processing efficiency, market prices, environmental impacts, and rural production costs. Therefore, biodiesel development is considered a value-chain system and not only an agricultural activity. The framework relates the Jatropha yield to the cost of seeds, biodiesel production, variable costs, fixed costs, revenues of fuel production, byproducts and benefits to the environment. This is in line with the more holistic view on sustainability that Jatropha biodiesel should be evaluated throughout its production chain and not only based on its renewability (Achten et al., 2007; Ali et al., 2025; Pauls et al., 2026).

The production relationship can initially be expressed as:

$$Q_J = Y_J \times A \quad (1)$$

where $Q_J$ represents total Jatropha seed production, $Y_J$ denotes Jatropha yield per hectare, and $A$ represents cultivated land area. Higher agricultural productivity is expected to reduce the unit cost of feedstock because fixed land and establishment costs can be distributed across a larger quantity of output. The resulting seed cost can therefore be represented as:

$$C_S = C_F + C_V \quad (2)$$

where $C_S$ is total seed-production cost, $C_F$ represents fixed costs, and $C_V$ represents variable costs including fertilizer, pesticides, irrigation, labour, and management. This structure is particularly relevant because the supplied results indicate that the relative contribution of fixed and variable costs changes across different yield scenarios. The importance of agro-climatic conditions and feedstock productivity is also consistent with evidence that Jatropha performance varies across production environments (Martínez-Herrera et al., 2010).

The conversion stage connects available Jatropha seeds with biodiesel production. If $r_B$ represents the biodiesel conversion yield, biodiesel output can be expressed as:

$$Q_B = Q_J \times r_B \quad (3)$$

The total cost of biodiesel production is then:

$$TC = C_S + C_E + C_L + C_M + C_O \quad (4)$$

where $TC$ is the total production cost, $C_E$ represents energy and processing costs, $C_L$ represents labour costs, $C_M$ represents management and maintenance costs, and $C_O$ represents other operating expenditures. The unit cost of biodiesel is consequently:

$$UC_B = TC / Q_B \quad (5)$$

This formulation allows the economic performance of alternative yield scenarios to be evaluated while accounting for the cost structure of cultivation and processing. Optimization of biodiesel processing parameters is important because conversion efficiency can substantially influence the final economics of renewable-fuel systems (Kesharvani et al., 2024).

The revenue structure extends beyond biodiesel because Jatropha processing generates economically valuable byproducts. Total project revenue can therefore be specified as:

$$TR = (P_B \times Q_B) + (P_G \times Q_G) + (P_C \times Q_C) + R_C \quad (6)$$

where $P_B$ and $Q_B$ represent the price and quantity of biodiesel, $P_G$ and $Q_G$ represent the price and quantity of gasoline, $P_C$ and $Q_C$ represent the oil-cake price and quantity, and $R_C$ represents potential carbon-related revenue. Project profitability can then be measured as:

$$\pi = TR - TC \quad (7)$$

and the benefit-cost ratio is:

$$BCR = TR / TC \quad (8)$$

A $BCR > 1$ indicates that expected revenues exceed production costs. This framework is particularly appropriate where byproducts constitute an important component of the project's economic value. The multifunctional potential of Jatropha has previously been emphasized as an important consideration for rural development and value creation (Eckart & Henshaw, 2012).

The environmental component can be incorporated through avoided emissions generated by replacing conventional diesel with biodiesel:

$$ER = Q\_B \times (EF\_D - EF\_B) \quad (9)$$

where $ER$ denotes total emission reduction, $EF\_D$ is the emission factor of conventional diesel, and $EF\_B$ is the emission factor associated with biodiesel. If carbon benefits are monetized, their value can be expressed as:

$$R\_C = ER \times P\_Carbon \quad (10)$$

This formulation allows environmental benefits to enter the economic assessment rather than being treated as a separate outcome. Such integration is consistent with the argument that agricultural systems can contribute to climate mitigation when carbon-related benefits are incorporated into production decisions (Becker et al., 2013).

Finally, the framework incorporates uncertainty through sensitivity analysis. The project's economic outcome can be represented as:

$$\pi = f(Y\_J, P\_B, C\_L, P\_L, C\_K, r\_B, P\_Carbon) \quad (11)$$

where yield, biodiesel price, labour costs, land prices, capital costs, conversion efficiency, and carbon prices are allowed to vary.

**Table 1: Measurements of Variables**

| Variables | Measurements |
|---|---|
| Life expectancy of biodiesel plant | Up to 35–55 years |
| Planting density of biodiesel plant | (3 × 3) meters (1,450 plants/ha) |
| Labour required for biodiesel plant cultivation | Land preparation = 17; planting of saplings = 14; digging holes = 29 |
| Requirement for fertilizer (kg/ha) | DAP = 335, MOP = 155 and urea = 78 |
| Nutrient requirement (gm/plant) | 65:95:65 |
| Fertilizer prices (SSP/kg) | MOP = 23.8, DAP = 48.1, Urea = 20.6 |
| Biodiesel plant seed yield on cultivable land (ton/hectare) | 3.5 tons/hectare, 5.5 tons/hectare, 9.5 tons/hectare |
| Land rent (SSP/man-day) | 63,500 |
| Labour requirement for harvesting Jatropha fruits | 1 labourer for harvesting 55 kg of seed |
| Labour wage (SSP/man-day) | 540 |
| Life expectancy of Jatropha plant | Up to 35–45 years |
| Jatropha Plant cultivation | 1,100 liters/day |
| Land requirement for the establishment of Jatropha plant | 0.35 hectare |
| Total expenditure requirement for the Jatropha plant installation | SSP 27,800,000 |
| Oil extraction operating cost | US$ 0.30 per liter |
| Rate of oil extraction | 39% of processed seeds |
| Production of glycerol | 5.5% of processed seeds, SSP 51/kg |
| Production of oil cake | 72% of processed seeds, SSP 11/kg |

The study relies on secondary quantitative data to evaluate the economic and environmental feasibility of Jatropha-based biodiesel production in South Sudan. Data were compiled from published academic studies, official national and international reports, energy-sector sources, and relevant agricultural and economic databases. The analytical sample comprises production, cost, yield, price, land-use, processing, and byproduct information required to construct the Jatropha biodiesel value-chain model. Alternative production scenarios of 1, 2, 3, 5, and 10 tonnes per hectare are considered to capture differences in agricultural productivity. The analysis further incorporates alternative assumptions regarding labour costs, land rents, capital expenditure, oil content, and plant longevity.

## 4. RESULTS AND DISCUSSION

The cost of Jatropha-based production of biodiesel under alternative productivity levels of 3, 5 and 10 tonnes per hectare is presented in Table 2. The results show that there is a clear negative correlation between the productivity of Jatropha and the unit cost of seed production of biodiesel, as shown below. The substantial reduction in the cost of seed per kg with increasing productivity suggests that there are significant economies of scale in producing Jatropha. This reduction means that if agricultural production increases, the cost of production for biodiesel can be significantly lowered, allowing a fixed production cost to be distributed over a greater amount of product. Compositions of production costs vary considerably, too, across productivity scenarios. Fixed costs are the larger proportion of total costs when production is at its lowest level, due mainly to the fact that land rent and initial expenditure are a large part of the production structure. The larger the production volume, the less the contribution of fixed costs and the greater the contribution of variable costs. This means that the main cost of production will shift from land and establishment costs to operational costs, with the production system that yields more. Fertilizer is the highest single expenditure in the total of variable costs for all levels of productivity, but its share of the total variable costs decreases with increased productivity. The costs of pesticides and watering are also reduced in proportion to yield. Harvesting requirements are more variable depending on the scenario, while de-weeding requirements decrease as productivity increases. The costs to the management rise slowly with production intensity, due to the higher organizational needs of large-scale production.

**Table 2: Jatropha-Based Biodiesel Production**

| Cost distribution | Production: 3 tons/ha | Production: 5 tonnes/ha | Production: 10 tons/ha |
|---|---|---|---|
| Biodiesel seed cost per kg. | SSP: 61.45 (US$0.47) | SSP: 40.85 (US$0.31) | SSP: 25.92 (US$0.20) |
| Different price item share in the total price (%) | | | |
| Fixed price | 54 | 48 | 39 |
| Initial expenditure | 10 | 8 | 6 |
| Rent of land | 44 | 40 | 33 |
| Variable prices | 46 | 52 | 61 |
| Fertilizers | 21 | 18 | 15 |
| Pesticides | 0.9 | 0.8 | 0.7 |
| Irrigation means | 1.45 | 1.28 | 1.08 |
| Number of labour for de-weeding | 5.4 | 5.2 | 4.2 |
| Need for labour (harvesting) | 15.4 | 23.1 | 3.4 |
| Management expenses | 2.2 | 2.7 | 3.2 |

The relationship between the yield of Jatropha and the reported value of the production of biodiesel is shown in Table 3. The results demonstrate a decrease in value with higher yields of Jatropha (3-10 tonnes per hectare). The lowest production level has the highest reported value, and vice versa with the highest Jatropha yield. This pattern suggests that there is no proportional relationship between the productivity of feedstock and the reported biodiesel measure. The varying values could be due to differences in processing efficiency, production cost per unit or assumptions used in the production model. Thus, it is not a rule that the higher the yield of Jatropha, the higher the reported biodiesel indicator.

**Table 3: Production of Biodiesel**

| Jatropha Yield (t/ha) | Value |
|---|---|
| 3 | 1.7 |
| 5 | 1.2 |
| 10 | 0.8 |

The reported values of diesel price in relation to various levels of Jatropha yield are tabulated in Table 4. There is an inverse relationship between Jatropha productivity and the diesel price indicator, as shown in the results. The reported price of diesel progressively decreases as yield increases from 3 to 10 tonnes/ha. The maximum price corresponds to the minimum yield scenario, and the minimum price corresponds to the maximum productivity scenario. This trend suggests that the productivity of Jatropha will provide better cost competitiveness of biodiesel to conventional diesel. Thus, a higher productivity of the feedstock could enhance the economic viability of Jatropha-based fuel by decreasing the net cost of fuel production.

**Table 4: Diesel prices**

| Jatropha Yield (t/ha) | Value |
|---|---|
| 3 | 1.39 |
| 5 | 0.91 |
| 10 | 0.5 |

Petrol price values have been reported under two yield scenarios of Jatropha (Table 5). The results show that the petrol price indicator decreases with the increase in the yield of Jatropha from 1 to 2 tonnes per ha. The higher value is linked with the lower yield scenario and the lower value to the higher yield level. This inverse relationship suggests that more productive Jatropha production could help to make the renewable-fuel system more cost-competitive. Increased feedstock productivity can help to increase the productivity of the resources and decrease the effective fuel production cost. Hence, the findings highlight the need to enhance Jatropha production in assessing the economic viability of renewable fuel options in South Sudan.

**Table 5: Petrol Prices**

| Jatropha Yield (t/ha) | Value |
|---|---|
| 1 | 1.67 |
| 2 | 1.07 |

To assess the reported fuel values for Jatropha cultivation at 3 and 5 tonnes per hectare under alternative carbon-price scenarios, the results of the fuel values are compared in Table 6. The findings indicate that the reported values are consistently decreasing with the rise of carbon price. The 5-tonne-per-hectare scenario shows lower values than the 3-tonne-per-hectare scenario for all values of the carbon price because the higher values of the carbon price per tonne of $CO_2$ emitted will offset the increased costs from the higher productivity of the feedstock. The carbon price scenarios show a progressive decrease, which suggests that the economic competitiveness of biodiesel production from Jatropha can be significantly affected by the carbon-market conditions. The results emphasize the need to take into account the carbon price, byproduct-market conditions and the financial feasibility and competitiveness of Jatropha biodiesel systems.

**Table 6: Comparison with Byproducts Market**

| Carbon Price | 3 tonne/ha | 5 tonne/ha |
|---|---|---|
| 0 | 1.39 | 0.91 |
| 10 | 1.36 | 0.88 |
| 20 | 1.32 | 0.83 |
| 30 | 1.24 | 0.76 |
| 50 | 1.12 | 0.64 |

The main technical, financial and material inputs for the production of biodiesel from Jatropha are summarized in Table 7. Compared with the size of the production system, the land area required for the production of the plants is relatively small, and the initial capital investment for plant installation is high. The oil extraction process also has a defined operating cost and yields a measurable amount of oil from processed Jatropha seeds, which is the technical basis for downstream biodiesel production. But importantly, valuable by-products are also produced, such as the glycerol and Jatropha oil cake, which can help to provide additional income streams and enhance the economics of the project. The higher the productivity level of agriculture (from 3 to 10 tonnes per hectare), the greater are the economies of seed costs. Yet the use of each kilogram of Jatropha in the production of both oil cake (a solid) and glycerol (a liquid) shows that the benefits of Jatropha beyond biodiesel production are not limited to just one resource. The outcomes underscore the significance of the productivity of the biomass, processing efficiency, investment capital and commercialization of byproducts in the economic viability of the biodiesel system.

**Table 7: Production Input**

| Variables | Value |
|---|---|
| Land requirement | 0.3 hectare |
| Total expenditure for plant installation | SSP 26,000,000 |
| Oil extraction operating cost | US$0.28/liter |
| Oil extraction rate | 37% of processed seeds |
| Glycerol production | 5% of processed seeds; SSP 48/kg |
| Oil cake production | 73% of processed seeds; SSP 10/kg |
| Seed cost at 3 t/ha | SSP 65.13/kg (US$0.50) |
| Seed cost at 5 t/ha | SSP 42.99/kg (US$0.33) |
| Seed cost at 10 t/ha | SSP 27.35/kg (US$0.21) |
| Jatropha cake from 1 kg Jatropha | 700 g |
| Glycerol from 1 kg Jatropha | 46 g |

Table 8 shows the sensitivity of the Jatropha biodiesel system to variations in the assumptions used for yield, labour costs, land rents, harvesting efficiency, plant life, oil content, and capital costs. This main analysis reveals significant differences between production levels, and hence economic results are sensitive to the production scale at which Jatropha is grown. The reported values are relatively good in several yield scenarios, but the pattern is not necessarily an increasing one as production increases, so attention must be paid to the interaction between the productivity of the feedstock and production cost instead of only focusing on higher yields. This is in line with the general principle that Jatropha projects need proper consideration of the agronomic and economic conditions before they can be implemented on a large scale (Achten et al., 2007). Wage-rate scenarios illustrate that varying the wage rates can have a significant impact on outcomes. An increase in wages by 15% brings about relatively small changes, while a greater increase in wages results in more significant changes, especially at lower levels of production. South Sudan is particularly sensitive to this because farming of biodiesel and harvesting require a lot of labour, which can provide rural employment opportunities, but also be a high cost of the project. The reported outcomes also differ, depending on the land-rent scenario, although it has varying impacts at different levels of production. These results highlight the significance of land availability and the need for suitable land-use planning in renewable-energy projects (Eckart & Henshaw, 2012). The results reported in the harvesting-efficiency scenario are generally improved throughout the production levels. Hence, the economic performance of Jatropha can be improved by increasing labour productivity and harvesting skills. Likewise, the longer the productive life of the Jatropha plants, the more favourable the overall results are, especially in lower yields. Longer productive periods can be used to spread initial establishment costs over more production cycles, which can improve the economic sustainability of the system. Operational efficiency is also relevant to the research that focuses on optimizing energy use in the Renewable Energy Systems (Espindola et al., 2021).
The highest sensitivities seem to occur in the reduction in oil scenario. The values reported also rise significantly with the yield categories, such that the biodiesel system is strongly influenced by the amount of oil that can be extracted from the Jatropha feedstock. The result is significant, as it is known that variations in Jatropha characteristics, agro-climatic conditions and seed composition may influence oil productivity, which in turn is a factor influencing biodiesel production (Martínez-Herrera et al., 2010). Therefore, the need for seed quality and production improvement are necessary to ensure predictable production performance. Finally, the relatively small changes at the higher production levels result from a 15% increase in capital costs, while there is no result from the lowest two production yields. This pattern suggests that the scale of production may affect the capacity of the system to absorb investment-cost increases. In conclusion, the sensitivity analysis revealed that the factors- oil content, labour efficiency, longevity of plant, cost of land and productivity of feedstocks are significant factors that affect the feasibility of Jatropha biodiesel production. The findings suggest a cautious, high-yield approach to development in South Sudan, especially in the face of the current energy needs of rural areas and the need for economically sustainable renewable energy systems in the country (Ladu & Samikannu, 2022; Husein & Kim, 2020).

**Table 8: Results of Sensitive Analysis**

| Sensitivity scenario | 10 t/hectare | 5 t/hectare | 3 t/h | 2 t/ha | 1 t/ha |
|---|---|---|---|---|---|
| Main Analysis | 0.86 | 1.14 | 1.66 | 1.07 | 1.63 |
| Our sensitivity analysis – Wage rate increment by 15% and 50% | 0.82 / 0.94 | 1.18 / 1.36 | 1.68 / 1.88 | 1.08 / 1.27 | 1.76 / 1.91 |
| 15% increased land rent | 0.84 | 1.25 | 1.77 | 1.13 | 1.79 |
| Harvesting of biodiesel plant seeds and labour efficiency (45 kg per day) | 0.91 | 1.35 | 1.79 | 1.18 | 1.84 |
| Life expectancy of Jatropha up to twenty years | 0.89 | 1.27 | 1.86 | 1.21 | 1.98 |
| 6.5% to 10% decrement in oil contents | 1.08 | 1.58 | 2.24 | 1.41 | 2.26 |
| Capital prices increment of 15 percent | 0.87 | 1.19 | 1.64 | n.a. | n.a. |

## 5. CONCLUSIONS

This study investigated the economic viability, production potential and environmental sustainability of using Jatropha as a renewable energy source in South Sudan. The analysis reveals that cultivation of Jatropha can meet the needs for alternative feedstock for biodiesel production, help improve economic activity in the rural communities, decrease the reliance on traditional fossil fuels, and contribute to the overall energy security goals. The findings are especially relevant to South Sudan, where the lack of energy infrastructure and access to reliable modern energy services is an important constraint on rural and economic development. The production-cost analysis shows that the productivity of Jatropha is the key factor in the economic performance of the biodiesel system. Increased yields help to decrease the price of Jatropha seeds per unit, showing economies of using fixed resources more efficiently. In addition, the relative importance of fixed costs decreases with increasing productivity, while variable production costs are more significant. Optimization of fertilizer, labour, irrigation, pesticides and management is therefore needed. These findings suggest that efforts to increase the productivity of the Jatropha crop, rather than just planting more land, should continue to be an important factor in the creation of a commercially viable Jatropha-based biodiesel industry. The production analysis also shows that the economic value of Jatropha can't just be measured in terms of biodiesel production. The oil cake and glycerol generated as valuable by-products of the processing system offer potential new sources of revenue and resource efficiency. The existence of these secondary products will further enhance the potential of an integrated Jatropha value chain, in which the production of oil and byproduct commercialization are interconnected with the oil extraction and production processes. Such integration would improve the economic value of biodiesel production to rural communities and minimize waste during biodiesel production. The performed sensitivity analysis also gives evidence of the robustness of the proposed system. The findings show that labour costs, land rents, harvesting efficiency, plant life, oil content & capital expenditure can be significant factors impacting project results. In this regard, the changes in oil content are of special importance, and thus it is essential to use the appropriate Jatropha varieties, agro-climatic conditions and cultivation techniques. Economic performance will also be enhanced by harvesting efficiency and increasing the productive life of Jatropha plants. Therefore, investments in biodiesel infrastructure should be complemented with technological development, agronomic research, farmer training, and efficient management. An environmental benefit of using biodiesel instead of traditional diesel is that it is a substitute for petroleum-based fuels and may help to decrease carbon dioxide emissions. But the environmental gains are subject to good land management, effective processing and sustainable farming. The development of Jatropha should, therefore, not be competing with food production where it is not necessary, nor be promoting environmentally unsustainable land conversion.

## REFERENCES


Abebe, F. F., Nallamothu, R. B., Ancha, V. R., Teklehaimanot, H., & Tefera, N. T. (2025). Optimized biodiesel production from Maesa lanceolata seeds and its emission analysis: A sustainable non-edible feedstock for renewable energy. *Biomass and Bioenergy, 200*, 108045.

Achten, W. M. J., Mathijs, E., Verchot, L., Singh, V. P., Aerts, R., & Muys, B. (2007). Jatropha biodiesel fueling sustainability. *Biofuels, Bioproducts and Biorefining, 1*(4), 283–291.

African Development Bank. (2020). *An infrastructure action plan for South Sudan*.

Ahmad, K., Nawab, M. A., Audi, M., & Ali, A. (2026). Climate Adaptability and Low-Carbon Efficiency of Air-Source Heat Pumps: Evidence from Provincial China. *Contemporary Journal of Social Science Review*, *4*(1), 367-383.

Ahmed, F. A. (2019). Exploring the Environmental Kuznets Curve: Economic Growth and CO2 Emissions Dynamics. *Journal of Business and Economic Options*, *2*(1), 35-44.

Ahmed, J., & Hu, L. (2025). Green investment, digital technological progress, and the dynamics of carbon emissions in China: A review. *Journal of Energy and Environmental Policy Options*, *8*(4), 30-39.

Ali, A., Abbas, N., & Ahmad, K. (2025). Technological Innovation and Green Finance: Catalysts for Sustainable Development in Developing Economies. *Qualitative Research Review Letter*, *3*(1), 46-82.

Ali, A., Haider, A., & Ismail, S. (2025). Climate Disclosure and Corporate Valuation: Evidence from S&P 500 Companies. *Policy Journal of Social Science Review*, *3*(4), 645–658.

Ali, A., Usman, M., & Ahmad, K. (2025). Environmental Risks and Sovereign Credit Ratings: Evidence from Developed and Developing Economies. *Competitive Research Journal Archive*, *3*(01), 356-370.

Ali, S. M. A. (2022). Post-secession Sudan and South Sudan: A comparative study of economic performance, export diversification, and institutions. *Journal of Asian and African Studies*, *58*(6).

Anus, M., Audi, A., & Ali, A. (2025). The Dynamics of Budget Deficits: Growth, Governance, And Debt Sustainability in Developing Economies. *Contemporary Journal of Social Science Review*, *3*(2), 2669-2675.

Ariöz, E., Kurtul, B., & Koçkar, Ö. M. (2022). Catalytic fast pyrolysis of safflower biomass for synthetic bio-oil production. *International Journal of Energy for a Clean Environment*, *23*, 53–62.

Arshad, R., Audi, M., & Ali, A. (2025). Environmental Disclosure and Financial Performance: Evidence from Environmentally Sensitive Sectors Across Global Markets. *Policy Journal of Social Science Review*, 3(8), 383–399.

Arshi, A., Ali, A., & Audi, M. (2025). Evaluating the Impact of Sustainability Reporting on Financial Performance: The Mediating Role of ESG Performance and the Moderating Role of Firm Size. *Bulletin of Business and Economics (BBE)*, *14*(2), 42-54.

Audi, M., Ali, A., & Poulin, M. (2026). Modelling Urban Expansion, Energy Consumption, and Environmental Sustainability: The Moderating Role of Environmental Taxes in Developing Countries. *Sustainability*, *18*(9), 4473.

Batool, A., Ali, A., & Audi, M. (2025). Assessing the Impact of Sustainability Initiatives on Greenhouse Gas Emissions in Sweden and Finland. *Annual Methodological Archive Research Review*, *3*(6), 150-176.

Becker, K., Wulfmeyer, V., Berger, T., Gebel, J., & Munch, W. (2013). Carbon farming in hot, dry coastal areas: An option for climate change mitigation. *Earth System Dynamics*, *4*(2), 237–251.

Bhushan, D., Vaishnav, M., Srivastava, Y., & Mondal, P. (2026). Synergistic Production of Fuel-Grade Bio-Oil and Carbon Rich Biochar from Co-Pyrolysis of Spent Coffee Grounds and HDPE: Process Optimization Using Response Surface Methodology and Machine Learning. *Industrial & Engineering Chemistry Research*, *65*(31), 16698-16717.

Butt, M. A., & Ahmad, K. (2026). Sustainable Finance and Sustainable Development Goals Performance: Comparative Evidence from OECD and Non-OECD Countries. *Bulletin of Business and Economics (BBE)*, *15*(1), 41-50.

Chernova, N. I., & Singh, N. (2017). Biofuel production from microalgae by means of hydrothermal liquefaction: Advantages and issues of the promising method. *International Journal of Energy for a Clean Environment*, *18*(2), 133–146.

Daud, A., Jadoon, A. K., Ali, A., & Audi, M. (2026). Green Finance Regulations and Disclosure Effectiveness: The Role of Governance and Enforcement Capacity.

Eckart, K., & Henshaw, P. (2012). Jatropha curcas L. and multifunctional platforms for the development of rural sub-Saharan Africa. *Energy for Sustainable Development*, *16*(3), 303–311.

El Marji, L., Sharara, M., El Chakik, D., Nakad, M., Assaf, J. C., & Estephane, J. (2026). A Comparative Review of Biomass Conversion to Biodiesel with a Focus on Sunflower Oil: Production Pathways, Sustainability, and Challenges. *Processes*, *14*(3), 441.

Espindola, J., Nourin, F. N., Qandil, M. D., & Abdelhadi, A. I. (2021). Energy saving analysis using energy intensity usage and specific energy consumption methods. *International Journal of Energy for a Clean Environment*, *22*(1), 15–29.

Etuka, R., Gimba, A., & Salihu, A. (2026). Characterization and Optimization of Bio-Oil Produced from the Catalytic Pyrolysis of Gmelina Arborea Sawdust. In *SPE Nigeria Annual International Conference and Exhibition* (pp. SPE-235210). SPE.

Fil, H. E., & Akansu, S. O. (2022). Experimental investigation of diesel-ethanol fuel blends in a compression ignition engine. *International Journal of Energy for a Clean Environment*, *23*, 139–151.

Francis, G., Oliver, J., & Sujatha, M. (2013). Non-toxic Jatropha plants as a potential multipurpose multi-use oilseed crop. *Industrial Crops and Products*, *42*, 397–401.

Gillani, S. I. H., Ali, A., & Audi, M. (2026). Examining the Impact of Environmental Taxation, Economic Growth, and Political Instability on Sustainability. *Journal of Management Science Research Review*, 5(1), 2574-2602.

Gudo, A. J. A. A., & Deng, J. (2020). Estimation of small onshore wind power development for poverty reduction in Jubek State, South Sudan, Africa. *Sustainability*, *12*(4), 1483.

Husein, M., & Kim, H.-J. (2020). The impact of policy and technology parameters on the economics of microgrids for rural electrification: A case study of remote communities in Bolivia. *Energies*, *13*(4), 877.

Hussain, S. H., Audi, M., & Alam, M. (2026). Economic Freedom, Financial Development, and Sustainable Economic Growth: Panel Evidence from South Asia. *Contemporary Journal of Social Science Review*, *4*(2), 154-167.

Ito, Y., & Zhang, R. (2025). Examining economic and technological drivers of carbon dioxide emissions in developing countries: A policy perspective. *Journal of Energy and Environmental Policy Options*, *8*(2), 1-12.

Javed, H., Audi, M., & Ali, A. (2026). *Corporate Governance and Sustainability Disclosure: An Empirical Analysis of Environmental Reporting Practices*. University Library of Munich, Germany.

Jiya, A. N., & Sama, M. C. (2020). Infrastructure trade openness and economic transformation in Common Market for Eastern and Southern Africa member countries. *Social Sciences & Humanities Open*, *2*(1), 100072.

Kasad, M. R., Jackson, J. E., Barton, S. C., Mukarakate, C., Schröder, U., & Saffron, C. M. (2026). Electrocatalytic hydrotreatment of bio-oil: exploring interactions between functional groups. *Energy Advances*.

Kesharvani, S., Dwivedi, G., & Verma, T. N. (2024). Optimization of process parameter of biodiesel derived from hybrid blend of Karanja and Chlorella vulgaris oil. *International Journal of Energy for a Clean Environment*, *25*, 47–60.

Khan, M. S., Audi, M., & Ali, A. (2025). Foreign Direct Investment, Financial Development, and Sustainable Growth: Empirical Evidence from Developing Countries. *Journal of Social Signs Review*, 3(8), 189–211.

Kingston, G. (2020). Practical Guide to Estimating Power Output and Costs of Small Wind Turbines. *Journal of Energy and Environmental Policy Options*, *3*(2), 65-71.

Kwai Kut, K. M., Sarswat, A., & Bundschuh, J. (2019). Water as key to the sustainable development goals of South Sudan: A water quality assessment of Eastern Equatorial State. *Groundwater for Sustainable Development*, *8*, 255–270.

Ladu, N. S. D., & Samikannu, R. (2022). Feasibility study of a standalone hybrid energy system to supply electricity to a rural community in South Sudan. *Scientific African*, *16*, e01157.

Lin, J., Zhou, X., Wang, J., Jiang, P., & Tang, K. (2010). Purification and characterization of curcin, a toxic lectin from the seed of Jatropha curcas. *Preparative Biochemistry and Biotechnology*, *40*(2), 107–118.

Longston, P., Ali, A., & Audi, A. (2025). Environmental, Social & Governance Disclosures and Corporate Financial Performance: Evidence from Selected Asian Economies. *Pakistan Journal of Social Science Review*, *4*(1), 22–49.

Majeed, R., Audi, M., & Ali, A. (2026). Environmental, Social, and Governance Reporting and Financial Reporting Quality in Emerging Markets. *Policy Journal of Social Science Review*, *4*(3).

Martin, P., & Camerone, G. (2025). Green economic growth and environmental governance: A panel analysis of G-20 countries. *Journal of Energy and Environmental Policy Options*, *8*(3), 17-27.

Martínez-Herrera, J., Martínez Ayala, A., Makkar, H. P. S., Francis, G., & Becker, K. (2010). Agro climatic conditions, chemical and nutritional characterization of different provenances of Jatropha curcas L. from Mexico. *Journal of Food Quality*, *35*, 152–158.

Masaud, S., Audi, M., & Naveed, Z. (2026). Firm-Specific Determinants of Sustainability Disclosure: Evidence from Pakistan Stock Exchange Listed Companies. *Contemporary Journal of Social Science Review*, *4*(2), 134-153.

McKenna, P. (2009, June 9). All washed up for Jatropha? The drought-resistant “dream” biofuel is also a water hog. *Technology Review*.

Mehdi, H., Ali, A., & Audi, M. (2025). Tourism, Sustainability and Growth: An Empirical Investigation Of Long-Run Economic Impacts In Pakistan. *Contemporary Journal of Social Science Review*, *3*(1), 1479-1493.

Naeem, H. Ali, A., & Audi, M. (2025). The Impact of Financial Stability on Environmental Degradation: Mediating Role of Green Investment and Moderating Role of Environmental Awareness. *Policy Journal of Social Science Review*, *3*(1), 448–469.
Nur, H., & Kumar, A. (2023). The Dynamics of Energy Use Economic Growth and Financial Development in India and China. *Journal of Energy and Environmental Policy Options*, *6*(3), 8-18.
Pauls, G., Pienihäkkinen, E., Sorsa, O., Ohra-aho, T., & Guizani, C. (2026). Upcycling water-soluble fraction from demolition wood fast pyrolysis bio-oil as a carbon coating precursor over graphite in lithium-ion batteries. *Journal of Analytical and Applied Pyrolysis*, 107945.
Piyachon, A., Aungkulanon, P., Prasartkaew, B., & Sukpancharoen, S. (2026). Intelligent process simulation framework for bio-oil production from Wolffia globosa fast pyrolysis via Aquila Optimizer. *Energy Nexus*, 100713.
Radon, J., & Logan, S. (2020). South Sudan: Governance arrangement, war and peace. *Journal of International Affairs, 73*(1), 145–154.
Rizwan, M., & Iqbal, W. (2025). Decarbonization pathways in developing economies: Digitalization, finance, and renewable energy in Pakistan. *Journal of Energy and Environmental Policy Options*, *8*(3), 38-50.
Rolandsen, O. H. (2015). Small and far between: Peacekeeping economies in South Sudan. *Journal of Intervention and Statebuilding, 9*(3), 353–371.
Rutah, D. F., Mudhoo, A., & Surroop, D. (2026). Effects of process parameters on transesterification of waste cooking oil for biodiesel production: A review. *Chemical Papers*, 1-31.
Simanungkalit, S. P., Jones, I., Zhang, Z., & Zhang, D. (2023). The effect of $Al_2O_3$, $CeO_2$, and $ZrO_2$ on the performance of Cu/ZnO catalyst in methanol synthesis from biomass pyrolysis syngas. *International Journal of Energy for a Clean Environment, 24*(8), 15–27.
Singh, N., & Kaushal, R. (2024). Study of modified bio-nano diesel emulsion fuels to save energy, reduce pollution, and improve diesel engine performance. *International Journal of Energy for a Clean Environment*, *25*(4), 1–15.
Tahir, S., Audi, M., & Ali, A. (2026). Growth Dynamics of Green and Brown Foreign Direct Investment in Central and Eastern Europe: Evidence from ARDL and NARDL Models. *Policy Journal of Social Science Review*, *4*(2), 810-832.
Tan, C., & Lee, E. (2025). Financial Development, Energy Consumption, and Environmental Quality: Testing the EKC Hypothesis in ASEAN Countries. *Journal of Energy and Environmental Policy Options*, *8*(3), 28-37.
ur Rehman, F., & Ali, A. (2026). Digital Transformation, Financial Performance, and Environmental Sustainability: Evidence from Technology Adoption Announcements. *Bulletin of Business and Economics (BBE)*, *15*(2), 48-58.
William, C., & Lipman, E. (2021). Energy-Efficient Practices in Reinforcing Steel Activities During Construction. *Journal of Energy and Environmental Policy Options*, *4*(3), 21-27.
World Agroforestry Centre. (2007). *When oil grows on trees*.
Ye, Y., Aslam, M. M. A., Chen, G., Qiu, P., & Peng, C. (2026). From conventional to integrated pyrolysis of biomass: pathways for bio-oil production and refining. *Biomass Conversion and Biorefinery*, *16*(15), 288.
Yousuf, B., & Audi, M. (2026). Financial Consequences of Aggressive Growth Strategies: Evidence from Leading Global Quick Commerce Companies. *Contemporary Journal of Social Science Review*, *4*(1), 407-421.
Zahid, H., Audi, M., & Ali, A. (2026). The Role of Cryptocurrency Regulations in Determining Financial Reporting Quality: An Empirical Analysis. *Contemporary Journal of Social Science Review*, *4*(1), 940-952.


**Funding:**
The authors received no external funding for the publication of this article.
**Data Availability Statement:**
All data generated or analyzed during this study are not included in this submission but can be made available upon reasonable request.
**Conflicts of Interest:**
The authors have no conflicts of interest related to this research.