OPEN JOURNAL SYSTEMS
ISSN:2237-2202

Available on line at Directory of Open Access Journals
Journal of Hyperspectral Remote Sensing v.13, n.5 (2023) 693-704
www.periodicos.ufpe.br/revistas/jhrs

Journal of Hyperspectral Remote Sensing
www.ufpe.br/jhrs

Energy crops in Brazil: challenges and perspectives for climate change mitigation

Allívia Rouse Carregosa Rabbani * Thyane Viana da Cruz** Roberto Muhájir Rahnemay Rabbani ***

*Instituto Federal de Educação, Ciência e Tecnologia da Bahia (IFBA) - Campus de Porto Seguro, Brasil. Núcleo de Estudos em Ciências e Tecnologias Agroambientais (Necta - IFBA); Programa de Pós-Graduação em Ciências e Tecnologias Ambientais (PPGCTA/IFBA/UFSB). IFBA, Rod br 367, R. José Fontana, 1, Porto Seguro - BA, 45810-000. E-mail: alliviarouse@hotmail.com

**Instituto Federal de Educação, Ciência e Tecnologia da Bahia (IFBA) - Campus de Porto Seguro, Brasil. Núcleo de Estudos em Ciências e Tecnologias Agroambientais (Necta - IFBA); Programa de Pós-Graduação em Ciências e Tecnologias Ambientais (PPGCTA/IFBA/UFSB). IFBA, Rod br 367, R. José Fontana, 1, Porto Seguro - BA, 45810-000. E-mail: thyvc@yahoo.com.br

***Universidade Federal do Sul da Bahia (UFSB) - Campus Sosígenes Costa. Programa de Pós-Graduação em Ciências e Tecnologias Ambientais (PPGCTA/IFBA/UFSB). UFSB, S/n Rodovia BR-367 Km 10 Zona Rural, Porto Seguro - BA, 45810-000. E-mail: robertorabbani@gmail.com

Received 20 December 2023; accepted 30 December 2023

Abstract

This article explores Brazil's current energy crop cultivation scenario, emphasizing strategies to increase diversity and sustainability in biofuel production. The study underscores the importance of investments in research and development, focusing on the identification of new plant species adaptable to various climatic conditions. It highlights the need for integrated approaches, including agricultural zoning based on soil and climate information, to support crop diversification and sustainable agricultural practices such as crop rotation, species consortium, and agroecological methods to maximize resource utilization and minimize environmental impact. Moreover, it emphasizes the need for integrated approaches, including agricultural zoning based on soil and climate information, to support crop diversification. Sustainable agricultural practices, such as crop rotation, species consortium, and agroecological methods, are underscored to maximize resource utilization and minimize environmental impact. The article also discusses the pivotal role of tax incentives and subsidies in encouraging the adoption of energy crops, particularly within the context of family farming. Additionally, it underscores the potential of utilizing residual biomass from agricultural, industrial, and residential activities to further reduce reliance on specific energy crops. The article delves into the significance of scientific knowledge in policy formulation, particularly addressing biodiversity concerns and ensuring a sustainable approach to biofuel production. Furthermore, it highlights that collaborative efforts are essential among governments, private sectors, and research institutions to forge a resilient, equitable, and sustainable future for bioenergy, thereby promoting a diversified and independent energy matrix of Brazil.

Keywords: biofuels, innovation, biodiversity, sustainability, climate.

As culturas energéticas no Brasil: desafios e perspectivas para mitigação das mudanças climáticas

Resumo

Este artigo explora o cenário atual do cultivo de culturas energéticas no Brasil, enfatizando estratégias para aumentar a diversidade e sustentabilidade na produção de biocombustíveis. O estudo destaca a importância de investimentos em pesquisa e desenvolvimento, com foco na identificação de novas espécies de plantas adaptáveis a diversas condições climáticas. Enfatiza a necessidade de abordagens integradas, incluindo o zoneamento agrícola com base em informações de solo e clima, para apoiar a diversificação das culturas, além de práticas agrícolas sustentáveis, como rotação de culturas, consórcio de espécies e métodos agroecológicos, para maximizar a utilização de recursos e minimizar o impacto ambiental. Além disso, discute o papel fundamental de incentivos fiscais e subsídios para incentivar a adoção das culturas energéticas, especialmente no contexto da agricultura familiar. Também destaca o potencial do uso de biomassa residual de atividades agrícolas, industriais e residenciais para reduzir ainda mais a dependência de culturas energéticas específicas. Também explora a importância do conhecimento científico na formulação de políticas, especialmente no que se refere a biodiversidade e garantir uma abordagem sustentável para a produção de biocombustíveis. Além disso, ressalta que esforços colaborativos são necessários entre governos, setores privados e instituições de pesquisa para forjar um futuro resiliente, equitativo e sustentável da bioenergia, bem como de uma matriz energética diversificada e independente do Brasil.

Palavras-chave: biocombustíveis, inovação, biodiversidade, sustentabilidade, clima.

1. Introduction

The search for sustainable energy sources has intensified in recent years, driven by concerns about climate change and dependence on fossil fuels. Among these energies are biofuels, derived from biological raw materials, which have emerged as a promising alternative to mitigate environmental impacts by replacing total or partial dependence on fossil fuels and reducing greenhouse gas (GHG) emissions (Næss et al., 2023; Watanabe et al., 2023).

In industry, biomass is the organic matter that stores energy in chemical energy, undergoing various processing and transformation technologies, resulting in the production of biofuels (in liquid, gas, or solid forms). Concerning origin, biomass for energy purposes can be classified into three categories: 1) forest energy biomass, including products, by-products, or waste from the forestry industry; 2) agricultural energy biomass, encompassing energy crops as well as waste and by-products from agricultural activities, agro-industries, and animal production; and finally, 3) urban waste (EPE, 2022).

Biomass is relevant within the Brazilian energy policy, with 31% of the country's internal energy derived from organic matter (BEN, 2023). The largest contribution comes from sugarcane (15.4%), followed by firewood and charcoal (9.0%), and finally, leachate and other renewable energies (7.0%), including biodiesel, biogas, etc. Leachate, also known as black liquor, is a liquid, dense residue resulting from the pulp and paper industry production process, responsible for generating 3% of Brazil's energy.

As mentioned, there are different raw materials and various technological routes to produce biofuels, but most raw materials are obtained through energy crop production. "Energy crops" refers to plants cultivated primarily to produce biomass for bioenergy production (Hakeem et al., 2023; Usmani, 2023; Rabbani, 2023a).

Brazil has played a significant role in the production and promotion of energy crops, primarily ethanol and biodiesel, for biofuel transformation and utilization (Suali and Suali, 2023). This sector's contribution to the reduction of greenhouse gas emissions and maintenance of energy security has been widely acknowledged (Jayakumar et al., 2023).

The planet boasts a rich agricultural biodiversity, with dozens of species that possess the potential for biofuel production. However, it is a matter of concern that the energy crops utilized for fuel production exhibit a low diversity. This scenario calls for attention. Among the main energy crops used globally, a specific group stands out: sugarcane (*Saccharum officinarum* L.); corn (*Zea mays* L.); wheat (*Triticum* spp.); soybean (*Glycine max* L.); sugar beet (*Beta vulgaris* L.); oil palm (*Elaeis guineensis* Jacq.); rapeseed (*Brassica na*pus L.); maritime pine (*Pinus pinaster* Aiton); eucalyptus (*Eucalyptus* spp.); and sweet sorghum (*Sorghum bicolor* L.). When looking at Brazil, the highlighted species are even fewer, represented by soybean, corn, sugarcane, and eucalyptus (Rabbani, 2023a).

According to the International Energy Agency (IEA) in 2023, significant growth is expected in the production of biofuels over the next few decades. While bioenergy has been shown to have positive effects in reducing greenhouse gas (GHG) emissions and slowing global climate change, it should be noted that the expansion of biofuels production based primarily on cultivating energy crops may result in negative consequences. In fact, Gazzoni (2011) stated that such an expansion has the potential to intensify negative effects such as loss of natural habitats, increased presence of invasive species, conflicts arising from land use, and an expansion of fertilizer and pesticide use. Therefore, policymakers and industry leaders must consider the potential environmental impact of biofuel production and take necessary steps to address these challenges.

The present article aims to analyze the current Brazilian scenario, highlighting the main challenges associated with the limited number of plant species utilized for biofuel production in the country. Additionally, the article intends to explore the impacts and strategies that can promote regional energy independence. In this regard, the study will delve into the potential solutions that can help Brazil overcome the constraints it currently faces and establish a sustainable biofuel production industry.

2. Navigating the energy crops landscape

The purpose of this review is to provide an overview of the status of energy crops, the negative impacts associated with their cultivation, the advantages of crop diversification, and the key strategies required to achieve this goal. To gain comprehensive insights, we conducted extensive research across multiple databases, including ScienceDirect (http://www.sciencedirect.com/), Web of Science (https://www.webofscience.com/), Scielo (https://www.scielo.br/), and Google Scholar (https://scholar.google.com), as well as reliable sources such as the Brazilian Digital Library of Theses and Dissertations - BFTD (https://bdtd.ibict.br) and the Capes (Coordination of Superior Level Staff Improvement) Periodicals Portal (http://www-periodicos-capes-gov-br.ez51.periodicos.capes.gov.br/). After meticulously reviewing 55 articles published in renowned scientific journals, we have compiled the most pertinent information about the topics covered in this review.

Other data and information portals were also accessed, such as the IBGE (Brazilian Institute of Geography and Statistics) portal (https://sidra.ibge.gov.br/home/pms/brasil), Embrapa - Brazilian Agricultural Research Corporation (http://www.ainfo.cnptia.embrapa.br/), EPE - Energy Research Company (https://www.epe.gov.br/pt), IEA - International Energy Agency (https://www.iea.org/), IPCC - The Intergovernmental Panel on Climate Change (https://www.ipcc.ch/), and the European Parliament (https://www.europarl.europa.eu/portal/pt).

The search across different portals used keywords in Portuguese and English, such as "biomass", "biofuels", "carbon emissions", "monoculture", "farmers", "energy crops", and "species", with the purpose of better defining the research points.

3. The Current Scenario of Energy Crops

Atmospheric carbon dioxide (CO_2) has increased to 420 ppm compared to pre-industrial levels of 280 ppm, causing impacts of climate change on biodiversity and society. While reducing consumption, increasing energy efficiency, and transitioning to renewable energy and more sustainable agricultural systems are essential for meeting climate goals, increasing the removal of excess atmospheric CO_2 is crucial to limit warming to 1.5 °C (Smale et al., 2019; IPCC, 2022; Ross et al., 2023).

Energy crops have been cultivated specifically to produce biomass for energy generation. This presents a promising alternative to reduce dependence on fossil fuels and mitigate greenhouse gas (GHG) emissions. During plant growth through photosynthesis, carbon sequestration occurs in the production cycle. When used as an energy source, an equivalent amount of carbon is released into the atmosphere, closing a carbon-neutral cycle (EPE, 2020; Nalevaiko et al., 2021).

Brazil was the first country in the world to adopt biofuels in its energy matrix and different raw materials are used for this purpose (Vidal, 2021), with its exploitation prevailing through monocultures. The country has a diverse array of crops, with 35 main crops, however, the species considered for energy purposes are few, such as sugarcane, soybeans, corn, wheat, peanuts (*Arachis hypogaea* L.), sunflower (*Helianthus annuus* L.), coconut (*Cocos nucifera* L.), cotton, castor beans (*Ricinus communis* L.), and agave (*Agave sisalana* Pierre) (IBGE, 2023a).

From June 2022 to May 2023, 65% of crops were occupied by sugarcane, followed by soybean (14%) and corn (12%). These three crops encompass 95% of the national crop production (IBGE, 2023a). Sugarcane and corn are partially used in ethanol production, used as pure fuel, or blended with gasoline. Sugarcane can also produce thermal energy through bagasse burning, a byproduct of ethanol production. Soybean is the most cultivated and used crop for biodiesel production (75%) (Ferreira et al., 2018). The concentration of a few species for bioenergy production raises sustainability and energy security concerns. In recent years, sugarcane cultivation has significantly expanded to meet the demand for both sugar and ethanol production. This expansion may be attributed mainly to fiscal and financial incentives provided by the government to farmers.

Regarding cultivation for biodiesel production, significant growth has been observed in various crops, including soybean, peanut, and wheat. However, soybean stands out the most. Like sugarcane cultivation, it cannot be conclusively stated that the total increase in soybean cultivation is entirely for biodiesel production, as soybean has also experienced extraordinary growth in international demand for other purposes (Pauli et al., 2020). For forest products, there is also diversification, with over 38 products. However, 54% are concentrated in firewood, followed by roundwood (42%), mate (1.4%), charcoal (1.2%), and acai (0.6%). More than 55% of forest products generated are for energy use, with eucalyptus being the main species (IBGE, 2023b).

4. Impacts of Large Monocultures

The dominance of monocultures is a concerning reality in agricultural systems worldwide, especially in the context of energy crop production for biofuel generation. Monoculture refers to the extensive cultivation of a single plant species over large areas, with little or no cultivation of other species on the same land. While this practice has been widely adopted to maximize agricultural productivity and efficiency, it brings a range of negative impacts on the environment, biodiversity, and food security (Gazzoni, 2011). Large monoculture expanses require extensive use of natural capital, such as intensive pesticide use and significant water quantities. Concerning land use forms, there are always risks of deforestation and soil carbon release, contributing to net GHG emissions.

Another relevant point is the depletion of specific nutrients, requiring intensive use of chemical fertilizers, which can contaminate groundwater and water bodies, causing additional environmental damage. Monocultures may also lead to soil compaction, reducing its water retention capacity and increasing erosion. These negative impacts can have long-term consequences for agricultural productivity and the sustainability of agricultural and environmental systems (Miller and Spoolman, 2021). Compared to other renewable sources such as solar, wind, and hydroelectric power, bioenergy stands out for its carbon sequestration potential. During the growth process, plants undergo photosynthesis, absorbing carbon from the atmosphere. After harvest, carbon from the roots remains in the soil. This unique feature gives biofuels not only carbon-neutral generation technologies but also carbon-negative ones (Dias, 2021).

However, despite emitting fewer GHGs compared to fossil fuels, the cultivation process still emits CO_2 and other gases during planting, harvesting, and processing. Within the environmental issue, the pressure from monoculture expansion can result in habitat loss and the reduction of native species populations, negatively affecting regional biodiversity. Another aspect related to homogeneous crops is the loss of biological variety, as the abundance of species in each ecosystem is drastically reduced, making crops more susceptible to pests, diseases, and extreme weather conditions. This increases the vulnerability of agricultural production and jeopardizes food security, as a single disease or pest can devastate large expanses of plantations (Zimmermann, 2009; Gazzoni, 2011; PE, 2020).

The conversion of more lands into monocultures can lead to reduced evapotranspiration, which is the process by which plants release water into the atmosphere through transpiration. This reduction in evapotranspiration can create a localized heating microclimate known as the "Heat Island," as seen in India (Kumar et al., 2017). Moreover, such monoculture-based systems become increasingly vulnerable to extreme weather events, such as floods, prolonged droughts, or heavy rains, which can compromise agricultural production. Climate change exacerbates this vulnerability, thereby increasing the frequency and intensity of such events. It is essential to acknowledge and address these challenges to ensure sustainable agricultural practices.

The volatility of events in the global marketplace can significantly impact the availability and cost of raw materials required for biofuel production. This, in turn, can have a direct impact on the most vulnerable populations by driving up food prices. Miller and Spoolman (2021) highlight that this issue is further compounded by the social impact of monocultures, which can lead to a loss of cultural diversity and traditional knowledge with the cultivation of different agricultural species. It is essential to consider these issues carefully when evaluating the feasibility and sustainability of biofuel production.

Over time, knowledge about diversified agricultural practices may be lost, undermining the resilience of rural communities in the face of future challenges. Furthermore, there is observable displacement of populations from rural areas in expanding agricultural frontier regions to major cities due to monoculture introduction, driven by capital dominance (Kumar, 2015; Wang et al., 2023). As public policies favor agribusiness, there is a stimulus for the expulsion of the rural population, resulting in increased land concentration. The unbalanced migration from rural to urban areas leads to an exclusive appropriation, by capital, of free labor that has only its workforce to sell. The expansion of capitalism itself occurs through the appropriation of labor, which is the only force capable of creating value and wealth (Santos and Cruz, 2017). With the predominant presence of large companies in the field, areas once occupied by diverse family crops are replaced, resulting in a reduction of employment in the field and the capacity for traditional food production, compromising the food security of communities (Domingues and Bermann, 2012).

In other words, territorial management plays a fundamental role in the proper use and redistribution of natural resources, as well as in optimizing rural space and wealth balance. This management approach is of utmost importance in implementing planting projects (Zimmermann, 2009). Another aspect to consider is that the monopoly of soybean (biodiesel) and sugarcane (ethanol) monocultures in biofuel production in Brazil makes the sector vulnerable concerning energy security. Considering the effects of climate change, and the emergence of increasingly resistant pests and diseases, diversifying the productive matrix of energy crops becomes a fundamental strategy to reduce risks and ensure sectoral security.

5. The Positive Aspects of Diversification

Currently, the Brazilian agricultural sector faces a significant challenge, involving the development and implementation of technologies capable of meeting the growing demand for food, fibers, energy, wood, and non-wood products sustainably. This scenario seeks to ensure economic returns while carefully observing environmental and social aspects (Silva, 2020).

The different routes of biomass production and transformation vary according to the raw material used, benefiting regional or local economies in diverse ways. These variations promote economic development, requiring, for example, equipment supply, optimization of agro-industrial operations, technical assistance, and the development of other products. This reality favors the installation of biorefineries capable of producing multiple products, such as biofuels, bulk chemicals, and surplus energy and heat supply, contributing to the growth of product offerings and strengthening the bioenergy industry.

The increase in the number of energy crop types is crucial to ensuring the resilience of energy systems in the face of climate change and contributing to food security, as explained earlier. It is essential to note that, for fuel market allocation, the availability of raw materials for industrial-scale supply must also be considered. Although some species have priority applications in distinct technological areas, diversification will only materialize if the market has a satisfactory supply of raw materials (Santos et al., 2022).

New species, especially native ones, expand the production chain and contribute to maintaining water and soil quality, carbon sequestration, and even species preservation, becoming eligible for compensation through environmental services (Ferreira et al., 2018). Thus, it is expected that public policies will provide farmers with the perception that biodiverse areas can also improve the ecosystem services of supported regions. GHG emissions associated with biofuel production can have a significant impact on climate change.

Although biofuels are considered a more sustainable alternative to fossil fuels, it is essential to consider all stages of the life cycle of this bioenergy to assess its true emissions reduction potential. Therefore, it is crucial to examine the entire crop cycle before adopting it within an energy policy (Melnikova et al., 2022). In this context, the development of technologies that allow efficient and sustainable production is fundamental, seeking to maximize production without compromising ecosystem health and the well-being of rural communities.

The adoption of more sustainable agricultural and livestock practices, responsible use of inputs, promotion of agroecology, implementation of integrated natural resource management systems, and efficient use of water resources are some strategies that can contribute to achieving this goal. The expansion of the number of species, especially through environmentally friendly cultivation, can promote soil preservation, which is crucial due to its vital role in the functioning of terrestrial systems, including the water cycle, climate regulation, nutrient cycles, and biodiversity. All these aspects translate into significant benefits for food security, nutrition, health, and energy security related to bioenergy. In this context, the soil plays crucial structural functions as an essential component of the environment, going beyond being just a substrate for agricultural/forestry production. The soil is a complex and dynamic biosystem, where its functions are not linear, making it vulnerable to impacts from contamination or degradation of its properties (Dias, 2021).

Ecosystem services play a critical role in maintaining the health and functionality of our planet. These services are defined as the benefits that humans and all living organisms derive from ecosystems, such as pollination, water purification, soil fertility, climate regulation, and biodiversity maintenance (Figure 1). They form the foundation of the well-being of societies and the stability of the natural world. Ecosystem services contribute significantly to food and water security, support agriculture, mitigate climate change impacts, and provide resources for medicine and industry. They are fundamental to human survival, fostering resilience against environmental challenges and ensuring the balance and sustainability of Earth's diverse ecosystems (Oliveria et al., 2022; Simões et al., 2022). Recognizing and valuing these services is crucial for informed decision-making in land use, resource management, and conservation efforts, emphasizing the interconnectedness between nature and human societies. Therefore, there is no way to dissociate the issue of energy crops from their real function within ecosystems, as we could be changing or intensifying environmental problems.

6. Strategies to Expand the Diversity of Energy Crops

Investing in research and development (R&D) is crucial for identifying new plant species with the potential for energy biomass production. Research programs can explore native and exotic species adapted to different climatic conditions and soil types, aiming to diversify the options available for cultivation (Rosegrant et al., 2022).

As the global production of biofuels continues to expand, there has been a parallel increase in the availability of biomass (IEA, 2023). This growth has prompted a greater interest from the scientific community to invest in the development of field production and processing technologies to meet the demands of the industry. In turn, this interest has led to an increase in the technological maturity of the biofuel production process, resulting in a more efficient and sustainable approach over time. To ensure continued progress in this field, research efforts must remain focused on improving the technical aspects of biofuel production, including field production and processing of raw materials.

For a country to obtain technologies that promote the reduction of natural resource consumption, environmental impact mitigation, improved production efficiency, and diversification of agricultural activities for sustainable sector development, investments in research and technological innovation are essential to developing solutions adapted to different realities and sector demands. Investments in agricultural/forestry innovation allow technological development and commercial viability of new energy crops that can emerge as an attractive alternative to meet demands, considering criteria such as lower environmental impact, and driving regional energy independence.

Another important point is the implementation of agricultural zoning, specific to different energy crops, based on edaphoclimatic information. Zoning favors the adoption of public policies tailored to local realities by adopting crops adapted to the specific edaphoclimatic conditions of each region (Cordes, 2002), promoting regional energy independence. Through zoning, it is possible to find regional solutions, contributing to optimizing the use of natural resources, avoiding the disorderly expansion of crops, and minimizing conflicts with areas designated for food production (Wollmann and Galvani, 2013).

In this context, specifically regarding energy crops, it is crucial that zoning is associated with R&D so that it is possible to develop knowledge networks, establish research lines, and create systems for the introduction and testing of crops to establish efficient agricultural zoning.

Bioenergy is a crucial source of renewable energy that can be obtained from two primary sources: energy crops grown explicitly for this purpose and residual biomass generated from various activities such as agricultural/forestry, industrial, or residential undertakings. In the agricultural/forestry sector, certain crops, also known as "flex crops," can produce multiple products simultaneously. This approach enables greater flexibility in adapting to market variations, as evident in the sugarcane industry (Msangi, 2016; Dias, 2021; Rabbani, 2023a). In simpler terms, a single species can produce food, biofuels, and other products, including chemicals. This approach promotes the efficient utilization of agricultural resources, thereby augmenting production efficiency.

Diversification of energy crops can be facilitated by promoting incentives for agroecology and sustainable practices. The implementation of such practices can include crop rotation, species consortium, integrated pest and disease management, encouragement of double planting, polycultures, or integrated systems that combine agricultural production with animal husbandry or the cultivation of planted forests. Additionally, the adoption of sustainable practices, such as a reduction in the use of pesticides and chemical fertilizers, can contribute to the conservation of natural resources and the protection of biodiversity (Sachet et al., 2021; Schwarz et al., 2022).

The adoption of agroecological practices can contribute to making agricultural systems more resilient and sustainable. For effective reductions in greenhouse gas emissions, the production of energy crops must be associated with low-carbon agricultural technological processes for greater energy efficiency of biofuels (Cruz et al., 2014).

It is essential to preserve and use potential energy native species (Table 1), often forgotten or underutilized, can be one of the solutions to broaden the diversity of energy crops. This approach can also contribute to the conservation of regional flora and traditional knowledge, such as *Jatropha mollissima*, which is native to Brazil, and exhibits strong drought resistance (Pompelli et al., 2011; Paiva et al., 2021). These species can be studied and adjusted for ideal conditions of use to produce liquid, solid, and gaseous biofuels.

To tackle the issues related to the prevalence of monocultures, public policies must be put in place to incentivize crop diversification and promote sustainable farming techniques. These policies will play a crucial role in creating a more equitable and healthy future for both the environment and society (Gallardo-López et al., 2018).

The implementation of biofuel production public policies in Brazil holds immense significance in determining the nation's energy landscape. Such policies promote sustainability, bolster economic progress, and establish global leadership in renewable energy. They serve as a critical framework to harmonize economic expansion with environmental preservation, resulting in a more lasting and robust energy outlook (Jarma et al., 2011).

The RenovaBio, for example, is a Brazilian national biofuels policy that was established to promote the sustainable development of the bioenergy sector (Law 13,576/2017). The primary goal is to increase the share of biofuels in the country's energy mix, reduce greenhouse gas emissions, and contribute to Brazil's commitments to mitigating climate change (ANP, 2023). The policy is a pivotal component of bioenergy strategy, connecting with various public policies to provide a comprehensive and market-driven approach to incentivizing biofuels. It establishes a framework that aligns economic interests with environmental sustainability (Figura 2).

However, there is a flaw in RenovaBio, there are no incentives for the diversification of energy crops. Effective public policies supporting energy crop diversification require a multi-faceted approach that combines financial incentives, research support, sustainable practices, and market mechanisms. These policies should be adaptive, considering the dynamic nature of the bioenergy landscape and the evolving challenges associated with climate change and energy security.

The cultivation of crops for energy production has the potential to foster sustainable agricultural practices and enhance agro-ecosystem resilience, thereby reducing dependence on external inputs. Therefore, the promotion of energy diversity in crop systems can play a pivotal role in advancing sustainable agriculture and ecosystem management objectives.

:

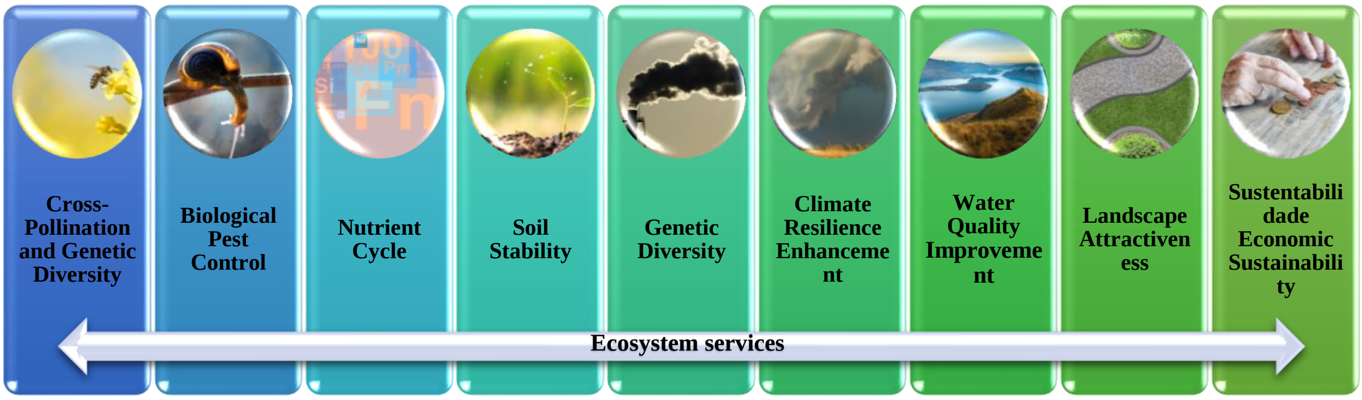

Figure 1 - Examples of ecosystem services are promoted by the diversity of crops for energy purposes. Source: the authors.

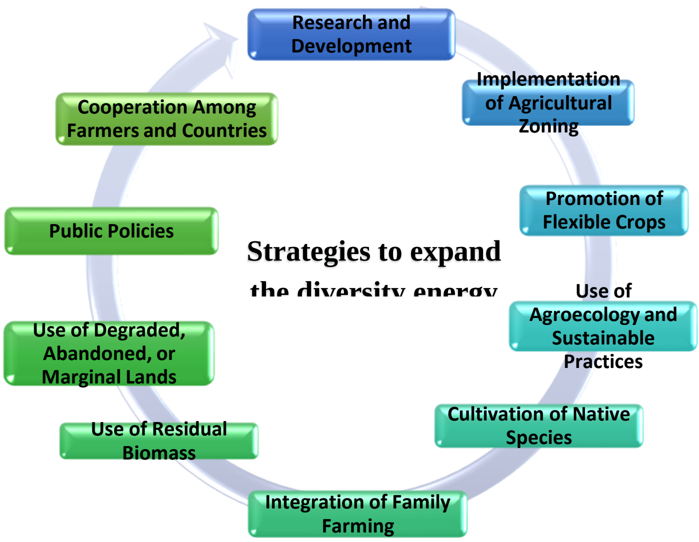

Figure 2 - Key Strategies for promoting diversity in energy crops and the sustainability of bioenergy. Source: the authors.

Table 1 - Examples of promising vegetal species for use as energy crops.

Species	Biofuel types	Studies
Euterpe oleracea Mart.	Solid	Passinho et al., 2019
Carapa guianensis Aubl.	Liquid	Stachiw et al. (2016)
Attalea speciosa Mart. ex Spreng.	Liquid	Stachiw et al. (2016); Anjos et al. (2021)
Orbignya phalerata Mart.	Liquid and Solid	Reis et al. (2015); Lima et al. (2007)
Pennisetum purpureum Schum.	Solid	Fernandes et al. (2020); Tavares e Santos (2013)
Copernicia prunifera (Mill.) H.E. Moore.	Liquid and Solid	Tavares e Santos (2013)
Cártamo (*Carthamus tinctorius* L.	Liquid	Rocha et al. (2019)
Bertholletia excelsa Bonpl.	Liquid	Stachiw et al. (2016)
Crambe abyssinica Hochst)	Liquid	Queiroz et al. (2021)
Theobroma Grandiflorum (Willd. Ex Spreng. Schum)	Liquid and Solid	Santos et al. (2015); Marasca et al. (2022)
Sapium sp	Solid	Nagaishi et al. (2020)

Elaeis guineenses Jacq.	Liquid	Ferreira et al. (2018); Messis et al. (2020); Peixoto et al. (2022)
Guatteria sp.	Solid	Fortaleza et al. (2019)
Schizolobium parahyba (Vell.) Blake	Solid	Narita et al. (2018)
Nectandra cusoidata (Mart. Ex Nees]	Solid	Nagaishi et al. (2020)
Acromia aculeata Jacq.	Liquid	WWF (2022); Guerra et al. (2023)
Cassia scleroxylon Ducke	Solid	Nagaishi et al. (2020)
Schizolobium amazonicum Herb	Solid	Ferreira et al. (2021); Vidaurre et al. (2022)
Caryocar brasiliense Camb.	Liquid	Souza et al. (2020)
Jatropha ribifolia (Pohl) Baill.	Liquid and Solid	Paiva et al. (2021)
Jatropha mollissima (Pohl) Baill.	Liquid andSolid	Paiva et al. (2021)
Jatropha curcas L.	Liquid	Ferreira et al. (2018)
Ceiba pentandra (L.) Gaertn.	Solid	Fortaleza et al. (2019)
Astrocaryum tucuma Mart.	Liquid	Stachiw et al. (2016)

7. Conclusions

Energy crops in Brazil play a significant role in the country's efforts to address climate change and mitigate its impacts. Brazil has been a pioneer in the use of bioenergy, particularly from crops like sugarcane and soybeans to ethanol and biodiesel. However, it is necessary to pay attention to the diversity of crops used. The exploration of diverse strategies to enhance the variety of energy crops is imperative for fostering sustainability in the realms of biofuel production. The translation has elucidated key approaches, including investment in research and development, incorporation of agroecological practices, incentivizing the use of new species, and leveraging residual biomass. Furthermore, the emphasis on sustainable policies, economic incentives, and collaboration across sectors and regions emerges as essential components. By prioritizing these strategies, nations can navigate the complex landscape of energy production, ensuring resilience, mitigating environmental impact, and paving the way for a more sustainable Brazilian secure energy future.

8. Acknowledgments

We want to express our gratitude to the Federal Institute of Education, Science, and Technology of Bahia (IFBA), especially to the Pro-Rectory of Research, Postgraduate Studies, and Innovation (PRPGI/IFBA), and the Federal University of Southern Bahia for the institutional and financial support (Call No. 14/2022/PRPGI/IFBA; CAPES/PROAP/PPGCTA/UFSB/2023) provided for this research.

Referências

Anjos, S. S. N. dos, Neto, J. O. do N., 2021. Avaliação do impacto de política de subvenção econômica na cadeia produtiva de biodiesel de Babaçu. Revista em Agronegócio e Meio Ambiente 14 (Supl. 1), 1–16. https://doi.org/10.17765/2176-9168.2021v14Supl.1.e8348

ANP, 2023. RenovaBio. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis. https://www.gov.br/anp/pt-br/assuntos/renovabio

BEM, 2023. Relatório Síntese: ano base 2022. Balanço Energético Nacional. Ministério de Minas e Energia. Brasil. https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-748/topico-681/BEN_S%C3%ADntese_2023_PT.pdf

Bonassa, G., Schneider, L. T., Canever, V. B., Cremonez, P. A., Frigo, E. P., Dieter, J., Teleken, J. G., 2018. Scenarios and prospects of solid biofuel use in Brazil. Renewable and Sustainable Energy Reviews 82 2365–2378. https://doi.org/10.1016/j.rser.2017.08.075

Brasil, 2022. Portaria SAF/MAPA nº 280, de 27 de maio de 2022. Dispõe sobre os critérios e procedimentos relativos à concessão e manutenção do direito de uso do Selo Biocombustível Social. Ministério da Agriculturas, Pecuária e Abastecimento, Brasil. https://www.in.gov.br/en/web/dou/-/portaria-saf/mapa-n-280-de-27-de-maio-de-2022-403689855

Cordes, M. W., 2001. Agricultural zoning: Impacts and future directions. N. Ill. UL Rev. 22, 419. https://ssrn.com/abstract=2808594

Cruz, T. V., Cunha, F., de Carvalho, N. B., Lima, A., Assis, M. G., Lino, J. C., Conceição, I. R. A., 2014. Agricultura de baixo carbono para produção sustentável de biocombustíveis. VIII Workshop Agroenergia. http://www.infobibos.com.br/Agroenergia/CD_2014/Resumos/ResumoAgroenergia_2014_034.pdf

Csikós, N., Tóth, G., 2023. Concepts of agricultural marginal lands and their utilization: a review. Agricultural Systems 204, 103560

Dias, T. A. C., 2021. Avaliação da disponibilidade de terras e do potencial bioenergético em 2050 considerando os limites da segurança alimentar [Dissertação Mestrado em Engenharia de Energia, - Universidade Federal de Itajubá]. Repositório https://repositorio.unifei.edu.br/jspui/bitstream/12

3456789/2509/1/Disserta%C3%A7%C3%A3o_2021177.pdf
Domingues, M. S., Bermann, C., 2012. O arco de desflorestamento na Amazônia: da pecuária à soja. Ambiente & Sociedade 15, 1–22. https://doi.org/10.1590/S1414-753X2012000200002
EPE, 2022. Balanço Energético Nacional 2022: ano base 2021. Empresa De Pesquisa Energética. https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-675/topico-638/BEN2022.pdf
Fernandes, F., Carvalho, M., Ramos, A., Braga, G., da Fonseca, C. E. L., Ledo, F. D. S., Machado, J., 2020. Biomassa de genótipos de capim-elefante para produção de energia. Embrapa Cerrados. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/222752/1/Bolpd-358-versao-final-bibl.pdf
Ferreira, W. L., Hüther, C. M., Pereira, C. R., da Silva, I. M., 2018. Desafios ao uso de biodiesel frente à evolução da demanda mundial de energia. IV Workshop de Engenharia de Biossistemas - WEB 4.0. https://app.uff.br/riuff/bitstream/handle/1/8377/Anais%20WEB_IV_2018-12-20.pdf?sequence=1&isAllowed=y#page=31
Ferreira, P. H., da Silva, G. A. A., Ervite, L., Castro, D. P., 2018. O Cenário da Produção de Biocombustível no Brasil. Revista Agroveterinária, Negócios e Tecnologias 3(1), 89-102
Ferreira, V. R. D. S., Takahashi, V. M., DE Cademartori, P. H. G., Carneiro, M. E., Da Silva, D. A., 2021. Qualidade energética de resíduos madeireiros paricá e Pinus. Energia na Agricultura 36(2), 230-238. http://dx.doi.org/10.17224/EnergAgric.2021v36n2p230-238
Fortaleza, A. P., Ceretta, R. P. D. S., Barros, D. D. S., Silva, S. S. D., 2019. Biomassa de espécies florestais para produção de carvão vegetal. Ciência Florestal 29, 1436-1451. https://doi.org/10.5902/1980509831639
Gallardo-López, F., Hernández-Chontal, M., Cisneros-Saguilán, P., Linares-Gabriel, A., 2018. Development of the Concept of Agroecology in Europe: A Review. Sustainability 10(4), 1210. https://doi.org/10.3390/su10041210
Gazzoni, D. L., 2011. Biocombustíveis e biodiversidade. BiodiselBR. https://www.biodieselbr.com/noticias/colunistas/gazzoni/biocombustiveis-biodiversidade-04-11-09
Guerra, A. L. D. S. C., Ságio, S. M., dos Santos, E. P., Pinheiro Filho, I. S., dos Santos Silva, L. G., Tavares, K. M., 2023. Criatividade e Inovação na Indústria: Uso da Macaúba na Produção do Biodiesel. Revista de psicologia 17(66), 413-422. https://doi.org/10.14295/idonline.v17i66.3784
Hakeem, K. R., Bandh, S. A., Malla, F. A., Mehmood, M. A., 2023. Environmental Sustainability of Biofuels. Elsevier. https://doi.org/10.1016/C2020-0-04172-1
IBGE, 2023c. Tabela 291 - Quantidade produzida e valor da produção na silvicultura, por tipo de produto da silvicultura. Produção da Extração Vegetal e da Silvicultura. SIDRA - Sistema IBGE de Recuperação Automática. Instituto Brasileiro de Geografia e Estatística. https://sidra.ibge.gov.br/tabela/291
IBGE, 2023b. Tabela 5930 - Área total existente em 31/12 dos efetivos da silvicultura, por espécie florestal. Produção da Extração Vegetal e da Silvicultura. SIDRA - Sistema IBGE de Recuperação Automática. Instituto Brasileiro de Geografia e Estatística. https://sidra.ibge.gov.br/tabela/5930
IBGE, 2023a. Tabela 6588 - Série histórica da estimativa anual da área plantada, área colhida, produção e rendimento médio dos produtos das lavouras. Levantamento sistemático da produção agrícola. SIDRA - Sistema IBGE de Recuperação Automática. Instituto Brasileiro de Geografia e Estatística. https://sidra.ibge.gov.br/tabela/6588
IEA, 2023. Bioenergy. Energy system. Renewables. International Energy Agency. https://www.iea.org/energy-system/renewables/bioenergy
IPCC, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (Eds.). Painel Intergovernamental sobre Mudanças Climáticas. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/
Jarma O, A. D. J., Pompelli, M. F., de Oliviera, M. T., Monteiro Rodrigues, B. R., Oliveira Barbosa, M., Guida Santos, M., de Almeida Cortez, J. S., 2011. Crise energética mundial e o papel do Brasil na problemática de biocombustíveis. Agronomía Colombiana 29(2), 423–433
Jayakumar, M., Kaleab Bizuneh Gebeyehu, Lata Deso Abo, Amberbir Wondimu Tadesse, B. Vivekanandan, Venkatesa Prabhu Sundramurthy, Bacha, W., Veeramuthu Ashokkumar, Gurunathan Baskar, 2023. A comprehensive outlook on topical processing methods for biofuel production and its thermal applications: Current advances, sustainability and challenges. Fuel 349, 128690–128690. https://doi.org/10.1016/j.fuel.2023.128690

Kumar, R., 2015. Risking the Farm: Will the Smallholder Survive? Economic and Political Weekly 50 (32), 27–31. https://www.jstor.org/stable/24482522

Kumar, R., Mishra, V., Buzan, J., Kumar, R., Shindell, D., Huber, M., 2017. Dominant control of agriculture and irrigation on urban heat island in India. Scientific Reports 7(1). https://doi.org/10.1038/s41598-017-14213-2

Lima, J. R. de O., Silva, R. B. da, Silva, C. C. M. da, Santos, L. S. S. dos, Santos Jr., J. R. dos, Moura, E. M., Moura, C. V. R. de., 2007. Biodiesel de babaçu (Orbignya sp.) obtido por via etanólica. Química Nova 30(3), 600–603. https://doi.org/10.1590/s0100-40422007000300019

MAPA, 2022. Selo Biocombustível Social promove a inclusão e capacitação técnica de agricultores familiares. Agricultura Familiar. Ministério da Agricultura e Pecuária. https://www.gov.br/agricultura/pt-br/assuntos/noticias-2022/mudancas-na-concessao-do-selo-biocombustivel-social

Marasca, N., Mateus Rodrigues Brito, Michele, Cristiane Pedrazzi, Scapin, E., Diel, K., 2022. Analysis of the potential of cupuaçu husks (*Theobroma grandiflorum*) as raw material for the synthesis of bioproducts and energy generation. Food Science and Technology 42. https://doi.org/10.1590/fst.48421

Melnikova, I., Boucher, O., Cadule, P., Tanaka, K., Gasser, T., Tomohiro Hajima, Yann Quilcaille, Hideo Shiogama, Séférian, R., Kaoru Tachiiri, Vuichard, N., Tokuta Yokohata, Philippe Ciais, 2022. Impact of bioenergy crop expansion on climate–carbon cycle feedbacks in overshoot scenarios. Earth System Dynamics 13(2), 779–794. https://doi.org/10.5194/esd-13-779-2022

Mendes, M. C. de Q., Gonzalez, A. A. C., Menezes, M., Nunes, J. M. de C., Pereira, S., Nascimento, I. A., 2012. Coleção de microalgas de ambientes dulciaquícolas naturais da Bahia, Brasil, como potencial fonte para a produção de biocombustíveis: uma abordagem taxonômica. Acta Botanica Brasilica 26(3), 691–696. https://doi.org/10.1590/s0102-33062012000300019

Messias, U., Silva, M., Silva Filho, F. A., Veloso, M. D. C., Antonini, J. D. A., Maria da Luz Lima Silva, U. F. R. P. E., Francisco Artur, Silva Filho, U. E. S. P. I., 2020. Potencial físico-químico do óleo do dendezeiro cultivado em Parnaíba, Piauí, para produção de biocombustível. Comunicado Técnico nº 255. Embrapa. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/223595/1/PotencialFisicoQuimicoOleoDendezeiro.pdf

Miller, G. T., Spoolman, S. E., 2021. Ciência Ambiental. CENGAGE Learning.

Næss, J. S., Hu, X., Gvein, M. H., Iordan, C. M., Cavalett, O., Dorber, M., Cherubini, F., 2023. Climate change mitigation potentials of biofuels produced from perennial crops and natural regrowth on abandoned and degraded cropland in Nordic countries. Journal of Environmental Management 325, 116474. https://doi.org/10.1016/j.jenvman.2022.116474

Nagaishi, T. Y. R., Kato, O. R., Dionisio, L. F. S., Aragão, D. V., Numazawa, S., Lima, E. G. da S., Bronze, A. B. da S., Nagaishi, M. da S. C. F., 2020. Biocombustíveis alternativos na agricultura familiar na Amazônia. Brazilian Journal of Development 6(9), 65475–65496. https://doi.org/10.34117/bjdv6n9-106

Nalevaiko, J. Z., Cremonez, P. A., Teleken, J. G., 2021. Utilização de subprodutos agroindustriais na produção de briquetes. Revista Brasileira de Engenharia de Biossistemas 15(1), 1-26. http://dx.doi.org/10.18011/bioeng2021v15n1p1-10

Narita, D. K., Nakashima, G. T., Róz, A. L. D., Pires, A. A. F., Yamaji, F. M., 2018. Uso do guapuruvu (*Schizolobium parahyba*) para fins energéticos. Ciência Florestal 28, 758-764. https://doi.org/10.5902/1980509832089

Oliveira, P. J. L. de, Guedes, J. F., Costa, D. F. da S., 2022. Serviços ecossistêmicos de regulação em uma bacia hidrográfica no semiárido do brasil. Mercator 21, e21028. https://doi.org/10.4215/rm2022.e21028

Paiva, C. Z. M. S., Rabbani, A. R. C., Silva, A. G.,Setubal, A. C., Santos, D. S. S., 2021. *Jatropha mollissima* (Pohl) Baill. e *Jatropha ribifolia* (Pohl) Baill.:espécies promissoras para a bioenergia? In Rabbani, A. R. C., Fabris, J. P. (Orgs.), Desafios Ambientais e Culturas Agrícolas, Backup Books Editora, pp. 163–192. Disponível em: https://backupbooks.com.br/index.php?route=product/product&product_id=60

Passinho, M. S., Barbosa, D., Souza, M. J., Xavier, N., 2019. Uso da semente de açaí como alternativa energética na indústria de beneficiamento de polpa de açaí. Enciclopédia Biosfera 16(29), 1473–1484. https://www.conhecer.org.br/ojs/index.php/biosfera/article/view/298

Pauli, R. I. P., Zajonz, B. T., Schulz, J. R. da S., Freitas, C. A. de., 2020. A segurança alimentar e nutricional (San) vem sofrendo restrições pela produção de biocombustíveis? uma análise a partir do modelo de Zockun. RDE - Revista de Desenvolvimento Econômico 2(46). https://doi.org/10.36810/rde.v2i46.6774

PE, 2020. Perda de biodiversidade: quais as causas e as consequências? Atualidade. Parlamento

Europeu. Palarmento Europeu. https://www.europarl.europa.eu/news/pt/headlines/society/20200109STO69929/perda-de-biodiversidade-quais-as-causas-e-as-consequencias

Peixoto, R. D. L., Moura, L. F. O., Sousa, A. B. P., Santos, M. V. D., Medeiros, V. M. B., Bicudo, T.C., 2022. Dependência das propriedades de fluxo e da estabilidade à oxidação com o grau de insaturação do biodiesel obtido de misturas dos óleos de dendê e soja. In Editora Científica Digital (Orgs.), Open science research IX. Editora Científica Digital. https://doi.org/10.37885/221211252

Pereira, E. R. de L., Araújo, V. B. da S., Lira, E. B. de, Morais, V. M. M., Sassi, C. F. da C., Fernandes, H. F., Medeiros, M. B. de, Sassi, R., Athayde-Filho, P. F. de., 2020. Bioprospecção de espécies de microalgas regionais do Nordeste do Brasil para aplicação na produção de biocombustíveis. Revista Brasileira de Gestão Ambiental e Sustentabilidade 7(16), 809–833. https://doi.org/10.21438/rbgas(2020)071624

Queiroz, I. R., Costa, A. S. V. da, Almeida, I. C., Barros, G. F., Alves, W. M., Souza, M. C. de & Franco, M. L., Pompermayer, R. de S., Souza, A. O., Ferreira, A. C. 2021. Biofuels in Brazil: potentialities of *Crambe abyssinica* culture for biodiesel production. Research, Society and Development 10(5), 11510514618. https://doi.org/10.33448/rsd-v10i5.14618

Rabbani, A. R. C., 2023a. Culturas energéticas e o estado da Bahia. Petim 4, 32-36. https://online.fliphtml5.com/yzprc/whji/

Rabbani, A. R. C., Rabbani, R. M. R. Kohlman Rabbani, E., 2023b. Somos todos um! In: Arenas, P. A. R. (Org.), Cidadania Mundial: um sonho possível. Ed. dos Autores.

Regan, J. T., Marton, S., Barrantes, O., Ruane, E., Hanegraaf, M., Berland, J., Nesme, T., 2017. Does the recoupling of dairy and crop production via cooperation between farms generate environmental benefits? A case-study approach in Europe. European journal of agronomy 82, 342-356. https://doi.org/10.1016/j.eja.2016.08.005

Reis, A. R. S., Reis, J. S. F., Silva, J. R., Carvalho, J. C., Souza, D. V., Reis, L. P., 2015. Comparação entre Carvão de Coco Babaçu e Carvão de Resíduos Madeireiros Comercializados em Altamira – PA. Revista Ciência Da Madeira - RCM 6(2), 100–106. https://doi.org/10.12953/2177-6830/rcm.v6n2p100-106

Rocha, É., Silva, Araújo, E., Isabel, A., & Juliana Espada Lichston., 2019. Perfil dos agricultores familiares da agrovila canudos, Ceará-Mirim/RN, e aceitação do Carthamus tinctorius L. – oleaginosa promissora para biodiesel. Nature and Conservation 12(3), 17–24. https://doi.org/10.6008/cbpc2318-2881.2019.003.0003

Rodrigues, A., 2022. Produção de biocombustíveis a partir de microalgas – uma revisão. Revista Ambientale 14(2), 10–21. https://doi.org/10.48180/ambientale.v14i2.370

Rosegrant, M. W., Sulser, T. B., Wiebe, K., 2022. Global investment gap in agricultural research and innovation to meet Sustainable Development Goals for hunger and Paris Agreement climate change mitigation. Frontiers in Sustainable Food Systems, 6. https://doi.org/10.3389/fsufs.2022.965767

Ross, F. W. R., Boyd, P. W., Filbee-Dexter, K., Watanabe, K., Ortega, A., Krause-Jensen, D., Lovelock, C., Sondak, C. F. A., Bach, L. T., Duarte, C. M., Serrano, O., Beardall, J., Tarbuck, P., Macreadie, P. I., 2023. Potential role of seaweeds in climate change mitigation. Science of the Total Environment 885, 163699. https://doi.org/10.1016/j.scitotenv.2023.163699

Sachet, E., Mertz, O., Le Coq, J.-F., Cruz-Garcia, G. S., Francesconi, W., Bonin, M., Quintero, M. (2021). Agroecological Transitions: A Systematic Review of Research Approaches and Prospects for Participatory Action Methods. Frontiers in Sustainable Food Systems 5. https://doi.org/10.3389/fsufs.2021.709401

Santos, A. C. D., Anjos, S. S. N. dos, Braga, M., Viana, N. M., Soares, I. P. 2022. Aplicação industrial de óleos vegetais em biocombustível: um estudo prospectivo e análise de sinais para apontar tendências de mercado. Cadernos de Ciência & Tecnologia 39(2), 26995. https://doi.org/10.35977/0104-1096.cct2022.v39.26995

Santos, E. C. S. D., Souza, R. C. R., Seye, O., 2004. Aproveitamento da casca do cupuaçuzeiro para a produção de energia. Procedings of the 5th Encontro de Energia no Meio Rural. http://www.proceedings.scielo.br/pdf/agrener/n5v1/015.pdf

Santos, J. A. L., Cruz, C. D. S., 2017. Energias renováveis: potencialidades e desafios da produção de biodiesel na Bahia. Bahia Análise & Dados 27(1), 230-257. http://www.leste.igeo.ufba.br/sites/leste.igeo.ufba.br/files/renovaveis_biodiesel_bahia.pdf

Schwarz, G., Vanni, F., Miller, D., Helin, J., Pražan, J., Albanito, F., Zīlāns, A., 2022. Exploring sustainability implications of transitions to agroecology: a transdisciplinary perspective. EuroChoices 21(3), 37-47. https://zenodo.org/badge/DOI/10.1111/1746-692X.12377.svg

Silva, K. P., 2020 Culturas Energéticas Debates Agroenergéticos. PPV 688. Culturas Energéticas. Informativo. Programa de Pós-graduação em Produção Vegetal, Universidade Federal dos Vales do Jequitinhonha e Mucuri, Brasil. http://site.ufvjm.edu.br/ica/files/2020/07/6-Sistemas-integrados-de-cultivo-alimentos-e-energia.pdf

Simões, G. dos S., Fiore, F. A., Silva, L. C., 2022. Mapping of ecosystem services provided by the Paraíba do Sul river alluvial plains APA. Ambiente & Sociedade 25, e01882. https://doi.org/10.1590/1809-4422asoc20210188r2vu2022L2OA

Smale, D. A., Wernberg, T., Oliver, E. C. J., Thomsen, M., Harvey, B. P., Straub, S. C., Burrows, M. T., Alexander, L. V., Benthuysen, J. A., Donat, M. G., Feng, M., Hobday, A. J., Holbrook, N. J., Perkins-Kirkpatrick, S. E., Scannell, H. A., Sen Gupta, A., Payne, B. L., Moore, P. J., 2019. Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nature Climate Change, 9(4), 306–312. https://doi.org/10.1038/s41558-019-0412-1

Souza, M. G. S., Guimarães, J. M. G., Rodrigues, J. P., Ghest, J. F., 2019. Caracterização e Utilização de Óleo Residual de Pequi (*Caryocar brasiliense*) na Produção de Biocombustíveis Líquidos. Revista Interdisciplinar de Pesquisa Em Engenharia 5(2), 41–49. https://doi.org/10.26512/ripe.v5i2.28222

Stachiw, R., Ribeiro, S. B., Jardim, M. A. G., Possimoser, D., Alves, W. da C., Cavalheiro, W. C. S., 2016. Potencial de produção de biodiesel com espécies oleaginosas nativas de Rondônia, Brasil. Acta Amazonica 46(1), 81–90. https://doi.org/10.1590/1809-4392201501151

Suali, E., Latifah Suali, 2023. Impact assessment of global biofuel regulations and policies on biodiversity. Sustainability of Biofuels, 137–161. https://doi.org/10.1016/b978-0-323-91159-7.00012-6

Tavares, S. R. de L., Santos, T. E. dos. Uso de diferentes fontes de biomassa vegetal para a producão de biocombustíveis sólidos. Holos v. 5, p. 19, 4 dez. 2013. https://doi.org/10.15628/holos.2013.1850

Usmani, R. A. 2023. Biofuel consumption and global climate change: Solutions and challenges. In Hakeem, K. R., Bandh, S. A., Malla, F. A., Mehmood, M. A. (Eds.), Environmental Sustainability of Biofuels, pp. 183-200. Elsevier. https://doi.org/10.1016/B978-0-323-91159-7.00019-9

Vidal, M. F., 2023. Produção e uso de biocombustíveis no Brasil. https://www.bnb.gov.br/s482-dspace/bitstream/123456789/914/1/2021_CDS_184.pdf

Vidaurre, G. B., Carneiro, A. D. C. O., Vital, B. R., Santos, R. C. D., Valle, M. L. A., 2012. Propriedades energéticas da madeira e do carvão de paricá (*Schizolobium amazonicum*). Revista Árvore 36, 365-371. https://doi.org/10.1590/S0100-67622012000200018

Wang, J., Jiang, H., He, Y., 2023. Determinants of Smallholder Farmers' Income-Generating Activities in Rubber Monoculture Dominated Region Based on Sustainable Livelihood Framework. Energy Conversion and Management 12(2), 281–281. https://doi.org/10.3390/land12020281

Marcos D.B. Watanabe, Hu, X., Vedant Ballal, Otávio Cavalett, Cherubini, F., 2023. Climate change mitigation potentials of on grid-connected Power-to-X fuels and advanced biofuels for the European maritime transport. Energy Conversion and Management 20, 100418–100418. https://doi.org/10.1016/j.ecmx.2023.100418

Wollmann, C. A., Galvani, E., 2013. Zoneamento agroclimático: linhas de pesquisa e caracterização teórica-conceitual. Sociedade & Natureza 25(1), 179–190. https://doi.org/10.1590/s1982-45132013000100014

WWF, 2022. Viabilidade da macaúba para a produção de biocombustível. Resumo Executivo. World Wide Fund for Nature. Disponível em: https://wwfbrnew.awsassets.panda.org/downloads/resumoexecutivo_macauba_final_v3.pdf

Zimmermann, C. L., 2009. Monocultura e transgenia: impactos ambientais e insegurança alimentar. Veredas do Direito 6(12), 79-100. https://core.ac.uk/download/pdf/211934062.pdf