Critical Review: Strategic Supply and Transportation Planning of a Supply Chain for Agricultural Biomass to Hydrogen and Syngas

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SUMMARY

In the evolving landscape of renewable energy, the management of agricultural biomass supply chains has emerged as a critical success factor for sustainable fuel production, this article presents a critical review of the research conducted by Nugroho and Zhu (2024) regarding the strategic supply and transportation planning of an agricultural biomass supply chain for hydrogen and syngas production. The primary study addresses a significant gap in renewable energy management by proposing a bi-level optimization framework that utilizes Stackelberg game concepts to model non-cooperative interactions between biofuel producers and biomass suppliers. The review identifies several methodological strengths, including the integration of process-level material balances with supply chain decisions and the use of mixed-integer nonlinear programming (MINLP) to handle realistic cost components like holding and production costs. However, the analysis also highlights critical limitations, such as restrictive behavioral assumptions regarding risk neutrality and perfect information, which may not reflect real-world opportunistic conduct. Furthermore, the generalizability of the findings is constrained by a narrow focus on an Indonesian case study and a dual-sourcing strategy that may face scalability issues in larger regional networks. Ultimately, while the reviewed work is deemed an incremental rather than landmark contribution, it offers valuable structured recommendations for practitioners and project developers building biomass supply chains in agricultural regions.

Keywords: *Critical Review, Method, Biomass, Supply Chain, Transportation.*

I. INTRODUCTION

In the evolving landscape of renewable energy, the management of agricultural biomass supply chains has emerged as a critical success factor for sustainable fuel production (Hong et al., 2016; Liang et al., 2016). A significant challenge in this field is the optimization of logistics, as the costs associated with the supply of biomass can account for as much as 90% of the total expenditure in biofuel production. This high cost underscores the need for robust strategic planning to coordinate interactions between various stakeholders, including farmers, transporters, and producers (Nugroho & Zhu, 2024).

The research (Nugroho & Zhu, 2024) addresses this gap by proposing a bi-level optimization framework specifically designed for the strategic supply and transportation planning of agricultural biomass for hydrogen and syngas production. Unlike previous studies that often assumed centralized decision-making and cooperative behavior among agents, this primary study utilizes Stackelberg game concepts to model non-cooperative interactions. This methodological innovation allows for a more realistic simulation of strategic interactions between independent agents within the supply chain.

Furthermore, the framework integrates supply chain optimization with detailed process models to ascertain energy and material balances, providing a comprehensive view of the biomass conversion pathway. To solve this complex bi-level problem, the authors employ mixed-integer nonlinear programming (MINLP) alongside piecewise linear relaxation (PLR) and branch-and-reduce algorithms. This article provides a systematic critical review of the work by Nugroho and Zhu. Rather than providing a purely descriptive summary, this review evaluates the methodological validity, theoretical robustness, and practical generalizability of the proposed framework to identify significant research gaps and contributions to the field of public administration and renewable energy management.

II. METHOD

This study employs a critical literature review methodology (Anh, 2024; Franzke et al., 2022; Gan et al., 2026; Henry & Liu, 2026; Karmakar et al., 2026; Mêda et al., 2026; Norman et al., 2025) to systematically evaluate, synthesize, and critique the existing body of knowledge regarding public administration. Unlike a traditional descriptive review, a critical review goes beyond merely summarizing past research; it actively evaluates the methodological rigor, theoretical underpinnings, and empirical findings of the selected literature to identify contradictions, inconsistencies, and significant research gaps. This approach allows for the development of new conceptual frameworks and perspectives within the field of public administration.

The core of this methodology is the critical appraisal of the selected literature. Each included article was systematically analyzed using a standardized data extraction protocol. The assessment focused on several critical dimensions:

a. Methodological Validity: Evaluating the appropriateness of the research designs, sample sizes, and data analysis techniques used in prior studies.
b. Theoretical Frameworks: Examining the robustness of the theories underpinning the research.
c. Contributions and Limitations: Identifying what each study adds to the field and, crucially, recognizing their explicitly stated or implicit limitations.
d. Bias and Objectivity: Assessing potential biases in data interpretation or author conclusions.

III. RESULTS AND DISCUSSIONS

3.1 Strengths and Contributions

3.1.1 Significant Problem Formulation

The study (Nugroho & Zhu, 2024) tackles a well-researched and commercially important issue in the field of renewable energy. The authors accurately point out that logistics costs for the supply of biomass account for a significant amount of the costs associated with producing biofuel, possibly accounting for up to 90% of the overall cost of feedstock. The article closes a significant vacuum in the literature by concentrating on supply chain coordination between farmers, transporters, and producers. The practical relevance of the research is demonstrated by the realization that biomass availability is a crucial success factor in renewable energy systems, especially within the European Union.

A workable compromise between single and multiple sourcing approaches is provided by the dual sourcing strategy suggested in this work. With this strategy, biofuel producers can exercise significant purchasing power while maintaining supply security. Inter-fuel and inter-biomass substitutability are theoretically justified by the authors, who also demonstrate how these factors can be measured and managed to increase supply chain resilience.

3.1.2 Methodological Innovation

A significant methodological addition is the use of bi-level optimization to simulate non-cooperative connections in the supply chain. This work directly models the strategic interactions between independent agents, in contrast to earlier research that assumed centralized decision-making and cooperative behavior. Although the authors admit that other researcher (Bai et al., 2012) developed notions that are similar to theirs, they make substantial improvements by include holding costs, production costs, and variable biomass yields. The model becomes more practically applicable to real farm operations by including these realistic cost components.

A technical improvement over earlier methods is the solution methodology that combines branch-and-reduce algorithms with piecewise linear relaxation (PLR). The authors show that their approach handles larger-scale supply networks more effectively while yielding accuracy comparable to other methods (Yue et al., 2014). When expanding the strategy to regional or national biomass supply networks, this is very crucial.

3.1.3 Comprehensive System Integration

This approach is unique in that it integrates supply chain optimization with process models. To ascertain the energy and material balances for the biomass conversion pathway to hydrogen and syngas, the authors (Nugroho & Zhu, 2024) create a thorough process flow diagram. Because of this integration, the model can take into consideration how feedstock requirements and production costs are impacted by conversion efficiency and product specifications. The precise management of technological realism is demonstrated by the explicit modeling of biomass commonality (α) and process commonality (β) factors.

The Indonesian case study, which makes use of local agricultural data and illustrates the framework's usefulness, offers insightful background. The authors' biomass cost and yield characteristics (Nugroho & Zhu, 2024) are based on regional agricultural practices and real data from the Indonesian Statistics Bureau, which strengthens the validity of their numerical findings.

3.1.4 Equilibrium and Fair Profit Distribution

A practical issue that is frequently disregarded in optimization studies is the paper's clear discussion of equitable profit allocation between suppliers and the biofuel manufacturer. The findings show that the model finds the best order allocations so that suppliers and the biofuel manufacturer split profits equally. Stakeholder support for such arrangements may be facilitated by taking equitable arrangements into account, which is essential for the actual execution of supply contracts.

3.2 Significant Limitations and Weaknesses

3.2.1 Restrictive Behavioral Assumptions

The assumption that all supply chain players are risk-neutral and don't engage in opportunistic conduct is a basic weakness that the authors (Nugroho & Zhu, 2024) themselves admit. Empirical data indicates that agricultural suppliers often act strategically, which makes this premise dubious. Although "biomass suppliers, for instance, may store biomass and sell it at a higher price to external buyers," the authors (Nugroho & Zhu, 2024) point out that their model is unable to account for this kind of behavior. This indicates a significant discrepancy between the supply chain dynamics of the real world and the theoretical model.

It is likewise impractical to assume that all players have perfect knowledge. Information asymmetries between farmers, transporters, and biofuel manufacturers are important in real agricultural supply chains and have a direct impact on strategic decision-making. The results' relevance to real contract negotiations is limited by the incapacity to simulate these knowledge gaps.

3.2.2 Limited Consideration of External Uncertainties

Three harvest yield scenarios (low, medium, and high) with equal probabilities are included in the model; nevertheless, the handling of uncertainty is somewhat basic. The optimal solution's performance under different probability distributions or when there are yield correlations amongst providers is not sufficiently discussed in the paper. Given that both crops are subject to similar meteorological and economic influences, it is dubious to assume that farmers of maize stover and rice straw have independent yield uncertainty.

Although the authors (Nugroho & Zhu, 2024) admit that supply chains are susceptible to external influences such as fuel cartels, government laws, and public acceptance of biomass for biofuels, these aspects are only briefly discussed. The economic viability of biomass-to-hydrogen plants is greatly impacted by policy uncertainties, carbon pricing methods, and changes in renewable energy subsidies, all of which are not taken into account by the model. The inability to consider regulatory possibilities is a significant constraint for a study that focuses on strategic planning.

3.2.3 Scale and Generalizability Issues

The case study only looks at one Indonesian product conversion pathway, from rice straw and maize stover to hydrogen and syngas. Although this offers useful specificity, it calls into doubt the generalizability of the concept. The framework's performance with different biomass mixtures, different geographical areas with different transportation infrastructures, or different end-use applications is not examined in the article. The transportation cost structure (US$300 per day for a 20-ton truck) is unique to Indonesian settings and might not apply to other areas with varying labor prices or levels of infrastructural development.

The model's application is further limited by the restriction to two suppliers (dual sourcing). Although the authors provide theoretical justification for this decision, many biomass supply networks in the real world have more than two providers. It is unclear whether the solution approach is still computationally tractable since the MINLP formulation's scalability to issues involving more than two suppliers is not shown.

3.2.4 Technology and Product Assumptions

For biomass conversion, the presumption of fixed technology platforms is restrictive. In reality, biomass conversion technologies are always changing, and businesses have to decide on sourcing strategy, plant capacity, and technology at the same time. The process flow diagram is treated as predetermined in the article, which might not accurately represent real-world strategic planning situations where the choice of technology is an endogenous decision variable. The specifications for the gasification process (1100 K temperature, 1 bar pressure) represent current technology, however they do not permit technical advancement or replacement with different conversion techniques.

A Pearson correlation of 99.83% is utilized to support the model's assumption that rice straw and maize stover are perfectly interchangeable after taking the α parameter into account. Conversion efficiency and product quality are, however, greatly impacted by feed quality attributes other than energy content, such as ash composition, sulfur level, or particle size distribution. Important quality control issues may be hidden if biomass heterogeneity is reduced to a single substitutability metric.

3.2.5 Computational and Mathematical Concerns

Although the branch-and-reduce approach with piecewise linear relaxation is an improvement, there is little proof of its computing effectiveness on more complex problems in the study. For the case study, the model statistics reveal just two discrete variables and fifty-two block variables, indicating a comparatively small problem size. This method's scalability to actual regional supply networks with hundreds of possible providers is not proven.

By using Karush Kuhn Tucker (KKT) conditions to reformulate the bi-level problem into a single-level mixed-integer nonlinear programming (MINLP), significant mathematical constraints are introduced that could rule out workable solutions to the original problem. Although the authors state that criteria are "necessary and sufficient to locate the inner problem optimal relaxed integer solution," solutions where the lower-level issue is non-convex may be excluded by this reformulation technique. A more thorough explanation of when this reformulation is appropriate and the implications for solution quality that result from possible constraint exclusions will improve the study.

3.2.6 Limited Validation and Sensitivity Analysis

The model finds the best costs and manufacturing volumes, according to the paper's results, however there is no validation against real supply chain data. Although the case study employs reasonable parameter settings, the results are not compared to actual biomass supply chain outcomes. Sensitivity analysis is restricted to analyzing the impact of product substitutability degrees (high versus low), despite being highlighted as crucial in the conclusions. Critical factors including demand projections, yield volatility, storage costs, and transportation costs are not systematically sensitivity analyzed in the work. This kind of examination would increase trust in the resilience of the model.

The suggested dual sourcing solution's profitability and supply dependability are not contrasted with those of other sourcing approaches (single sourcing, three-supplier systems, or market-based procurement) in this article. Although the authors make a theoretical case for dual sourcing, their recommendations would be strengthened by an empirical comparison with alternatives.

3.3 Literature Positioning and Gaps

3.3.1 Relationship to Existing Work

The authors (Nugroho & Zhu, 2024) adequately place their writing in relation to a number of important literary movements. By modeling competitive interactions rather than fully coordinated supply networks where all players collaborate, they set themselves apart from previous research (You et al., 2011). Although the research may benefit from a more thorough explanation of why competitive models are more realistic in emerging biomass markets where longterm ties may not yet be created, this is a significant distinction.

The authors of the well-developed comparison with previous research (Yue & You, 2014) explain how their model incorporates farmers' profit maximization explicitly, takes into account dual suppliers of different quality, and incorporates multi-period planning. It would be beneficial for the paper to address when previous research (You et al., 2011) coordinated strategy could be better (such in integrated agricultural-energy cooperatives) and under which governance structures either technique would be applicable.

3.3.2 Knowledge Gaps Not Addressed

The study (Nugroho & Zhu, 2024) points out knowledge gaps in the areas of supply chain coordination, sensitivity to changes in biomass availability, and analytical techniques for evaluating crop compatibility, although a number of significant gaps are still unfilled. First, although acknowledged, the relationship between competing biomass uses (food, feed, fiber) and biomass availability for renewable energy is not modeled. Although the research makes the assumption that farmers can freely divide their land between rice, corn, and other crops, actual land-use options are limited by existing land tenure patterns, crop rotation restrictions, and regulatory limitations.

Second, the study doesn't discuss how supply chain choices influence or are influenced by lifecycle emissions and carbon accounting. In carbon-constrained futures, the supply chain must provide quantifiable carbon benefits for the production of hydrogen and syngas through biomass gasification to be economically feasible. Carbon accounting and the impact of supply chain design on lifecycle emissions are not included in the model.

Third, the treatment of storage and inventory management is minimal. Real biomass supply chains require sophisticated storage infrastructure and inventory management to mitigate supply seasonality (particularly for agricultural residues that are harvested once or twice annually). The model does not endogenously determine optimal storage locations, capacities, or inventory policies.

3.4 Empirical and Practical Considerations

3.4.1 Data Requirements and Availability

The model needs a lot of information about market prices, transportation networks, yield distributions, and production costs at the farm level. Although the authors offer these for their Indonesian case study, the publication does not go into great detail about the difficulties in gathering data that practitioners might encounter when using this framework in other areas. The dearth of trustworthy agricultural information in many developing nations makes it difficult to parametrize such models. Guidelines on data requirements and sources that researchers and practitioners should look for would improve the study.

3.4.2 Implementation Challenges

The report does not address the contractual, organizational, and behavioral issues that arise when moving from an optimum solution to actual implementation. The paper does not examine how contract terms derived from optimization models translate into legally binding agreements or how disagreements over quality assessment and yield realization would be settled, although the authors note that supply contracts should contain information about quality standards, prices, and delivery schedules with flexibility.

The model makes the assumption that producers, farmers, and transporters can quickly put the best choices into practice. The static optimization approach does not account for the time and money needed for organizational changes, infrastructure expenditures, and capacity development.

3.4.3 Specificity of Regional Context

Although very specialized, the Indonesian case study is valuable. The abundance of biomass, very low labor costs in agriculture, and particular government backing for renewable energy make Indonesia particularly advantageous. The findings might not apply to industrialized nations with more expensive labor or areas with fewer biomass resources. Parametric analysis examining how solutions vary with geographical factors (land costs, labor costs, transportation infrastructure, biomass productivity) would be beneficial for the paper.

3.5 Technical Quality Assessment

3.5.1 Mathematical Rigor

With precise nomenclature and clearly defined constraint sets, the mathematical formulation is generally sound. The sequential decision-making of suppliers and the biofuel producer is suitably captured by the bi-level formulation. The piecewise linear relaxation technique and the addition of binary variables for yield scenarios are suitable methods to deal with non-convexity.

Some technical details, nevertheless, might be made clearer. The transformation from non-convex terms (signomial-forms) through logarithmic substitution and discretization is presented in the work, although theoretical error bounds for the piecewise linear approximation are not given. It would be beneficial for practitioners employing this technique to comprehend the accuracy reduction resulting from discretization. The relative optimality gap for the case study is 0.1%, according to the report, but it doesn't explain how this gap was determined or what it means for the quality of the solution.

3.5.2 Verification of Solution Method

The authors (Nugroho & Zhu, 2024) only offer a partial proof sketch for their theorem, which states that "Solution of the lower bound (LB) is always lower than the upper bound (UB)". The technical presentation would be strengthened by a comprehensive demonstration that the algorithm's convergence properties are valid. The algorithm's practical performance would also be demonstrated by comparing solution quality metrics (computation time, gap size, iterations required) across problems of different sizes.

3.5.3 Presentation of Numerical Results

The presentation of numerical results could be improved. Tables 1 and 2 provide capacity and profit-sharing information, but the paper lacks clear interpretation of sensitivity to key parameters. For instance, how sensitive is the optimal dual sourcing strategy to changes in transportation costs, which constitute a major cost component? How robust is the equal profit distribution to variations in biomass yield uncertainty?

Table 1. Capacity and profit sharing at higher degree of biomass substitutability.

Component	Higher degree of inter-fuel substitution		
	Capacity	Profit (x10^4)	Price/ton
S1	50,500	4.06E + 04	81.72
S2	39,500	3.56E + 04	102
H2	8005	4.85E + 04	1739
Syngas	8005	4.85E + 04	1371

Table 2. Capacity and profit sharing at lower degree of biomass substitutability

Component	Higher degree of inter-fuel substitution		
	Capacity	Profit (x10^4)	Price/ton
S1	50,500	8.86E + 04	120.72
S2	39,500	8.51E + 04	603
H2	8005	8.91E + 04	1739.9
Syngas	8005	8.91E + 04	1371.9

3.6 Significance and Impact Assessment

3.6.1 Field Contribution

This paper makes meaningful contributions to supply chain optimization in the renewable energy sector by: (1) explicitly modeling competitive supplier interactions rather than assuming cooperation; (2) integrating process-level and supply chain-level decisions; (3) providing practical guidance on dual sourcing and profit sharing; and (4) developing solution methods suitable for non-convex MINLP problems in supply chain contexts.

However, the impact is somewhat limited by the narrow focus on a single biomass conversion pathway in a single region. The findings about dual sourcing strategy and fair profit distribution are interesting but not entirely novel, as the authors build explicitly on prior work by previous researchers (Nugroho & Zhu, 2019) on rice straw and cooking oil sourcing.

3.6.2 Relevance to Practitioners

This article (Nugroho & Zhu, 2024) provides a methodical approach to sourcing choices for biomass project developers and supply chain managers in areas with resources of maize stover and rice straw. The case study shows how resilience can be maintained while sustaining competitive pressure by keeping a primary supplier who receives roughly 56% of orders and a backup supplier who receives 44%. If empirically verified, this advice may enhance supply chain stability in emerging biofuel sectors. The article (Nugroho & Zhu, 2024) does not, however, offer much advice on how to put these sourcing techniques into reality or how to adjust the strategy when real supply chain conditions differ from model assumptions.

3.7 Presentation Quality

3.7.1 Clarity and Organization

The problem motivation, literature review, problem formulation, solution techniques, case study, and results are all logically presented in this generally well-structured paper. The paper (Nugroho & Zhu, 2024) is somewhat dense due to the significant use of equations and mathematical language, which is important for rigor. The technological environment is successfully illustrated by the addition of material balances and process flow diagrams (Figures 1-2 and Table 3).

Table 3. Material Balances of H_2/Syngas Platform

Stream No:	Mass Flow (10^3 kg/day)	Temperature (K)	Pressure (bar)
1	2667	298.15	1
2	2222	363.15	1
3	744	422.15	128
4	4000	473.15	1.98
5	444	393.15	1.98
6	114	323	26.62
7	3823	1573.15	26.62
8	3823	1573.15	27.62
9	4000	476.15	26.62
10	1502	313	24.82
11	3867	476.15	25.93
12	550	463.15	10
13	4417	513.15	24.8
14	2961.9	335.15	22.75
15	180	335.2	26.6
16	2961.9	335.15	22.75
17	2961.9	334.15	22.75
18	2961.9	334.15	22.75
19	519.5	334.15	22.75
20	2442.4	334.15	22.75
21	519.5	334.15	22.75
22	519.5	298.15	15

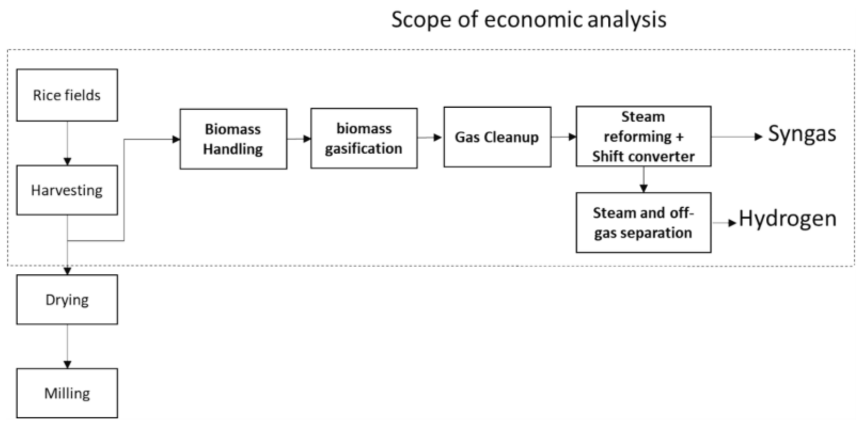

Figure 1. Technology Platforms of Biomass to Biofuels Conversion

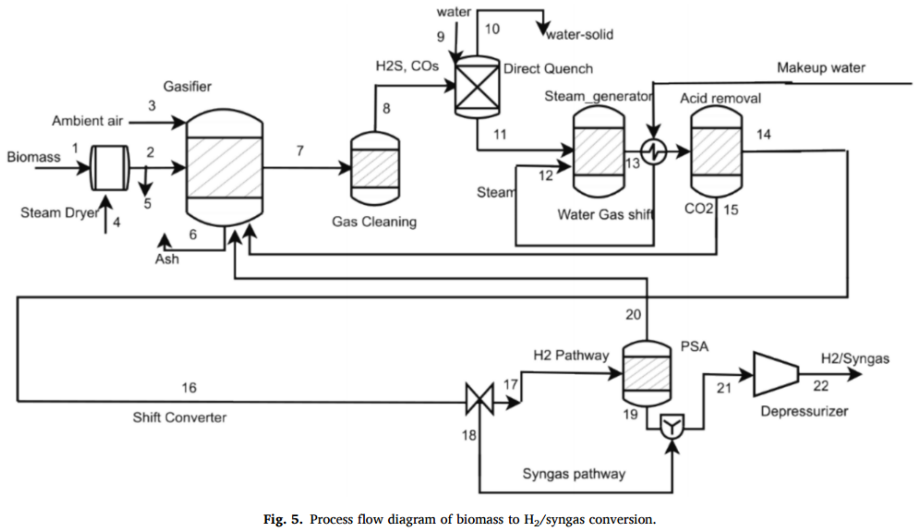

Figure 2. Process Flow Diagram of Biomass to H_2/Syngas Conversion

3.7.2 Areas for Improvement

For better accessibility, several portions may be made simpler. In order to allow the main paper to concentrate on insights and ramifications, the solution technique section (Section 5) contains a great deal of mathematical material on piecewise linear relaxation and branch-and-reduce algorithms that would be better given as a separate technical appendix. Although useful, the nomenclature part may be arranged more logically (possibly by combining sets, parameters, and decision variables). There are numerous grammatical and typographical errors throughout. The "CRediT authorship contribution statement" formatting, for instance, indicates a submitted version as opposed to a published one. Before publishing, the paper would benefit from final copyediting.

IV. CONCLUSION

A current and significant issue in renewable energy is addressed in the paper that work on strategic supply and transportation planning for agricultural biomass to hydrogen and syngas generation. The integration with process models shows advanced system thinking, and the bi-level optimization framework accurately captures competitive supplier interactions. The case study shows how the framework can be applied to a practical issue using real agricultural data.

Although somewhat incremental, the main contributions, showcasing equal profit distribution mechanisms, optimal dual sourcing techniques, and solutions for non-convex MINLP issues in supply chain contexts, are significant. This cannot be considered a landmark contribution because to the substantial limitations with regard to behavioral assumptions, uncertainty treatment, and empirical validation. However, our work offers useful organized recommendations for strategic sourcing and transportation options for practitioners building biomass supply chains for sustainable hydrogen and syngas production, especially in agricultural regions like Indonesia.

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