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Optimizing Profit and Reducing Waste in Small-Scale Coconut Oil Industry: A Goal Programming Model

Syamsul Anwar[1], Meilizar[2*]

1 Department of Agro-Industrial Engineering, Politeknik ATI Padang, Padang, West Sumatera, Indonesia
2 Department of Agro-Industrial Logistics Management, Politeknik ATI Padang, Padang, West Sumatera, Indonesia

* E-mail: meilizar@poltekatipdg.ac.id

ABSTRACT

The small-scale coconut oil agro-industry supports rural economic development but faces key challenges such as fragmented processing, underutilized biomass waste, and limited integration with circular economy practices. This study proposes a multi-period goal programming model to optimize an integrated coconut processing system by balancing profit maximization, input supply stability, waste minimization, and inventory control in line with circular economy principles. The model optimizes total profit while minimizing deviations from coconut input targets, reducing residual waste such as coconut shells and pulp, which are further processed into charcoal and coconut flour, and controlling excess inventory of unprocessed coconut shells over multiple periods. By explicitly modeling trade-offs among competing objectives, the framework serves as a decision-making tool for planning circular production systems in small-scale coconut oil industries in rural areas. The model is applied to a small-scale coconut oil supply chain comprising three oil units, one charcoal unit, and one flour unit, subject to constraints on processing capacity, conversion ratios, and minimum target levels. Results show that the model successfully achieves profitability and resource efficiency through optimal input allocation and waste utilization, with no deviations from input and waste targets, demonstrating its effectiveness in aligning operational and sustainability goals. This approach offers practical insights for effective resource management by guiding input planning, processing operations, and waste conversion in small-scale agro-industrial systems.

KEYWORDS: Coconut oil industry; goal programming; multi-period planning; small-scale agro-industries; waste valorization

INTRODUCTION

Coconut is a national strategic commodity that plays a vital role in promoting economic development, particularly in rural areas. Its primary products—coconut oil, shell charcoal, and dreg flour—have high economic value, and its biomass waste holds significant potential for sustainable utilization (Naik *et al.*, 2015; Panjaitan, 2021). Along with the increasing push for the implementation of a circular economy, the development of a coconut agro-industry that integrates primary processing and waste utilization is an urgent need to support resource efficiency and increase added value (Azizan & Asyraf, 2024; Elfahmi *et al.*, 2024; Haslenda & Jamaludin, 2011; Vieira *et al.*, 2024).

Field observations and previous studies indicate that Padang Pariaman Regency—the largest coconut-producing area in West Sumatera Province—faces several challenges in its coconut processing system (Meilizar *et al.* 2021). Currently, the processing practices are still fragmented and lack integration, resulting in suboptimal utilization of biomass waste such as coconut shells and pulp (Karouw *et al.*, 2019; Ulia *et al.*, 2024). Other challenges include harvest fluctuations, limited processing capacity, and a lack of integration between primary processing and waste valorization, which collectively contribute to low supply chain efficiency and limited support for circular economy adoption (Doe *et al.*, 2023; Muriuki *et al.*, 2024; Vimal *et al.*, 2019).

To address these challenges, this study develops a multi-period optimization model based on a goal programming approach that integrates primary coconut processing with waste management. This model enables the simultaneous optimization of economic goals (e.g., profit maximization) and environmental goals (e.g., waste minimization), an approach that has proven effective in other agro-industrial systems (Petridis *et al.*, 2018; Setiawan *et al.*, 2019; Silva *et al.*, 2019). In the context of coconut, the integration of economic and ecological functions is essential in designing production strategies that are adaptive to resource and market dynamics (Gagliardi *et al.*, 2022; Gunawan *et al.*, 2025).

Furthermore, this study contributes to the literature by incorporating key operational aspects, including facility activation, waste inventory management, and biomass conversion into value-added products such as charcoal and coconut flour (Limpianchob, 2017; Maillé & Frayret, 2016; Yulvianti, *et al.*, 2015). It also builds upon a broader research agenda on supply chain optimization using coordination-based models, previously developed for commodities such as gambier (Anwar *et al.*, 2025). Thus, this work offers both practical decision-making insights for coconut agro-industries in Padang Pariaman and scientific contributions toward the application of goal programming approaches in tropical agro-industry systems.

The remainder of this paper is organized as follows. The Methodology section presents the research design, sampling approach, data collection techniques, and analytical methods. The Results and Discussion section covers model development, computational results, and analysis. Finally, the Conclusion section summarizes key findings, highlights both practical and scientific contributions, and outlines directions for future research.

METHODOLOGY

This study employs a quantitative approach based on mathematical optimization modeling to support decision-making in sustainable coconut agro-industry systems with integrated waste utilization.

Research Design

This study employs a quantitative approach based on optimization modeling to support decision-making in a sustainable coconut agro-industry with integrated waste utilization. The research adopts a case study strategy with an exploratory and descriptive framework to develop and evaluate a multi-period goal programming model. The model integrates primary coconut processing and biomass waste utilization to balance profitability, input stability, waste minimization, and inventory control.

Population and Sample

The population of this study consists of small-scale coconut oil processing units located in Padang Pariaman Regency, West Sumatera, Indonesia. Several representative facilities (units) were observed to capture operational diversity. The selected sample reflects the dominant type of local operation and serves as the basis for a generalized modeling framework for integrated coconut processing with waste valorization.

Data Collection Techniques

Data were collected through field observations at coconut production sites, informal interviews with local processors, and an extensive literature review. Technical data concerning production capacity, conversion ratios, and waste generation were drawn from both primary sources and supporting references such as Gunawan *et al.* (2025), Karouw *et al.* (2019), and Vieira *et al.* (2024), ensuring realistic and context-specific modeling parameters.

Research Instruments

The optimization model was implemented using gurobipy package in a Python environment. The mathematical model includes linear and integer decision variables and accounts for multi-objective optimization via a weighted goal programming framework. Microsoft Excel was also utilized for initial data tabulation and preprocessing prior to model execution.

Data Analysis Method

The model is analyzed using a weighted goal programming approach with four key objectives: (1) maximizing total profit, (2) minimizing residual waste, (3) minimizing deviations from minimum input targets, and (4) minimizing deviations from the minimum production target of value-added products. Each objective is assigned a weight to reflect its relative importance. The model operates across multiple time periods and considers capacity, inventory dynamics, waste conversion, and facility activation. The analysis covers multiple periods and accounts for facility activation, capacity, inventory flow, and waste conversion between profitability and sustainability. The optimal solution is evaluated by examining decision variables, inventory levels, and goal deviations to generate strategic recommendations for circular production planning.

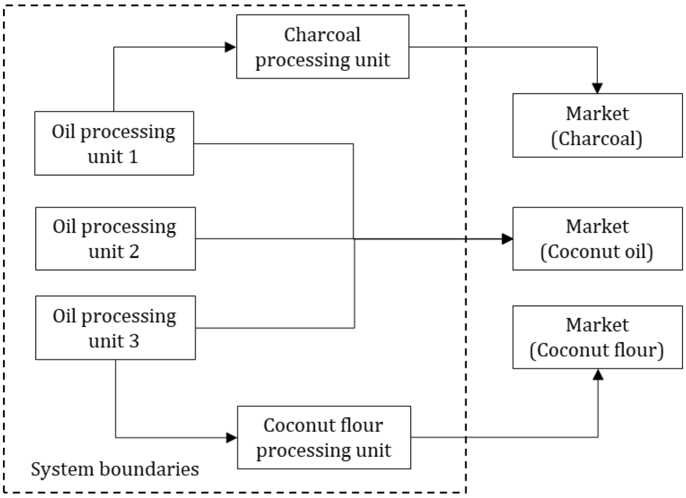
RESULTS AND DISCUSSION

Problem Definition

The coconut agro-industry in rural areas such as Padang Pariaman Regency plays a crucial role in local economies but faces challenges including limited integration between processing stages, underutilized byproducts, and inefficient waste handling, all of which lead to reduced profitability and missed opportunities for value creation. An illustration of the modeled system is presented in Figure X to provide a visual overview of the key components and their interactions.

Figure 1

System Description



As illustrated above, the modeled system consists of three oil processing units, one charcoal processing unit, and one flour processing unit, all operating at a small scale. In this study, we develop a multi-period goal programming model as a decision-support tool to optimize raw coconut allocation, production, and inventory across these small-scale coconut oil, charcoal, and flour processing units. The model addresses multiple and sometimes conflicting objectives, including maximizing profit, minimizing residual waste, and meeting production targets, while accounting for capacity limits, conversion rates, and sustainability considerations. By aligning operational planning with circular economy principles, the model offers a strategic framework for improving efficiency and sustainability in small-scale coconut processing systems.

Assumptions

To simplify model development, several assumptions are made as presented in Table 1.

Table 1
List of Assumptions

Deterministic parameters	All input data (e.g., demand, conversion ratios, capacities, costs) are assumed known and constant across periods.
Linear relationships	Input-output relations and cost-revenue functions are assumed linear to enable linear programming formulation.
Homogeneous oil processing units	All coconut oil processing units are assumed to have identical characteristics in terms of production capacity, shell storage capacity, and input-output conversion rates.
Fixed conversion rates	Each coconut weighs 1.2 kg, with 25% shell (0.208 kg) and 28.5% dreg (0.238 kg). One kg of shell converts to charcoal, and one kg of dreg converts to flour.
No product substitution	Each facility produces only one specific product and cannot be repurposed for other outputs.
Inventory	Inventory is only considered for coconut shell due to its stable nature; dreg is excluded from inventory modeling because of its perishable characteristics.
No labor or utility constraints	Labor, energy, and water are assumed to be sufficiently available and do not limit operations.

Data Source : Own considerations, 2025

Based on the assumptions defined, this subsection presents the mathematical formulation of the model.

Model Formulation
This section presents the mathematical formulation developed in this study, starting with the definition of sets and indices, followed by the model parameters, decision variables, and the core mathematical model.

Sets and Indices

I : Set of coconut oil processing units, $i \in I, I = \{1,2,3\}$

L : Set of waste types, $l \in L, l = 1$ (coconut shell), $l = 2$ (coconut pulp)

J : Set of byproducts, $j \in J,\ j = 1$ (charcoal), $j = 2$ (coconut flour)

T : Set of time periods, $t \in T, T = \{1, \dots t^{max}\}$

Parameters

$p_{l,j}$: Selling price of byproduct j from waste l ($j = 1$ in IDR/kg; $j = 2$ in IDR/kg).

$c_{l,j}$ Variable cost of byproduct j from waste l (IDR/kg)

p^{oil} : Selling price of coconut oil (IDR/L)

c^{oil} : Variable cost of coconut oil (IDR/L)

w_l : The amount of waste l produced per coconut unit ($l = 1$ for coconut shell in unit, $l = 2$ for coconut dreg in kg)

$r_{l,j}$: Conversion ratio of waste l to product j ($l = 1, j = 1$) and ($l = 2, j = 2$)

b : Weight of 1 coconut unit (kg)

r^{oil} : Oil produced per unit of coconut (L)

$C_{l,j}$: Maximum capacity of processing waste l into product j (kg/period)

F : Fixed cost for activating oil processing unit (IDR/period)

K : Maximum capacity of coconuts processed in each oil processing unit (coconut/period)

T^{co} : Coconut target per period (coconut unit)

T^{p} : Profit target over the time horizon (IDR)

inv^{max} : Maximum limit of shell inventory at the end of the period (kg)

y^{flo}	:	Minimum limit of flour production during the horizon (kg)
w_k, w_p, w_l	:	Objective weight for coconut deviation, profit, and waste
w_{inv}	:	Objective weight for inventory penalty

Decision variables

$x_{i,t}$	:	Number of coconuts processed at unit i in period t (coconut units).
$y_{i,t}^{oil}$	:	Quantity of coconut oil produced at unit i in period t (L).
$u_{i,t}$	:	1 if facility i is active in period t.
$q_{l,j,t}$	:	The amount of waste l sent/processed to produce byproduct j in period t (in kg)
$y_{l,j,t}$	:	The amount of byproduct j produced from waste l in period t (charcoal in kg, coconut flour kg)
$inv_{1,t}$	:	Inventory (remaining) shells (waste 1) at the end of period t.
d_t^+	:	Positive deviation from the coconut processed target in period t (coconut units)
d_p^-	:	Negative deviation from the total profit target (IDR).
d_l^+	:	Positive deviation of shell inventory at the end of the horizon (kg shells).

After the notation for sets and indices, parameters, and decision variables are presented, the next step is to formulate the mathematical model as follows.

Mathematical models

The objective function:

$Min.\ Z = w_k \sum_{t \in T} d_t^+ + w_p d_p^- + w_l d_l^+ c^{pen} \sum_{t \in T} inv_{1,t}$

Constraints:

1. Coconut processing target per period
   $\sum_{i \in I} x_{i,t} + d_t^+ \geq T^{co}, \quad \forall t$
2. Coconut oil production
   In each processing unit:
   $y_{i,t}^{oil} = r^{oil}.b.x_{i,t}, \quad \forall i,t$
   Total production:
   $y_t^{oil} = r^{oil}.b.\sum_{i \in I} x_{i,t}, \quad \forall t$
3. Capacity limits of coconut oil production units
   $x_{i,t} \leq K.u_{i,t}, \quad \forall i,t$
4. Waste (shell and dreg) balance
   For coconut shell ($l = 1$):
   $inv_{1,1} = \sum_{i \in I} w_1.b.x_{i,1} - q_{1,1,1}, \quad t = 1$
   $inv_{1,t} = inv_{1,t-1} + \sum_{i \in I} w_1.b.x_{i,t} - q_{1,1,t}, \quad t > 1$
   For coconut dreg ($l = 2$):
   $q_{2,2,t} = \sum_{i \in I} w_2.b.x_{i,t}, \quad \forall t$
5. Converting waste to byproducts
   For charcoal:
   $y_{1,1,t} = r_{1,1}.q_{1,1,t} \quad \forall t$
   For coconut flour:
   $y_{2,2,t} = r_{2,2}.q_{2,2,t} \quad \forall t$
6. Capacity of byproduct production in unit j
   For charcoal:
   $y_{1,1,t} \leq C_{1,1}, \quad \forall t$

For coconut flour:

$y_{2,2,t} \leq C_{2,2}, \quad \forall t$

7. Target of profit

$\sum_{t\in T}\left(\sum_{(l,j)} p_{l,j}.y_{l,j,t} + p^{oil}.y_i^{oil}\right) - \sum_{t\in T}\left(\sum_{(l,j)} c_{l,j}.y_{l,j,t} + c^{oil}y_i^{oil} + \sum_{i\in I} F.u_{i,t}\right) + d_p^- \geq T^p \;\; \forall l,j$

8. Shell inventory limit at the end of the horizon:

$inv_{1,t^{max}} \leq inv^{max} + d_l^+$

9. Minimum coconut flour production along the horizon:

$\sum_{t\in T} y_{2,2,t} \geq y^{flo}$

Requirements for variable values:

$x_{i,t};\ y_{i,t}^{oil};\ q_{l,j,t};\ y_{l,j,t};\ inv_{1,t};\ d_t^+;\ d_p^-;\ d_l^+ \ \geq 0 \qquad \forall i,j,t u_{i,t} \in \{0,1\} \qquad \forall i,t$

The following subsection presents the numerical simulation and implementation of the proposed model.

Numerical Computations

Implementing the developed model requires a set of parameter values. These values were obtained through observations in the coconut agro-industry in Padang Pariaman, West Sumatra, Indonesia. Some parameters were estimated based on relevant information from literature, reports, and various documents. The complete set of parameters used for the model simulation is presented in Table 2.

Table 2

Parameter Values

Notation	Value	Unit (Note)
T	1,2,3	Planning period/time horizon (3 periods)
r^{oil}	$\frac{1}{11}$	1 liter of coconut-oil requires 11 coconut units
w_1	0.208	The average coconut weighs 1.2 kg. The proportion of shell to coconut is 25%. Thus, the weight of the shell per coconut is 0.25/1.2.
w_2	0.238	The proportion of dreg to coconut is 28.5%. Thus, the weight of the dreg per coconut is 0.285/1.2.
$r_{1,1}$	0.35	Conversion of 1 kg of coconut shell to charcoal
$r_{2,2}$	0.35	Conversion of 1 kg of coconut dreg to coconut flour
p^{oil}	50,000	Selling price of coconut oil (IDR/L)
$p_{1,1}$	6,800	Selling price of charcoal (IDR/kg)
$p_{2,2}$	12,000	Selling price of flour (IDR/kg)
$c_{1,1}$	3,000	Variable cost of producing charcoal (IDR/kg)
$c_{2,2}$	12,000	Variable cost of producing of flour (IDR/kg)
F	200,000	Fixed cost is same for all oil processing units (IDR/period)
b	1.2	Weight of 1 coconut unit (kg)
K	100	Maximum capacity is same for all processing units (coconut/period)
T^{co}	70	Coconut target per period (coconut unit)
$C_{1,1}$	80	Max. capacity of charcoal processing unit (kg/period)
$C_{2,2}$	60	Max. capacity of flour processing unit (kg/period)
T^p	800,000	Profit target over the time horizon (IDR)
inv^{max}	100	Maximum limit of shell inventory at the end of the period (shell kg)
y^{flo}	30	Minimum limit of flour production during the horizon (kg)
w_k, w_p, w_l, w_{inv}	1; 1; 1; 1	Equal weight values are assigned to the objective function.

Data Source : Observation and self-estimation, 2025

Subsequently, the model was implemented using the Python programming language, utilizing the gurobiy package (version 12.0.2). The results for the quantity of coconuts processed and the amount of oil produced from the model are presented in Table 3.

Table 3
Summary of Processed Coconuts and Produced Coconut Oil

Period	Processing Unit	Processed Coconut (Unit)	Produced Oil (L)
1	1	50	5.45
	2	100	10.91
	3	50	5.45
2	1	20	2.18
	2	50	5.45
	3	19.3	2.11
3	1	40	4.36
	2	30	3.27
	3	30	3.27

Data Source : Self-calculation, 2025

For the complete values of other variables, please refer to Table 4 below.

Table 4
Summary of Generated Waste and Byproducts

Decision variables (unit)	Period 1	Period 2	Period 3	Total
Processed coconut (unit)	200	89.3	100	389.9
Coconut oil production (L)	21.82	9.74	10.91	42.47
Number of shells (kg)	49.99	22.31	25	97.3
Charcoal production (kg)	17.50	7.81	8.75	34.06
Amount of pulp (kg)	57	25.44	28.5	110.94
Coconut flour production (kg)	19.95	8.90	9.98	38.83
Shell inventory (kg)	0	0	0	0
Total profit (IDR)	800,000			

Data Source : Self-calculation, 2025

The next section provides an analysis of the model optimization results.

Results Analysis

The goal programming model developed in this study was applied to a representative small-scale coconut oil production system over a multi-period planning horizon. The model generated optimal values for key decision variables, including coconut input allocation, production quantities of oil and byproducts, and inventory levels. These outputs provide valuable insights into production planning, waste conversion, and inventory management across the planning period. The system successfully met the coconut processing targets while maximizing profit and minimizing residual waste.

Model run results showed that all capacity constraints were met, and production targets were achieved without significant deviations, demonstrating the robustness and practical feasibility of the model. Optimization successfully balanced conflicting objectives. Although two of the three oil processing units were active during the planning horizon, one unit remained inactive due to the model's cost-minimization approach. Since total demand can be efficiently met by two active units, activating a third unit would result in additional expenditures without commensurate benefits. These results underscore the model's inherent emphasis on economic efficiency in resource allocation. This analysis highlights the importance of facility coordination and waste valorization in enhancing the sustainability and competitiveness of small-scale coconut processing. These findings offer practical implications for developing an integrated agro-industrial framework in rural areas.

Discussion

The development and application of the optimization model in this study provide key insights into the integration of coconut processing and waste valorization within a circular economy framework. The results demonstrate the feasibility and benefits of coordinating primary production with byproduct management, which are often fragmented in small-scale coconut industries. By accounting for product conversion rates and inventory constraints, the model efficiently allocates coconut inputs across multiple periods, enabling more adaptive and sustainable production planning. It also captures operational constraints typical of small-scale industries, such as limited facility capacity and storage space, offering a realistic foundation for strategic infrastructure development and policy support.

From a production standpoint, the system tends to prioritize coconut oil processing due to its higher profit margin. Nevertheless, the incorporation of waste utilization components such as charcoal from coconut shells and flour from pulp proves effective in reducing residual biomass and mitigating environmental impacts. This aligns with circular economy principles and promotes green agro-industrial practices, particularly in rural settings. The model's goal programming structure also reveals valuable trade-offs; for example, increasing the weight of environmental objectives such as waste minimization shifts production decisions and facility utilization, sometimes at the expense of short-term profitability. This reflects the real-world challenge of balancing economic viability with sustainability goals.

Compared to previous studies on agricultural waste management and agro-industrial optimization, this study offers a tailored multi-period model adapted to local operational realities. It enriches the literature on goal programming applications in agro-industrial systems and provides a prototype for other tropical commodities with high-value byproducts. Overall, the integrated approach proposed here has practical implications for policymakers, cooperatives, and entrepreneurs aiming to enhance the performance and sustainability of coconut-based industries in Indonesia and similar contexts.

CONCLUSION

This study developed a goal programming-based optimization model to support decision-making in an integrated coconut processing system under a circular economy framework. The model simultaneously addresses economic and environmental objectives by maximizing profits from coconut oil and its byproducts, namely charcoal and flour, while minimizing residual waste. The results indicate that the model provides valuable insights into balancing profitability and sustainability through efficient production planning and waste utilization.

Despite these contributions, the study has several limitations. The current scope includes only one main product (coconut oil) and two byproducts (charcoal and flour), which may not fully capture the broader potential of coconut biomass. Additionally, the model relies on deterministic parameters, whereas real-world systems often face uncertainties in yield rates, market prices, and processing capacities. Future studies should address these limitations by expanding the product scope and incorporating uncertainty into the optimization framework.

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