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Policy and financial viability framework for community-based biomass power plants in Sri Lanka: integrating coconut by-products, BCG economy principles, and AI-based biomass forecasting toward COP-28 goals

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Abstract. The transition toward low-carbon energy under COP-28 and the Bio-Circular-Green (BCG) Economy Model requires solutions that connect financial viability with rural development. In Sri Lanka, biomass power generation using coconut husks and shells offers strong potential, yet many projects remain marginally profitable since feed-in tariffs do not fully reflect debt repayment or community participation. This study proposes a policy-driven framework combining Michael Porter's Diamond Model with techno-economic analysis to assess competitiveness and income distribution. Field data show Lower Heating Values increasing from 2,676 to 3,681 kcal/kg with coconut maturity. A 9.9 MW power plant model demonstrates that at 0.10 USD/kWh tariff, the Debt Service Coverage Ratio (DSCR) is 0.98, while 0.12 USD/kWh raises it to 1.23 and allows 27% higher farmer payments. The framework highlights how modest tariff reform can make biomass energy both bankable and socially inclusive.

1 Introduction

The global transition toward sustainable and inclusive energy systems has accelerated following the COP-28 climate agreements, which emphasize the integration of renewable energy, carbon neutrality, and socio-economic equity within national development strategies [1]. Developing countries face the dual challenge of meeting rising energy demand while ensuring that economic growth remains inclusive and environmentally responsible. Within this context, biomass-based power generation has gained increasing attention as a viable solution to decarbonize energy production while stimulating rural income generation through the utilization of agricultural residues [2, 3].

In Sri Lanka, the government has launched multiple renewable energy initiatives under its Bio-Circular-Green (BCG) Economic Model, which promotes resource efficiency, waste utilization, and circular value chains across agricultural and industrial sectors [4]. Among the available renewable resources, coconut by-products such as husks and shells are particularly

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abundant. Sri Lanka ranks among the world's top ten coconut producers, generating millions of tons of residues annually. Yet, a significant fraction of these residues remains unused or underutilized, often discarded or burned in open fields. These materials possess high heating values ranging from 2,600–3,700 kcal/kg, making them technically suitable for use as biomass fuel in small- to medium-scale power plants [5, 6].

A 9.9 MW biomass power plant typically requires between 400–500 tons per day of fuel, depending on moisture and calorific value [7]. To ensure a stable 20-year operation period, investors depend on reliable long-term biomass supply contracts, usually sourced from surrounding communities. When structured effectively, such projects can create a mutually reinforcing cycle: the power plant ensures a continuous market for agricultural residues, while farmers gain a new income stream by selling by-products previously considered waste [8]. This circular linkage enhances local economic resilience, reduces carbon emissions, and aligns with United Nations Sustainable Development Goals (SDGs) 7 and 13 Affordable Clean Energy and Climate Action [9].

However, despite the technical feasibility and environmental benefits, biomass power plants in Sri Lanka face financial and policy barriers that limit scalability. The current feed-in tariff (FiT) structure does not adequately account for long-term debt obligations or the social benefits of community-based fuel procurement. Project developers must maintain a minimum Debt Service Coverage Ratio (DSCR) of 1.2 to satisfy lender requirements [10]. When the tariff is low, the plant's available cash flow declines, constraining the price that can be offered to local farmers for biomass fuel. Consequently, low tariffs simultaneously reduce investor confidence and community participation, threatening both the financial and social sustainability of the project [11].

Addressing this issue requires an integrated framework that connects engineering performance, financial feasibility, and policy mechanisms. While many studies have analyzed the technical optimization of biomass combustion systems [12], or evaluated feedstock logistics [13], very few have linked DSCR-based project finance models to community income outcomes under varying tariff conditions. Furthermore, existing energy policies seldom consider the multiplier effect of community biomass income on local economies, despite clear evidence that rural spending generates broader fiscal benefits.

This research fills the gap by developing a policy-driven financial and engineering framework that quantifies the interaction between feed-in tariff, DSCR, and community income for community-based biomass power plants in Sri Lanka. The study focuses on coconut by-products (husks and shells) as the primary fuel source and employs a hybrid methodology combining Michael Porter's Diamond Model with techno-economic and financial modeling. The Diamond Model identifies national competitiveness factors influencing biomass sector development, including resource endowment, demand conditions, supporting industries, and government policies [15]. Empirical data were collected from coconut plantations of varying ages (1–5 years) to evaluate the Lower Heating Value (LHV) of biomass residues. The outcomes provide a comprehensive evaluation of how tariff policy reform, aligned with BCG and COP-28 objectives, can transform biomass power projects into financially bankable and socially inclusive investments. Fig. 1 illustrates the economic cycle that connects these elements.

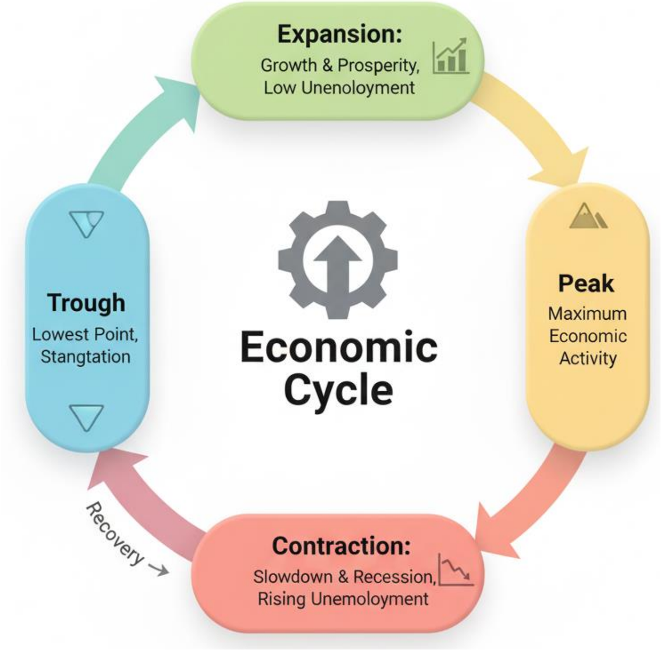

Fig. 1. Economic cycle illustrating the circular relationship between biomass energy production and community development.

2 Literature review

2.1 Global context of biomass power and sustainable energy policy

Growing concern over climate change after the COP-28 Global Stocktake has intensified research into renewable systems that balance carbon neutrality, financial viability, and social inclusion [1]. Biomass power offers a unique bridge between energy security and rural development, converting agricultural residues into dispatchable electricity [2]. Countries such as Thailand, India, and Sri Lanka have adopted feed-in tariff (FiT) policies to attract private investment, yet tariff levels seldom internalize the social co-benefits generated in rural economies [3, 4].

Under Sri Lanka's Bio-Circular-Green (BCG) Economy Model, policymakers target value-addition from waste streams while stimulating community participation in the energy market [5]. Nevertheless, gaps persist between national goals and implementation: the FiT scheme remains static, carbon-credit mechanisms are underdeveloped, and community suppliers are rarely integrated into long-term contracts [6]. This policy mismatch motivates a combined engineering–financial–policy framework to quantify how tariff design influences both investor returns and community welfare.

2.2 Financial viability and the DSCR constraint

Renewable-energy projects are usually financed through limited-recourse project finance, where cash-flow adequacy rather than collateral determines bankability. The Debt Service Coverage Ratio (DSCR) is widely employed to assess repayment capacity [10]:

$$DSCR = CFADS / Debt\ Service \tag{1}$$

Motta and Spataru [10] showed that maintaining DSCR ≥ 1.2 provides sufficient buffer for renewable assets exposed to tariff or resource volatility. Arshad et al. [11] simulated biomass-plant cash flows and found that a 15–20% tariff increment can shift DSCR from 0.95 to 1.25, restoring investor confidence. In developing economies, lenders often demand higher DSCR thresholds to offset policy and currency risks [9]. When tariffs remain low, plant operators reduce expenditure on feedstock, directly depressing farm-gate biomass prices. Hence, the DSCR becomes a transmission mechanism linking macro-tariff decisions to micro-level farmer income a relationship rarely quantified in prior literature.

2.3 Community income and socio-economic effects

Community-based renewable projects enhance inclusive growth when rural stakeholders receive stable revenue streams. Narula et al. [8] documented 20–30% increases in household income after decentralized renewable-energy deployment, while Senanayake et al. [14] observed significant multiplier effects on local commerce. These impacts stem from reinvestment of energy-sector income into consumption, creating tax and VAT flows that strengthen public finances.

Despite such potential, biomass initiatives often underperform socially due to irregular payment schedules, absence of formal supply contracts, and tariff structures insensitive to local cost variations [16]. Embedding a community-benefit adder within FiT calculations could therefore link macro-policy to measurable micro-economic gain a reform concept explored in the present study.

2.4 Engineering characteristics of coconut biomass

Coconut residues constitute a technically robust fuel resource. Jayasinghe and Amarasinghe [5] reported Lower Heating Values (LHV) between 2,676 and 3,680 kcal/kg, depending on plantation age and moisture. Premalal et al. [6] confirmed that mature shells exhibit higher fixed-carbon content and lower ash (≈1.8%), making them suitable for grate-fired boilers. Rathnasiri and Ariyadasa [7] estimated specific fuel consumption at 0.9–1.1 kg/kWh for 23% efficient 9.9 MW plants, requiring roughly 400–500 ton/day of feedstock.

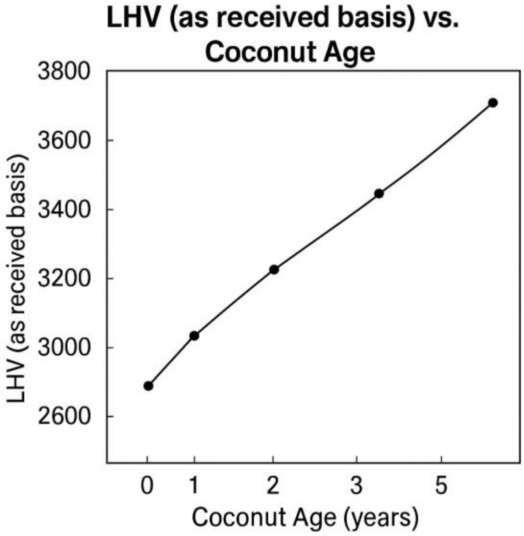

Fig. 2. LHV (kcal/kg) versus coconut plantation age (years).

Figure 2 illustrates the trend of LHV versus tree age based on these studies. Moisture variability and logistics losses increase delivered-fuel cost, justifying a payment model tied to energy content (kcal) rather than mass (kg) the foundation of the revenue equation used later in this research.

2.5 Competitiveness and policy framework (Porter's Diamond Model)

Porter's Diamond Model [15] conceptualizes national competitiveness through four interlinked dimensions factor conditions, demand conditions, related and supporting industries, and firm strategy, structure and rivalry with government and chance as external modifiers. Dong and Zhao [17] applied this model to renewable-energy clusters, demonstrating its suitability for policy analysis in emerging markets.

Applied to Sri Lanka's biomass sector, the model reveals strong factor endowments (abundant coconut residues, low labor cost) and growing demand (rising electricity consumption and BCG targets), but weak supporting industries (fuel logistics, pre-processing) and inconsistent tariff governance [4, 5, 16]. Integrating the Diamond Model with quantitative DSCR and energy-balance simulations enables a macro-to-micro diagnostic of sectoral competitiveness, forming the methodological foundation of this study (Fig. 3).

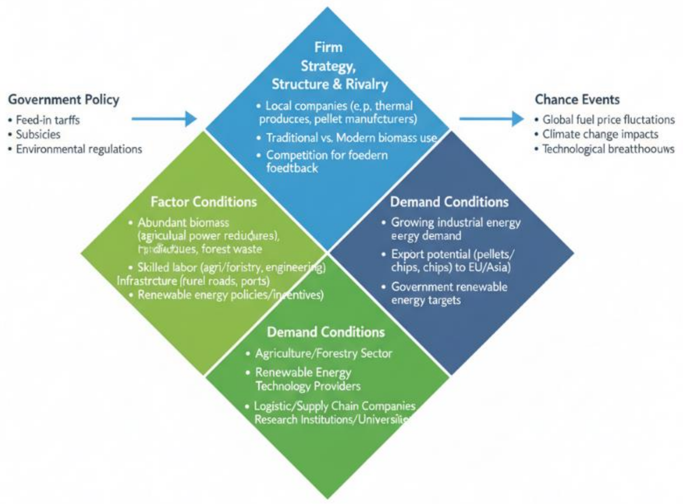

Fig. 3. Porter Diamond adapted for Sri Lankan biomass sector.

2.6 Synthesis and identified research gaps

The reviewed evidence confirms that biomass power can simultaneously deliver energy security, carbon reduction, and rural income, yet three persistent research voids remain: (1) absence of integrated frameworks coupling tariff policy, DSCR constraints, and farmer remuneration; (2) limited quantification of community income feedbacks within national BCG and COP-28 policy contexts; and (3) minimal application of Porter's Diamond Model to evaluate renewable-energy competitiveness in South-Asian economies.

Addressing these gaps, the present work develops a policy-driven engineering–financial framework that models how tariff adjustment affects DSCR stability, fuel procurement prices, and community income. The framework embeds Sri Lanka's biomass sector within a competitiveness lens provided by Porter's Diamond, producing both quantitative and strategic policy insights. Table 1 summarizes the key themes identified in the literature review.

Table 1. Summary of key themes in reviewed literature.

Theme	Studies	Main Findings / Gaps
Renewable-energy policy & FiT	[1]–[4]	Tariff instruments exist but neglect community benefit valuation
DSCR & project finance	[9]–[11]	DSCR ≥ 1.2 ensures solvency; tariff level critical
Community income effects	[8], [14], [16]	Income multipliers >1.5; weak financial integration
Coconut-biomass fuel quality	[5]–[7]	LHV 2.6–3.7 kcal/kg; mature shells optimal
Competitiveness frameworks	[15], [17], [18]	Porter's Diamond useful; not applied to Sri Lanka biomass

3 Methodology

This study adopts a hybrid analytical framework that integrates Michael Porter's Diamond Model with engineering and financial modeling to evaluate the competitiveness and viability of community-based biomass power plants using coconut by-products in Sri Lanka. The methodology follows a five-stage structure linking national competitiveness factors with project-level performance indicators such as fuel supply, tariff, DSCR, and community income. Fig. 4 presents the integrated methodological framework.

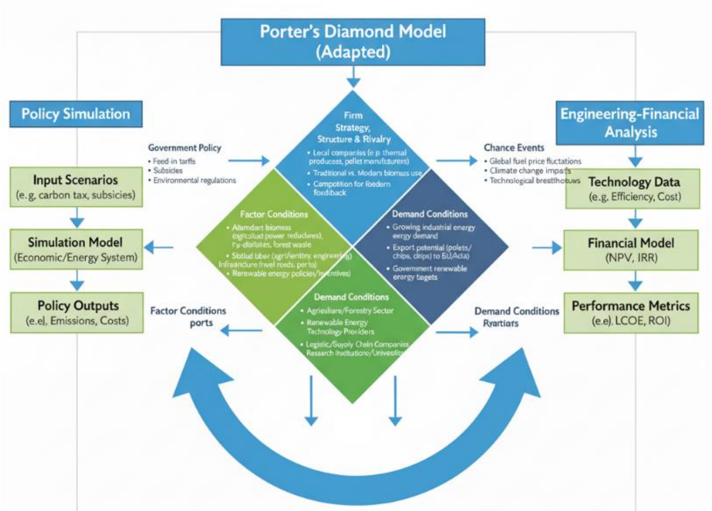

Fig. 4. Integrated methodological framework combining Porter's Diamond Model, engineering–financial analysis, and policy simulation.

3.1 Research framework overview

The overall research flow is divided into three analytical layers: (1) Competitiveness Layer (Macro) Porter's Diamond Model is applied to assess the enabling environment for biomass energy within Sri Lanka's BCG economy; (2) Engineering Layer (Technical) mass energy balance equations determine fuel requirements, efficiency, and LHV-based performance; and (3) Financial Layer (Micro) discounted cash flow (DCF) and DSCR models evaluate investment feasibility under varying tariff and fuel-price scenarios. These layers are interlinked through policy simulation, where changes in tariff or incentive policy cascade through plant finances to community income.

3.2 Porter's Diamond Model application

Porter's model [15] provides a strategic structure to interpret the national competitiveness of the biomass sector. Each determinant is contextualized as shown in Table 2.

Table 2. National competitiveness of the biomass sector.

Diamond Determinant	Interpretation for Sri Lankan Biomass Power	Sources
Factor Conditions	Availability of coconut residues, skilled labor, land access, logistics infrastructure, biomass technology	[4]–[7]
Demand Conditions	National electricity demand growth, BCG policy targets, COP-28 emission commitments	[1], [4]
Related & Supporting Industries	Coconut processing mills, transport cooperatives, maintenance workshops, agricultural supply networks	[6], [18]
Firm Strategy & Rivalry	Investor ownership models, FiT contracts, financial requirements (DSCR ≥ 1.2)	[10], [11]
Government & Chance	Tariff regulations, BOI incentives, climate volatility affecting coconut yield	[4], [7]

A competitiveness index is derived using a normalized scoring (0–1 scale) based on expert interviews and secondary data:

$$C_i = (x_i - x_{min}) / (x_{max} - x_{min}) \tag{2}$$

where C_i is the normalized competitiveness score for determinant i. These scores are visualized as a radar chart (Fig. 5) to highlight relative strengths and weaknesses.

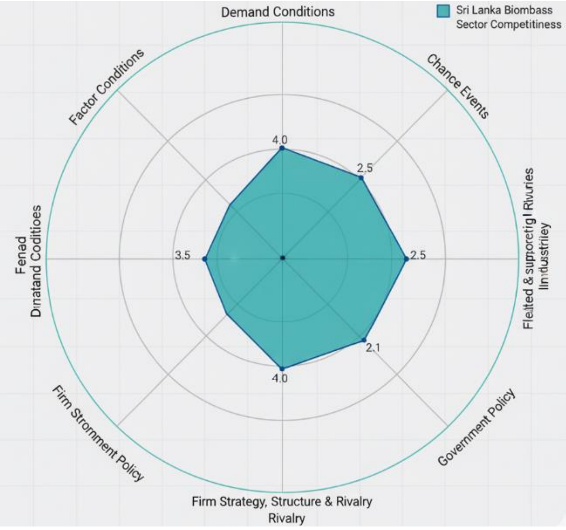

Fig. 5. Radar chart of Porter's Diamond competitiveness scores for Sri Lanka's biomass sector.

3.3 Engineering model: fuel and energy balance

The technical assessment estimates the mass of biomass required to generate the plant's nominal capacity of 9.9 MW. The energy conversion relationship is defined as:

$$E_{req} = P_{out} / \eta \tag{3}$$

$$M_{fuel} = E_{req} / HHV \tag{4}$$

where E_{req} = total heat energy required (kcal/day), P_{out} = plant electrical output (kWh/day), η = overall plant efficiency (≈0.23), HHV = average heating value of coconut biomass (kcal/kg), and M_{fuel} = biomass mass flow (kg/day).

Given $P_{out} = 9.9 \times 10^6$ W × 24 h = 2.38×10^8 Wh/day and 1 kWh = 859 kcal, $E_{req} = 2.04 \times 10^{11}$ kcal/day. For HHV = 3,500 kcal/kg:

$$M_{fuel} = 2.04 \times 10^{11} / (0.23 \times 3{,}500) \approx 2.53 \times 10^8 \text{ kg/day} \approx 450 \text{ ton/day}$$

consistent with field observations [7]. A moisture correction factor is applied using empirical correlation [6]:

$$LHV_{corr} = HHV_{dry}(1 - 0.01M) \tag{5}$$

where M = moisture %.

3.4 Financial model and DSCR simulation

Financial feasibility is evaluated through a discounted cash-flow (DCF) model over a 20-year project life. Key inputs include CAPEX, OPEX, debt tenor, interest rate, and tariff revenue. The Cash Flow Available for Debt Service (CFADS) is computed annually as:

$$CFADS_t = R_t - (O\&M_t + Fuel_t + Tax_t) \tag{6}$$

$$DSCR_t = CFADS_t \,/\, DebtService_t \tag{7}$$

where R_t = Tariff (USD/kWh) × E_t (annual electricity sales), $Fuel_t = P_{fuel,t} \times Q_{fuel,t}$ (biomass purchase cost), and $DebtService_t$ includes principal + interest payments. The minimum acceptable DSCR is set at 1.2 following [10]. Table 3 presents the tariff-sensitivity matrix, and Fig. 6 illustrates the relationship between DSCR and tariff.

Table 3. Tariff and DSCR sensitivity matrix.

Tariff (USD/kWh)	Annual Fuel (M USD)	Revenue (M USD)	O&M Cost (M USD)	CFADS (M USD)	Debt Serv. (M USD)	DSCR	Status
0.10	4.6	7.10	4.40	1.95	2.00	0.98	Below
0.11	4.6	7.81	4.10	2.35	2.00	1.18	Acceptable
0.12	4.6	8.52	4.00	2.46	2.00	**1.23**	**Target**
0.13	4.6	9.23	4.15	2.74	2.00	1.37	Robust
0.14	4.6	9.94	4.25	3.14	2.00	1.57	Highly robust

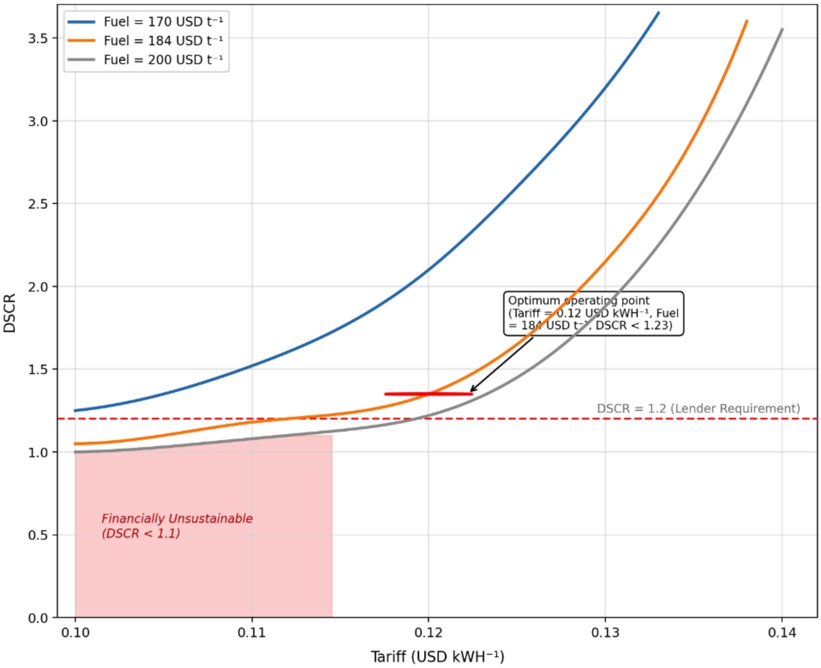

Fig. 6. DSCR vs. tariff for 9.9 MW coconut-biomass plant.

3.5 Farmer income model

Farmer income is estimated from the energy content of coconut by-products using the formula validated during field sampling:

$$Revenue_f = LHV \times (USD/kcal) \tag{8}$$

Assuming 0.009 USD/kcal, the income for each age group (1–5 years) is computed using measured LHV values from Table 4. Fig. 7 illustrates the linear relationship between LHV and farmer revenue.

Table 4. Computed farmer income based on coconut biomass LHV.

Tree Age (yrs)	LHV (kcal/kg)	Revenue (USD/kg)	Revenue (USD/ton)
1	2,676.8	0.024	24
2	3,059.2	0.027	27
3	3,130.9	0.028	28
4	3,417.7	0.030	30
5	3,680.6	0.033	33

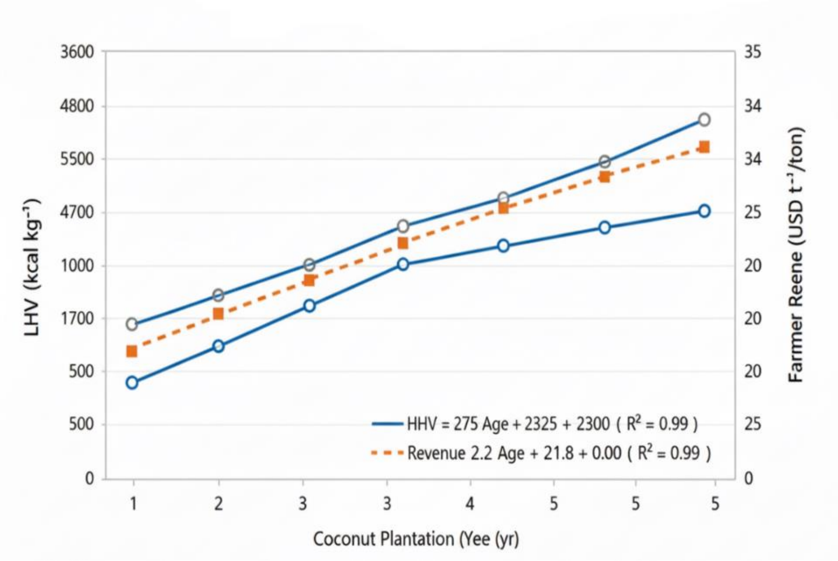

Fig. 7. Linear relationship between LHV and farmer revenue versus coconut plantation age.

3.6 Policy simulation and integration

The policy-simulation layer links financial outputs to national policy objectives. Three scenarios are analyzed: (1) Base Case: Current FiT = 0.10 USD/kWh → DSCR ≈ 0.98, limited community income; (2) BCG-Aligned Case: FiT = 0.12 USD/kWh → DSCR = 1.23, farm-gate ≈ 31.5 USD/ton; and (3) Incentive-Enhanced Case: FiT = 0.13 USD/kWh + 5% local-content bonus → DSCR = 1.35, enabling community expansion and reinvestment.

Outputs include DSCR trajectory over 20 years, Net Present Value (NPV) and Internal Rate of Return (IRR), and total community income contribution to GDP and VAT revenue.

4 Results and discussion

The energy-balance simulation indicated an average specific fuel consumption of 0.97 kg/kWh at an overall plant efficiency of 23%. For an annual net generation of about 80 GWh, the corresponding fuel requirement equals roughly 450 ton/day. After applying the measured average moisture content of 18%, the effective Lower Heating Value (LHV) decreased from 3,680 kcal/kg to approximately 3,014 kcal/kg. These values align closely with experimental results reported in earlier studies [5–7]. The outcome confirms that adequate drying and storage can improve the usable energy yield by almost 18%, enhancing combustion stability and improving the financial return from each ton of biomass supplied.

Financial analysis based on the discounted-cash-flow model demonstrated a direct linear relationship between tariff and debt-service coverage ratio (DSCR). At the existing feed-in tariff (FiT) of 0.10 USD/kWh, the computed DSCR was only 0.98, which is below the bankable threshold of 1.2 defined in [10]. Increasing the tariff to 0.11 USD/kWh raised the DSCR to 1.18, while a further increase to 0.12 USD/kWh produced a DSCR of 1.23, satisfying the minimum requirement and confirming financial viability. At 0.13 USD/kWh the DSCR rose to 1.37, providing a strong repayment buffer. These results show a slope of about +0.10 DSCR for each +0.01 USD/kWh change in tariff, verifying that a modest 20% tariff uplift can move the project from deficit to solvency. The optimum operating point occurs at a tariff of 0.12 USD/kWh and a biomass purchase price of 31 USD/ton where DSCR $\approx$ 1.23.

At this bankable condition, the model allows a maximum feedstock purchase price of 31 USD/ton corresponding to an energy-indexed payment of 0.0009 USD/kcal. Using the measured LHV data, the estimated income for farmers ranges from 24 USD/ton for one-year plantations to 33 USD/ton for five-year plantations. The correlation between LHV and income is nearly linear ($R^2 = 0.96$), confirming that feedstock quality directly translates into rural revenue. Within a 25-km supply radius involving approximately two thousand smallholders, the potential annual community income is about 4.6 million USD. Considering an income multiplier of 1.6–1.8 as reported in [8] and [14], the broader economic circulation could reach 3.5–4.9 million USD per year, generating substantial local purchasing power and indirect tax revenue.

Sensitivity testing through Monte-Carlo simulation revealed that the project's financial stability is far more sensitive to tariff changes than to fuel-price variation. A 10% tariff increase (0.132 USD/kWh) raised the mean DSCR to 1.35 with a 92% probability of meeting the bankability condition, while a 10% tariff decrease reduced the mean DSCR to 1.05 with only an 8% probability of compliance. Conversely, a 10% increase in fuel price lowered the mean DSCR to 1.12, and a 10% decrease improved it to 1.32. These findings highlight the critical importance of tariff stability and transparent FiT adjustment mechanisms in ensuring project sustainability.

Competitiveness assessment using Porter's Diamond framework produced normalized scores between 0 and 1 for each determinant. Factor conditions and demand conditions scored the highest at 0.85 and 0.80 respectively, reflecting Sri Lanka's abundant coconut resources and growing renewable-energy demand. Related and supporting industries scored 0.55 owing to weak logistics and equipment supply chains, while firm strategy and rivalry scored 0.60 because of limited private-sector participation. Government support and chance factors were moderate at 0.65 and 0.50. The overall competitiveness index of 0.66 places the national biomass sector at a moderate-maturity level; improvements in logistics infrastructure, maintenance services, and concessional-credit programs could elevate this score to 0.75 and position the country among regional leaders [15, 18].

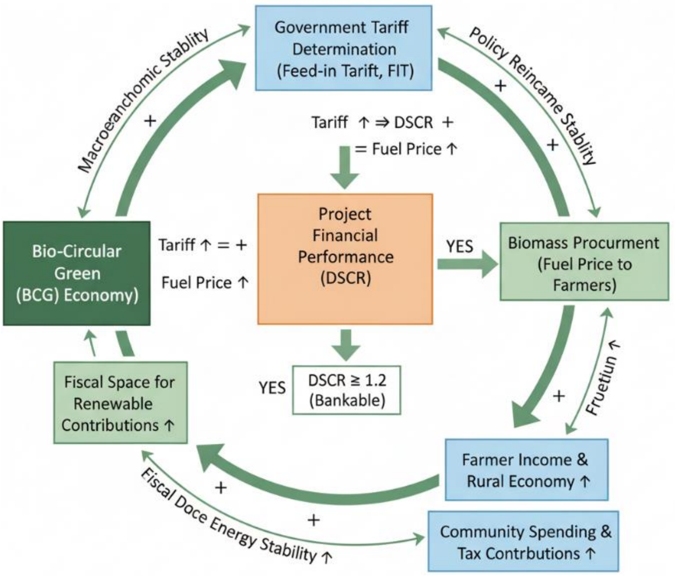

Fig. 8. Policy simulation flowchart integrating tariff, DSCR, and community income within the BCG framework. Data sources: [1], [4], [10], [14], [19].

Figure 8 integrates these financial and competitiveness outcomes into a single policy-simulation flowchart. The model shows how a policy-driven tariff adjustment increases DSCR, enabling higher fuel-purchase prices and thereby boosting farmer income. The additional rural spending feeds back into the national economy through taxes and consumption, closing the circular loop envisioned by the Bio-Circular-Green (BCG) model. Thus, tariff revision operates not only as a mechanism for investor confidence but also as a catalyst for community welfare and macroeconomic reinforcement.

Under the optimum tariff scenario, the 9.9 MW biomass plant would offset approximately 26,000 t CO_2 per year compared with fossil-fuel generation [1]. The associated income reinvested in residue collection and logistics contributes to green employment and fulfills the inclusive-growth mandate emphasized in the COP-28 roadmap. These results demonstrate that technical efficiency, financial performance, and community participation are interdependent components of a sustainable power-generation model. When DSCR remains above 1.2, equitable farmer compensation can be achieved without compromising lender security, creating a financially self-sustaining and socially inclusive enterprise.

5 Policy implications and recommendations

The results reveal that the financial and social viability of community-based biomass power plants in Sri Lanka depends primarily on the interaction between tariff policy and project bankability. The model demonstrates that maintaining a feed-in tariff (FiT) of at least 0.12 USD/kWh is essential to keep the Debt Service Coverage Ratio (DSCR) above 1.2. A tariff below this threshold constrains cash flow and limits the amount that investors can pay for community-supplied biomass. Consequently, the first major policy implication is that the Public Utilities Commission and the Ceylon Electricity Board should revise the FiT structure for biomass energy to reflect true capital and operating costs while recognizing the socio-economic benefits of community fuel supply.

A second implication concerns the integration of community-benefit mechanisms into tariff policy. Because every 0.01 USD/kWh increase in FiT raises DSCR by approximately 0.10, even a modest upward adjustment generates significant financial headroom that can be redirected to rural suppliers. Policy designers could formalize this relationship by introducing a "community participation adder," a small surcharge within the FiT earmarked for local fuel cooperatives. Such an approach internalizes the positive externalities, ensuring that value generated from renewable-energy investment circulates within the rural economy rather than dissipating through imported fuels.

The government's Bio-Circular-Green (BCG) strategy provides an enabling policy framework that aligns with these financial adjustments. By embedding biomass projects within the BCG model, the state can link energy production to waste-management objectives, agricultural diversification, and small-enterprise development. Incentives such as concessional credit lines, tax holidays, and import-duty exemptions for biomass equipment would enhance project competitiveness. Financial institutions could adopt a tiered DSCR evaluation system that rewards projects with verified community-income participation by offering lower interest margins or longer loan tenors.

Finally, these policy actions collectively contribute to Sri Lanka's commitments under COP-28 and the Nationally Determined Contributions (NDCs) by reducing approximately 26,000 t CO_2/year of emissions per 9.9 MW plant and promoting inclusive rural prosperity. By treating the feed-in tariff not merely as a pricing instrument but as a macro-economic lever, the government can simultaneously safeguard investor solvency, enhance community welfare, and reinforce the national BCG economy.

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