Deconstructing The Socio-Technical And Institutional Friction In Indonesian Sustainable Aviation Fuel Transition: A 'System-In-Waiting' Analysis

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Abstract

A sustainable aviation fuel (SAF) blend can be demonstrated in flight before the organisations needed for recurrent supply are able to commit to it. This article uses Indonesia to explain how that gap persists. It draws on semi-structured interviews with 45 informants across policy, industry and community levels, supplemented by field observation and document review. The parent interview corpus comprises 2,830 coded units across governance, economics, system integration, feedstock, technology and infrastructure. The case reveals a system-in-waiting, a condition in which actors defer investments, purchases or supply commitments because they depend on assurances controlled elsewhere in the value chain. Feedstock organisers need a dependable outlet, refiners need traceable inputs and credible demand, and airlines need reliable supply and workable cost recovery. When these commitments are deferred, actors have less evidence on which to make the next commitment. The article integrates General System Theory, Socio-Technical Systems theory and New Institutional Economics and Sociology to explain why the capacity to deploy an innovation repeatedly depends on relationships between actors as well as technical capability. The Indonesian case identifies conditions under which similar patterns may arise in other energy transitions that require distributed investment and coordinated supply.

Keywords: sustainable aviation fuel; energy transitions; system readiness; socio-technical systems; institutional coordination

1. Introduction

Aviation decarbonisation forms part of a wider Asian energy challenge. Lo [1] argues that Asian economies must meet growing energy demand while addressing energy security, pollution and climate change. Aviation illustrates this tension because long-haul aircraft depend on liquid fuels and emissions include both carbon dioxide and non-CO_2 effects [2,3]. International aviation

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decarbonisation roadmaps envisage net-zero carbon emissions by 2050, with SAF expected to make a substantial contribution [4]. Achieving this ambition requires coordinated action on technology, finance and governance [5]. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) provides a policy mechanism through which eligible alternative fuels can contribute to international aviation decarbonisation [6].

Sustainable aviation fuel (SAF) is a near- to medium-term option for reducing aviation's life-cycle greenhouse gas emissions. Drop-in compatibility applies to finished fuel that meets the relevant aviation turbine-fuel specification. The blend components and permitted blending limits depend on the approved pathway [7]. Life-cycle emissions vary with feedstock, production process and supply-chain conditions [8–10]. In Indonesia, aviation supports connectivity across an archipelago. Municipal waste and agricultural and plantation residues offer potential domestic inputs for SAF production [11]. The practical question is how much of that resource can be collected, verified and supplied reliably to domestic producers.

Indonesia's energy policy context includes Government Regulation No. 40 of 2025 on National Energy Policy [12]. Indonesia has developed palm-based aviation biofuels, including J2.0 and J2.4. However, their implementation continues to face challenges concerning sustainability requirements, production volumes, availability and potential price increases [13]. Research on used cooking oil (UCO)-based SAF also examines the conditions for economic viability through different business-model scenarios [14]. These developments raise questions about the transition from initial fuel development to recurrent commercial deployment. The evidence needed to establish recurring commercial deployment concerns the continuity of supply, purchasing arrangements and cost recovery.

The case therefore asks how operating milestones coexist with uncertainty about recurrent domestic deployment. We use the term 'system-in-waiting' for a condition in which technically feasible operations have been demonstrated, but the actors needed for deployment each make their next commitment conditional on arrangements controlled by others. The multi-level perspective situates these difficulties within the interaction of emerging innovations and established regimes [15]. The present study examines the specific dependencies through which delay is reproduced between actors in the supply chain.

General System Theory (GST) is used here as an interpretive lens for examining relationships among system components. Contemporary multi-system transition research complements this perspective by examining how technologies, actors, institutions and resources become connected across system interfaces [16–18]. The Indonesian SAF supply chain connects waste collection, refining, logistics, regulation and airline operations. A reliable material flow depends on information and commitments travelling across the same interfaces. For example, collection volumes are of limited operational value to a refinery unless the parties can verify quality and organise delivery. This perspective directs attention to the links that allow individual capabilities to function together.

The study uses New Institutional Economics and Sociology (NIES) as a combined institutional lens. Research on household transaction costs and market intermediation shows how uncertainty and institutional arrangements shape participation and exchange [19,20]. Participants in a supply chain use regulations, contracts, trading routines and interpersonal relationships to organise exchange. Where responsibilities, standards or funding arrangements remain uncertain, actors face greater costs in locating suppliers, negotiating agreements and verifying performance. This perspective helps explain why actors may postpone commitments that would be valuable to the system collectively.

Socio-Technical Systems (STS) theory provides a lens for examining the joint organisation of technical capabilities and social practices. Recent studies apply socio-technical approaches to refinery decarbonisation, aviation fuels and everyday practices [21–23]. In aviation, qualification of

a fuel pathway addresses part of the technical task. Recurrent deployment also requires organisations to establish procurement, quality assurance and operating routines and to communicate those procedures to users. Research on social practices and the embedding of new technologies helps frame these requirements [20,23]. A recent review of SAF research also identifies limited attention to economic and social dimensions alongside technological and environmental aspects [24].

SAF research has examined conversion routes, production costs, life-cycle emissions and supply-chain design [25–28]. Studies such as the assessment of SAF implementation in Southeast Asia have also examined deployment gaps in regional settings [29]. Irianto and Wasesa [30] examine how Indonesia's electricity transition interacts with tariff and subsidy arrangements and household affordability. Their electricity-sector analysis provides a comparison for examining how cost recovery and public support shape the distributional consequences of an energy transition. Geng and Lo [31] identify limited attention to the Global South in research on transnational environmental governance. The Indonesian SAF case examines how international aviation objectives are translated into domestic decisions across government, industry and communities. Our question is how actors' interdependent commitments across policy, industry and communities shape the shift from SAF demonstration to recurrent domestic deployment in Indonesia.

2. Methods

2.1. Research Design and Paradigm

This study uses a constructivist qualitative case-study design [32,33]. Its unit of analysis is the emerging Indonesian SAF system, with attention to how actors describe their responsibilities, dependencies and options. The case-study design supports comparison across organisational levels and interpretation of how actors' accounts fit together within the policy and supply-chain context [34,35].

2.2. Study Area and Informant Sampling

The interview chronology, based on transcript dates and the reconciled session register, covers September 2025 to June 2026. The study covered 17 cities in Indonesia and included international perspectives from Bangkok, Thailand, and Ottawa, Canada. Purposive sampling covered 45 informants across three analytical levels [36]. The macro group comprised 11 informants from regulation, planning and policy. The meso group comprised 16 informants from industry and related organisations. The micro group comprised 18 informants, including participants involved in community collection and aviation users. The identifiers MA01–MA11, ME01–ME16 and MI01–MI18 link evidence to informants while protecting their identities.

2.3. Data Collection and Triangulation

Semi-structured interviews were supplemented by field observation and document review to support triangulation across data sources and methods [37]. Interviews addressed policy coordination, production, procurement, feedstock collection, logistics and perceptions of fuel use. Observations in South Tangerang examined community and small-business practices relevant to used cooking oil (UCO), and observations in Cilacap provided context on refining infrastructure. Policy documents and ICAO materials were used to establish the regulatory and technical context and to compare institutional requirements with participants' accounts.

2.4. Thematic Analysis and Coding

The interview transcripts were analysed thematically [38]. The researcher identified units of meaning, assigned initial codes, grouped related codes into categories and compared accounts across the three analytical levels. Excel supported coding and traceability and NVivo supported the descriptive lexical analysis [39]. The parent corpus comprised 2,830 coded units, with 660 at the macro level, 1,196 at the meso level and 974 at the micro level. Six dimensions emerged from the thematic analysis: governance, economics, system integration, feedstock, technology and infrastructure. The theoretical lenses were used to interpret relationships among these dimensions. A retrospective category-coverage check grouped evidence by interview date and recorded the first appearance of each final category, both overall and within each analytical level.

3. Results and Discussions

3.1. Word Cloud and Lexical Frequency Analysis

Figure 1 provides a descriptive overview of terms used in the interview transcripts. Larger text indicates more frequent occurrence in the NVivo lexical query. References to UCO, waste, prices and SAF help orient the reader to the interview material. Interpretation of the six dimensions draws on contextual coding and cross-level comparison of accounts.



Figure 1: *Word Cloud of SAF Development in Indonesia*

3.2. Retrospective Category Coverage

The retrospective check (Section 2.4) traced the first appearance of 30 categories in the pooled interview record. After all 30 categories had appeared in the pooled record, later interviews still

provided the first evidence at the meso and micro levels for some categories already documented at another level. These later interviews broadened coverage within those levels without adding categories to the pooled record. The check applied the final categories retrospectively to the interview sequence.

3.3. The Six Interdependent Dimensions of System Misalignment

The 2,830 coded units were distributed across governance (514), economics (609), system integration (453), feedstock (1,108), technology (46) and infrastructure (100). These counts describe the composition of the coded corpus and are not measures of the relative importance of each dimension. The six dimensions organise different parts of the same deployment problem. Governance and economics shape authority and the terms of exchange. System integration concerns how information and commitments travel among actors. Feedstock, technology and infrastructure concern the material and operational capabilities that must be connected to deliver fuel.

3.3.1 Governance and Implementation Authority

Macro-level accounts distinguished policy direction from implementation authority. MA06 described a roadmap identifying organisations expected to coordinate on supply, demand and enabling measures, while MA05 distinguished the transport ministry's remit from a levy or additional tax requiring interministerial coordination. These accounts suggest that assigning responsibilities does not itself secure the authority needed to implement them. Sukasno et al. similarly distinguish coherent policy objectives from consistent instruments in Indonesia's biomass transition [40], while Apriliyanti et al. identify uneven institutional power across decarbonisation decisions [41]. For SAF, the implementation problem concerns how a shared direction becomes a set of decisions that the relevant authorities can authorise and deliver.

Industry accounts show how this distribution of authority enters commercial decisions. ME02 linked airline uptake to domestic policy and SAF's higher price; ME01 questioned whether a blending target could be implemented while responsibility for its economic and airfare implications remained elsewhere. The credibility of a target therefore depends partly on whether firms can anticipate the arrangements for meeting its additional costs. Breen et al. identify related interactions between regulatory fragmentation, funding and production capacity in European SAF deployment [42]. A study of residential rooftop solar adoption in Pune likewise links uptake constraints to multilevel institutional arrangements [43]. The Indonesian accounts locate a specific dependency: purchasing commitments remain conditional on financing and implementation decisions that individual firms cannot resolve through operational planning alone.

At community level, MI01 described mobilising neighbourhood leaders to organise UCO collection. This demonstrates local organisational capacity, while recurrent industrial supply requires agreements on delivery, quality and purchasing beyond the neighbourhood's authority. Through the NIES lens, the gap concerns the institutions that make exchange credible across these interfaces. Research on transaction costs and market intermediation helps explain the effort required to connect dispersed participants with formal markets [19,20]. Masudin et al.'s waste-to-biogas supply-chain model similarly connects institutional weaknesses with financial and operational instability [44]. An intermediary could organise supply information, communicate quality requirements and establish contracting routines. These are implications of the observed dependencies, rather than demonstrated capabilities; their effectiveness would depend on commitments from collectors, buyers and the authorities governing exchange.

CORSIA eligibility adds an information requirement to this coordination problem. Sustainability compliance is assessed through ICAO-approved certification schemes, supported by traceability and chain-of-custody arrangements [45]. Collecting UCO and documenting its eligibility thus require connected responsibilities for material transfers and supporting records. The interview evidence identifies traceability as an implementation task, rather than an established capability across the chain. Requiring verifiable information without arrangements for producing and checking it could increase the burden on smaller collectors. Deng and Zhang's solar cases in China also show that administrative coordination can accelerate projects while weakening oversight and marginalising local participants [46]. Institutional orchestration therefore involves connecting authorised policy decisions, credible procurement and practicable verification requirements. This interpretation explains the 'system-in-waiting' condition: actors can organise parts of the transition, but recurring deployment depends on complementary commitments controlled by others.

3.3.2 Economics: The Green Premium and Financial Vulnerability

Participants described a price premium over conventional jet fuel and linked it to feedstock costs, production investment and logistics. ME02 described a project evaluating UCO-based SAF for domestic sale or export, with pricing assumptions following prevailing market prices. This distinction between production costs and expected selling prices matters when interpreting commercial viability. Farooq et al.'s meta-analysis shows that SAF cost estimates depend on feedstock prices, capital and financial assumptions, process design and co-product valuation [47]. Hermawan et al.'s Indonesian UCO study further demonstrates how logistics configurations influence estimated production costs [48]. These studies support treating the premium as contingent on project and market conditions, rather than as a single fixed differential applicable to all domestic deployment.

For airlines, participants questioned how additional fuel costs could be recovered within regulated domestic fare arrangements. ME08 suggested that a limited introduction in charter services might be easier because pricing is bundled. This is a proposed entry strategy, not evidence that charter operations necessarily recover the premium. Chen et al.'s modelling shows that SAF mandates can affect fares, traffic and profits differently across airline types [49], while Müller and Wittmer identify procurement structures, budgets and internal decisions as influences on corporate SAF purchasing [50]. Together, these findings strengthen the case for examining market segments separately: the same fuel premium can create different purchasing conditions depending on who pays, how the service is priced and whether additional costs can be passed through.

The institutional issue is therefore how a cost gap becomes financeable and recoverable. Brandt et al. show that combinations of US federal and state incentives can change SAF minimum selling prices, with outcomes differing across pathways, feedstocks and plant maturity [51]. Their results demonstrate the importance of policy design, without establishing which instruments would work in Indonesia. Kumar et al. review green bonds, sustainability-linked loans and other financing mechanisms for aviation decarbonisation [52]. Financing investment and covering recurring incremental fuel costs nevertheless remain distinct tasks: access to capital does not by itself identify who will fund the premium over time. In the Indonesian case, a credible purchasing commitment consequently depends on an arrangement specifying who can absorb, recover or share that cost and under what conditions.

Affordability further limits the assumption that the premium can simply be transferred to passengers. Hong and Huh's South Korean survey finds positive stated willingness to pay for SAF-powered flights [53], but this cannot establish willingness or ability to pay among Indonesian passengers. Chen et al.'s model also links the consequences of a mandate to passenger preferences and airline characteristics [49]. The interview accounts therefore identify a distributional question

rather than quantify its outcome: which market segments and payer groups would bear additional costs under a particular fare and support arrangement? Financial vulnerability arises when an actor is expected to commit expenditure before the means of recovering it are credible. Assessing a future measure thus requires attention to its coverage, payer responsibilities and purchasing conditions, alongside its effect on production costs.

3.3.3 System Integration: Value Chain Fragmentation

Horizontal integration involves aligning the decisions of agencies and organisations responsible for energy, aviation, industry and waste. A coordination team can convene these actors, while funding, standards and procurement still require decisions from the responsible organisations. This distinction is consistent with Andersen et al.'s system-interface perspective, which examines how technologies, actors, institutions and resources must be connected across systems [18]. For SAF, coordination becomes operational when decisions in one domain provide conditions on which actors in another can act.

Vertical integration, understood here as coordination along the value chain, depends on credible information and commitments moving both ways. Collectors need to know the volume, quality and price a buyer will accept; refiners need reliable inputs and a market for their output; airlines need delivery assurances and a way to handle the premium. ME02 described an investment project still awaiting a final decision despite favourable policy signals. ME03 stated: "They need a long-term offtake contract for ten years, while the offtaker says you need to have a lender first" (translated from Indonesian). The account illustrates mutually conditional requirements that can delay the first commitment. Siegfried et al. identify a related market-entry problem in intermediate bioenergy carriers and emphasise stable frameworks and long-term offtake agreements [54].

Viewed through GST, these dependencies explain how uncertainty at one interface can constrain action elsewhere. When buyers defer commitments, producers have less demand certainty; when producers defer expansion, buyers have less evidence of reliable future supply. Andersen et al.'s study of Norwegian ferry electrification shows how unresolved tensions between systems can lead to operational workarounds rather than fully coordinated arrangements [18]. The comparison supports examining the interfaces through which individual capabilities become usable together. In the Indonesian SAF case, the ME03 account identifies a specific interface between purchasing commitments and project financing; it does not establish that every project faces the same contractual conditions.

Waste collection and industrial fuel production also operate with different routines. Community collection may depend on volunteers and collection days, whereas industrial procurement requires predictable volumes, quality and delivery. Ebrahimi et al.'s review of bioenergy logistics highlights collaborative planning, shared infrastructure and coordination of collection, transport and preprocessing as means of connecting dispersed biomass sources with industrial demand [55]. Aggregators and common procurement arrangements could perform such connecting functions for UCO, provided responsibilities and commercial terms are clear. Prussi further shows why traceability must accompany material flows through chain-of-custody arrangements [45]. Integration therefore requires agreements that connect delivery obligations, purchasing conditions and supporting records, alongside coordination at the policy level.

3.3.4 Feedstock: Paradox of Potential and Collection Inefficiencies

Indonesia has waste-derived feedstock resources, including UCO and oil recoverable from palm oil mill effluent (POME) [14, 56]. Their contribution to domestic SAF production depends on recoverable quantities, input quality, sustainability requirements and procurement arrangements.

These conditions need to be distinguished when interpreting resource-potential estimates. Hermawan et al.'s analysis of Indonesian UCO-to-SAF business models shows that the organisation of refining, collection, storage and logistics influences economic viability [14]. Yeoh and Goh examine POME oil as a potential input for hydrotreated fuels and discuss export demand and uncertain market conditions [56]. POME oil originates from mill operations, so household UCO collection mechanisms cannot be assumed to describe its recovery.

ME01 described limited UCO supply and long collection chains, explaining why the refinery sought material closer to the point of collection. MA02 reported that additional uses and export demand increased UCO's value. Together, these accounts suggest that physical recoverability and domestic availability are connected through market allocation. A higher price could encourage collection while also increasing competition among buyers; it does not establish that the additional material will reach domestic refiners. The implementation question is therefore which collection and purchasing arrangements can secure a reliable domestic flow under competing demand. The interviews identify this dependency without estimating the proportion of recoverable UCO available for SAF or demonstrating that export demand is its sole constraint.

At neighbourhood level, MI01 described using neighbourhood leaders to encourage collection, while noting that delivering oil to a collection point at the appointed time could still prevent participation. The same informant accepted the price of an easily contacted collector because alternatives were difficult to identify. These examples connect supply with the practical effort of participation and access to trading options. Lee et al.'s Japanese study finds that collection methods and awareness are associated with household participation [57]. In Semarang, Hartini et al. incorporate community behaviour into the design of collection points and routes [58]. These comparisons support examining awareness campaigns together with pickup arrangements, accessibility and payment conditions when assessing whether household oil can enter a recurring supply chain.

From an STS perspective, procurement depends on the fit between industrial input requirements and everyday collection practices. Li et al.'s SAF-focused review shows how impurities and variation in waste cooking oil affect pretreatment requirements and hydrotreatment catalysts [59]. Collection arrangements therefore influence both the quantity recovered and the condition of the material delivered. Aggregation, suitable storage, quality verification, pickup and payment need to operate as connected routines, with responsibilities and commercial terms understood by collectors and buyers. The discussion consequently extends feedstock assessment from estimated generation to the arrangements through which material is recovered, qualified and allocated. Reliable domestic supply emerges when these social, technical and commercial conditions can be sustained together.

3.3.5 Technology and Operational Confidence

HEFA is among the most established SAF conversion pathways internationally, while alcohol-to-jet and biomass-to-liquid routes, including biomass gasification followed by Fischer–Tropsch synthesis, offer alternatives with different feedstock, process and investment requirements [26, 60]. International pathway maturity provides a basis for technology selection, but domestic deployment depends on the conditions under which a particular configuration can operate. Ding et al. identify feedstock availability, refining infrastructure and certification as interconnected constraints on SAF adoption [60]. The technological question for Indonesia therefore extends from whether a conversion route exists to whether its input requirements, production conditions and assurance arrangements can be sustained locally.

Nugroho et al. document Indonesia's development of palm-based J2.0 and J2.4 aviation

biofuels [13]. Such milestones provide evidence of specific development achievements; recurrent deployment requires evidence that production and fuel conformity can be maintained across successive batches and operations. Boehm et al. emphasise the quality requirements and fuel-property assessment involved in the design and qualification of aviation fuels [61]. The distinction between a blending component and a finished fuel is important because compatibility depends on meeting the applicable specification under the relevant blending conditions. Assurance must therefore be embedded in production, verification and handling routines, with responsibilities for maintaining conformity understood by the organisations involved.

Scaling also requires attention to the conversion of technical capability into operating capacity. Martulli et al.'s global and EU analysis distinguishes announced SAF capacity from capacity realised on schedule, demonstrating that project announcements can overstate timely supply availability [62]. This evidence does not establish Indonesia's production trajectory, but it reinforces the need to assess implementation through observable production and delivery milestones. For the present case, relevant questions concern repeatable output, consistent quality and procurement arrangements that support continued operation. Technical development and commercial deployment are connected through these routines: a viable process needs reliable inputs and purchasing conditions, while buyers need credible evidence that specified fuel can be supplied repeatedly.

The interview accounts also reveal different interpretations of technological change. MI10 supported the development of renewable energy technology, whereas MI04 requested further study and referred to public debates about terrestrial biodiesel. Together, these accounts show why communication needs to address the questions through which participants interpret a new fuel. Engelmann et al.'s German study of CO2-based jet fuel finds that perceived risks and benefits vary across production steps and participant groups [63]. Its context differs from Indonesian waste-based SAF, but it supports examining how people understand particular processes rather than assuming a uniform response to the technology. Explaining aviation fuel qualification, blending and handling could address the assurance questions raised here, alongside transparent evidence of operational performance.

3.3.6 Infrastructure Across the Supply Chain

Downstream use of a compliant blend addresses only part of infrastructure readiness. Recurrent SAF deployment also depends on upstream and midstream facilities for aggregation, storage, pre-treatment and transport. Liang et al.'s review identifies the complexities of multi-stage processing, feedstock variability and production scalability as interconnected supply-chain challenges [28]. Infrastructure readiness should therefore be assessed by function and location along the chain, including whether successive facilities can accommodate the volumes and schedules required by one another. A facility may be technically available while the collection, transport or receiving arrangements needed for its regular use remain incomplete.

ME07 described airport storage serving both domestic and international operations and raised practical difficulties with separating supply. This account identifies a management problem within an existing downstream system, but its implications depend on the fuel stage and the physical and documentary requirements applicable to the operation. Prussi distinguishes fuel compatibility from the chain-of-custody arrangements used to substantiate sustainability claims [45]. The interview therefore supports examining how shared storage, delivery scheduling and records interact; it does not establish that all SAF requires dedicated tanks. The relevant infrastructure question is whether the actual configuration can maintain fuel conformity and provide the documentation needed for the intended use and claim.

At community level, MI01 described organising collection and pickup around limited storage.

Here, storage serves as a buffer between dispersed collection and onward transport, so its usefulness depends on how quickly material is accumulated and removed. Olmez et al.'s UCO network model treats collection-centre locations, bin numbers, household coverage and vehicle routing as linked decisions [64]. Hartini et al.'s Semarang study similarly connects community behaviour with the design of collection points and routes [58]. These studies support examining storage together with pickup frequency, accessibility and transport capacity. Adding containers alone may provide limited relief if onward collection remains irregular, while convenient pickup can improve the use of existing storage.

The two interview accounts consequently locate infrastructure constraints at different interfaces: managing compliant fuel within an airport system and maintaining feedstock handling before refining. Oppioli et al.'s study of airport circular-economy practices places infrastructure decisions within operational strategy, stakeholder engagement and multilevel governance [65]. This provides a comparison for examining who controls facilities, who schedules transfers and who maintains records across organisational boundaries. In the Indonesian SAF case, the analytical implication is to assess whether capacity and operating responsibilities are matched across successive stages. Infrastructure investment would need to address the specific interruption in the flow, with arrangements for use and maintenance that allow facilities to support recurrent deliveries.

3.4. Socio-Technical and Institutional Misalignment Synthesis

The six dimensions reveal a gap between the ability to use SAF in flight and the ability to sustain its supply and purchase. Recurrent deployment requires feedstock to be collected and verified, fuel to be delivered and the additional cost to be covered across successive transactions. Zou and Chen [66] identify a comparable gap between pilot projects and mainstream SAF adoption in emerging markets, where feedstock bottlenecks, fragmented incentives and investment risks remain unresolved. Liang et al. [28] likewise locate scalability problems across processing, logistics and regulation. These studies help position the Indonesian findings as a problem of connecting capabilities across organisations. We use 'system-in-waiting' to describe the more specific mechanism through which an actor defers a commitment because the assurance it requires depends on a decision elsewhere in the system, and that deferral reduces another actor's ability or willingness to commit.

The decisions are linked through the exchange of material, information and financial assurances. A collector needs a dependable buyer to justify regular collection and storage. A producer needs reliable feedstock and credible demand before expanding capacity. An airline needs confidence in delivery and a workable way to recover or share the premium before committing to purchases. Speich and Ulli-Beer [67] conceptualise energy ecosystems as networks of interlinked business models exchanging goods, money, services and information. Their framework helps explain why a viable activity at one stage may remain dependent on an incomplete arrangement at another. Haque's [68] analysis of technology action plans also highlights resource mobilisation and legitimacy as priorities in clean technology diffusion. In the Indonesian case, these functions become operational through identifiable decisions about who supplies, pays, guarantees performance and accepts risk.

ME03's account of project financing in Section 3.3.3 provides the clearest illustration of reciprocal waiting. The project needed a long-term offtake agreement to secure financing, while the prospective buyer wanted financing in place before committing to purchase. The lender sought evidence of future revenue; the buyer sought evidence that production could be delivered. Each requirement was reasonable from the perspective of the organisation exposed to the risk, yet their sequencing left both decisions pending. Siegfried et al. [54] identify a related market-entry problem

for intermediate bioenergy carriers and connect stable regulatory conditions with investment security and long-term offtake agreements. Zhou et al. [69] model strategic interactions among governments, airlines and SAF producers across industrialisation stages. ME03's account adds a transaction-level explanation of how such interdependence can operate. The model's numerical policy thresholds are conditional on its assumptions and do not establish appropriate subsidy or cost-sharing levels for Indonesia.

This mechanism also clarifies the role of risk allocation. Committing first can expose a producer to investment without confirmed revenue or expose a buyer to a contract with an incompletely financed supplier. Waiting may therefore protect an individual organisation while postponing an arrangement that would benefit several parties. Luukka et al.'s [70] study of twelve companies involved in Finnish green hydrogen supply chains similarly identifies heterogeneous actor constraints and the importance of standards and long-term offtaker arrangements. This cross-sector comparison suggests that coordination needs to address the particular uncertainty preventing a commitment. In the Indonesian SAF case, the analytical question is which contractual or institutional assurance would make the next decision credible, who could provide it and what obligation that provider would accept. A willingness to cooperate does not by itself settle these terms.

The three theoretical perspectives explain different aspects of these linked decisions. General System Theory directs attention to feedback: uncertain offtake weakens the case for expanding production, while delayed expansion gives buyers less confidence in delivery. Socio-Technical Systems theory directs attention to the routines through which technical capability becomes repeatable procurement, quality assurance and operation. New Institutional Economics and Sociology directs attention to the credibility of the rules, contracts and relationships through which actors manage uncertainty. These are complementary interpretations of the interview evidence. The ecosystem analysis of Speich and Ulli-Beer [67] and the multi-actor findings of Luukka et al. [70] provide contemporary comparisons for examining their connections. Together, the perspectives suggest that readiness depends on whether capabilities and commitments can be assembled in the sequence required for recurrent transactions.

The policy implication concerns the authority to resolve specific dependencies. Olbrich et al. [71] show that sectoral policy silos and doubts about policy credibility can create planning insecurity and fear of sunk investments during energy sector integration. Dong and Sheng [71] find that fragmented governance in China's green hydrogen transition can enable experimentation while also producing infrastructure delays and duplicated investment. These comparisons help explain why convening actors may be insufficient when funding, standards and purchasing remain under different authorities. In Indonesia, an implementation arrangement would need to connect each unresolved decision to the organisation able to authorise it. A roadmap can identify a shared direction, but buyers and investors also need credible arrangements governing the costs and obligations that follow from participation.

The timing and durability of support matter alongside its nominal amount. Martinez-Valencia et al. [73] use financial analysis and system dynamics to show how policy support for environmental services affects investment risk and the development of waste-based SAF production in the United States. Their results support examining when support becomes available and how it affects project revenues; their estimates cannot be transferred directly to Indonesia. Applied to the interview findings, a measure intended to encourage airline purchases would need to connect with producers' financing schedules and feasible delivery commitments. Conditional purchase agreements, staged financing or guarantees are possible subjects for policy appraisal, rather than measures validated by this study. Their usefulness would depend on enforceable conditions, funding authority and whether the risks they redistribute can actually be borne by the receiving

actor.

The mechanism also requires a clear distinction between a bottleneck and reciprocal waiting. ME03 described another project in which potential buyers were already waiting while the developer concentrated on feedstock recovery. This account identifies an upstream constraint; demonstrating reciprocal waiting would require evidence that feedstock recovery itself depended on commitments withheld elsewhere. Chireshe et al. [74] show how supply-chain configuration changes SAF production economics in South Africa, while Hermawan et al. [48] model the economic and environmental consequences of alternative UCO logistics configurations in Indonesia. Siluvai Antony et al. [75] further show, for Canadian canola-based SAF, that facility-siting decisions and coordination affect recoverable production potential. These studies indicate that the location and organisation of supply can constrain deployment even where buyers express interest. They support examining upstream arrangements without treating every material shortage as evidence of circular deferral.

The contribution of 'system-in-waiting' is therefore to specify a mechanism within a broader transition process. Its empirical assessment requires identifying the decision each actor controls, the assurance sought before committing, the actor able to provide it and the consequences of withholding that commitment. Evidence of mutual dependence is needed to distinguish the mechanism from a one-way shortage, a technical limitation or an investment judged commercially unattractive. The financing–offtake account provides such a reported relationship, while the feedstock account illustrates the need for further tracing. The case does not establish that reciprocal waiting explains every dimension or project. It shows how uneven progress can persist when organisations possess relevant capabilities but cannot obtain the connected assurances needed to use them repeatedly. This provides a basis for comparison with other energy transitions where recurrent delivery spans several organisations and acting ahead of others entails material risk.

4. Conclusion

The Indonesian SAF case shows how a technically feasible innovation can remain difficult to deploy repeatedly. Feedstock collection, refining and airline purchasing each depend on commitments made elsewhere in the supply chain. When actors defer investment or procurement while waiting for credible assurances on supply, demand or cost recovery, they weaken the conditions under which other actors can move. The resulting 'system-in-waiting' explains how the transition can record successful flights while recurring domestic deployment remains uncertain.

The general theoretical contribution is to explain system readiness as a property of relationships among actors. General System Theory identifies the feedback through which a deferral at one point affects decisions elsewhere. Socio-Technical Systems theory explains why demonstrated technical capability must be embedded in operating and procurement practices. New Institutional Economics and Sociology explains how rules, contracts and informal arrangements affect the credibility of commitments. The case brings these insights together in a proposition: where complementary decisions are distributed across organisations, uneven readiness persists when actors require reciprocal assurances and have no credible way to secure them. This specifies how a gap between technical capability and deployment can reproduce itself over time.

The proposition can guide comparison with other early-stage energy transitions in Asia where demonstrations precede regular supply and investment depends on several organisations. This single case establishes the plausibility of the mechanism in the Indonesian SAF setting and identifies conditions for comparative study. For Indonesia, the analysis points to measures that address connected decisions: traceable feedstock procurement and aggregation, credible offtake

arrangements, and a workable allocation of the green premium. Their relevance lies in the commitments they make possible across the value chain.

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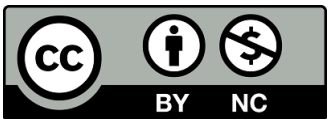
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