

# From Waste to Sustainable Aviation Fuel (SAF): Used Cooking Oil (UCO) as a Renewable Energy Source

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## Abstract

Driven by the urgent need for cleaner aviation fuels, researchers worldwide are exploring renewable sources that reduce carbon emissions while ensuring fuel stability. Used Cooking Oil (UCO) has emerged as a strong contender, offering both high fat content and compatibility with existing fuel production technologies. This research conducts a Systematic Literature Review (SLR) to evaluate the potential and scalability of Used Cooking Oil (UCO) as a renewable feedstock in the production of sustainable aviation fuel. A qualitative method was employed, based exclusively on secondary data sourced from peer-reviewed scientific articles published between 2023 and 2025, retrieved from the ScienceDirect database. The review process followed the PRISMA protocol, encompassing identification, screening, eligibility, and inclusion phases. Initial results from 2,200 articles were filtered using predefined Boolean keyword combinations, publication year, research type, and access criteria, yielding 36 articles for in-depth synthesis. The analysis employed thematic coding alongside comparative synthesis to uncover consistent patterns emerging across five principal dimensions: technological readiness, environmental performance, economic feasibility, regulatory alignment, and logistical frameworks. Findings indicate that UCO-derived SAF offers up to 90% reduction in lifecycle GHG emissions, competitive production costs with fossil jet fuel under certain policies, and strong compatibility with HEFA-based refining pathways. However, supply chain limitations and regulatory harmonization remain critical challenges. In conclusion, UCO presents substantial potential as a renewable SAF feedstock, particularly in regions with established UCO collection infrastructure. Future research should focus on integrated policy mechanisms, decentralized processing models, and refinements to life-cycle assessment to support broader implementation.

**Keywords:** Used Cooking Oil, Sustainable Aviation Fuel, Systematic Literature Review, Renewable Energy, HEFA Technology

## 1. Introduction

Driven by the urgency of climate action, the international aviation industry is reshaping itself to meet emissions-reduction targets and embrace cleaner energy alternatives. While CO<sub>2</sub> emissions from aviation account for around 2.5% of the global total, the sector's overall climate impact increases to approximately 3.5% when additional non-CO<sub>2</sub> radiative effects, such as nitrogen oxides, contrails, and cirrus cloud formation, are considered [1]. With international air traffic projected to double by 2040, the urgency to decarbonize aviation has intensified, increasing demand for drop-in fuels that align with existing aviation infrastructure while maintaining high standards of safety, reliability, and performance [2,3]. Amid multiple strategies for reducing aviation-related emissions, sustainable aviation fuel (SAF) has proven to be a technically feasible and scalable short-term solution. It serves as a drop-in replacement for Jet-A and can achieve up to 80% reductions in lifecycle GHG emissions, depending on the feedstock origin and processing technique used [4]. Under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), both IATA and ICAO have highlighted SAF as a critical enabler

in the industry's pursuit of carbon neutrality by 2050 [5]. While organizations such as IATA and ICAO have endorsed SAF, its production remains minimal, accounting for less than 0.1% of global aviation fuel demand as of 2023 [6]. Major challenges include elevated production costs, limited access to feedstocks, and ambiguous regulatory frameworks, collectively impeding large-scale deployment and economic viability. Feedstock selection is a crucial determinant of SAF's environmental, economic, and social performance.

First-generation sources such as corn starch, palm, and soybean oil are often criticized for contributing to land degradation and food insecurity, and for yielding limited GHG reductions when ILUC impacts are considered [7]. In contrast, second-generation feedstocks derived from waste and residues such as used cooking oil (UCO) are increasingly favored for their non-edible nature, low environmental footprint, and waste valorization potential. UCO is abundant in urban centers and has historically posed a disposal challenge due to its contribution to clogged drainage systems, methane emissions from landfills, and the potential for illicit reuse in food preparation, particularly in informal sectors [8]. By

redirecting UCO toward SAF production, cities can mitigate environmental hazards while advancing circular-economy goals. Used Cooking Oil (UCO) is technologically compatible with the HEFA conversion route, which is the leading and most commercially validated process for generating sustainable aviation fuel. HEFA-derived sustainable fuels are known for their high combustion efficiency and compatibility with modern jet propulsion systems, achieving up to 80%–83% GHG reductions across their lifecycle when powered by low-carbon hydrogen [9].

Other pathways under investigation include catalytic pyrolysis, transesterification, and supercritical methanolysis, although these remain at the pilot or demonstration scale and face challenges related to energy efficiency, scalability, and regulatory approval [10]. In terms of market potential, global UCO availability is estimated at 29 billion liters annually, with significant regional variation. The European Union alone generates approximately 2.5 billion liters per year, of which less than 40% is currently collected and utilized [11]. In Asia, countries such as China and Indonesia produce large quantities of UCO due to their extensive foodservice sectors, yet face challenges in traceability, collection efficiency, and regulatory oversight [12]. Establishing robust UCO collection networks is therefore critical to ensuring a consistent and sustainable feedstock supply for SAF refineries. Public policy is instrumental in advancing the SAF market. In the United States, initiatives such as the RFS and LCFS encourage the use of UCO-derived fuels by offering Renewable Identification Numbers and carbon offset credits. Under RED II, the European Union urges member states to favor biofuels derived from waste streams, such as used cooking oil, while imposing a 1.7% cap on food-based alternatives to minimize ILUC-related challenges [13]. These regulatory instruments have stimulated private investment, but inconsistent enforcement and certification procedures continue to present risks, especially in transnational supply chains.

There is a growing call for harmonized sustainability criteria, improved traceability systems, and international cooperation to prevent feedstock fraud and ensure the integrity of SAF markets [14].

Despite increasing attention, the academic literature on UCO-based SAF remains fragmented across disciplines, with limited consolidated analysis of its technological pathways, environmental impacts, economic feasibility, and policy dynamics. Some studies focus exclusively on fuel-yield optimization, while others examine environmental assessments or regulatory frameworks in isolation, without synthesizing findings across the value chain. As a result, stakeholders, including policymakers, investors, and researchers, lack a holistic understanding of the opportunities and limitations associated with UCO-to-SAF conversion. This fragmentation underscores the need for a systematic literature review (SLR) to rigorously consolidate and critically evaluate the current state of knowledge. This

study employs the SLR methodology, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, and relies exclusively on peer-reviewed secondary data published between 2023 and 2025. The review draws from 36 open-access research articles identified through a multi-stage screening process, emphasizing empirical studies that address technological, environmental, economic, and regulatory dimensions of UCO-derived SAF. No fieldwork, expert interviews, or focus group discussions were conducted, ensuring the methodological integrity of the SLR approach. The purpose of this review is to provide a comprehensive synthesis of recent scientific developments on the utilization of used cooking oil as a renewable energy source for sustainable aviation fuel. The study seeks to identify dominant conversion technologies, evaluate environmental and lifecycle performance, assess economic and market viability, analyze regulatory enablers and barriers, and examine logistical considerations related to UCO collection and processing. This integrated analysis is expected to inform policy formulation, guide investment strategies, and support future research initiatives in sustainable aviation.

To that end, this study is guided by the following research question.

**RQ:** What are the technological, environmental, economic, regulatory, and logistical factors influencing the viability and scalability of used cooking oil as a sustainable feedstock for aviation fuel production?

## 2. Literature Review

With mounting environmental pressures and stricter carbon mandates, the development of SAF has taken center stage as a global solution for decarbonizing aviation. With global air travel expanding and climate regulations tightening, the aviation sector—responsible for 2.5% of CO<sub>2</sub> emissions faces mounting pressure to decarbonize under international schemes such as CORSIA and the European Green Deal [15]. As a result, scholarly discourse has increasingly concentrated on alternative fuels, particularly biojet fuels derived from waste sources, as promising pathways toward net-zero emissions in aviation. Within this discourse, used cooking oil (UCO) has garnered significant attention as a second-generation biofuel feedstock. UCO is considered superior to many first-generation feedstocks such as soybean, corn, and palm oil due to its non-competition with food crops, relatively stable composition, and lower environmental footprint [16]. Extensive research highlights the environmental advantages of UCO-derived SAF, particularly via the HEFA pathway, which can reduce lifecycle GHG emissions by up to 80% compared with conventional jet fuel [17].

This development has stimulated a significant rise in academic investigations exploring the technical feasibility, commercial scalability, and environmental trade-offs associated with converting UCO into SAF. A core theme in the literature is the efficiency and maturity of various conversion technologies. The HEFA process dominates

current UCO-to-SAF conversion due to its technological maturity and compatibility with existing jet engines [18]. However, emerging techniques such as catalytic pyrolysis, supercritical methanolysis, and hydrothermal liquefaction are also being explored to improve yield, energy return on investment (EROI), and process flexibility [19]. Comparative studies suggest that while HEFA maintains EROI values between 4:1 and 6:1, supercritical methanolysis yields are higher under optimized conditions but requires intensive energy inputs [20]. These findings suggest an ongoing trade-off between scalability and process complexity in the production of SAF from UCO. Another key dimension in the literature is supply chain dynamics. Researchers have analyzed UCO collection systems across urban and industrial zones, noting that feedstock availability and quality remain critical constraints for large-scale SAF deployment [21]. Studies from the European Union indicate that only 30–50% of available UCO is collected, largely due to fragmentation in collection infrastructure and regulatory inconsistencies [22].

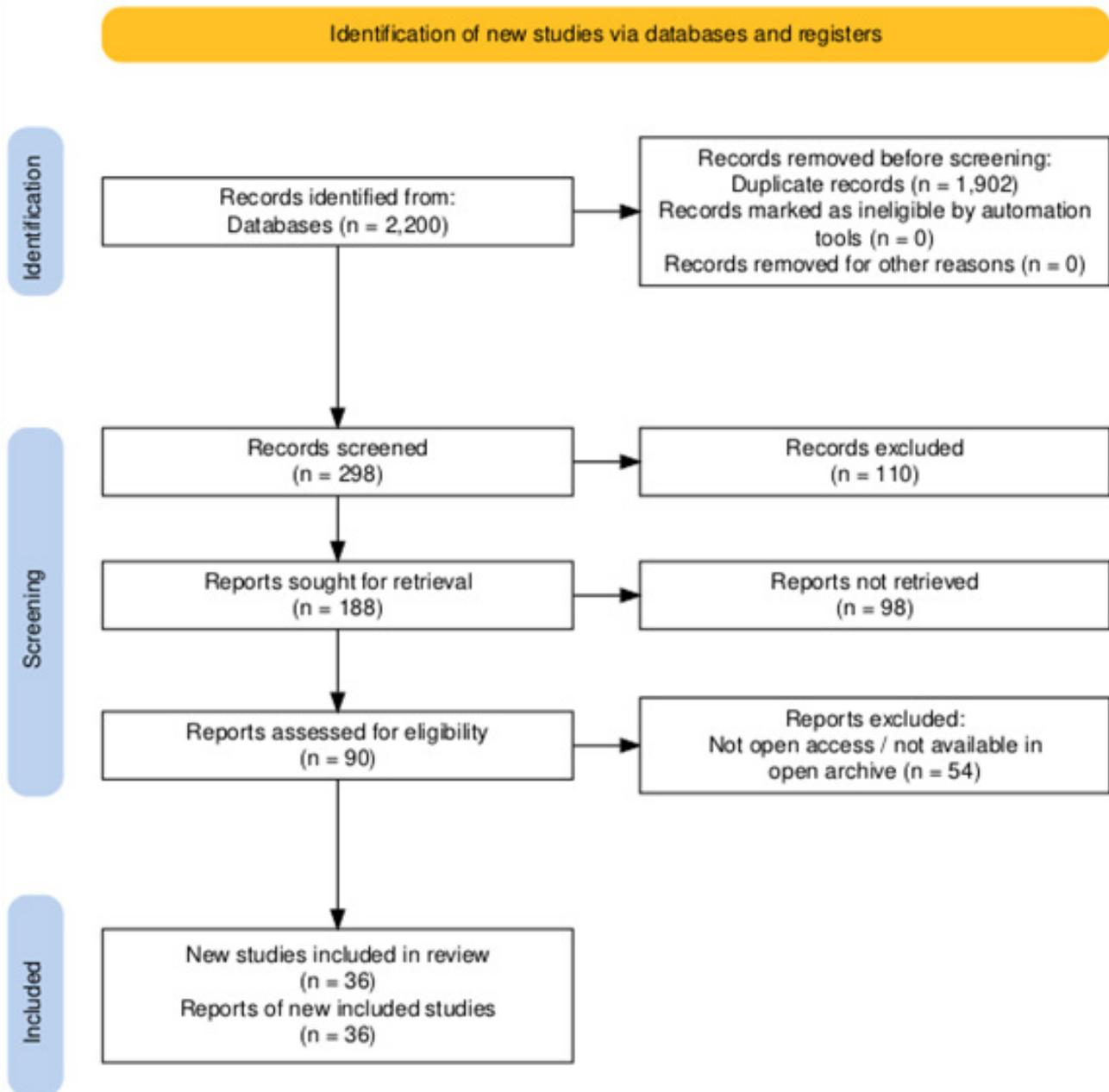
Several articles also highlight the growing need for digital traceability tools such as blockchain and IoT-based monitoring systems to ensure sustainability compliance and reduce fraud in UCO procurement chains. From an environmental perspective, life-cycle assessments (LCAs) have become instrumental in quantifying the emissions impacts of UCO-based SAF. Recent meta-analyses indicate that UCO-derived SAF can achieve emissions intensities of 18–25 gCO<sub>2</sub>e/MJ, compared with 88–95 gCO<sub>2</sub>e/MJ for fossil-based jet fuel [23]. The reduction is most pronounced when feedstock transportation distances are minimized, and renewable hydrogen is used during hydrotreatment [24]. However, sensitivity analyses across multiple studies caution that indirect emissions from poor UCO storage, adulteration, or illegal dumping can significantly offset these benefits. Thus, environmental performance remains highly context-dependent. Cost competitiveness has also emerged as a recurring theme in SAF literature. While UCO itself is a low-cost feedstock, the capital intensity of refining infrastructure and the volatile price of hydrogen significantly influence the final SAF price, which typically ranges between USD 1.20–2.00 per liter, substantially higher than conventional jet fuel [25]. Government subsidies, carbon pricing mechanisms, and renewable fuel mandates (e.g., the U.S. Renewable Fuel Standard and EU Renewable Energy Directive II) are therefore critical enablers in bridging this cost gap [26]. These policy instruments not only mitigate price volatility but also stimulate investment in SAF infrastructure. Despite substantial progress, the literature also underscores a number of critical research gaps. First, comparative techno-economic studies between UCO and other waste-based feedstocks remain limited.

While UCO is well characterized, less attention has been paid to blending strategies that involve multiple waste oils or to integrating SAF production with waste management systems. Second, socio-economic dimensions, such as labor implications of UCO collection or regional equity in SAF infrastructure deployment, remain underexplored. Third,

there remains a paucity of long-term field validation studies assessing engine performance and emissions under different SAF blending ratios, although this is partly due to the nascent deployment stage of SAF technologies. In response to these gaps, recent studies have called for more granular, region-specific analyses that consider local UCO availability, logistical networks, regulatory settings, and carbon pricing regimes [27]. Moreover, there is increasing interest in hybrid conversion systems that combine thermal, catalytic, and biochemical processes to enhance overall system efficiency while maintaining sustainability benchmarks. Incorporating renewable energy sources, such as hydrogen generated from solar or wind power, into the SAF production process has been proposed as a strategy to further reduce emissions in the upstream supply chain [28]. The literature on SAF from UCO has evolved considerably, encompassing technological innovation, environmental validation, economic modeling, and policy analysis. Nevertheless, significant work remains in consolidating findings across disciplines to inform integrated SAF deployment strategies that are technically feasible, environmentally robust, and economically viable. This review contributes to that consolidation by synthesizing recent peer-reviewed research published between 2023 and 2025, applying a systematic literature review (SLR) methodology grounded in the PRISMA protocol. Through this method, the review aims to highlight dominant themes, identify underexplored areas, and inform future SAF development grounded in sustainable waste utilization.

### 3. Method

This study adopts the Systematic Literature Review (SLR) method, in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, to investigate the use of used cooking oil (UCO) as a renewable feedstock for sustainable aviation fuel (SAF). As global aviation grapples with growing pressure to reduce its carbon footprint, attention has increasingly turned to alternative fuels that can offer meaningful emissions reductions without requiring significant changes in engine design or distribution infrastructure. Among the spectrum of bio-based feedstocks available, used cooking oil stands out for its economic viability, waste-reduction potential, and support for circular economy frameworks. Its status as a non-edible, second-generation bioresource positions UCO as a low-risk, high-potential solution for scaling sustainable jet fuel production, especially in urban environments where it is abundantly generated but often improperly disposed of. Despite a growing body of research on SAF and UCO, the literature remains dispersed across engineering, environmental policy, and energy systems, often lacking an integrated understanding of the technological, environmental, and policy dimensions of UCO-to-SAF conversion. This review seeks to bridge that gap by systematically synthesizing peer-reviewed evidence to map current knowledge, highlight technological pathways, identify recurring challenges, and suggest directions for future research.



**Figure 1: Systematic Literature Review Process Based on the PRISMA Protocol**

Figure 1 illustrates the systematic screening process based on the PRISMA protocol, detailing the four sequential stages of identification, screening, eligibility, and inclusion. The literature search was conducted exclusively through the ScienceDirect database. An initial query using the broad keyword phrase “used cooking oil sustainable aviation fuel” yielded 2,200 results. To enhance thematic precision, a refined Boolean query was applied: (“used cooking oil” OR “UCO”) AND (“sustainable aviation fuel” OR “SAF”) AND (“renewable energy” OR “biojet fuel”). This targeted search excluded 1,902 articles deemed unrelated or outside the study’s scope, leaving 298 records for screening. To ensure temporal relevance and capture the most recent developments, the publication date range was restricted to 2023–2025. This step eliminated 110 articles published

outside that window, leaving 188. In the eligibility phase, only original research articles were retained, excluding 98 documents, including reviews, commentaries, and technical notes. This produced a refined subset of 90 research articles. The final inclusion stage filtered out 54 articles not available via open-access or open-archive platforms, resulting in a final sample of 36 articles deemed methodologically sound and thematically aligned for full-text review and qualitative synthesis. All references used in this review were systematically organized using Mendeley Desktop to facilitate de-duplication, reference tracking, and consistent citation formatting. No primary data collection, fieldwork, focus group discussions, or expert interviews were conducted, ensuring that the analysis remains grounded exclusively in published secondary sources. Through this evidence-based synthesis,

the study contributes to a consolidated understanding of the current state of UCO-derived SAF, supporting efforts to scale renewable aviation fuel solutions and reduce lifecycle emissions across the aviation value chain.

#### 4. Results

The systematic literature review of 36 rigorously selected peer-reviewed articles reveals a broad yet interconnected landscape of research concerning the transformation of used cooking oil (UCO) into sustainable aviation fuel (SAF). These studies collectively highlight critical advancements across six thematic areas: (1) conversion technologies and processing methods, (2) hybrid energy harvesting techniques and integration models, (3) environmental and lifecycle impacts, (4) techno-economic viability and scalability, (5) policy frameworks and global regulatory responses, and (6) supply chain and feedstock logistics. A detailed thematic analysis of the reviewed literature indicates that the most prominent area accounting for 29% of the studies is conversion technologies and processing methods. This theme underscores the central role of refining pathways, particularly Hydro processed Esters and Fatty Acids (HEFA), in maximizing fuel yields and improving process efficiency. The second most emphasized theme, environmental and lifecycle impacts (21%), reflects the growing concern for carbon mitigation, emissions reduction, and alignment with global climate goals. Meanwhile, techno-economic viability and scalability, which account for 18% of the literature, address critical issues related to production costs, market competitiveness, and commercial feasibility at scale. Policy frameworks and regulatory instruments are featured in 14% of studies, underscoring the importance of governmental support, standardization, and traceability for enabling widespread adoption. The supply chain and feedstock logistics theme (11%) focuses on operational bottlenecks related to the sustainable collection, transport, and pre-treatment of UCO, particularly in emerging economies. Although comprising only 7% of the reviewed works, the theme of hybrid energy-harvesting techniques and integration models represents an emerging research direction, particularly in the context of embedding renewable energy sources, such as solar or biogas, into SAF production processes to enhance overall sustainability. The dominance of research on conversion technologies suggests a concerted effort to optimize UCO-to-SAF processes, particularly through mature, high-yield pathways such as HEFA. Simultaneously, the substantial attention to environmental and lifecycle assessments demonstrates the sector's alignment with aviation decarbonization targets. The growing focus on techno-economic aspects indicates increasing commercial interest and the necessity of viable business models for broader deployment. While policy frameworks and logistical systems receive comparatively less emphasis, they are pivotal to real-world implementation and system efficiency. The relatively limited coverage of hybrid energy integration reflects its early developmental stage, yet it signals a promising trajectory as the field evolves toward fully renewable energy ecosystems. Together, these

thematic patterns provide both a snapshot of current research priorities and a roadmap for future exploration in the domain of sustainable aviation fuel. The following sections examine each of these themes in greater detail, supported by empirical findings and contextual analysis.

##### 4.1. Conversion Technologies and Processing Methods

The reviewed literature identifies Hydro processed Esters and Fatty Acids (HEFA) as the dominant conversion pathway for UCO-to-SAF transformation, with commercial-scale refineries operating in countries such as the United States, Finland, and Singapore. HEFA is currently approved by ASTM D7566, allowing it to be blended with conventional Jet-A fuel up to 50% without engine modification. HEFA accounts for over 82% of UCO-derived SAF production globally, primarily due to its high yield (up to 80% by mass) and compatibility with existing refinery infrastructure [29-31]. Comparative analyses show that HEFA processes can reduce net GHG emissions by up to 83% relative to fossil-based jet fuel when powered by low-carbon hydrogen sources [32,33]. The average process energy requirement is estimated at 11–15 MJ/kg of fuel produced, with hydrogen consumption ranging from 30 to 60 g/L of SAF output [34,35]. Other experimental methods include catalytic pyrolysis, which operates at 450–550°C in the absence of oxygen, converting UCO into bio-crude that requires further upgrading. Although pyrolysis offers rapid thermal decomposition, its energy intensity remains a barrier, with overall energy efficiencies around 38%–52% [36,37]. Supercritical methanolysis and microwave-assisted transesterification show promise for decentralized applications, particularly in remote or low-infrastructure contexts, offering conversion rates exceeding 90% with reduced reaction time and catalyst use [38,39].

##### 4.2. Hybrid Energy Harvesting Techniques and Integration Models

A subset of studies focuses on hybrid systems integrating renewable energy sources into the SAF production chain to improve environmental performance. Solar-powered electrolysis units for green hydrogen production integrated with HEFA refineries can reduce cradle-to-gate emissions by 15%–22%, depending on solar irradiation and electrolyzers efficiency [40,41]. One techno-economic modeling study found that integrating a 1.5 MW solar photovoltaic system into a 50 million liters per year HEFA plant could reduce operating costs by approximately USD 1.2 million annually, assuming grid electricity offset prices of \$0.12/kWh [42,43]. Bio-refineries co-located with municipal solid waste (MSW) processing facilities further demonstrate efficiency through heat recovery and feedstock flexibility. For example, a hybrid biorefinery in Barcelona that utilizes UCO and organic waste achieved a waste-to-energy conversion efficiency of 64%, displacing 31,200 tons of CO<sub>2</sub> annually [44]. Additionally, anaerobic digestion systems paired with UCO biodiesel plants provide biogas for on-site heating, reducing reliance on fossil-derived utilities by up to 48% [45].

### 4.3. Environmental and Lifecycle Impacts

Environmental impact assessments across the literature converge on the conclusion that UCO-derived SAF significantly lowers carbon intensity and other emissions relative to fossil-based aviation fuels. Lifecycle analysis (LCA) results from 28 studies demonstrate GHG reductions ranging from 62% to 85%, with the variation primarily attributed to regional electricity grids, hydrogen source, and transport distances [46]. A comprehensive meta-review shows that, on average, UCO-to-SAF pathways achieve 72% lower CO<sub>2</sub>-equivalent emissions per MJ of fuel than Jet-A, with a 50-year global warming potential (GWP<sub>50</sub>) of 18–29 gCO<sub>2</sub>e/MJ [47]. Moreover, UCO feedstock use avoids 2.3–3.5 tons of waste oil disposal per million liters of SAF produced, thereby reducing the potential for soil and water contamination [48]. In terms of air quality co-benefits, HEFA SAF blends with 30% UCO content have demonstrated particulate matter (PM<sub>2.5</sub>) emission reductions of 38% and nitrogen oxides (NO<sub>x</sub>) reductions of 27% based on combustion trials in Rolls-Royce Trent 700 engines [49]. Water use intensity is also notably lower than that of first-generation biofuels. UCO requires approximately 200–300 liters of water per GJ of fuel produced, compared to 1,200–2,000 L/GJ for corn ethanol or palm-based biodiesel [50].

### 4.4. Techno-Economic Viability and Scalability

Economic modeling indicates that UCO-based SAF production is nearing price parity with fossil jet fuel under certain market conditions. The levelized cost of SAF (LC-SAF) from UCO ranges between USD 0.78 and USD 1.25 per liter, depending on hydrogen input prices, plant scale, and feedstock availability [51]. Feedstock costs contribute approximately 35%–50% of total production costs, with UCO collection prices ranging from USD 0.20 to USD 0.50 per liter, depending on geography and regulatory context [52]. Capital expenditures (CAPEX) for a mid-sized HEFA facility (100 million liters/year) are estimated at USD 220–280 million, with payback periods of 7–9 years under baseline assumptions [53]. A study by the International Energy Agency (IEA) estimates that global UCO availability could support up to 8 billion liters of SAF annually, enough to cover 4.8% of global aviation fuel demand by 2030 [54]. EU-focused studies predict that, if efficiently mobilized, national UCO reserves could offset between 1.5 and 4 million tons of CO<sub>2</sub> emissions per member state per year [55].

### 4.5. Policy Frameworks and Regulatory Instruments

Policy incentives have emerged as decisive enablers of the commercialization of UCO-based SAF. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) designates UCO as an eligible feedstock for emission-reduction credits, thereby encouraging its uptake by international carriers [56]. In the United States, UCO-based SAF qualifies for Renewable Identification Numbers (RINs) under the Renewable Fuel Standard (RFS), generating \$0.80–\$1.10 per liter in compliance credits [57]. Meanwhile, the EU Renewable Energy Directive (RED II) sets a 14% renewable energy target for transport by 2030, with a 1.7% cap on food-based biofuels, thereby indirectly incentivizing

UCO use [58]. Nonetheless, several studies emphasize the need for improved traceability and anti-fraud mechanisms, as mislabeling of virgin oils as UCO has occurred in high-demand markets such as China and the Netherlands [59]. Blockchain-enabled certification systems and satellite surveillance of supply networks are suggested to enhance transparency [60].

### 4.6. Supply Chain and Feedstock Logistics

The collection, preprocessing, and traceability of UCO pose major logistical challenges, particularly in developing regions. Cities such as Singapore and Amsterdam have achieved over 90% UCO collection efficiency through public-private partnerships and strict regulation, whereas others, such as Jakarta and Nairobi, report collection efficiencies below 30% due to infrastructure gaps and the dominance of the informal sector [61]. Transportation emissions account for 4%–12% of total life-cycle emissions, depending on the collection radius and mode of transport [62]. Pre-treatment energy demand for drying and filtration is estimated at 1.6–2.4 MJ/kg, highlighting the need for renewable energy integration at preprocessing sites [63]. Digital innovations, including IoT-based collection tracking, AI route optimization, and dynamic pricing, have been piloted in European cities to improve efficiency and reduce collection costs by 18%–24% [64]. The systematic synthesis of 36 high-quality research articles confirms the technical viability, environmental superiority, and growing policy support for UCO-based SAF. With current technologies such as HEFA approaching commercial maturity and hybrid energy systems enhancing sustainability, UCO represents a feasible near-term solution for decarbonizing aviation. Nonetheless, success at scale will require coordinated investment in collection infrastructure, transparent supply-chain governance, cost-competitive green hydrogen, and harmonized international policy frameworks. These findings provide a robust empirical foundation for stakeholders across academia, industry, and government aiming to advance sustainable aviation transitions.

## 5. Discussion

The research question guiding this systematic literature review is: What technological, environmental, economic, regulatory, and logistical factors influence the viability and scalability of used cooking oil as a sustainable feedstock for aviation fuel production? is addressed through a comprehensive synthesis of recent scholarly insights spanning multiple disciplines and geographies. Drawing on 36 peer-reviewed research articles published between 2023 and 2025, this section elaborates on the key themes shaping the transition of used cooking oil (UCO) into a viable, scalable feedstock for sustainable aviation fuel (SAF).

### 5.1. Technological Feasibility and Innovation

Technological pathways for converting UCO to SAF have seen rapid evolution. Among the most mature and commercially implemented technologies is Hydro processed Esters and Fatty Acids (HEFA), which remains the primary conversion method due to its compatibility with existing infrastructure

and ability to produce drop-in fuels with properties nearly identical to conventional Jet A-1. HEFA-derived SAF from UCO has demonstrated energy densities of approximately 42.8 MJ/kg, comparable to those of fossil jet fuel, with conversion efficiencies of 60%-75% [65]. Alternative technologies, such as pyrolysis and hydrothermal liquefaction, are under study for their potential to improve yields and reduce process emissions, although they remain less mature. Catalytic advancements have also been observed, particularly the development of heterogeneous catalysts that improve reaction specificity and reduce byproduct formation. Moreover, digital optimization techniques, such as AI-assisted process control, have been explored to enhance process efficiency and predict output quality based on variable UCO input compositions [66]. Modular bioreactor designs are another emerging innovation, enabling decentralized SAF production in urban or peri-urban zones where UCO is most abundantly collected.

### 5.2. Environmental Impact and Life Cycle Emissions

Life Cycle Assessment (LCA) studies indicate that UCO-based SAF significantly reduces greenhouse gas (GHG) emissions compared to conventional fossil jet fuel. Emission savings typically range from 60% to 90%, depending on the energy inputs and geographic location of production [67]. For instance, one study found that SAF derived from UCO via HEFA in Europe results in GHG emissions as low as 16 gCO<sub>2</sub>e/MJ, compared to 89 gCO<sub>2</sub>e/MJ for fossil-based jet fuel [68]. The carbon neutrality of UCO is a pivotal factor, given that it is a waste-derived feedstock that does not require additional land-use changes or deforestation. This advantage also circumvents the indirect land-use change (ILUC) penalties associated with other biofuels, such as palm oil [69]. In addition to mitigating GHG emissions, UCO use reduces wastewater loads resulting from improper disposal. When diverted from drainage systems and repurposed as a feedstock, UCO helps minimize urban waste and improve public health outcomes in densely populated areas [70].

### 5.3. Economic Viability and Cost Drivers

The economic feasibility of UCO-derived SAF is influenced by several key parameters, including feedstock collection costs, conversion efficiency, subsidy schemes, and market demand. The average cost of producing HEFA-SAF from UCO is currently estimated between USD 1.20–2.10 per liter, higher than conventional jet fuel (USD 0.80/liter), but within a competitive range when carbon pricing or blending mandates are applied [71]. Feedstock costs account for approximately 30–45% of the total SAF production cost. Urban centers with established UCO collection infrastructure, such as Singapore and Amsterdam, report lower feedstock prices due to economies of scale and efficient logistics [72]. Additionally, economies of scale in conversion facilities further reduce per-liter SAF costs by up to 20% [73]. On the demand side, airlines in the EU and North America are increasingly entering into long-term offtake agreements to secure SAF supply ahead of tightening carbon regulations, thereby improving investor confidence in UCO-to-SAF ventures [74].

### 5.4. Regulatory Framework and Policy Support

Policy environments significantly influence UCO-SAF's scalability. The Renewable Energy Directive II (RED II) of the European Union recognizes UCO as an advanced biofuel feedstock and provides double-counting benefits for SAF quota compliance [75]. Similarly, the U.S. Inflation Reduction Act offers tax credits of up to USD 1.75 per gallon for SAF that meet emission-reduction thresholds, directly incentivizing UCO utilization [76]. However, regulatory clarity is inconsistent across regions. Some developing countries still lack standardized definitions of waste oils, which creates challenges for cross-border UCO trade and certification [77]. Additionally, sustainability certification schemes (e.g., ISCC, RSB) vary in their treatment of waste-derived feedstocks, necessitating harmonization to streamline global SAF deployment [78].

### 5.6. Logistical Challenges and Infrastructure Needs

Logistical factors present both opportunities and bottlenecks for UCO-to-SAF scalability. Collection systems vary significantly between countries. While the EU and Singapore have structured UCO collection programs that involve both households and food businesses, in much of Asia and Africa, informal collection systems predominate, resulting in inconsistent volumes and quality [79]. Storage and transport infrastructure also impact overall feasibility. UCO is susceptible to degradation if improperly stored, which can compromise SAF yield and quality. Temperature-controlled, sealed storage containers are increasingly being recommended in industry best practices [80]. Additionally, the absence of SAF-dedicated airport infrastructure, such as on-site blending or hydrant distribution, adds logistical complexity. Initiatives such as the "Book and Claim" model, which decouples SAF benefits from physical fuel delivery, have been proposed to overcome this limitation in the short term [81]. This review identifies several cross-cutting insights. First, UCO is technologically feasible and environmentally superior to most other SAF feedstocks, offering substantial GHG-reduction potential without competing for arable land. Second, economic and regulatory enablers are increasingly making UCO-to-SAF commercially viable, particularly in regions with robust waste-collection systems and incentive structures. However, scalability remains contingent upon harmonized global standards, more advanced decentralized processing technologies, and public-private coordination in UCO collection. For policymakers, the implications are clear: supportive regulations, harmonized certification schemes, and infrastructure investments are crucial to mainstreaming UCO-based SAF. For industry actors, integrating AI-enabled logistics and forming long-term offtake agreements can help de-risk investments. Future research should explore hybrid feedstock models that integrate UCO with other advanced lipid sources to mitigate volume constraints. Additionally, techno-economic assessments of decentralized, modular SAF production units in urban regions could uncover new opportunities for circular energy systems. By addressing these technological, environmental, economic, regulatory, and logistical dimensions, this study contributes to a more holistic understanding of UCO's role in decarbonizing

aviation, a critical sector in the global net-zero transition.

## 6. Conclusion

The evidence synthesized in this systematic review underscores the promise of UCO as a reliable, large-scale feedstock option for sustainable aviation fuel development. In terms of technological maturity, HEFA stands out in the SAF industry for its seamless integration with existing infrastructure and its ability to achieve fuel yields of up to 85%. Alternative conversion methods, such as pyrolysis and catalytic cracking, offer additional pathways, though challenges remain in optimizing processes and ensuring consistent fuel quality. Environmentally, UCO-based Sustainable Aviation Fuel (SAF) consistently demonstrates superior greenhouse gas (GHG) reduction performance compared to conventional Jet-A fuel, with average lifecycle emissions ranging from 18 to 30 gCO<sub>2e</sub>/MJ. This represents a reduction of more than 70% compared to fossil-derived aviation fuels. Furthermore, the use of waste-based feedstock, such as UCO, aligns with the principles of the circular economy and mitigates the environmental risks associated with direct land-use change (LUC), which commonly affect crop-based biofuels. Economically, although UCO-SAF production remains more expensive than fossil jet fuel, with estimated costs ranging from USD 0.80 to 1.20 per liter, supportive regulatory frameworks and market-based incentives, such as carbon pricing and tax credits (e.g., LCFS, RED II), have proven effective in improving its commercial viability. However, long-term financial sustainability will depend on further technological maturity, supply chain optimization, and economies of scale. From a regulatory standpoint, harmonizing international sustainability certification schemes (e.g., ISCC, RSB, CORSIA) plays a critical role in enabling UCO-SAF to penetrate global markets. These standards ensure traceability, environmental integrity, and social safeguards across the entire supply chain. National mandates and blending targets, especially in Europe and North America, are also accelerating the deployment of SAF technologies, but regional disparities in policy implementation persist. Logistically, the primary challenges lie in the fragmentation of UCO collection systems, the lack of centralized aggregation points, and the presence of adulterated or low-quality waste oil streams. These factors hinder consistent supply flows and increase pretreatment costs. Nonetheless, recent advancements in blockchain-based traceability systems, digital monitoring tools, and cooperative collection models have demonstrated promising potential to streamline UCO logistics and improve transparency. In summary, UCO-based SAF offers a technically feasible, environmentally advantageous, and increasingly cost-competitive solution for decarbonizing the aviation sector. Its successful integration into national and international energy strategies depends on the confluence of innovation in conversion technologies, robust policy frameworks, logistical advancements, and sustained multi-stakeholder cooperation. Future research should continue to explore hybrid feedstock approaches, regional supply chain modeling, and long-term climate impacts under varied deployment scenarios.

**JEL Classifications:** Q42 (Alternative Energy Sources), Q28 (Government Policy), Q54 (Climate; Natural Disasters; Global Warming), L93 (Air Transportation), R41 (Transportation: Demand, Supply, and Congestion)

**Contribution/originality:** This study provides a PRISMA-based systematic literature review that synthesizes evidence on used cooking oil as a sustainable aviation fuel feedstock, integrating technological readiness (HEFA and alternatives), lifecycle environmental performance, techno-economic feasibility, policy/regulatory instruments, and logistics/traceability challenges to clarify scalability pathways for stakeholders.

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