

Investigating the Economic Influence of Bio-Propylene Production on Agriculture and Rural Economies

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DOI: 10.46609/IJSSER.2025.v10i04.013 URL: <https://doi.org/10.46609/IJSSER.2025.v10i04.013>

Received: 1 April 2025 / Accepted: 19 April 2025 / Published: 3 May 2025

ABSTRACT

The increasing global reliance on plastic has raised significant environmental concerns, driving the search for sustainable alternatives such as bio-based polypropylene (bio-PP). This research evaluates the economic implications of bio-PP production, particularly its influence on rural economies and agricultural sectors. By examining shifts in revenue streams, employment opportunities, and long-term economic growth, the study highlights bio-PP's potential to support sustainable development. Through its use of renewable biomass sources, bio-PP offers a viable solution to reducing dependence on fossil fuels while fostering economic resilience in agricultural communities.

Introduction

Plastics are integral to modern society, with global production exceeding 400 million metric tons in 2022, reflecting a 1.6% annual growth [1]. Polypropylene (PP), a versatile thermoplastic polymer, constitutes a significant portion of this production, finding applications across various sectors, including medical devices and automotive components. However, conventional PP production's reliance on fossil fuels and its environmental impact have spurred interest in bio-based alternatives. Bio-PP, derived from renewable biomass sources, offers the same chemical composition and material properties as traditional PP, potentially reducing environmental footprints and creating economic opportunities in agriculture and rural communities. The transition towards bio-PP presents a compelling pathway for mitigating environmental challenges while fostering economic development in rural areas dependent on agriculture.

Overview of Polypropylene (PP) and Bio-based Polypropylene (bio-PP)

Conventional PP's widespread use is attributed to its strength, flexibility, and chemical resistance, making it the second-most produced plastic globally, accounting for approximately

16% of the plastic market [2]. However, its production's heavy reliance on fossil fuels contributes to greenhouse gas emissions and resource depletion. Moreover, PP's recycling rate is alarmingly low, estimated at only 1%, exacerbating plastic waste accumulation [3]. The linear economic model of "take-make-dispose" for conventional plastics leads to significant environmental burdens, prompting a shift towards more circular and sustainable alternatives.

Bio-PP presents a sustainable alternative by utilizing renewable feedstocks such as sugarcane, corn, and other agricultural resources. The production process involves converting biomass into bioethanol, which is then transformed into bio-based propylene and subsequently polymerized into bio-PP. This approach reduces reliance on fossil fuels and lowers the carbon footprint of polymer production, aligning with global efforts to mitigate climate change and promote resource efficiency. Life Cycle Assessment (LCA) studies increasingly demonstrate the environmental benefits of bio-PP compared to its fossil-based counterpart, particularly in terms of reduced greenhouse gas emissions and lower fossil fuel consumption [7].

The environmental impact of conventional plastics, including PP, has become a critical global issue. Unsustainable production practices and inadequate waste management have led to increased plastic pollution, with microplastics and hazardous chemicals contaminating ecosystems and posing risks to human health. Transitioning to bio-based alternatives like bio-PP is crucial, as they not only reduce dependence on fossil fuels but also promote a circular economy. Biobased feedstocks are part of a renewable cycle, contrasting with the extraction and use of finite fossil fuels. Additionally, the shift to bio-based plastics can stimulate innovation in sustainable materials and processes, driving economic growth and creating new opportunities in agriculture and manufacturing. The adoption of bio-based packaging materials represents a vital step toward sustainability. Policy initiatives aimed at promoting bio-based plastics can further accelerate this transition and support the development of a more sustainable economy.

Economic Impact of the Biobased Products Industry

The biobased products industry significantly contributes to the U.S. economy, supporting employment and reducing fossil fuel consumption. In 2021, the industry contributed \$489 billion to the U.S. economy, up from \$464 billion in 2020, marking a 5.1% increase [9]. Employment in the sector decreased slightly from 4.05 million jobs in 2020 to 3.94 million in 2021, with each job supporting an estimated 1.4 additional jobs in other sectors. Biobased products also displaced approximately 10.7 million barrels of oil equivalents in 2021, contributing to environmental sustainability [10][11]. Government incentives and research funding have played a crucial role in fostering the growth of the biobased products industry, underscoring the importance of policy support for sustainable technologies.

Research Question and Objectives

Given the environmental imperative and economic potential of bio-PP, this research investigates the economic influence of bio-propylene production on agriculture and rural economies. The primary research question is: How does the production of bio-propylene from agricultural feedstocks impact revenue streams for farmers, job creation in rural areas, and long-term economic growth prospects for agricultural regions? To address this question, the research pursues the following objectives:

1. To analyze the potential revenue streams for farmers from bio-PP feedstock cultivation, considering different agricultural feedstocks and market conditions.
2. To assess the impact of crop diversification, including bio-PP feedstocks, on farm income and economic stability for agricultural households.
3. To evaluate the job creation potential in bioplastics manufacturing and agriculture related to bio-PP production in rural areas.
4. To examine the infrastructure development, including transportation and processing facilities, required to support bio-PP production in rural economies.
5. To explore the long-term economic growth prospects for rural regions resulting from the development of a bio-PP industry. This research aims to provide insights into the economic viability and sustainability of bio-PP production, informing policy decisions and investment strategies.

Environmental Concerns of Plastic Production

The production of plastics is predominantly reliant on fossil fuels, raising significant environmental issues. Approximately 99% of plastics are synthesized from petrochemicals derived from oil and natural gas [4]. The extraction and transportation of these fossil fuels are energy-intensive processes that emit substantial greenhouse gases, including carbon dioxide (CO₂) and methane (CH₄), both potent contributors to global warming. For instance, in the United States, the extraction and transport of natural gas for plastic production are estimated to generate between 12.5 to 13.5 million metric tons of CO₂-equivalent emissions annually, comparable to the emissions from nearly 3 million passenger vehicles over the same period [22]. These emissions contribute significantly to the overall carbon footprint of the plastics industry.

Furthermore, the refining and manufacturing stages of plastic production exacerbate environmental degradation. Processes such as ethylene production, a key component in plastics, emitted approximately 184 to 213 million metric tons of CO₂-equivalent globally in 2015, equating to the annual emissions of about 45 million passenger vehicles [6]. Overall, plastics generated 1.8 billion tonnes of greenhouse gas emissions in 2019, accounting for 3.4% of the

world's total emissions [5]. These emissions significantly contribute to climate change, highlighting the urgent need for sustainable alternatives to conventional, fossil fuel-based plastics. The transition to bio-based materials and circular economy practices is essential to mitigate these environmental impacts.

Economic Impacts of Bioplastics in Agriculture and Rural Economies

The burgeoning bioplastics industry, particularly the production of bio-based polypropylene (bio-PP), presents substantial economic opportunities for agriculture and rural economies. By creating new markets for agricultural products, bioplastics production offers farmers additional revenue streams and reduces reliance on traditional commodity crops. Feedstocks such as corn, sugarcane, and soybeans, commonly used in bio-PP manufacturing, can diversify farm income and enhance economic resilience in rural communities [21]. Crop diversification is increasingly recognized as a key strategy for improving the sustainability and profitability of agricultural systems. [23]

The establishment of bioplastics manufacturing facilities in rural areas can significantly stimulate job creation. In 2017, the U.S. biobased products industry supported 4.6 million American jobs, encompassing direct employment in production and indirect roles in related sectors [12]. Notably, for every biobased job, an additional 2.79 jobs were generated in other sectors, highlighting the industry's extensive economic reach. These jobs often provide stable employment opportunities in rural communities, contributing to local economic development.

Moreover, the bioplastics sector offers competitive wages, with average annual salaries around \$73,000, attracting skilled professionals such as engineers, chemists, and manufacturing experts to rural areas. This influx of skilled labor can lead to knowledge transfer and further innovation within these communities. The presence of skilled professionals also enhances the attractiveness of rural areas as places to live and work, supporting long-term economic growth.

Investments in bioplastics manufacturing also drive improvements in rural infrastructure, including transportation networks and processing facilities, thereby enhancing the overall economic competitiveness of these regions. For instance, the U.S. Department of Agriculture (USDA) invested \$9.5 million in 2022 to support the scale-up of sustainable bio product manufacturing, boosting economic development in rural America [14]. The development of robust infrastructure is essential to support the efficient production and distribution of bioplastics.

The global bioplastics market is experiencing rapid growth, with production capacity projected to increase from over 2.1 million tonnes in 2020 to 2.9 million tonnes by 2025. This expansion underscores the increasing demand for sustainable alternatives to conventional plastics,

positioning rural economies to benefit from the shift towards bio-based products. Market trends indicate a growing consumer preference for environmentally friendly products, creating new opportunities for bioplastics manufacturers and agricultural producers.

Technical Overview of Bio-Based Polypropylene (Bio-PP) Production and Agricultural Feedstocks

Bio-based polypropylene (Bio-PP) is an emerging sustainable alternative to conventional polypropylene, primarily produced from renewable agricultural feedstocks. The production process of Bio-PP involves several key stages, beginning with the sourcing and processing of biomass. Common feedstocks used in Bio-PP production include sugarcane, corn, and non-edible plant materials. These feedstocks are processed through methods such as fermentation and enzymatic hydrolysis to convert them into bio-intermediates, such as sugars. These bio-intermediates are then subjected to catalytic reactions or other chemical conversion methods to produce propylene, the monomer used in polypropylene production. Finally, the propylene is polymerized into Bio-PP, which, despite its renewable origins, retains the same chemical structure and material properties as conventional polypropylene. This ensures that Bio-PP can be used in a wide range of applications, substituting for conventional PP without compromising performance.

A prominent method for producing Bio-PP is the ethanol-to-propylene (ETP) process, which uses bioethanol derived from biomass as a precursor [19]. In this process, bioethanol is converted into propylene through catalytic reactions. This method offers a significant advantage, as it utilizes renewable feedstocks and aligns with global efforts to reduce reliance on fossil fuels, contributing to a more sustainable circular economy. The ETP process has attracted significant research interest, with ongoing efforts to improve its efficiency and reduce its cost [19].

The choice of agricultural feedstock plays a crucial role in the Bio-PP production process, with sugarcane, corn, and other non-edible plant materials being the most common. Sugarcane, for instance, is a widely used feedstock, particularly in Brazil, where it is converted into ethanol for Bio-PP production. Similarly, in the United States, corn is a common feedstock for producing ethanol, which is then converted into propylene [20]. Each of these feedstocks has its own set of advantages and challenges, which influence their suitability for large-scale Bio-PP production. Factors such as land availability, water requirements, and environmental impacts must be considered when selecting the optimal feedstock.

Advantages and Challenges of Bio-PP Production Compared to Conventional PP

The production of Bio-PP offers several notable advantages over conventional polypropylene, particularly in terms of environmental impact. One of the key benefits is the significant reduction

in greenhouse gas emissions [8]. Studies have shown that using renewable feedstocks, such as sugarcane and corn, can substantially lower carbon emissions compared to the production of traditional polypropylene, which relies on fossil fuels. In fact, the global bio-based polypropylene market is expected to grow significantly, with projections indicating a rise from USD 255.8 million in 2024 to USD 3,824.1 million by 2032 [16][17]. This growth reflects not only the increasing market confidence in Bio-PP but also its environmental advantages in terms of reducing carbon footprints in industrial production. The environmental benefits of Bio-PP can be further enhanced through the implementation of sustainable agricultural practices and efficient production processes.

In addition to reducing greenhouse gas emissions, Bio-PP production also decreases reliance on fossil fuels. By replacing petroleum-based feedstocks with renewable plant-based alternatives, Bio-PP represents a step towards a more sustainable future. For example, the sugarcane segment accounted for around 60% of the Bio-PP market revenue in 2023, underscoring the growing dependence on agricultural feedstocks in the production of sustainable plastics [18]. This change towards renewable resources can contribute to energy security and reduce the environmental risks associated with fossil fuel extraction and transportation.

Furthermore, under specific conditions, Bio-PP may also be biodegradable, offering additional environmental benefits when managed in industrial composting facilities. The biodegradability of Bio-PP depends on the specific type of biopolymer used and the environmental conditions in the composting facility. Further research is needed to develop Bio-PP materials with enhanced biodegradability properties.

However, the production of Bio-PP is not without its challenges. One of the primary obstacles is the higher production cost. Bio-PP is estimated to be about 15% more expensive than conventional polypropylene, primarily due to the costs associated with sourcing and processing biomass feedstocks. These feedstocks often represent 60–70% of the total production cost, and variability in feedstock quality, market volatility, and the infrastructure required for converting agricultural materials into bio-intermediates all contribute to the higher costs. As a result, maintaining a reliable supply of affordable, high-quality feedstock is essential for Bio-PP to remain competitive with traditional polypropylene. Strategies for reducing feedstock costs include improving agricultural yields, optimizing logistics, and developing more efficient conversion processes.

Another challenge is the technological limitations in the current production processes. Although Bio-PP production technologies are advancing, further improvements are needed to enhance efficiency and scalability. Significant research and development efforts are focused on optimizing the conversion processes, such as enzyme and metabolic engineering, to improve the

efficiency of converting biomass into bioethanol and ultimately into propylene. Addressing these technological hurdles is essential not only for reducing production costs but also for ensuring the long-term sustainability of the Bio-PP industry. Innovations in catalysis and bioprocessing technologies can play a crucial role in overcoming these challenges.

Economic, Agricultural, and Infrastructure Impacts of Bio-PP Feedstock Cultivation

The cultivation of feedstocks for Bio-PP production has the potential to offer significant economic and agricultural benefits. By diversifying crop portfolios, farmers can gain access to new revenue streams and mitigate the financial risks associated with market volatility. For instance, the production of Bio-PP feedstocks can help farmers reduce their reliance on traditional commodity crops, providing an opportunity to tap into a growing market for bioplastics. This diversification can improve farm income and contribute to greater economic stability in rural areas. Government policies that support crop diversification and promote the adoption of sustainable agricultural practices can further enhance these benefits.

In addition to economic benefits, the cultivation of Bio-PP feedstocks can promote more sustainable agricultural practices. Crop diversification, which includes the incorporation of Bio-PP feedstocks, can improve soil health, reduce the need for synthetic inputs, and enhance overall sustainability. For example, planting bio-PP feedstocks such as non-edible plants can provide ecological benefits by improving biodiversity and reducing the environmental impact of monoculture farming. Sustainable agricultural practices, such as reduced tillage and cover cropping, can further enhance the environmental benefits of Bio-PP feedstock cultivation.

The decision to switch from traditional crops to Bio-PP feedstocks involves both costs and benefits. Farmers must consider factors such as the initial investment in new equipment and infrastructure, the learning curve associated with new farming techniques, and the potential market risks associated with bio-based feedstock production. However, the potential benefits, such as access to new markets and enhanced environmental sustainability, may outweigh these initial challenges for many farmers. Government subsidies and long-term contracts with bioplastics manufacturers can help mitigate these risks and encourage farmers to adopt Bio-PP feedstock cultivation.

Since feedstock costs comprise a significant portion of Bio-PP production costs, ensuring access to affordable, reliable feedstocks is critical for maintaining the competitiveness of the Bio-PP industry. The development of efficient supply chains and the establishment of regional processing facilities can help reduce transportation costs and improve the availability of feedstocks.

The development of the Bio-PP industry also has the potential to create numerous job opportunities in both agriculture and manufacturing. As bioplastics manufacturing facilities are established in rural areas, they generate direct employment opportunities for local residents. These jobs include roles in feedstock cultivation, processing, and manufacturing. Additionally, indirect jobs are created in related sectors such as transportation, logistics, and facility maintenance. The multiplier effect of bioplastics manufacturing can significantly boost rural economies by increasing household incomes and fostering local economic growth [13]. Investments in education and training can help ensure that rural communities have the skilled workforce needed to support the growth of the Bio-PP industry.

Investments in infrastructure are another critical aspect of developing the Bio-PP industry. For instance, transportation networks must be improved to efficiently move feedstocks from farms to processing facilities. Similarly, advanced processing plants capable of converting biomass into bio-intermediates and ultimately into Bio-PP are essential for scaling up production. These infrastructure improvements not only support the bioplastics industry but also benefit other sectors by enhancing the overall economic competitiveness of rural regions. Government funding and private investment are needed to support the development of robust infrastructure for the Bio-PP industry.

Policy Implications and Recommendations

To fully realize the economic and environmental potential of Bio-PP, policymakers must take proactive steps to support its development. Based on the analysis presented in this paper, we recommend the following:

1. *Incentivize Research and Development: Governments should allocate funding for research aimed at improving the efficiency and scalability of Bio-PP production technologies. This includes investments in enzyme engineering, catalytic processes, and advanced manufacturing techniques.*
2. *Provide Financial Support: Offer tax credits to farmers who dedicate a portion of their land to cultivating feedstocks for Bio-PP. Additionally, provide low-interest loans to companies investing in bioplastics manufacturing facilities in rural areas.*
3. *Develop Infrastructure: Invest in improving transportation networks and processing facilities in rural regions that have the potential to become hubs for Bio-PP production.*
4. *Promote Public Awareness: Launch public awareness campaigns to highlight the environmental benefits of Bio-PP and other bioplastics.*

5. Establish Regulatory Frameworks: *Develop clear standards for the production, use, and disposal of bioplastics.*

These policy recommendations are designed to create a supportive environment for the growth of the Bio-PP industry, encouraging economic development in rural areas while promoting sustainability.

Future Prospects for Bio-Based Polypropylene

The future of Bio-PP looks promising as global demand for sustainable materials continues to rise. Advances in technology are expected to drive down production costs, making Bio-PP more competitive with conventional polypropylene. Additionally, growing consumer awareness about environmental issues is likely to increase demand for bio-based products across various industries.

The agricultural sector stands to benefit significantly from this transition. By cultivating feedstocks for Bio-PP production, farmers can diversify their income sources while contributing to global sustainability goals. Rural communities will also experience economic growth through job creation and infrastructure development associated with bioplastics manufacturing.

On a global scale, the adoption of Bio-PP could play a pivotal role in combating climate change by reducing greenhouse gas emissions from plastic production. As countries strive to meet international climate targets, bio-based alternatives like Bio-PP will become increasingly important components of sustainable development strategies.

Final review

The production of bio-based polypropylene represents a transformative opportunity for both agriculture and rural economies while addressing pressing environmental challenges associated with conventional plastics. By leveraging renewable feedstocks such as sugarcane and corn, Bio-PP offers a sustainable alternative that reduces greenhouse gas emissions and promotes resource efficiency.

However, realizing the full potential of Bio-PP requires overcoming challenges such as high production costs, technological limitations, and market acceptance barriers. Policymakers, industry stakeholders, and researchers must work to address these issues through targeted investments in research, infrastructure development, and public awareness campaigns.

As global demand for sustainable materials grows, the adoption of Bio-PP has the potential to drive economic growth in rural areas while contributing to broader environmental goals. By fostering innovation in bioplastics production and supporting agricultural communities, Bio-PP

offers a pathway toward a more sustainable future. Further research and development efforts are needed to optimize Bio-PP production processes, reduce costs, and enhance its environmental performance.

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