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The socio-economic impact assessment of biofuels production in South Africa: A rapid structured review of literature

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Abstract: Biofuels as a substitute for conventional aviation and motor vehicle fuels have received considerable global interest over the past decades mainly due to their perceived economic, social, and environmental benefits. Despite these economic benefits, most developing countries, including South Africa (SA), have yet to produce commercial biofuels. This study aims to inform South African policymakers. Prospective producers of biofuels about the potential socio-economic returns from producing biofuels at a commercial level through a structured rapid review of the literature differs from the peer-reviewed studies to date in South Africa, which focussed more on assessing the economic viability and environmental impacts of biofuels production. The systematic review methodology was used. About 48% of the published empirical studies reviewed integrated the socio-economic and environmental impact assessment, followed by studies that only examined the social impacts of biofuel (about 26%), about 15% of the studies examined economic impact only, and 11.54% examined the socio-economic impact. The results revealed that although the production of biofuels is associated with a positive socio-economic benefit, the biofuel industry is not viable without government support and the selling price of biofuel is not competitive relative to gasoline and petroleum alternatives. Lastly, the results revealed a need for more objective empirical studies in South Africa that can quantify the economy-wide implications of biofuels (especially second-generation biofuels) production. Only two ($n = 2$) of the 28 reviewed studies were conducted in South Africa from 28 studies reviewed. Both studies conducted in South Africa were feasibility studies focusing more on bioethanol; no study quantified the economy-wide impacts. The study recommends the implementation of the biofuels support mechanism by the government. Furthermore, amendments to the existing biofuels regulatory framework are recommended in order to support the production of advanced biofuels.

Subjects: Agriculture & Environmental Sciences; Power & Energy; Production Engineering; Technology; Development Economics; Environmental Economics

Keywords: Biofuels; Socio-economic; South Africa; Impact Assessment, Bioethanol, Biodiesel

1. Introduction

Globally there is a consensus that blending biofuels with conventional fuels for transport and aviation results in producing fuels with less harmful particles to human health. This is because biofuels reduce the greenhouse gas (GHGs) emissions associated with the production and use of conventional transport fuels (Department of Mineral Resources and Energy, [DMRE, 2020). In addition to the environmental benefits, producing biofuels commercially can boost countries' economic performances by creating new employment opportunities (Demafelis et al., 2020). In developing countries with agriculture as a dominant economic activity, producing biofuels, especially first-generation (crop-based) biofuels, can boost their agricultural sector performance. While there is an increasing global interest in the production of biofuels, the production of biofuels, however, needs to be done in such a manner that it does not lead to water shortages, food security risks (food versus fuel debate), and ecological fears associated with an expansion of land and water-intensive biofuel crops (Kohler, 2016).

There are three types of potential biofuel feedstock, namely, first-generation (1 G), second-generation (2 G), and third-generation (3 G) biofuels. The 1 G biofuels are made from agricultural products rich in starch or sucrose using conventional techniques (Bertrand et al., 2016). They include ethanol and biodiesel (Lee & Lovole, 2013). The common biofuel feedstocks include but are not limited to sugarcane, sorghum, sugar beet, soya bean, barley, and potato wastes. 2 G biofuels refer to biofuels produced from feedstocks that are generally not considered food crops or food crops wastes, and they are derived using technologically advanced manufacturing methods (DMRE, 2020). The commonly used feedstocks in the production of 2 G biofuels include non-food parts of food crops (stems, leaves, etc.), non-food crops (i.e., grass), and solid municipal waste (DMRE, 2020). 3 G biofuels refer to biofuels produced from algal biomass, which has a distinctive growth yield relative to classical lignocellulose biomass (Lee & Lovole, 2013). *Most countries globally produce 1 G biofuels. According to Bertrand et al. (2016), globally, first-generation bioethanol alone contributes about 25 billion gallons of bioethanol, with the United States and Brazil accounting for approximately 85% of the global production predominantly based on corn and sugarcane*. This increases food security concerns. In response to food security concerns, the South African biofuel industry strategy (BIS), prohibited the use of staple crops, mainly maize, i. e., a major staple crop consumed by approximately 70% of the population (DMRE, 2020).

In South Africa, several interventions have been made by the South African government to stimulate the production of biofuels at a commercial level. These interventions include the exemption of biofuels from the existing fuel levy. Prospective biodiesel producers were given a 50% fuel levy exemption, while prospective bioethanol producers were given a 100% fuel levy exemption (Kohler, 2016). The mandatory blending regulation is another intervention aimed to ensure the certainty of the demand for biofuels (captive market). Subject to the availability of locally produced biofuels, a minimum of 2% was set for blending bioethanol into petrol, and a minimum of 5% was set for blending biodiesel into mineral diesel (DMRE). However, despite all these attempts, South Africa still needs a commercial biofuel plant (Pradhan & Mbohwa, 2014). The South African biofuel development is still settling at the legislative stage and is yet to be commercialized at a large scale. Several authors have quoted the lack of interest at the policy level, which is shown by the delays in the implementation of the mandatory blending policy by the government and a lack of government subsidy. Several studies revealed that at the current prices of biofuels feedstocks and the prevailing crude oil prices, the production of biofuels is only economically feasible if subsidies are provided (Kohler, 2016; Ndokwana and Fore, 2018; Maphumulo, 2021)

In the National Development Plan (NDP) 2030, the SA government arguably broke from its previous policy paradigm of promoting economic development as a goal to prosperity, opting for a more developmental approach. The NDP aims to eliminate poverty and reduce inequality by 2030. South Africa can realize these goals by drawing on the energies of its people, growing an inclusive economy, building capabilities, enhancing the state's capacity, and promoting leadership and partnerships throughout society. Thus, greater emphasis is placed on the needs of groups previously excluded mostly from policy attention. Instead, the impact of policy tools (including tax incentive schemes for example) needs to be assessed in a broader framework that includes such actors and stakeholders in economic development. It is for these contextual and policy-relevant reasons that this article, therefore, seeks to contribute towards informing the decision of policy-makers on whether or not to invest on the development of commercial biofuel plants in South Africa by determining the socio-economic impacts of producing biofuels at a commercial level in South Africa using a structured rapid review of literature.

Rapid structured reviews are used to summarise and synthesize research findings within the constraints of time and resources (Smith et al., 2013). Resources constraints provided a reason for choosing this review method over a systematic literature review (extensive search of literature). Due to financial resource constraints, the Web of Science database was not accessed. However, the methods used for conducting the review were informed by guidance for conducting systematic reviews by Xiao and Watson (2019). Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were also used (Page et al., 2021). This literature review treats the review process like a scientific process. It applies the concepts of empirical research to make the review process more transparent and replicable and to reduce the possibility of bias (Booth et al. 2012). The global empirical evidence drawn from this study could inform investors (policymakers and prospective biofuels producers) about the value of their money and hence inform policy-makers' decisions on whether or not to support the development of the commercial biofuel industry in South Africa. This article also seeks to contribute to the existing literature on biofuels in South Africa by providing a rapid review of the literature on the Socio-economic Impact Assessment (SEIA) of biofuels in South Africa. To the authors' full knowledge, there is no literature to date in Africa that has evaluated the SEIA of biofuels using a structured rapid review of literature; most of the literature reviews conducted are traditional literature reviews.

2. Recent global literature reviews on various attempts to stimulate biofuels production

Although the global production of biofuels has increased, it is still lower relative to the production of fossil-based fuels, accounting for less than 3% of the global transportation fuel supply (Aghbashlo et al., 2021; Coyle, 2007; Guo, 2020). According to Aghbashlo et al. (2021), over 80% of the global energy requirement is currently satisfied by fossil fuels, namely, petroleum, coal, and natural gas. The increasing concerns about the sustainability of biofuels, i.e., species habitat concerns and food and water security concerns, are also challenging to increase biofuels production. Various methods have been considered, specifically in developing countries, to stimulate biofuel production while simultaneously ensuring sustainability. This method uses machine learning and reactor technologies to stimulate biodiesel and bioethanol production. The production of biofuels from food waste is also increasingly considered.

Xing et al. (2021) reviewed machine learning (ML) methods utilized in the biodiesel production phase, including quality optimization and estimation, process conditions, and quantity. The common methods in the soil stage were found to include random forest, Gaussian process model and support vector machines. In the feedstock stage, the common methods were artificial neural network (ANN), multiple linear regression, statistical regression and multiple non-linear regression. The ANN methods prevailed for quality prediction and optimization, yield estimation and optimization, and process efficiency. Aghbashlo et al. (2021) also reviewed the application of ML technology in biodiesel research. They found ML technology to be superior to conventional modelling techniques. However, they argued that despite its superiority and reliability the ML technique could not be regarded as a solution to all problems in biodiesel research; instead, it must be used as a complement or supplement to conventional techniques. They also find the ANN technology widely used to solve function approximation, optimization, monitoring and control problems in biodiesel research.

Awogbemi and Von Kallon (2022) found the use of tubular reactor technology to be the key to stimulating biodiesel production, minimizing production costs, commercialization and better-quality production. The tubular reactor technologies considered included, batch-mode reactors, semi-batch-mode reactors, packed bed reactors, fluidized bed reactors, continuous-mode reactors, trickle bed reactors, oscillatory bed reactors, and micro-channel reactors. The positive socio-economic benefits of applying tubular reactor technologies included employment creation, environmental cleanliness, and utilization of quality biodiesel for diverse applications, amongst others. Tabatabaei et al. (2019) also reviewed the application of transesterification reactor technologies for biodiesel production and processing. They considered different types of reactors: tubular-flow reactors, simultaneous reaction separation reactors, cavitational reactors and microwave reactors. No reactor technology was found perfect over other reactors. Each reactor technology has unique qualities that cannot be found in other reactor technologies, and each has its weaknesses.

With the utilization of the first-generation feedstock in biofuel production triggering the food/feed versus fuel debate (increase in food/feed cost and hunger), Kazemi et al. (2022) reviewed the bioethanol production from food wastes rich in carbohydrates. Various types of food wastes (homogenous and heterogeneous) and pre-treatment methods to enhance bioethanol production were reviewed. The review suggested the conversion of food waste into bioethanol as proper and sustainable management of food waste and a key solution to the challenges mentioned above. Additional environmental benefits included a significant reduction of GHGs and ecological hazards.

Onyeaka et al. (2022) also conducted a literature review on the bioconversion of starch-based food waste into bioethanol. Despite food wastes containing a variety of biomaterials (carbohydrate starch, proteins, cellulose, lipids, amino acids and vitamins), which makes them a promising source in bioethanol production, they found the bioconversion to ethanol to be very limited. Furthermore, they advocated for the optimization of substrate medium to boost bioethanol production, as it improves ethanol yield by improving the growth of ethanologenic microorganisms. In complementing the usage of a substrate medium, they also found strain enhancement via genetic engineering methods to be a widely used approach. The problems noted and which need careful consideration when using carbohydrates-rich waste in the production of biofuels were associated with the collecting and transportation of food wastes

3. An overview of the socio-economic impact assessment framework

This SEIA framework is defined by MVRMA (2007) as a systematic analysis used during economic impact assessments (EIA) to identify and evaluate the potential socio-economic and cultural impacts of a proposed development project/initiative on the lives and circumstances of people, including their families and communities. The SEIA is a valuable tool for understanding the potential range of impacts of a proposed change and a possible response of those affected by the change (Tsuma & Monde, 2012). The concepts applied in SEIA are derived from various social disciplines, including political sciences, anthropology, sociology, economics, and geography (Vis et al., 2014.

According to McKenzie (2007), the principal objective of the SEIA is to reduce the adverse effects of development on human lives and maximize positive benefits to contribute to sustainable development. These benefits include i) improved standard of living due to increased household income (employment creation, business opportunities, more training, and education), and ii) increased funding for social infrastructure and cultural development programs. The other aim of the SEIA is to anticipate project implementation risks and identify measures to mitigate them (Department of Planning, Monitoring, and Evaluation, [DPME] 2015). Figure 1 outlines a SEIA framework adopted by Bloom (2019). The framework shows that assessing the financial feasibility and long-term viability of producing biofuels using various agricultural feedstocks in South Africa provides an essential background for SEIA as the long-term positive economic impacts can only be realized from a financially sustainable project and viable.

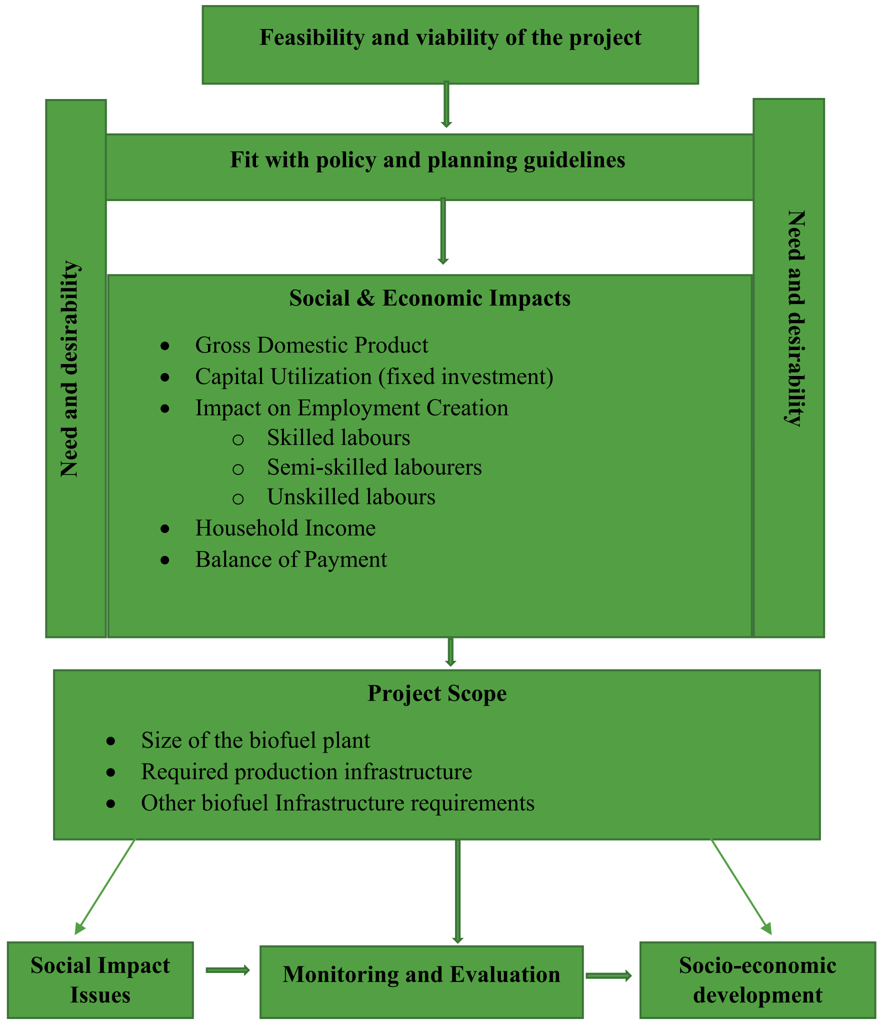


Figure 1. Conceptual framework of the SEIA of biofuel production in South Africa (Bloom, 2019).

4. Review methodology

In conducting the rapid literature review of the SEIA of biofuel production in South Africa, the study relied on the systematic literature review procedure by Xiao and Watson (2019) on how to conduct systematic reviews. The approach includes the following main steps.

(i) Literature search and evaluation (which includes literature identification, inclusion criterion, and quality and eligibility assessment), and

(ii) Data extrapolation, analysis, and results.

4.1. Scoping

The aim of this review is to assess the socio-economic impact of biofuel production in South Africa. The reason for assessing the socio-economic impact is that in South Africa, there still needs to be large-scale production of biofuel. A study by Conningarth Economist (2013) found that at the prevailing fuel prices, bioethanol production in South Africa is only feasible when there is enough government support, including subsidies, fuel levy exemptions, and mandatory blending of biofuels to conventional fuels. However, government support to stimulate biofuel production is still settling at the legislative stage and is yet to be implemented (Pradhan & Mbohwa, 2014). Therefore, this review aims to inform the country's policymakers and potential biofuel stakeholders about the possible socio-economic impacts (benefits and costs) of biofuel production in South Africa, using the global empirical evidence from the literature.

To achieve the above-mentioned objective, the review aims to answer three-related questions: To what extent has research on SEIA of biofuel production been conducted globally? To what extent has the research been conducted in Africa? And to what extent has the research been conducted in South Africa? What aspects were investigated the most? And what are the prevailing knowledge gaps in this subject area? The literature search was conducted using the Scopus database. Scopus was chosen because it is a database that indexes many peer-reviewed academic journals relative to other databases (Falagas et al. 2008).

4.2. Literature search

A search was conducted on the Scopus database using comprehensive and exhaustive keywords and synonyms (socio-economic OR economic AND impact AND assessment AND biofuels OR biogas OR biodiesel OR bioethanol). The Scopus search was restricted to articles published using the English language. Further restrictions were imposed to include articles published in peer-reviewed academic journals between 2016 and June 2022. The aim of restricting articles to peer-reviewed journal articles, implying the exclusion of conference contribution papers, books, book chapters, and grey literature, was to allow for quality assessment of the research evidence. Time restriction aimed to ensure that the most recent articles are reviewed to easily identify prevailing knowledge gaps surrounding this subject area. The articles were further limited to applied economics studies. To avoid possible bias in the results, the studies that integrated socio-economic and environmental impacts into their analysis were also considered for this review.

5. Results

5.1. Identification of potential studies

The initial search without any restriction produced about 1468 articles. Limiting articles from 2016-June 2022 resulted in an exclusion of 545 articles (Figure 2). Further, 199 review articles, conference contribution papers, and book chapters were excluded resulting in 724 articles. Another restriction was made to limit articles to applied economics studies resulting in an exclusion of 689 articles. 35 articles were then considered for abstract screening. The abstract screening excluded an extra 7 articles as they did not assess either the economic or socio-economic impact of biofuels production. Lastly, 1 more article was excluded because its methodology was not clear. All these resulted to a total of 27 studies being considered for a rapid structured literature review.

The selected studies were further grouped into four groups to make the analysis clear and straightforward. The first group included studies that only assessed the social impact of biofuel production. The social impacts included food security impacts, impacts on labour employment, water use impacts, natural habitats, employments and Land Use Changes (LUC). The second group included studies that conducted socio-economic assessments, mainly feasibility assessment studies and macro-economic impact studies. The third group included studies that examined both economic and environmental impacts (GHGs emissions, human and animal health). The fourth group included the integrated socio-economic and environmental impact assessment studies.

5.2. Characteristics of the included studies

The review included global studies conducted between 2016–2022 in both low and middle-income countries (Figure 3). Most of the studies reviewed were conducted in high-income (44%) and middle-income countries (44%). Most of the studies conducted in high-income countries were conducted in the USA (58%), followed by Germany (33%), and the least was Italy, with 8% of the studies conducted. The results conform to our expectations because the USA is the global leader in the production of biofuels, with an average of 643 thousand barrels of oil equivalent biofuels produced per day in 2021 (Sajid et al., 2021; Statista, 2022). Most of the studies conducted in the

Figure 2. Prisma flow chart of studies identification and selection process.

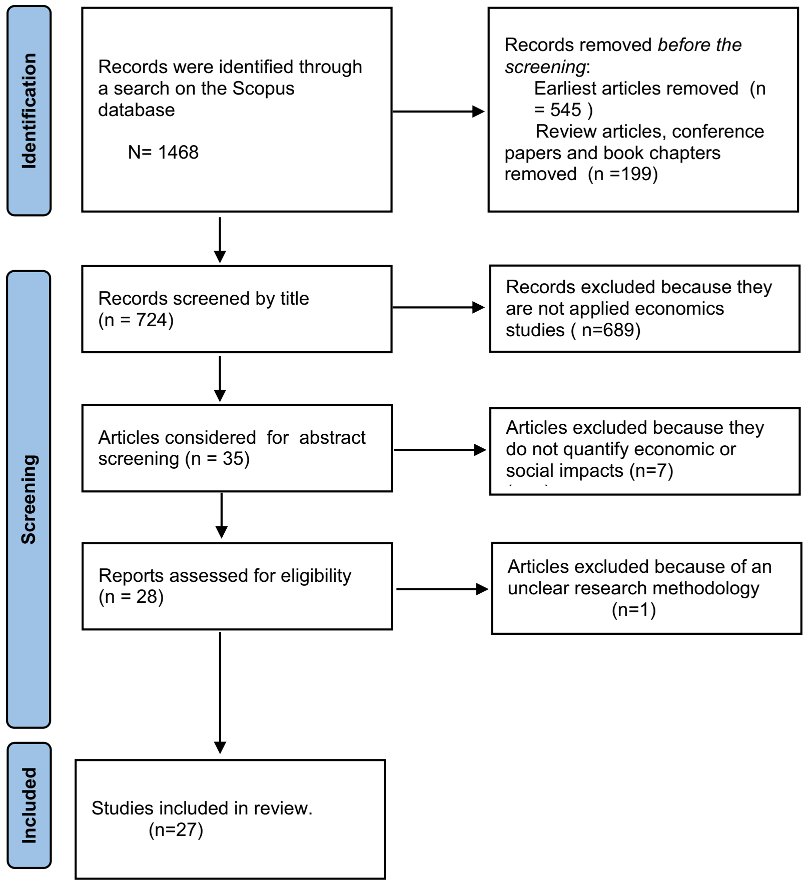
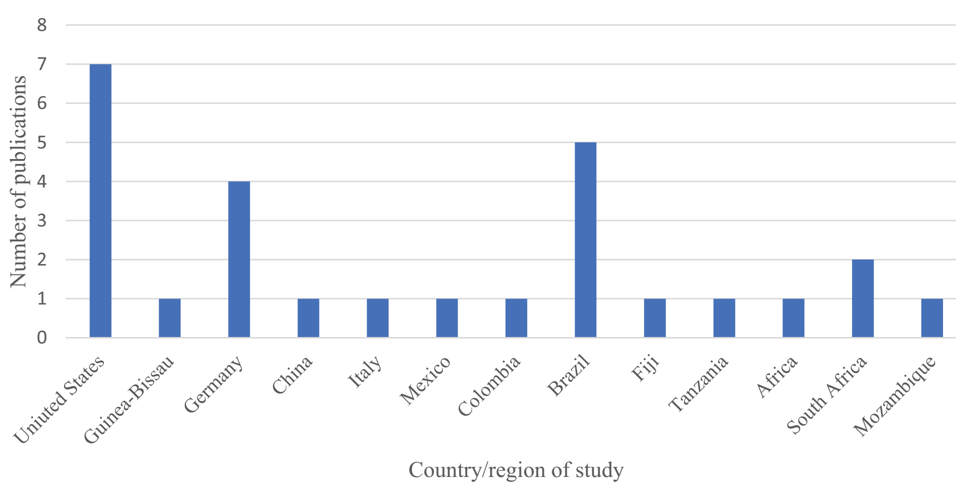


Figure 3. The number of publications by country/region of study.



middle-income countries were conducted in Brazil, with about 50% of the studies, and the other 50% were distributed almost equally amongst the other middle-income countries, namely, China, Mexico, Columbia, Fiji, South Africa and Tanzania. The findings were as expected because Brazil is the second-largest global producer of bioethanol and the largest producer of sugarcane-based bioethanol, owing to its competitive advantage in sugarcane production (de Souza et al., 2019).

The study in Guinea-Bissau and Mozambique were the only studies conducted in a low-income country within the review period.

The feedstocks that were considered by the reviewed studies (Figure 4), included forest residues ($n = 6$), guayule bagasse ($n = 1$), rapeseed ($n = 1$), algae ($n = 3$), waste plastic oils ($n = 1$), firewood ($n = 2$), sugar molasses, sugarcane and sugarcane residues ($n = 8$), miscanthus ($n = 1$), switch grass ($n = 2$), corn stover ($n = 1$), wheat straw ($n = 1$), sorghum ($n = 1$), Maize ($n = 1$) and short-rotation coppice ($n = 1$).

The findings showed an uneven distribution in the production of 1 G, 2 G, and 3 G biofuels, with 1 G biofuels being the most produced. In developed and middle-income countries, 2 G and 3 G biofuel production was low but better than in low-income countries. This was expected because capital investments required in producing 2 G and 3 G biofuels are expensive (Lee & Lovole, 2013 and Romo, 2019), making 2 G and 3 G biofuels an infeasible option for most developing countries. The types of biofuels or end-products considered by these studies included sustainable aviation fuels (SAF) ($n = 1$), biodiesel ($n = 4$), Naphtha ($n = 4$), hard rubber ($n = 1$), a combination of two or more biofuels ($n = 6$), wood charcoal ($n = 1$), cellulosic ethanol ($n = 1$), energy cogeneration ($n = 1$), bioethanol ($n = 7$), and biogas ($n = 1$). It was clear that most of the studies focussed on biodiesel and bioethanol for transport fuel blending, this was expected because, over the last decades, the primary priority of different countries' governments has been to reduce the GHG emission and climate change mainly caused by crude oil in transport fuels.

During the review period (2016–2022), there was a fluctuating trend in the number of empirical economic/social/socio-economic/integrated economic and environmental/integrated social, economic, and environmental studies conducted with the most significant number of studies conducted during the year 2016 and year 2019 (Figure 5). Most studies in this subject area focus more on environmental impact assessment. This was expected because most of the studies reviewed were conducted in high and upper middle-income countries, where the main priority in the development of biofuels is for energy security and to reduce GHG emissions, unlike lower-middle

Figure 4. Various biofuel feedstocks utilized.

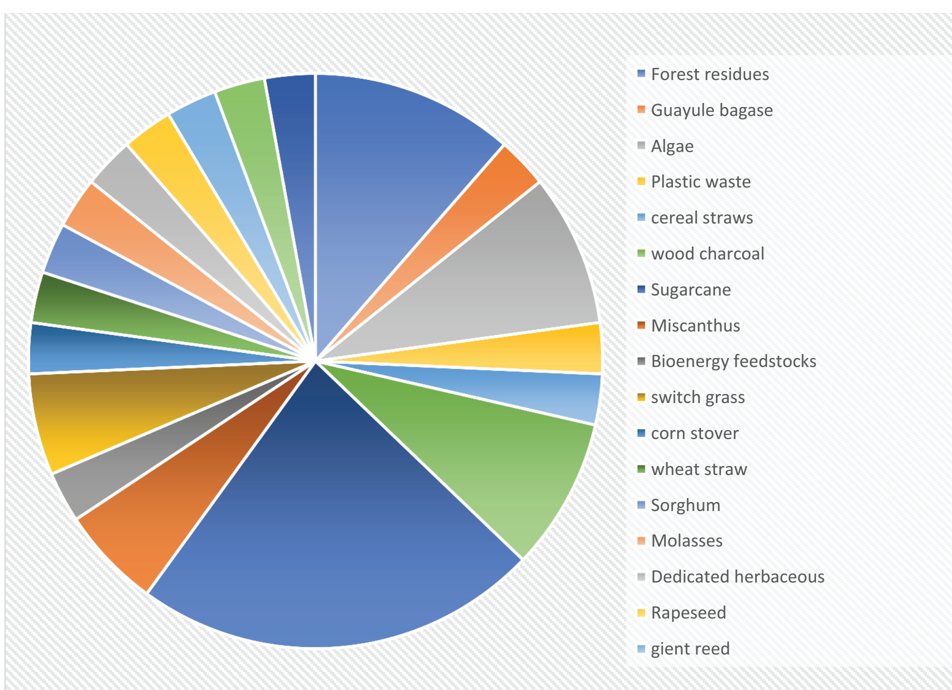
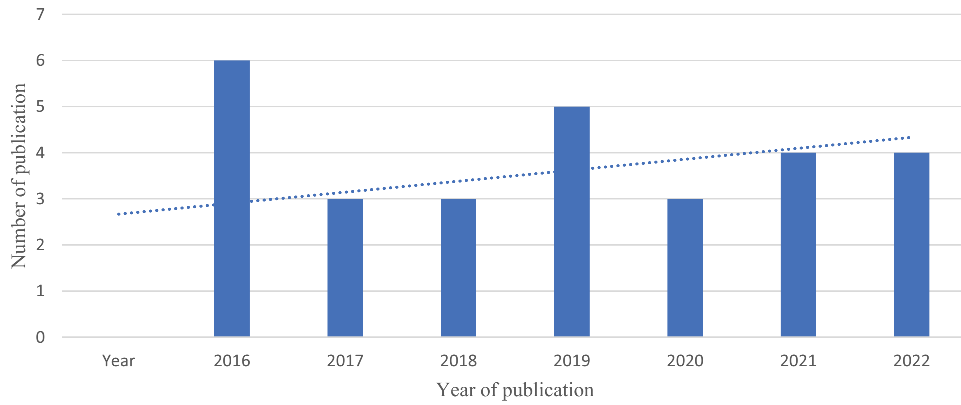


Figure 5. The number of publications by year.



income and low-income countries where the main objective is to increase economic growth (Kohler, 2016).

5.3. Research methods and objectives

The studies considered in this review used robust quantitative methods to quantify the economic, social, socio-economic, or integrated socio-economic and environmental impact assessments of biofuel production. The studies for social, economic, socio-economic, and integrated socio-economic and environmental impact assessments are outlined by the first authors' surnames in Tables 1, 2, Tables 3, and 4, respectively. Most studies (54%) integrated the socio-economic and environmental impact assessments during the review period. During the 2016–2018 period, at least one published study integrated biofuel production's socio-economic and environmental impacts. In most of these studies, the objective was to examine biofuel production's environmental and economic viability.

The second most common studies published examined the social impacts of biofuel production. Most of these Social Impact assessments (SIA) studies examined the impact of biofuels-induced LUC on country-level food security, water availability, and the impact on ecosystem balances. The third common type of study is the one that focuses on economic assessments ($n = 4$); two of these studies examined the economic viability of biofuels production by quantifying the break-even selling price of biofuels, one study examined the impact of increased biofuels production on the market for other essential food commodity. The other study examined the economy-wide impacts of biofuel production.

Most of the studies in this subject area included operations research techniques amongst other models used in their analysis, namely the Life Cycle Assessment (LCA) ($n = 10$), Techno-economic Analysis (TEA) ($n = 13$), simulations and optimization model ($n = 3$), land use allocation model ($n = 3$), geospatial techniques ($n = 1$), water allocation model ($n = 1$). Fewer studies used input-output models and Computable General Equilibrium Model (CGEM) ($n = 6$), econometrics ($n = 3$), and descriptive statistics ($n = 1$). The most commonly used operations research techniques were LCA and TEA. The LCA was mainly used for environmental impact assessments using GHGs emissions as a proxy. The TEA, on the other hand, was used to assess the economic viability of biofuel production through Cost-Benefit Analysis (CBA) and by quantifying the minimum selling price of biofuels. The input-output and CGEM were used to quantify biofuels' economy-wide implications, namely, impact on employment, multiplier effects on households' welfare, countries' economic growth, etc. The econometrics included regressions and multivariate models used to find the relationships between authors' variables of interest. The simulations and optimization models, geospatial, land use allocation/change models, and water use allocation were among the model used mainly for social and environmental impact assessments.

Table 1. Social impact assessment of biofuels

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Tian et al. (2021)	China	• Investigate the current and future potential of growing rapeseed in winter fallow fields across the Yangtze River Basin and • Impact on China's food security and energy security.	integrated agro-ecological assessment methodology and the CHINAGRO-II model	• The average potential yield of rapeseed was estimated to be 1 950 Kg/ha • China's oil and food security would also be significantly improved as a result of at least a 92% decrease in China's rapeseed imports, and the production of rapeseed would not crowd out the production of major food crops, i.e., rice, wheat, and maize.
van der Hilst et al. (2018)	Brazil	• Assess LUC dynamics and • GHG emissions result from an increased global demand for bioethanol (+26X10^{9}L) when no corrective measures are taken and when corrective measures are taken.	Computable general equilibrium model (CGEM), spatiotemporal land use allocation model (LUC), and GIS-based carbon model.	• When no corrective measures were taken, sugarcane production was projected to expand mainly at the expense of agricultural land, which lead to the loss of natural vegetation. An average emission of 26g of CO2eg/MJ bioethanol was also estimated when no corrective measures were taken. • All LUC mitigation measures had the potential to reduce the loss of natural vegetation at a range of 18% to 96% as well as the LUC-related GHG emissions by a range of 7%-60%
Teter et al. (2018)	US	To quantify and compare the spatially varying water impacts of biofuel crops stemming from LUC induced by US biofuel policies.	Agro-economic model, biofuel environmental policy analysis model (BEPAM), and process-based crop-water modeling.	The water use impacts were pronounced in the regions where cropland pasture is converted to biofuels crops (water flows change on the order of 10% to 50%) due to a 0.7% increase in net irrigation requirement and an increase in transpiration.

(*Continued*)

Table 1. (*Continued*)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Tarr et al. (2016).	US	Estimate the potential impact on habitat availability of meeting a realistic bioenergy target and the expected demand for wood pallets in North Carolina, US.	Forest economics models, spatially explicit state and transition simulations model, and species habitat models.	The realistic levels of demand for biofuels and wood pallets in North Carolina would be capable of causing considerable changes in the number of habitat species. The changes could be positive or negative depending upon species' habitat associations and the biomass sources utilized to meet bioenergy demand, i.e., species that inhabit dense, shrubby vegetation as a result of forest biomass harvest increased, whereas field sparrow experienced habitat loss due to decrease in conventional forestry.
Verategen et al. (2016)	Brazil	• Estimate direct and indirect LUC caused by increased demand for biofuels in Brazil. • To quantify the crucial uncertainties in the modelling chain.	CGEM and LUC model.	• Direct LUC's Probabilities ranged from 0 to 0.77, and indirect LUC ranged from 0 to 0.43, reflecting that it is difficult to project where exactly the direct and Indirect LUC will occur, with more difficulties for indirect LUC than for the direct LUC. • The direct LUC area was projected with great certainty (coefficient of variation =0.02), whereas indirect LUC remained uncertain (coefficient of variation of 0.72).
Schulze et al. (2016)	Germany	To estimate the impact of the expansion of short-rotation coppices (SRCs) on multiple ecosystem services (food crop yield, carbon storage, nutrient, and sediment retention) and biodiversity under different economic and policy-driven scenarios in the Mulde watershed in central Germany.	Spatially explicit economic simulation model and regression model	• Only a significant increase in SRCs production area beyond regional demand of combined heat and power plant (CHPP) will have a negative impact on food production positive impact on biodiversity. • The occurrence of sites with balanced ecosystem services (ESS) supply was strongly driven by biophysical factors than by SRC share in the landscape. • Furthermore, increase the provision of regulatory services.

(*Continued*)

Table 1. (*Continued*)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Bonsch et al. (2014)	Germany	To investigate the trade-offs between land and water requirements of large-scale bioenergy production.	Spatially explicit global land and water-use allocation model	It was found that the production of the targeted 300 EJ/year of bioenergy in 2095 from dedicated bioenergy crops is likely to double to 6400 KM^3 water withdrawals if no explicit water protection policies implemented. Under the scenario where irrigation of bioenergy crops is prohibited, the land requirement for bioenergy production increased substantially (+41%) and was mainly at the expense of cropland.

Table 2. Economic assessment studies of biofuels

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Landa et al. (2022)	Guinea-Bissau	Assess the economic feasibility of biodiesel production from microalgae in Guinea-Bissau.	TEA	The cost of biodiesel production was estimated to be 0.9 US$/kg on a cultivated area of 153 ha. This cost was found to be competitive with diesel production in the service station of Guinea-Bissau.
Pachón et al. (2020).	South Africa	assessed the techno-economic feasibility of sugarcane-based bioethanol production in South Africa.	TEA	The scenario of a sugar mill (SM)-lactic acid and fuel (LF) was found to the economically feasible scenario, while SM-furfural and fuel (FF) and SM and only fuel (OF) scenario were not economically viable
Ndokwana and Fore (2018)	South Africa	investigated the economic feasibility of using maize as feedstock to produce bioethanol in South Africa.	CBA	• Maize based bioethanol was not profitable. • The profitability of the bioethanol plant was largely influenced by the prices of feedstock and bioethanol.
Seyffarth (2016)	Brazil	Assess the impact of rising biofuel production on commodity food markets in Brazil.	Econometrics	A statistically significant positive impact on sugarcane production and a statistically significant negative impact on rice, beans, and soybeans acreage were obtained. However, there was no statistically significant impact on areas for corn and manioc.

5.4. Key findings

Most studies (globally and in South Africa) that assessed the economic viability of biofuels in the presence of conventional fuels found biofuel production to be only viable and profitable when there is enough government support (Ndokwana and Fore 2018; Amezcua-Allie et al., 2019; Landa et al., 2022; Pachón et al., 2020; Yang et al., 2022). The main contributor towards the biofuels

Table 3. Socio-economic impact assessment studies of biofuels

First Author Surname (year)	Country of study/region	Study objectives	Research methods	Key findings
English et al. (2022)	US	• To estimate the annual gross break-even revenue of investment on three biorefinery facilities that are expected to produce SAF, diesel, and naphtha in the Central Appalachian region. • Estimate the minimum selling price of sustainable aviation fuel. • Estimate the economic impacts of the biorefinery facility on the Central Appalachian region.	Techno-economic analysis (TEA) and Input-output (IO) model.	The annual break-even gross revenue for biorefinery facilities was estimated at \$193.7 million. The minimum selling price of SAF was estimated at \$1.68 to \$1.76 per liter, at the required rate of return on investment of 12.2%. The estimated economic impacts to the central Appalachian region include about \$2.67 billion in economic activity with a multiplier of 1.7, a gross regional product of \$1.28 billion, a 1200 direct employment increase and a \$700 increase in labour income.

(*Continued*)

Table 3. (*Continued*)

First Author Surname (year)	Country of study/region	Study objectives	Research methods	Key findings
Nyarko et al. (2021)	Africa	• Estimate the volumes of wood charcoal production in Africa, • Estimate the environmental impacts and • Socio-economic impacts of wood-charcoal production in Africa.	Descriptive statistics, multivariate analysis, and geospatial modeling techniques.	• East Africa had the highest average volume of wood charcoal production (43.2% of production), followed by West Africa (32.1% of production); North Africa, the Middle East, and South Africa were the least producers, with about 11.6%, 115.5%, and 1.6%, respectively. • Regions with the highest volume of wood charcoal production (East Africa and Africa) were estimated to have higher forest deforestation relative to regions with lower production volumes (North Africa, Middle East, and South Africa) • A strong positive correlation was estimated between higher wood charcoal production, export quantity, and GDP (r=+0.67)
Hartly et al. (2018).	Mozambique	Estimate the economy-wide impact of expanding biofuel production in Mozambique under both commercial and smallholder-type farming models	CGEM	• Expanding biofuel production was expected to increase Mozambique annual real GDP growth by 0.021%, increase employment by 56 000 jobs by 2025 and increase household welfare by 0.0012%

Table 4. Integrated socio-economic and environmental impact assessments

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Moreno et al. (2022)	US	• Estimate the economic viability of using guayule bagasse for bioenergy production in the Southwest US, and, • The environmental impact of producing bioenergy from guayule bagasse.	TEA and Life Cycle Assessment (LCA)	• The minimum selling price bagasse to fuel pathway required for the facility to be viable was estimated to be $9.26 per gallon of gasoline-equivalent and • The minimum selling price of pellets from bagasse was estimated to be $176 per ton.
Yang et al. (2021).	Germany	• Estimate the environmental and, • Economic benefits of rapeseed-based biodiesel production in Central Germany.	Regional LCA and reduced gradient non-linear optimization method.	• GHG emission for rapeseed was estimated to be lower by 56%-71% relative to the equivalent fossil-based fuels emissions. • The rapeseed-based biodiesel plant was found profitable (Positive NPVs), with profitability increasing with an increase in the operating capacity.
Pascheco-López et al. (2021)	US	• Compare the economic performances and • Environmental performances of fossil-based, biomass-derived, and plastic waste-sourced fuel alternatives.	TEA and LCA	• Diesel substitutes had a superior performance in terms of production cost reduction as an estimated 25% cost reduction was estimated. However, gasoline-based alternatives had a higher production cost than gasoline, about 57% to 130% higher. • The diesel substitutes were found to lead to an estimated life cycle impact reduction of 54% on humans, 40% on ecosystems, and 98% on resources. The gasoline substitute, on the other hand, had a reduction of about 35% to 80% in resource scarcity.

(*Continued*)

Table 4. (*Continued*)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Anejionu et al. (2020)	Italy	• Investigates the envir-onmental and • Socio-economic effects of large-scale production of advanced biofuels (2G) in Sardina (Italy).	Oil and water assessment tool, integrated valuation of ecosystem services, trade-offs, and linkages mapper.	• Overall the large-scale biofuel refinery could lead to positive environmental outcomes in Sardina in terms of improvement in habitat quality and reduction in GHGs emissions (3% GHG emission reduction per annum). However, negatives effects were projected on water availability, production of food and animal feed. • The positive economic outcomes were projected in terms of employment and energy security.
Beckstrom et al. (2019)	US	• Investigates the eco-nomic viability and • Environmental impact of an algae biorefinery that integrates the comple-mentarity functions of bioplastic feedstock and fuel production in the US.	TEA and LCA	• The minimum biofuel selling price ($970/tonne) was found to be uncompetitive with oil prices. • A drastic improvement in the environmental perfor-mance of biofuel was projected in the form of a 67–116% reduction in GHG emission relative to petroleum-based feedstocks.

(*Continued*)

Table 4. (Continued)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Amezcua-Allie et al. (2019)	Mexico	• To compare the economic feasibility of the implementation and, • Environmental impact of the sugar production process using fuel oil or sugarcane bagasse for energy cogeneration of a sugar mill in Southern Mexico.	TEA and LCA	• The use of sugarcane bagasse was cost-competitive relative to the fuel oil. The cost of using sugarcane bagasse was estimated to be 5.5 USD/GJ, while the fuel oil cost was 14 USD/GJ. • Usage of sugarcane bagasse was also found to have a less negative impact on the environment relative to the usage of fuel oil, i.e., a potential environmental impact index of 2528 vs 20,200 PEI/GJ for the latter.
Martinkus et al. (2019)	US	• Estimate the operational cost, • The environmental impact and, • Social effects of a wood-based. Biorefinery in the US.	TEA, LCA, and IO model	• The highest transport costs of the biorefinery facility were estimated to be \$86.4/BDMT. • The facility was estimated to provide a significant number of jobs and significantly reduce GHG emissions.
Derose et al. (2019)	US	• Assess the economic viability and • environmental impact of processing high productivity, low lipid, high ash content algae into biofuels.	TEA and LCA	• A minimum selling price of \$12.85 and \$10.41 GGE^{-1} was estimated for biochemical and thermal-chemical pathways, respectively. • A global warming reduction potential of 111.2g and 2g CO2 eq MJ $fuel^{-1}$ was estimated by biochemical and thermal chemical pathways, respectively.

(*Continued*)

Table 4. (*Continued*)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
de Souza et al. (2019)	Brazil	• Evaluates the economic, and • Environmental feasibility of sugarcane ethanol and cattle integration to avoid pasture and displacement into forests or sensitive lands.	TEA and LCA	• The economic evaluation results for ethanol alone were similar to the one for integration; however, integration was estimated to lead to an extra carbon credit revenue of US\$90 tonne^{-1} • Integration of ethanol and cattle production resulted in lower CO2 emission per kg (0.95 kg CO2eq) relative to ethanol alone (1.4kg CO2eq).
Wagner et al. (2018)	Germany	• Assessing the environmental and • Economic performance of miscanthus cultivated on marginal land for biogas production.	LCA and complementary life-cycle cost analysis	• The cost of miscanthus-based biogas generation was estimated at 45.12 €/GJ_{el}, and utilization were considerably lower than those of maize which are estimated at 61.30 €/GJ_{el}
Chandra et al. (2017)	Fiji	• Assess the economic, and • Environmental impact of producing ethanol from molasses or sugarcane juice in Fiji.	TEA and LCA	• Many economic benefits were identified, including an earning of FJ\$7.2 million, employment creation and livelihoods improvements in Fiji, and • The environmental benefit of saving 22 730 CO2 emissions annually.

(*Continued*)

Table 4. (*Continued*)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Mayer et al. (2016)	Brazil	• Assess the economic feasibility and • The economic impact of ethanol production at a small-scale distillery with a production capacity of 30L/hr of hydrous ethanol fuel (HEF)	TEA and LCA	• The feedstock cost was the major contributor to the net cost of HEF produced at a small scale. • Under the assumption of no taxation (direct trade between ethanol producer and a final consumer), ethanol production was competitive relative to gasoline (the selling price of ethanol was less than the price of gasoline. • If biofuels are taxed as other conventional fuels, ethanol production is not economically competitive (the selling price of ethanol was higher than the selling price of gasoline equivalent). • The agricultural production stage was responsible for the most serious damage to the environment Equivalent), although the scenario can still pose some risks if the feedstock prices increase considerably.

(*Continued*)

Table 4. (*Continued*)

First Author Surname (year)	Country of study	Study objectives	Research methods	Key findings
Thurlow et al. (2016)	Tanzania	• To evaluate the impacts of GHG emissions and • The economic impact of producing biofuels in Tanzania.	CGEM, TEA, and Ex-ante carbon balance tool model.	• The net GHG emissions were found higher when sugarcane is grown on land that is already cultivated. However, the net emissions were lower for small-scale production because they don't use improved inputs, such as fertilizer. • The carbon-payback period (CPP) for sugarcane-ethanol (number of years required to achieve carbon neutrality) produced on converted grasslands was 2–3 years, depending on the scale of farming. The sugarcane ethanol produced on deforested land has a much more extended period of 15–27 years. • Biofuel production was found to increase GDP at factor cost, with GDP growth effects found more significant under large-scale farming systems with 100% land clearing. • Biofuels also stimulate the growth of the rest of the economy by using other sectors' products or raising personal incomes and consumption, improving rural households' welfare while reducing rural poverty.

industry is not commercially viable without government support was found to include higher feedstock costs and significant start-up capital costs.

Furthermore, the majority of studies reviewed found biofuel selling prices being uncompetitive relative to fuel prices, including Mayer et al. (2016); Beckstrom et al. (2020); Pascheco-López et al. (2021). Mayer et al. (2016) found biofuel prices in Brazil to be only competitive relative to the price of gasoline-equivalent only if biofuels are tax exempted; otherwise, biofuels prices are not competitive. This may be attributed to high biofuel feedstock costs (a significant cost contributor in the production of 1 G biofuels) and high capital costs (a significant cost contributor to the production of advanced biofuels). The selling price of biofuel produced from algae in the US was also found by Backstrom et al. (2019) to be uncompetitive relative to conventional fuel prices due to high capital (growth systems, harvesting infrastructure, etc.) costs and low petroleum fuel prices. Pascheco-López et al. (2021) found biodiesel and bioethanol production to be not competitive. Raw material costs were identified as the significant cost contributors with biodiesel raw material costs (accounting for approximately 85% of the total production costs). Therefore, the investment from government and private investors aiming to stimulate biofuel production by guaranteeing biofuel producers a positive profit should be allocated more towards subsiding the feedstock and capital cost.

The studies that quantified economy-wide implications of biofuels estimated the positive effects due to energy security which improve economies' economic performances, leading to positive socio-economic effects in terms of Gross Domestic Product (GDP) growth, employment growth, labour income, net exports, and carbon tax credits (Thurlow et al., 2016; Chandra et al., 2017; Hartly et al. 2018; de Souza et al., 2019; Martinkus et al., 2019; Anejionu et al., 2020; Nyarko et al., 2021; English et al., 2022). With biofuels found to be not commercially viable without government, these positive socio-economic outcomes will only be realized when the viability of the biofuel industry is guaranteed through government support. According to Bloom (2019), long-term positive socio-economic outcomes can only be realized from a project that is financially sustainable and viable (Bloom, 2019).

The studies that assessed the environmental performance of biofuels relative to conventional fuels using GHG emission and environmental performance index as a proxy found better performance in biofuels (Amezcua-Allie et al., 2019; Anejionu et al., 2020; Beckstrom et al., 2020; Chandra et al., 2017; de Souza et al., 2019; Derose et al., 2019; Martinkus et al., 2019; Yang et al., 2022). Biofuels were found to reduce GHGs emissions, especially CO2 emissions in grams, contributing to better health for humans and the ecosystem. The environmental performance of advanced biofuels (2 G and 3 G) was even better in terms of GHGs emissions (Wagner et al. 2018). Furthermore, Thurlow et al. (2016) found the net GHG emission reduction even higher when sugarcane-ethanol is produced on unused grasslands and when small-scale farmers produce biofuel feedstocks since they do not use improved inputs (fertilizer). However, there was an increase in net GHGs emissions when sugarcane is grown on already maize-cultivated land. This is because maize has greater Soil Organic Content (SOC) than sugarcane. Hence, replacing maize with sugarcane reduces sequestration.

A mix of positive and negative social outcomes were projected because of biofuel production. The social outcomes investigated in the literature included country-level food security, LUC impacts, water use impacts, and impact on species habitat availability and quality, amongst others. Several studies considered in the review projected the negative impact of increased biofuel production on the country's food security status (Anejionu et al., 2020; Schulze et al., 2016; Seyffarth, 2016). The reason biofuel expansion is associated with a decrease in food security is because biofuel expansion is achieved at the expense of food cropland (Bonsch et al. 2016). However, two studies contradicted the outcomes of most studies as they projected improved country-level food security triggered by biofuel production (Thurlow et al., 2016; Tian et al., 2021.

Thurlow et al. (2016) projected positive food security impacts of sugarcane-based bioethanol in Tanzania due to economic growth stimulated by biofuel production, which leads to an increase in households' incomes and enables the consumption of a well-balanced diet. Tian et al. (2021) estimated a positive impact on the country-level food security of increased rapeseed-based biofuel production grown on marginal land in China because of an increase in households' income (due to employment) and rapeseed production not crowding out the production of major food crops, namely, rice, wheat, and maize. This implies that biofuels production can have a positive impact on the country and household-level food security if biofuel feedstocks are produced in a manner that does not compete with food production, i.e., biofuels produced on unutilized land (avoid diverting land away from food crops to biofuel feedstocks) or producers not redirecting crops away from food towards biofuels even if biofuels become profitable relative to food. Furthermore, using non-food energy feedstocks (rapeseed, algae, and switchgrass) produced from unutilized land can also minimize the adverse food security effects of producing biofuels. Using food waste can also help minimize the negative impacts as it will mean no competition with food crops.

The increased biofuel production was associated with both direct and indirect LUC, which did not only crowd out food production but also caused a loss of natural vegetation and habitat for certain species. van der Hilst et al. (2018) in Brazil found that when no corrective actions were taken, increased sugarcane production for biofuels was associated with a loss of natural vegetation. Tarr et al. (2016), in North Carolina in the US, also projected a significant change in the number of habitat species because of increased demand for forest-based biofuels. The change was, however, inconclusive; it was found positive for species that inhabit dense, shrubby vegetation as a result of forest biomass harvest, whereas the species whose habitat is forest (i.e., field sparrow) experienced habitat loss due to a decrease in the conventional forest. Anejionu et al. (2020) in Italy found the opposite results, as they estimated the positive environmental outcomes regarding habitat quality resulting from increased advanced (2 G and 3 G) biofuels production. The outcome was as expected because advanced biofuels are produced from plant-based biomass and do not affect species' habitats.

Furthermore, since they lead to a higher GHGs emission reduction relative to 1 G biofuels, they can improve habitat quality. The negative impacts on the water were also reported due to increasing biofuel production. According to Teter et al. (2018), in the US the negative water uses impacts associated with biofuel production were even pronounced in the scenarios where cropland pasture was converted to biofuels crops due to an increase in net irrigation requirements and high transpiration rates on biofuel crops. Anejionu et al. (2020) also projected the negative impact on water availability in Italy.

6. Results discussions and practical policy implications in South Africa

The literature results revealed that biofuel production is economically viable when there is enough government support and is generally associated with positive socio-economic outcomes, including economic growth, employment creation, improved households' welfare, and poverty reduction. However, despite the possible positive socio-economic outcomes, not all countries globally have commercialized their production of biofuels, especially developing countries (including South Africa). Amongst the factors accounting for less production of biofuels in developing countries includes the fact that biofuel selling prices is generally not competitive with conventional fuel prices. The prices of equivalent conventional fuels are considerably lower than those of biofuels (Beckstrom et al., 2020).

The feedstock costs (the cost of growing and harvesting biofuels feedstocks) and capital costs were found by several studies as the significant factors contributing to the break-even price of biofuels being higher than that of conventional fuels (Mayer et al., 2016; Ndokwana and Fore, 2018; Beckstrom et al. 2019; Pascheco-López et al., 2021). This is one of the reasons the development of biofuels in Africa, including South Africa, is still settling in the legislative stage and yet to commercialize, despite Africa, especially the sub-Saharan region having abundant renewable energy resources in the form of solar, and geothermal, and hydro energy (Pradhan & Mbohwa, 2014; International Energy Agency (IEA, 2018; Dtic, 2021; Maphumulo 2021).

Therefore, to make the price of biofuel competitive with crude fuel prices in South Africa, the study recommends monetary support from the government and other potential investors towards subsidizing capital and feedstock costs. According to Cavalcanti et al. 2011; Sajid et al. (2021), one of the reasons contributing to the USA and Brazil being the leading producers of biofuels globally is the vital role that their government institutions continue to play in stimulating biofuels production. This support includes financial incentives, namely subsidies, credits, and grants to support construction mills and biofuel refineries. Furthermore, the study recommends investment in research and development (R&D) to continuously improve existing biofuel production technologies and develop cost-effective and eco-friendly biofuel production technologies to make biofuels more competitive relative to conventional fuels.

The negative impact of increasing biofuels production on social factors, namely food security, water availability, and natural species habitats due to both direct and indirect LUC induced by increased biofuel production, were also reported by several studies reviewed (Schulze et al., 2016; Seyffarth, 2016; Tarr et al. 2016; Hilst et al. 2018; Anejionu et al., 2020). The increased biofuel production (especially 1 G biofuels) to meet global demand or government targets is usually achieved at the expense of cropland and natural habitats. Furthermore, water availability has become an issue of concern due to increased irrigation requirements in producing biofuel feedstocks (Bonsch et al. 2016). In the case of South Africa, sustainability concerns namely, food security concerns (food vs fuel debate), ecological fears, and water availability concerns are quoted among reasons for slow progress in the production of biofuels at the commercial level, with food insecurity and water scarcity being the main inhibitors (Pradhan & Mbohwa, 2014; Arndt et al., 2019; Maphumulo, 2021). Although these inhibitors have been quoted, there is still no proper action plan devised to ensure that increased biofuel production is not achieved at the expense of the country's food, ecology, and water security.

In dealing with food security concerns, maize and other essential food crops were prohibited from being used as feedstock in the production of biofuels (Kohler, 2016). However, this strategy will likely have less contribution due to direct and indirect LUC. This is because agricultural land is limited. Hence, even if maize and other food crops are prohibited, an increase in profitability of biofuels is likely to lead to a shift of land from the production of food crops towards the production of energy crops and raw material for biofuels, which will in turn, lead to a decrease in the supply of food leading to an increase the price of food, in turn threatening the availability and accessibility component of food security. The production of advanced biofuels from algae, switch grass, and energy crops such as Jatropha, energy cane, and Miscanthus on marginal land has also been recommended by several studies (Wegener et al. 2018; Pascheco-López et al., 2021; Stafford et al., 2019), as a critical strategy to address food security concerns since they will not compete with food crops for land. However, these studies do not consider the negative implications on water availability due to irrigation requirements of these crops, and the risk of food crop producers allocating more of their money to bioenergy crops if biofuel markets and profitability become more guaranteed than that of food crops.

To ensure sustainability (food security, water availability and natural habitat), the study recommends the promotion of advanced biofuels produced from starch-rich crop residues. This is because crop residues have already fulfilled their food consumption, and recycling them and using them as feedstock to produce biofuels can generate additional positive economic benefits. Furthermore, food residues do not compete with food crops for land, hence direct and indirect land use changes are avoided. Studies reviewed also supported advanced biofuels even in terms of environmental benefits, as the reduction in GHGs emissions was considerably higher than that of 1 G biofuels (Wagner et al. 2018). However, for that to be realized, amendments will be necessary to the current biofuel regulatory framework (documented on the South African biofuels' regulatory framework by the DMRE (2020)) to include support for the production of advanced biofuels.

The current biofuels regulatory framework does not provide an incentive mechanism to produce advanced biofuels. Amongst the reason for the exclusion of advanced biofuels is that South Africa currently does not have enough technologies to produce advanced biofuels, and they are significantly expensive relative to 1 G biofuels (Stafford et al., 2019). Amigun et al. (2006) also quote technological constraints amongst the barriers to the commercialization of biofuels in Africa. To minimize the cost of producing advanced biofuels, the study recommends continued investments in research and development (R&D) on biofuels. This could lead to improvements in the pre-treatment and hydrolysis technologies which may significantly reduce the cost of producing advanced biofuels. According to Stafford et al. (2019), many advanced biofuel technologies are still at an early stage of R&D, leading to more considerable cost uncertainties.

7. Conclusions and suggestions for future studies

The literature review revealed that the increased production of 1 G biofuels generally involves a mix of both positive socio-economic benefits (increased labour employment, growth in GDP, improved household welfare, reduction in poverty, etc) and negative socio-economic outcomes (LUC, loss of natural vegetation and species habitat, food insecurity, and water scarcity). This was one of the reasons countries' production of biofuels in developing regions, mainly Africa, including South Africa, is still at an early stage of development, with most implementations done at a small scale and for domestic purposes. However, if the production of biofuels is done cautiously, the net socio-economic benefits can be maximized. This includes investing more in advanced biofuels that are not competing with food crops for land, especially biofuels that use crop residues as the feedstock.

The results also showed that most prospective socio-economic empirical studies on biofuels were conducted in developed (mainly the USA and Germany) and upper-middle-income developing countries (mainly Brazil). In developing countries, mainly in Africa, studies are limited, i.e., during the review period, only four studies were conducted in Africa; of those four studies, one study was conducted in the African region, and the other three were conducted in Tanzania, Mozambique and Guinea-Bissau. In South Africa, there is still no objective empirical study assessing the national-level socio-economic impact of biofuel production. More objective empirical studies may influence the government on whether or not to implement a biofuels support mechanism still in the legislative phase and also influence prospective biofuels producers to consider investing more of their resources in biofuels production by projecting the social return from ethanol production. Furthermore, the ex-ante socio-economic impact assessments of advanced biofuels production, may also encourage more policy interventions and stimulates the production of advanced biofuels which were found in the literature to offer more extra-environmental benefits (more reduction in GHGs emission), economic benefits, and social benefits than the 1 G biofuels.

In 2014, the SA government launched the South African bio-economy strategy, which is a presidential initiative and, therefore, of the highest policy attention. The bio-economy concept has been steadily increasing the political agenda in recent years. The latest count shows that more than 50 countries have either a dedicated bio-economy strategy or policies consistent with a bio-economy. The South African bio-economy strategy aims to significantly contribute to South Africa's GDP by 2030. Initially, the Department of Science and Innovation had 5% as the target the bio-economy must make to the GDP. In the national strategy document, biofuel is specifically mentioned as one way the bio-economy can be grown. Therefore, this article makes a timely contribution given the heightened policy attention in this area and the instability of energy sources nationally and globally in 2022.

8. The Limitations of the study

Due to financial constraints, authors could not access data from the Web of Science data. Hence the literature review was limited to articles published on Scopus Database. Therefore, instead of a systematic or meta-analysis literature review, a rapid-structured review of the literature was used to summarise and synthesise research findings within the constraints of time and financial resources. Although the Scopus database indexes many peer-reviewed academic journals relative to other databases (Falagas et al.,2008). The findings of this study could have been broader if it was a systematic or a meta-analysis literature review as the results of several studies reviewed from the Web of Science database were going to be incorporated. Therefore, there is a need of systematic or a meta-analysis review of literature in this subject area to address the weakness of this study.

Abbreviations

ANN	Artificial Neural Network
BEPAM	Biofuel Environmental Policy Analysis Model
BIS	Biofuel Industry Strategy
CBA	Cost Benefit Analysis
CeISTII	Centre for Science, Technology and Innovation Indicators
CGEM	Computable General Equilibrium Model
CHPP	Combined Heat and Power Plant
CPP	Carbon Payback Period
DMRE	Department of Mineral Resources and Energy
DPME	Department of Planning, Monitoring and Evaluation
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GIS	Geographic Information System
HEF	Hydrous Ethanol Fuel
HSRC	Human Sciences Research Council
IEA	International Energy Egency
IO	Input-Output
LCA	Life Cycle Assessment
LUC	Land Use Change
ML	Machine Learning
NDP	National Development Plan
NPV	Net Present Value
NRF	National Research Foundation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analysis
R&D	Research and Development
SAF	Sustainable Aviation Fuels
SEIA	Socio-economic Impact Assessment
SIA	Social Impact Assessment
SOC	Soil Organic Content
SRC	Short-rotation Coppices
TEA	Techno Economic Analysis

Notations

1 G	First Generation Biofuels
2 G	Second Generation Biofuels
3 G	Third Generation Biofuels

4 G	Fourth Generation Biofuels
CO2	Carbon Dioxide
Symbols	
€	Euros
$	Dollars
CO2eq	Carbon Dioxide Equivalent
CO2 eq/mj	Grams of Carbon Dioxide Equivalent per Megajoule
FJ$	Fijian Dollar
GJ	Gigajoule
ha	Hectare
KM^3	Cubic Killometer
US$/kg	United States Dollar per Kilogram

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