

Soap Manufacturing from Waste Cooking Oil: A Review of Processes, Quality, Sustainability and Future Prospects

Dr. Suraksha Narang

Assistant Professor, Department of Family and Community Resource Management, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India

Abstract-- Waste cooking oil (WCO) has become an important environmental and public health concern because of its improper disposal and unsafe reuse. Although considerable research has focused on converting WCO into biodiesel, its potential for soap manufacturing has received far less attention, despite offering a simple, low-cost, and sustainable waste-to-resource alternative. This paper reviews the literature on using WCO for soap production, with particular emphasis on its environmental, economic, and circular economy implications in the Indian context. Drawing on peer-reviewed journal articles, technical reports, and policy documents published mainly between 2010 and 2026, the paper summarises what previous researchers have reported about the physicochemical changes that occur during repeated frying, the purification and saponification methods used to convert WCO into soap, the reported quality of the resulting soap, and its environmental, economic, and social implications. The literature indicates that, with appropriate purification and saponification techniques, WCO can be successfully converted into quality soap while reducing waste disposal and promoting more efficient use of natural resources. Past studies also highlight the potential of WCO-based soap production to support micro, small, and medium enterprises (MSMEs), self-help groups (SHGs), and household-level enterprises by creating value from an otherwise discarded resource. Despite these encouraging findings, the literature also points to important gaps, particularly in life cycle assessment, consumer acceptance, rural implementation, and the development of sustainable business models for the Indian context. Drawing together this body of past work, the paper outlines a conceptual understanding of WCO collection, processing, and soap manufacturing within a circular economy perspective, and suggests directions for future research and policy. The discussion is intended to provide useful insights for researchers, policymakers, entrepreneurs, and practitioners working towards sustainable waste management and resource-efficient manufacturing.

Keywords — Waste cooking oil; soap manufacturing; saponification; circular economy; RUCO; waste valorization.

I. INTRODUCTION

The growing demand for processed and fried foods, and the expansion of commercial food services, have led to a sharp rise in edible oil consumption across the world.

An unavoidable consequence of this trend is the increasing generation of waste cooking oil (WCO), also known as used cooking oil (UCO). Large quantities of WCO are produced every day from households, restaurants, hotels, food-processing industries, and institutional kitchens. Past studies generally describe it as vegetable or animal oil that is no longer fit for human consumption because repeated frying causes physical and chemical deterioration [1,2].

Earlier research shows that once cooking oil is exposed to high temperatures for prolonged periods, its composition begins to change. Oxidation, hydrolysis, polymerization, and thermal degradation occur simultaneously, leading to the formation of free fatty acids, peroxides, aldehydes, ketones, polymeric compounds, and total polar compounds. As these compounds accumulate, the oil gradually loses its original colour, odour, viscosity, and nutritional quality. Several studies have also linked the repeated consumption of degraded cooking oil with adverse health outcomes, including cardiovascular diseases, hypertension, liver disorders, cancer, and other chronic illnesses [3,4].

The problem extends beyond food safety. Previous research points to improper disposal of WCO as a significant environmental concern in many parts of the world. Oil discharged into drains, sewage systems, rivers, or soil interferes with wastewater flow, increases treatment costs, contaminates water bodies, and damages soil quality. Because WCO is insoluble in water, it tends to accumulate inside drainage systems, creating blockages and affecting aquatic ecosystems. Many developing countries continue to face additional challenges because organised systems for collecting and transporting WCO are either inadequate or absent.

These environmental concerns have shifted researchers' attention towards waste valorization. Rather than treating WCO simply as a waste product, recent literature increasingly frames it as a resource that can be recovered and converted into useful materials through chemical, biological, or thermal processes. Recent reviews describe a wide range of products derived from WCO, including biodiesel, sustainable aviation fuel, lubricants, surfactants, biosurfactants, polyurethanes, alkyd resins, plastics, hydrogen, and soaps [5].



Recovering WCO in this way reduces environmental pollution while decreasing dependence on virgin raw materials.

This approach also reflects the broader principles of the circular economy discussed in past literature. Instead of following the traditional "use and dispose" model, the circular economy promotes the continued use of resources through reuse, recycling, recovery, and regeneration. Converting WCO into value-added products not only helps reduce waste but also creates new economic opportunities by transforming a discarded material into a commercially useful resource. As a result, WCO valorization contributes simultaneously to environmental protection, resource conservation, and green entrepreneurship.

Although many products can be manufactured from WCO, biodiesel has received the greatest attention from both researchers and industry. Recent review articles, however, have pointed out that this strong emphasis on biofuel has often diverted attention from other promising applications. Olu-Arotiowa et al. observed that most published studies continue to focus on biodiesel even though products such as soaps, lubricants, biosurfactants, and biodegradable polymers also offer considerable potential. Kumar et al. similarly identified soap manufacturing as an increasingly important and sustainable alternative within the broader WCO valorization literature.

Among the available options, previous studies suggest that soap production has several practical advantages. Unlike biodiesel manufacture, it relies on a relatively simple saponification process and generally requires less sophisticated equipment, lower capital investment, and simpler operating conditions. These features make WCO-based soap production suitable not only for industrial units but also for households, self-help groups, community organisations, and micro-enterprises. Consequently, past authors have argued that soap manufacturing has considerable potential as a decentralised waste management strategy that can support local circular economy initiatives.

Evidence from experimental studies conducted in Africa, Asia, and Europe shows that this approach is technically feasible [6,9]. Properly purified WCO has been successfully converted into soaps that satisfy recognised physicochemical quality standards. Researchers have examined different purification methods, optimised saponification conditions, and incorporated natural additives such as orange peel, spent coffee grounds, and *Phytolacca dodecandra*. These studies report satisfactory cleansing performance, acceptable physicochemical properties, and, in some cases, improved antioxidant characteristics.

Overall, the available evidence demonstrates that purified WCO can serve as an effective alternative raw material for soap production.

The potential benefits reported in past work are not limited to product quality alone. Community-based initiatives described in the literature have shown that WCO-derived soap production can increase environmental awareness, strengthen practical skills, encourage entrepreneurship, and create livelihood opportunities, particularly for women, students, and local communities. Since the production process is comparatively simple and inexpensive, it is well suited to small-scale enterprises and community-level manufacturing.

Despite these encouraging findings, the available literature remains fragmented. Reviews dedicated to soap production primarily discuss technical and experimental aspects, whereas broader WCO valorization reviews continue to focus largely on biodiesel and other energy applications. Consequently, environmental, economic, policy, and circular economy perspectives have rarely been examined together in a single review. This gap is particularly noticeable in the Indian context. India generates large quantities of WCO, has introduced the Repurpose Used Cooking Oil (RUCO) initiative, and possesses an extensive network of Micro, Small and Medium Enterprises (MSMEs) and women's Self-Help Groups (SHGs) that could support decentralised soap production. Nevertheless, very few studies have considered these factors together.

This paper addresses this gap by bringing together, in narrative form, the available evidence on the use of waste cooking oil for sustainable soap manufacturing. It summarises what previous studies have reported on the physicochemical changes that occur during repeated frying, reviews the purification and saponification methods described in the literature, discusses reported soap quality and its environmental, economic, and social implications, and reviews the policy landscape with particular emphasis on India. By bringing together technical evidence with circular economy and policy perspectives drawn from prior research, the review offers a broader understanding of WCO-based soap manufacturing and identifies areas where further research and implementation are needed.

II. APPROACH AND SCOPE OF THIS REVIEW

This paper is a general, narrative review of the published literature on waste cooking oil and soap manufacturing rather than a systematic review or meta-analysis.

It draws on peer-reviewed journal articles, review papers, conference proceedings, and relevant government or institutional reports published mainly between 2010 and 2026, located through academic databases such as Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar, and supplemented by tracing citations within related review papers. Sources were considered relevant if they discussed waste cooking oil as a feedstock for soap manufacturing, saponification, purification, physicochemical soap quality, waste valorization, circular economy principles, environmental or economic outcomes, or related policy issues, whether from an Indian or international perspective.

Rather than applying a formal, pre-registered protocol for study selection, screening, and data extraction, as would be expected in a systematic review, the sections that follow synthesise the findings, arguments, and conclusions reported by previous authors and organise them thematically. The aim is to build a coherent, narrative picture of what the existing literature says about WCO-based soap manufacturing, the strength and limits of that evidence, and the gaps that remain — particularly in relation to India.

III. WCO AS A FEEDSTOCK FOR SOAP MANUFACTURING: WHAT PAST STUDIES REPORT

A. Why soap-making is described as a simpler valorization pathway

Several authors contrast soap-making with biodiesel production on technical grounds. Biodiesel production via transesterification requires feedstock with a comparatively low and consistent free fatty acid (FFA) content, together with catalyst systems, methanol recovery, and purification infrastructure that are sensitive to the compositional heterogeneity of WCO^[11]. Saponification, by contrast, has been reported to tolerate a wider range of FFA content and oxidation states, requiring only an alkali (NaOH or KOH), water, and basic heating or mixing equipment, and generating no problematic by-product streams beyond glycerol, which remains in the soap matrix in cold-process formulations^[12]. Past studies attribute this lower technical barrier to why soap-making has been demonstrated successfully at household, informal-sector, and small-institutional scale — including community-service and boarding-school settings in Indonesia^[3] and small private enterprises repurposing WCO domestically in Ethiopia^[13].

B. Physicochemical quality evidence reported in previous studies

Several experimental studies report that soaps produced from waste cooking oil generally meet quality standards for total fatty matter (TFM), pH, moisture content, and total alkali, although results differ depending on the type of WCO, the purification process, and the alkali used, as summarised in Table 1.

TABLE I
COMPARATIVE PHYSICOCHEMICAL QUALITY PARAMETERS OF WASTE COOKING OIL-BASED SOAP WITH ISO/EAS REFERENCE STANDARDS

Parameter	Adane (2020), Ethiopia — NaOH, restaurant/hotel/street-vendor WCO	Zayed et al. (2024), Czech Republic — cold process, NaOH	Hartini et al. (2021), Indonesia — KOH, liquid dish soap	ISO/EAS reference benchmark
pH	9.31–10.56	10.25–10.38	pH lowered by 22.5% KOH + cold method	9.0–11.0 (skin/fabric-friendly range)
Total fatty matter (TFM)	75.42–88.53%	90.61–91.90%	not reported	≥76% (ISO Grade 1)
Moisture content	6.67–14.47%	4.10–5.87%	not reported	≤30% (EAS laundry soap)
Total alkali	0.78–1.09%	0.00% (below detection)	lower with cold method + 22.5% KOH	≤2% (ISO)
Free/catalytic alkali	0.19–0.22%	—	—	≤0.2% (EAS)

Studies carried out in Ethiopia, the Czech Republic, and Indonesia used different purification methods, alkalis, and soap-making procedures, yet arrived at broadly similar conclusions. In each of these studies, purified waste cooking oil was successfully converted into soap that met ISO Grade 1–2 and regional quality standards such as EAS and SNI. Although the production methods reported were not identical, the findings consistently indicate that waste cooking oil can serve as a suitable raw material for soap manufacture.

The reviewed studies also indicate that reported soap quality is influenced by both the source of the waste cooking oil and the production process. Adane (2020) observed that soap prepared from street-vendor waste cooking oil had better cleansing performance than soap produced from hotel-sourced oil, which showed only medium cleansing ability, and suggested that these differences were related to the previous use and condition of the oil before collection. Rahayu et al. (2021) similarly found that changing the sodium hydroxide concentration affected the consistency of the final product: soap prepared with 10% NaOH remained liquid, 30% NaOH produced a semi-solid product, whereas 50% NaOH resulted in a firm soap bar. Taken together, these findings from past studies show that good-quality soap cannot be produced using a single fixed formulation; instead, the amount of alkali and the quality of the waste cooking oil need to be considered carefully—a point of particular relevance if standardised production methods are to be developed for MSMEs and informal-sector producers in India ^[14].

C. Purification methods and additive innovations described in the literature

A common finding across the reviewed community-based and applied studies is that waste cooking oil requires purification before soap production to improve its colour and remove rancid odour. Purification methods using low-cost adsorbents, such as sugarcane bagasse and orange peel, have been reported to produce clearer oil with better sensory quality, making it more suitable for soap manufacturing ^[3]. Accordingly, several studies have investigated low-cost agricultural-waste adsorbents as purification aids, including activated charcoal from sugarcane bagasse ^[14], bagasse combined with orange peel ^[3], and, in a further step, orange peel and spent coffee grounds incorporated directly into the finished soap rather than used only as a bleaching aid ^[9]. This last study found that adding orange peel and spent coffee grounds increased the antioxidant activity of the soaps, as measured by the ABTS assay, with soaps containing spent coffee grounds showing the highest flavonoid content.

Although the additives reduced the hardness of the soap bars in that study, they did not show a consistent effect on key quality parameters such as TFM, total alkali, moisture content, pH, or foam stability. These findings, drawn from past research, suggest that agricultural wastes such as orange peel and spent coffee grounds can be incorporated into soap formulations to improve functional properties without compromising basic quality requirements — an approach with clear relevance to India given the abundant availability of agricultural residues such as citrus peel, sugarcane bagasse, and spent coffee grounds.

D. Life-cycle and economic evidence from past research

Only one of the studies located for this review subjected WCO-to-soap conversion to a formal life-cycle assessment. Hartini et al. (2021) reported that the recycling process had its greatest environmental impacts in the climate change and acidification categories, primarily due to electricity consumption during processing. Their life-cycle assessment estimated an eco-cost of IDR 1,264 for producing 360 g of liquid dish soap from 100 g of waste cooking oil. When combined with the net economic value of the product, the process achieved an Eco-efficiency Index (EEI) of 1.31, which the authors classified as "affordable and sustainable", indicating that the economic benefits outweighed the associated environmental costs ^[15]. Among the studies reviewed here, this is the only one providing a quantitative assessment of environmental performance. Its findings should nonetheless be interpreted with caution: the analysis was based on a small-scale production system that assumed no labour or marketing costs, which does not reflect commercial manufacturing conditions, and the functional unit of 100 g of waste cooking oil represents a very small production scale that may not accurately reflect the environmental performance of larger or municipal recycling programmes.

E. Limitations of the existing literature

The literature this review draws on is skewed toward laboratory-scale and small community-based interventions; none of the soap-specific studies located report data from commercial-scale production, formal supply-chain logistics, or consumer market testing beyond internal or institutional use. Sample sizes in the experimental soap-quality studies are small (typically single-batch triplicates), and testing protocols, while broadly aligned with AOCS/ISO methods, are not fully harmonised across studies — different alkalis (NaOH vs KOH), different maturation periods, and different reference standards (EAS, SNI, ISO) make direct quantitative comparison difficult.

Geographically, the primary experimental evidence located originates from Ethiopia, Indonesia, and the Czech Republic rather than India itself; Indian-specific soap-quality data are, at the time of this review, largely absent from the peer-reviewed literature, and observations made in Section 5 regarding Indian applicability are therefore extrapolated from comparable developing-economy contexts rather than drawn from in-country experimental studies. This is itself a significant research gap, discussed further in Section 6.

F. Sustainability themes emerging from past studies

Taken together, the studies reviewed here point to a triple-bottom-line case for WCO-derived soap as a circular-economy intervention. Environmentally, past research indicates that it diverts oil from drains and landfill and, per the only available LCA [15], does so with a favourable eco-efficiency ratio despite non-trivial climate and acidification impacts from processing energy. Economically, previous studies suggest that it substitutes a near-zero-cost waste feedstock for imported palm oil or animal fat, the conventional soap-industry inputs whose supply is increasingly contested by competing biodiesel demand [6]. Socially, the community-based interventions reviewed here [14,15] report that the technology transfers successfully to non-specialist users — students, self-help groups, and small entrepreneurs — with reported skill-uptake rates above 80% in post-training evaluation, though these same studies caution that translating internal or institutional soap production into a tradeable, market-ready product (attractive packaging, consistent branding, quality certification) remains an unresolved final step even where the underlying chemistry is sound.

IV. SWOT THEMES DRAWN FROM THE LITERATURE

Synthesising the strengths, weaknesses, opportunities, and threats identified across the studies reviewed above helps to situate WCO-based soap manufacturing within the broader valorisation landscape, and is summarised in Table 2.

TABLE II
SWOT ANALYSIS OF WASTE COOKING OIL-BASED SOAP PRODUCTION AND VALORISATION

Strengths	Weaknesses
Near-zero-cost, abundant feedstock; substitutes imported palm oil/tallow	FFA content and degradation state vary with reuse frequency and food type, directly affecting soap TFM and cleansing power
Tolerates a wider FFA range than transesterification — needs no methanol, specialised	Alkali concentration and process type (hot vs cold, NaOH vs KOH) must be precisely controlled, e.g.

catalyst, or high-pressure equipment	10% NaOH yields unusable liquid soap
Demonstrated to meet ISO/EAS/SNI quality grades across independent studies on three continents	Unpurified WCO yields soap with poor colour/odour acceptability even when chemically within spec
Compatible with co-valorisation of other waste streams (citrus peel, spent coffee grounds, sugarcane bagasse) for added antioxidant value	No India-specific experimental soap-quality dataset exists in the current literature
Positive eco-efficiency index (1.31) in the one available LCA — economically viable even after internalising environmental cost	LCA evidence limited to a single small-batch Indonesian study; not yet validated at scale or for Indian energy-grid conditions
Opportunities	Threats
RUCO's existing WCO-collection infrastructure could be extended beyond biodiesel to soap, at far lower marginal capital cost	Biodiesel and other high-value pathways (bio-jet fuel, biolubricants) compete for the same WCO feedstock and currently receive greater policy and research attention
Growing Indian market segment for natural/handmade soap could absorb a differentiated, antioxidant-enriched WCO-soap product	No dedicated Indian quality standard exists for WCO-derived soap specifically (distinct from BIS IS 2888 for general toilet soap)
Skill-transfer model demonstrated in community settings is directly transferable to Indian self-help groups, ITIs, and municipal skill-development schemes	Consumer perception risk: recycled-oil soap may be perceived as lower-quality or unsafe absent clear certification and communication
Co-processing with India's large citrus and coffee-processing waste streams could differentiate product and add antioxidant functionality at negligible cost	Fragmented, informal WCO collection in India (particularly at household level) constrains consistent feedstock supply for any standardised production model

Read together, this synthesis suggests that the main challenges to producing soap from waste cooking oil, as reported in past studies, are no longer primarily about the soap-making process itself. Instead, the recurring barriers identified in the literature are the lack of India-specific quality data, the absence of dedicated regulatory standards, and limited systems for collecting waste cooking oil. Across the studies reviewed, the saponification process itself is consistently reported to be technically reliable when appropriate production methods are followed.

V. THE INDIAN PERSPECTIVE IN THE LITERATURE

India is described in past literature as one of the major generators of waste cooking oil (WCO), producing several million tonnes every year. Previous studies attribute this to the country's large population, growing consumption of edible oil, extensive street-food culture, and expanding quick-service restaurant sector^[15,16]. Even so, much of the collected WCO is reported to still be repeatedly used for frying or disposed of through informal channels — practices that past research links to contamination of drainage systems, soil, and water bodies^[19].

An important step towards addressing this problem, noted repeatedly in the literature, has been the Repurpose Used Cooking Oil (RUCO) initiative introduced by the Food Safety and Standards Authority of India (FSSAI). Previous accounts describe how the programme established a network of authorised aggregators to collect used cooking oil from food business operators and prevent its re-entry into the food chain. Although RUCO was originally developed to support biodiesel production, the revised guidelines also allow soap manufacturers to register as authorised non-food production units, making it possible to use the existing collection network for more than one recycling pathway. Based on the studies reviewed in this paper, soap production has the potential to complement biodiesel, since the manufacturing process is comparatively simple and requires less capital investment, and some batches of WCO that may not be suitable for biodiesel can still be converted into soap through saponification, allowing better utilisation of the collected resource^[20,21].

Several authors suggest that the availability of an established collection network means that expanding WCO-based soap production in India may not require an entirely new system. Instead, the existing RUCO framework could, in principle, be used more effectively by connecting it with soap manufacturers, particularly small enterprises, self-help groups, and community-based organisations. Since soap production involves relatively simple technology and modest investment, it has been argued to be well suited to decentralised manufacturing, and could contribute to the objectives of national programmes such as the Swachh Bharat Mission, Startup India, Skill India, and Atmanirbhar Bharat.

Despite these encouraging prospects described in the literature, a number of issues are consistently flagged as still needing resolution before WCO-based soap production can be adopted on a larger scale in India.

One frequently noted limitation is the absence of a dedicated Indian standard for soap produced from waste cooking oil; the current Bureau of Indian Standards specification for toilet soap (IS 2888) was developed for conventional raw materials and does not consider the variability associated with recycled feedstocks. Past studies suggest that the physicochemical properties reported internationally should be verified using Indian WCO samples before national standards can be formulated.

Another challenge repeatedly identified in the literature lies in the collection of household waste cooking oil. At present, RUCO mainly focuses on commercial and institutional sources, while household collection remains limited; a similar gap has also been reported in studies from Indonesia and Ethiopia^[24]. In addition, no published experimental study located for this review has yet evaluated the physicochemical quality of soap prepared from Indian waste cooking oil. Consequently, the discussion in this paper is based largely on evidence from other developing countries with broadly comparable conditions, and generating experimental data under Indian conditions is identified as an important next step for validating these findings.

VI. RESEARCH GAPS AND FUTURE DIRECTIONS IDENTIFIED IN THE LITERATURE

Based on the findings and limitations reported across the reviewed studies, five key research priorities emerge from the literature. First, several authors point to a need for India-specific experimental studies evaluating soaps produced from waste cooking oil against BIS IS 2888 standards and key physicochemical quality parameters, using WCO collected from Indian hotels, restaurants, and street-food vendors, since the composition of waste cooking oil may vary across countries due to differences in edible oil consumption patterns. Second, the literature suggests that future research should extend techno-economic and life-cycle assessment beyond the laboratory-scale conditions reported by Hartini et al.^[15], whose eco-efficiency study assumed zero labour cost; future analyses that consider realistic labour costs, commercial production conditions, and India's electricity-grid characteristics would provide a more reliable basis for assessing environmental and economic viability at scale.

Another area consistently flagged in past studies is the development of standardised purification methods suitable for Indian conditions.

The reviewed studies demonstrate that adsorbents such as sugarcane bagasse, orange peel, and activated carbon can reduce free fatty acid content and improve the colour of waste cooking oil before soap production ^[14,15]; however, comparable evidence is not yet available for agricultural residues that are abundant in India, including rice husk and groundnut shell, and evaluating these materials could help identify cost-effective purification options for domestic production.

Consumer acceptance and market feasibility also require greater attention according to the community-based studies reviewed here. These studies show that waste cooking oil can be converted into good-quality soap, while also highlighting practical issues related to packaging, product presentation, and marketing that may influence commercial adoption ^[3]. Understanding consumer preferences and purchasing behaviour is therefore identified as important before wider implementation can be achieved.

The literature also points to opportunities for integrating waste cooking oil with other organic waste streams. Zayed et al. ^[9], for example, reported that incorporating orange peel and spent coffee grounds into soap formulations improved antioxidant properties without adversely affecting major quality parameters; similar strategies could be explored using India's abundant agricultural and food-processing residues, expanding the circular economy benefits beyond the utilisation of waste cooking oil alone.

VII. CONCLUSION

The literature reviewed here, drawn from independent studies conducted in Ethiopia, Indonesia, and the Czech Republic and spanning both hot- and cold-process saponification with NaOH and KOH, converges on a broadly consistent conclusion: appropriately purified waste cooking oil is reported to reliably yield soap meeting recognised ISO, EAS, and SNI quality thresholds for pH, total fatty matter, and total alkali (Table 1), while offering markedly lower capital and technical barriers than biodiesel production. Because this conclusion is repeated across geographically and methodologically distinct studies, it rests on a broader evidentiary base than any single study could provide on its own.

What the existing literature does not yet establish is India-specific validation. RUCO provides an institutional foundation that could, in principle, be extended to soap manufacturing at low marginal cost, aligning with Swachh Bharat, Skill India, and Atmanirbhar Bharat objectives; but on the evidence reviewed here this remains a policy opportunity rather than a demonstrated one, since no Indian experimental soap-quality dataset yet exists in the literature and no dedicated regulatory standard addresses recycled-oil

soap specifically. The one life-cycle assessment located for this review offers encouraging evidence of the environmental and economic potential of recycling waste cooking oil into soap, but it was based on a small laboratory-scale production system and has not yet been validated under the production scale, cost structure, or operating conditions relevant to commercial deployment in India ^[15].

On the basis of this review, the path towards realising WCO-derived soap's potential in India appears to run through the research gaps identified in Section 6 rather than through further chemistry: benchmarking Indian WCO against the international quality evidence summarised here, conducting techno-economic assessment under realistic, non-subsidised-labour conditions, and — as several community-based studies independently concluded — addressing the market-readiness challenge of packaging, certification, and consumer trust that currently separates a technically sound product from a commercially viable one.

A. Overview of Key Studies Discussed in this Review

Table 3 summarises the studies most closely engaged with in the preceding discussion, to help orient readers to the primary sources of evidence this review draws upon.

TABLE III
REVIEW OF PUBLISHED STUDIES ON WASTE COOKING OIL–BASED SOAP PRODUCTION AND VALORISATION

Study (Author, Year, Country)	Type	What the study reports
Adane (2020), Ethiopia	Experimental	Prepared laundry soap from hotel-, restaurant-, and street-vendor-sourced WCO using NaOH; cleansing performance varied with the source and prior condition of the oil, and all samples met EAS/ISO quality limits.
Rahayu et al. (2021), Indonesia	Experimental	Converted WCO into soap at three NaOH concentrations; found that alkali concentration determined whether the product was liquid, semi-solid, or a firm bar.
Mahmudah & Shofiah (2023), Indonesia	Applied / community-service	Trained students to produce soap from boarding-school WCO through despicping, neutralisation, and bleaching; reported high success and skill-uptake rates among non-

		specialist participants.
Zayed et al. (2024), Czech Republic	Experimental	Incorporated orange peel and spent coffee grounds into WCO-based soap; additives increased antioxidant activity without compromising core quality parameters.
Hartini et al. (2021), Indonesia	Life-cycle assessment / eco-efficiency	Only identified LCA of WCO-to-soap conversion; reported a positive eco-efficiency index (1.31) for a small-scale liquid dish-soap production system.
Bahabelom et al. (2023), Ethiopia	Experimental	Combined WCO with Phytolacca dodecandra (endod) to produce high-grade laundry soap with favourable saponification characteristics.
Beghetto (2025)	Critical review	Surveyed strategies for converting WCO into high-value products, situating soap-making as one lower-barrier pathway within a wider valorisation landscape dominated by biodiesel.
Melikoglu (2026)	Global review (bibliometric)	Reviewed WCO valorisation pathways worldwide; confirmed India and China among the largest WCO-generating countries but found soap-making rarely quantified separately from biodiesel-focused research.
Kumar et al. (2025)	Review	Discussed challenges, current developments, and life-cycle considerations in WCO valorisation broadly, reinforcing the continuing dominance of biodiesel in the literature.
Olu-Arotiowa et al. (2022)	Review	Reviewed environmental impacts and valorisation routes for WCO, noting that non-fuel applications such as soap remain comparatively understudied.

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