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Biofuels in Southeast Asia: Strategic Transition Fuel or Limited Decarbonisation Option?

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POLICY BRIEF

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Highlights

1. A Biofuels face a structural mismatch between scalability and sustainability, with current supply dominated by pathways that compete with food and land resources.
2. The assumption of carbon neutrality is not robust, as life cycle emissions can vary significantly and may exceed fossil fuel benchmarks under certain conditions.
3. Scaling biofuels in Southeast Asia right now to meet global targets could lead to land conversion, and deforestation due to gaps in current regulations.
4. Inadequate measurement, reporting and verification create risks of misclassification, fraud and greenwashing and call for strengthening of sustainability classification framework
5. Without stronger governance, biofuel expansion may lock in resource intensive and low credibility pathways that undermine long term decarbonisation goals.

Summary

Biofuels are often presented as a practical pathway to decarbonise transport and enhance energy security in Southeast Asia. However, their large-scale deployment raises fundamental challenges related to deforestation, land conversion, sustainability, emissions performance and resource constraints. Current biofuel systems are dominated by feedstocks that compete with food production and land use, while more advanced alternatives remain commercially immature. At the same time, weak sustainability classification and verification frameworks undermine confidence in environmental outcomes. Evidence also shows that biofuels are not inherently carbon neutral when assessed across full life cycle boundaries. Scaling biofuels to meet global targets would require substantial land resources, intensifying trade-offs with agriculture and ecosystems. Policymakers should therefore prioritise robust governance frameworks, targeted deployment and alignment with food security and long-term decarbonisation objectives.

What's the issue?

The Southeast Asia faces a fundamental policy challenge in determining whether biofuels can be deployed at scale as a credible, sustainable and verifiable pathway for decarbonisation, rather than as a transitional solution with unresolved structural risks. Biofuels are often positioned as a near term option to reduce dependence on imported oil and support hard to abate sectors. However, this positioning relies on assumptions about sustainability, emissions performance and scalability that remain contested and insufficiently governed.

At the centre of this challenge is a structural misalignment between the technological reality of biofuel supply and the policy expectation of large scale deployment. The current system remains dominated by first generation biofuels derived from food crops, which are intrinsically linked to land, water and agricultural inputs and therefore raise persistent concerns over food security, land use change, including deforestation and ecosystem impacts. Second generation biofuels seek to reduce this tension by relying on residues and waste, yet their scalability is constrained by fragmented supply chains, competing uses for biomass and the physical limits of feedstock availability. Third and fourth generation biofuels are frequently cited as long term solutions with improved sustainability characteristics, but they remain commercially immature, capital intensive and uncertain in terms of regulatory acceptance. This creates a persistent gap between what is available at scale today and what is considered sustainable in the long term.

This gap is further compounded by the absence of a robust and harmonised sustainability classification system, including clear criteria, assessment frameworks and measurement, reporting and verification mechanisms. Current certification approaches rely heavily on documentation and mass balance accounting, with limited physical traceability across supply chains. Definitions of waste and residue feedstocks remain inconsistent, and verification practices are uneven across jurisdictions. These weaknesses create regulatory loopholes that allow misclassification of feedstocks, double counting and in some cases fraud, undermining environmental integrity and market confidence.

Underlying these governance challenges is a deeper uncertainty regarding life cycle emissions performance. Biofuels are often treated as carbon neutral on the assumption that emissions from combustion are offset by biomass regrowth. However, this assumption depends critically on system boundaries, temporal dynamics and land use effects. Evidence shows that this assumption does not always hold. In particular, analysis of the first-generation biofuel pathways demonstrates that bioenergy systems may not be carbon neutral when evaluated over appropriate life cycle system boundaries, and may in some cases result in higher emissions over relevant policy timeframes.[1] This challenges a core premise underpinning many existing policy frameworks.

At the same time, scaling biofuels requires extensive physical and logistical infrastructure across the entire value chain. This includes feedstock aggregation systems, preprocessing and conversion facilities, storage and transport networks, and end use infrastructure such as blending systems, engines and bunkering facilities. In sectors such as maritime transport, this involves coordinated investment across vessels, ports and fuel supply systems. These requirements introduce significant capital costs and lock in risks, particularly in the absence of clear long term policy signals and standardised fuel specifications.

[1] Victor Nian, "The Carbon Neutrality of Electricity Generation from Woody Biomass and Coal: A Critical Comparative Evaluation," Applied Energy 179 (2016): 1069–1080.

Taken together, these dynamics point to a central policy issue. Biofuels are being advanced as a scalable solution for decarbonisation and energy security, yet the systems required to ensure their sustainability, credibility and economic viability remain underdeveloped and misaligned. Without addressing these structural gaps in technology, governance, infrastructure and verification, there is a risk that biofuel deployment may deliver limited climate benefits while introducing new pressures on land, food systems and investment decisions.

Why is this important?

The current crisis has far-reaching implications that extend beyond immediate supply disruptions. The policy challenge surrounding biofuels has implications far beyond fuel substitution. It directly affects how Southeast Asia allocates land, capital and infrastructure investments, while shaping the region's long term industrial competitiveness, food security and participation in emerging low carbon trade systems.

Biofuels are expected to expand significantly under global decarbonisation pathways. Biofuels currently account for just over 3.5 per cent of global transport energy demand and are projected to increase to around 9 per cent by 2030 under net zero scenarios.[2] This projected growth is driven primarily by sectors where direct electrification remains technically difficult or economically constrained, particularly aviation, maritime transport and selected industrial applications. As a result, biofuels are increasingly viewed not merely as an energy commodity, but as a strategic transition resource tied to industrial competitiveness, trade positioning and energy security.

However, scaling biofuels introduces structural constraints that differ fundamentally from those associated with electricity based pathways such as e fuels and direct electrification. Biofuels remain intrinsically dependent on biological systems, meaning that expansion is constrained by land availability, water resources, agricultural productivity and ecological carrying capacity. Unlike electricity based decarbonisation pathways, biofuel expansion therefore creates unavoidable competition between fuel production, food systems, ecosystem conservation and other land intensive economic activities.

The scale of this expansion raises fundamental constraints. Supplying this level of biofuel demand would require approximately 120 to 250 million hectares of land, depending on feedstock and yield assumptions[3] When contextualised within Southeast Asia, this is equivalent to about 27 to 56 per cent of the region's total land area of approximately 450 million hectares, based on 2022 data.[4] More critically, Southeast Asia has only about 140 million

[2] International Energy Agency, Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach (Paris: IEA, 2023).
[3] Timothy D. Searchinger et al., "Assessing the Efficiency of Changes in Land Use for Mitigating Climate Change," Nature 564 (2018): 249–253.
[4] World Bank, *World Development Indicators: Land Area (sq. km)* (Washington, DC: World Bank, 2022).

hectares of agricultural land.[5] Even the lower bound of global biofuel land requirements would therefore approach the entire agricultural land base of the region, while the upper bound would exceed it significantly. This demonstrates that large scale deployment cannot realistically rely on "surplus" land and would instead directly compete with existing agricultural production systems, land use priorities and environmental conservation objectives.

These pressures are particularly important for Southeast Asia because agriculture remains deeply connected to employment, rural livelihoods and export competitiveness. Poorly managed biofuel expansion could therefore contribute not only to food price volatility and pressure on ecosystems, but also to wider socio economic inequality between urban industrial growth centres and rural agricultural communities. This is especially relevant for commodity producing economies where biofuel expansion may become closely linked with broader land use and industrial development strategies.

At the same time, uncertainty surrounding life cycle emissions performance raises important questions regarding the actual climate benefits of biofuels. Emissions outcomes vary significantly depending on feedstock source, cultivation practices, transport logistics, conversion technologies and land use change effects. Evidence from the literature indicates that some biomass pathways, particularly woody biomass systems, may not achieve carbon neutrality over policy relevant timeframes when carbon stock dynamics are properly accounted for. This creates the risk that policy frameworks relying on simplified carbon accounting assumptions may overstate emissions reductions while underestimating broader environmental impacts.

Weak governance systems amplify these risks. Sustainability certification, life cycle assessment methodologies and measurement, reporting and verification frameworks remain fragmented across jurisdictions and sectors. Inconsistent definitions of sustainable feedstocks, limited physical traceability and uneven enforcement create opportunities for greenwashing, double counting and regulatory arbitrage. As international markets increasingly move towards carbon border adjustment mechanisms, sustainability disclosure requirements and stricter green fuel standards, weak governance systems may become a strategic liability for Southeast Asian producers and exporters.

The implications extend beyond policymakers. Energy companies, shipping operators, airlines, commodity producers, financial institutions and infrastructure developers all face increasing exposure to transition risks associated with fuel choice, technology lock in and evolving sustainability standards. Investment decisions made today regarding refineries, blending facilities, bunkering infrastructure and supply chains may shape industrial competitiveness and stranded asset risks for decades.

For regional hubs such as Singapore, the issue is therefore not simply whether biofuels should be promoted, but whether Southeast Asia can develop a credible and

[5] Food and Agriculture Organization, *FAOSTAT Land Use Database* (Rome: FAO, 2022).

internationally trusted sustainable fuels ecosystem. The ability to establish transparent governance systems, verifiable emissions accounting and resilient supply chains will influence the region's role in future maritime, aviation and industrial fuel markets.

What should the policymakers do?

1. Establish an integrated sustainability classification system and corresponding measure, reporting and verification framework

Southeast Asia requires a unified sustainability governance framework that integrates sustainability classification, life cycle assessment methodologies and robust measurement, reporting and verification systems. Current frameworks remain fragmented across jurisdictions and industries, creating inconsistencies in how sustainability is defined, assessed and enforced. Without harmonisation, the region risks undermining market confidence and reducing the credibility of its biofuel exports and domestic transition pathways.

This framework should establish clear criteria across life cycle emissions, direct and indirect land use change, biodiversity impacts, water use, labour standards and broader social outcomes. Importantly, it should differentiate between feedstocks and generations of biofuels rather than applying a uniform sustainability label across fundamentally different pathways. First generation crop-based fuels, residue-based fuels, algae systems and synthetic biofuel pathways present very different environmental and economic implications and should therefore be evaluated differently.

Measurement, reporting and verification systems should move beyond paper-based certification and incorporate digital traceability, geospatial monitoring, supply chain mapping and physical verification where feasible. Emerging technologies such as blockchain-enabled traceability, satellite monitoring and digital product passports could strengthen transparency and reduce opportunities for fraud and double counting.

This recommendation is equally important for private sector actors. Investors, commodity traders, shipping companies and fuel buyers increasingly require credible sustainability assurance to meet corporate disclosure obligations and international market requirements. A harmonised regional framework would reduce compliance uncertainty and improve market confidence across Southeast Asia.

2. Align biofuel deployment with national food security objectives

Biofuel policy should not be developed independently from agricultural and food system planning. Southeast Asian economies should establish explicit safeguards to ensure that biofuel expansion does not undermine food availability, affordability or long-term agricultural resilience.

This requires moving beyond generic sustainability commitments towards measurable indicators such as food to fuel ratios, land use allocation thresholds, fertiliser consumption intensity and agricultural productivity benchmarks. Policymakers should integrate biofuel planning into broader land use strategies, rural development plans and food security frameworks to ensure that expansion remains aligned with national development priorities.

At the same time, governments should encourage pathways that complement rather than displace food systems. This includes prioritising agricultural residues, municipal organic waste and other lower conflict feedstocks where technically and economically feasible. Investments in agricultural productivity, waste management systems and circular economy approaches may help reduce some trade-offs, although they are unlikely to eliminate them entirely.

For agribusinesses and commodity producers, this approach provides greater long-term certainty regarding land use expectations, sustainability obligations and market access conditions.

3. Adopt a selective and sequenced deployment approach based on national energy and climate priorities as well as feedstock availability

Biofuels should not be treated as a universal decarbonisation solution across all transport and industrial sectors. Policymakers should prioritise deployment in applications where alternatives remain technically or economically constrained, particularly aviation, maritime transport and selected industrial processes.

This selective approach is important because scaling biofuel and its supply are inherently limited. Using scarce biofuel resources in sectors that can be electrified more efficiently may result in suboptimal allocation of capital and feedstocks. Direct electrification should therefore remain the preferred pathway for road transport and other applications where technological maturity and infrastructure readiness already exist.

Deployment should also be sequenced according to feedstock availability, infrastructure readiness and technology maturity. Premature large-scale deployment may create stranded asset risks, distort agricultural markets and lock in inefficient pathways before sustainability governance systems are sufficiently mature.

For industries such as maritime and aviation, a sequenced approach also allows time for infrastructure adaptation, engine compatibility upgrades and fuel standardisation to evolve in parallel with supply development.

4. Account for full system costs and infrastructure requirements

Biofuel deployment requires far more than fuel production alone. Scaling the sector involves coordinated investment across feedstock aggregation systems, preprocessing facilities, conversion technologies, transport logistics, storage infrastructure and end use applications.

In maritime sectors, this may include bunkering infrastructure, vessel retrofitting and fuel handling systems. In aviation, supply chain certification, blending infrastructure and airport logistics become equally important. These system wide requirements significantly increase the real cost of deployment and may create long term lock in risks if infrastructure is developed prematurely or around pathways that later become uncompetitive.

Policymakers and industry stakeholders should therefore adopt system level cost assessments rather than focusing narrowly on fuel production costs alone. Infrastructure planning should account for technology uncertainty, fuel flexibility and long-term competitiveness under evolving carbon pricing and sustainability regulations.

Financial institutions and infrastructure investors also need clearer long term policy signals to manage investment risks. Without credible policy direction, the region risks underinvestment in critical infrastructure or misallocation of capital towards pathways with limited long-term viability.

5. Strengthen regional coordination, mandates and market infrastructure

Regional coordination is essential because biofuel supply chains and markets are inherently transboundary. Fragmented national regulations create loopholes, increase compliance costs and weaken overall market integrity.

ASEAN should work towards harmonised sustainability standards, MRV methodologies and greenhouse gas accounting frameworks to support interoperability across regional markets. Common accounting principles would improve consistency in emissions reporting and reduce opportunities for regulatory arbitrage.

Where blending mandates are implemented, policymakers should consider both lower and upper bounds rather than fixed targets alone. Lower bounds can provide investment certainty and minimum demand signals, while upper bounds can help prevent excessive dependence on feedstocks that may create sustainability or food security concerns.

The region should also explore common digital trading and certification platforms for biofuels and sustainable fuel credits. Transparent market infrastructure can improve price discovery, reduce compliance uncertainty and strengthen traceability across regional supply chains.

For industries operating across borders, particularly shipping, aviation and commodity trading, greater regional coordination would significantly reduce transaction complexity and improve investment confidence.

6. Embed rigorous life cycle assessment criteria and frameworks on biofuels to ensure sufficient disclosure of true environmental impacts

Life cycle assessment frameworks should be expanded and standardised to account for the full environmental footprint of non-fossil fuel production systems. This includes emissions associated with feedstock cultivation, fertiliser use, direct and indirect land use change, transport, processing, storage and final combustion.

Carbon accounting should follow a full field to wheel approach and incorporate temporal carbon dynamics where relevant. Simplified assumptions regarding carbon neutrality should be avoided unless supported by rigorous evidence and clearly defined system boundaries.

Importantly, life cycle assessment should extend beyond carbon emissions alone. Broader indicators including biodiversity impacts, water intensity, soil degradation and ecosystem resilience should also be incorporated into sustainability evaluation frameworks.

For companies and investors, stronger life cycle assessment methodologies are increasingly necessary to meet emerging disclosure requirements, sustainable finance criteria and international market standards.

7. Maintain flexibility and inclusiveness in transition pathways to allow for adoption of appropriate fuel options

Significant uncertainty remains regarding the long term competitiveness of different low carbon fuel pathways. Advanced biofuels, e-fuels, and hydrogen (and its derivatives) technologies are all evolving rapidly, while sustainability standards and carbon pricing mechanisms continue to develop.

Policymakers and industry stakeholders should therefore avoid prematurely locking in specific technologies, infrastructure systems or fuel pathways before long term competitiveness and sustainability performance become clearer. Flexible policy frameworks can help reduce stranded asset risks and preserve optionality as technologies evolve.

This requires adaptive regulation, technology neutral incentives and phased deployment strategies that allow the energy system to respond dynamically to technological progress and market developments.

Biography

Dr Victor Nian is a Founding Co-Chairman of the Centre for Strategic Energy and Resources. His expertise spans energy and climate policy, sustainability and net-zero strategy, long-term planning, and industrial economy. He is a recognised authority on nuclear energy, digital transformation, and sustainability governance in Southeast Asia. He advises public and private organisations on the geopolitics and market dynamics of strategic technologies. Dr Nian leads efforts in energy policy development, technology commercialisation, value chain development, and private-public collaboration to accelerate the energy transition in emerging Asian economies. He holds a PhD in Mechanical Engineering and a BEng (Hons) in Electrical Engineering with a Minor in Management of Technology from the National University of Singapore.

Jude Lee is the Regional Policy and Program Director for Asia-Pacific at Transport & Environment (T&E), where she leads the organisation's regional expansion and strategy. Based in Australia, she oversees T&E's work on shipping, aviation, road transport decarbonisation, and energy transition, with Singapore serving as a key hub. She collaborates with NGOs, funders, and policymakers to align Asia's transport and energy decarbonisation with global climate frameworks.

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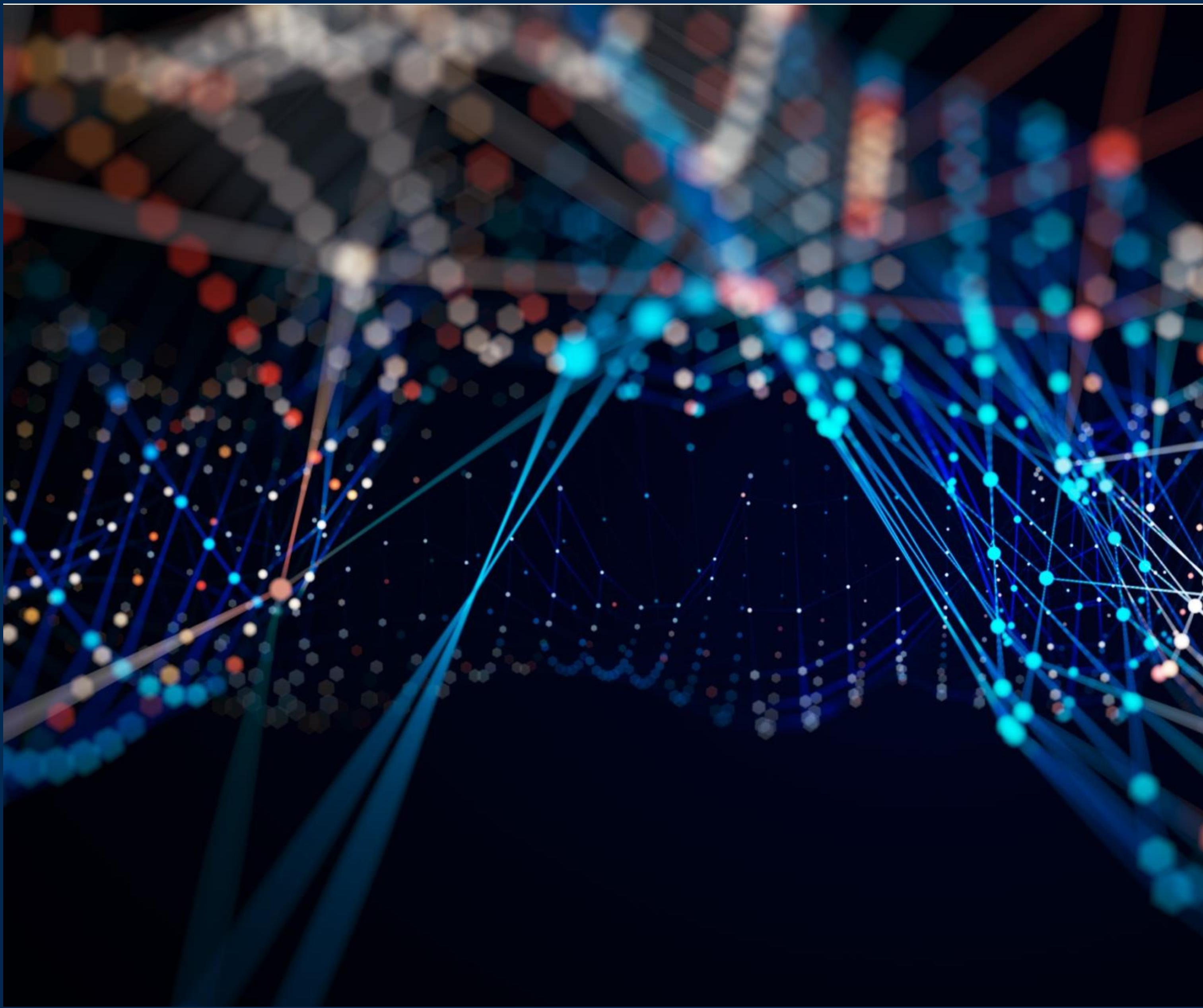

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