



## The role of biofuels in the sustainable development of the agricultural supply chain: using artificial computational intelligence methods

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Received Date: 15 April 2025 Accepted Date: 20 June 2025

### Abstract

**Background and Objective:** With increasing environmental pressures and the growing need for clean energy, the use of biofuels has been considered as a solution to improve the sustainability of the agricultural supply chain. This study aimed to analyze the role of biofuels in the sustainable development of the agricultural supply chain using a systematic, focus group, and computational intelligence-based modeling approach.

**Methodology:** In the first stage, a systematic review method based on the PRISMA guideline was used to identify key variables. With the participation of 20 experts in the focus group format, the most important influential parameters, including biofuel production technology, support policies, energy infrastructure, and economic and environmental indicators, were identified. Subsequently, random forest algorithms and Relief feature selection were used to analyze the data.

**Results and Findings:** The modeling showed that the random forest algorithm was able to effectively cluster supply chains with different levels of sustainability with an accuracy of 85% (AUC=0.98). Clustering indicated that indicators such as direct employment generation in rural areas, pollution reduction, energy cost reduction, and distance to processing centers had the greatest impact on promoting sustainability, while the type and amount of biofuel consumed had a lesser impact. The findings indicate that sustainable development of the agricultural supply chain requires a focus on improving production technologies, biofuel infrastructure, targeted support policies, and educational programs for farmers. While providing a new framework for integrating renewable energies into the agricultural supply chain, it can provide a basis for policy decisions and optimization strategies to achieve sustainable development in the agricultural sector of Iran and other developing countries.

**Keywords:** Biofuel, Sustainable development, Agricultural supply chain, Computational intelligence, Random forest.

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**Cite this article:** Maleki, L., Ardabili, S. and Hashemi, F. (2026). The role of biofuels in the sustainable development of the agricultural supply chain: using artificial computational intelligence methods. *Journal of Sustainable Urban & Regional Development Studies (JSURDS)*, 7(2), 292-313

## **EXTENDED ABSTRACT**

### **Introduction**

In light of growing environmental pressures and the urgent need for clean energy, biofuels have emerged as a promising solution to enhance the sustainability of agricultural supply chains. This study investigates the role of biofuels in advancing sustainable development within agricultural supply systems, with a focus on integrating computational intelligence methods to analyze multidimensional factors. The research is particularly relevant for developing countries like Iran, where agricultural sustainability is critical to economic and environmental resilience.

Sustainable development in agriculture means using natural resources in a way that meets current needs while maintaining their capacity for future generations. This type of development is based on three main pillars: preserving natural resources, increasing productivity, and social justice. The use of biofuels as part of sustainable energy strategies can play an important role in reducing the environmental impact of agriculture, reducing energy costs, and strengthening local economies. Also, the use of agricultural and livestock waste for fuel production contributes to better waste management, organic fertilizer production, and increased productivity cycles, all of which are in line with sustainable and inclusive development in agriculture (Lal and Stifand, 2009, Eschenbach, 2010). The question that arises here is that given the importance of moving towards the use of biofuels, what will be their role in the sustainability of the agricultural supply chain?

### **Methodology**

The study employs a hybrid methodological approach combining systematic review, focus group discussions, and computational modeling. First, a systematic literature review was conducted following the PRISMA guidelines, identifying 666 potential records, which were refined to 212 relevant studies. Subsequently, a focus group of 20 experts—including academics, renewable energy specialists, and agricultural supply chain professionals—was convened to identify key variables influencing sustainability. These variables included biofuel production technology, support policies, energy infrastructure, and economic and environmental indicators.

Data analysis was performed using a combination of Relief feature selection and Random Forest algorithms. Relief was used to filter the most impactful features, while Random Forest was applied for clustering and predictive modeling. Model performance was validated through calibration curves, lift analysis, and statistical metrics such as AUC, accuracy, precision, and recall.

### **Results and Findings**

The Random Forest model achieved 85% accuracy (AUC = 0.98) in clustering agricultural supply chains by sustainability level. Feature selection revealed that indicators such as direct rural employment, pollution reduction, energy cost savings, and proximity to processing centers had the most significant impact on sustainability. In

contrast, the type and quantity of biofuel consumed showed relatively lower influence. ANOVA results from the focus group analysis further emphasized the importance of biofuel production technology, supportive policies, and farmer training programs. The clustering heatmap illustrated two distinct groups of supply chains—those with higher sustainability scores were associated with better infrastructure, stronger policy support, and advanced technologies.

The results of modeling, clustering, and feature selection clearly show that policymakers and managers of agricultural chains should focus on key indicators such as job creation, pollution reduction, energy cost reduction, processing infrastructure, and government support to improve sustainability.

The findings of this study show that the research trend in recent years, especially after 2020, has been towards the use of new, high-efficiency technologies. These technologies can make a significant contribution to improving energy efficiency and increasing the acceptance of biofuels among agricultural operators. Access to biofuel infrastructure, including distribution stations and fuel conversion equipment, is another prominent challenge mentioned in the reviewed sources. Limited infrastructure, especially in developing countries, is a major obstacle to the expansion and institutionalization of biofuel use in agricultural chains. Government policies and incentives, including tax exemptions and research support, have been proposed in the reviewed literature as the main driving force in expanding the use of biofuels. The significant increase in scientific production in this field after 2020, along with the increased attention of policymakers to the issues of sustainable energy development and food security, indicates a positive interaction between academic research and executive policies in this field.

## **Conclusion**

This study confirms that biofuels can significantly contribute to the sustainable development of agricultural supply chains, provided that complementary policies, infrastructure, and technological advancements are in place. The findings suggest that policymakers should prioritize investments in biofuel infrastructure, targeted financial incentives, and educational programs for farmers. Additionally, integrating artificial intelligence and machine learning models can support data-driven decision-making and optimize sustainability strategies. The proposed framework offers a viable pathway for Iran and other developing nations to enhance agricultural sustainability through the integration of renewable energy.

The results of this study clearly show that biofuels can play a key role in promoting the sustainability of the agricultural supply chain, provided that the necessary policies and infrastructure are developed simultaneously. Analyses conducted based on machine learning models showed that economic, environmental and infrastructure indicators such as direct employment creation in rural areas, reduced pollution, reduced energy costs and access to processing centers have the greatest impact on improving the sustainability of the chains. However, variables such as the type of biofuel consumed and its consumption amount have played a lesser role compared to other parameters.

Improving farmers' awareness and skills through training and extension courses will play a significant role in accelerating the adoption of biofuel technologies. Targeted training can reduce the existing knowledge gap and increase farmers' ability to optimally utilize these technologies. Emphasis on the development of high-yield, low-emission biofuel

production technologies, especially second- and third-generation technologies, should be prioritized in research and development programs. Supporting technological innovations can help reduce production costs and increase the competitiveness of biofuels in energy markets. It is recommended that artificial intelligence-based decision support systems be designed and implemented to identify supply chains with high potential for sustainable development and to more accurately target support policies towards these chains. This can improve the effectiveness of policy interventions and accelerate the transition to sustainable supply chains.

## Declarations

**Funding:** This research is supported by the University of Mohagheh Ardabili.

**Authors' Contributions:** All authors contributed equally to the conceptualization and writing of the article. The authors approved the manuscript's content and agreed on all aspects of the work.

**Conflict of Interest:** The authors declare no conflict of interest.

**Acknowledgments:** The authors extend their gratitude to all scientific consultants who provided invaluable insights during this research.

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