# Lifecycle Assessment of Bioenergy Production from Waste Cooking Oil: A Review and Case Study

*Chun Lim* Siow[1*], *Amin Santo* Istiyak[1], *Yee Ho* Chai[2], *Razali* Nur Mazlini[3] and *Yusoff* Lukeman[4]

[1]COE Robotics & Sensing Technologies, Multimedia University, 63100 Cyberjaya, Selangor, Malaysia
[2]Institute of Sustainable Energy and Resources Sciences, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia
[3]Universiti Tenaga Nasional (UNITEN), Putrajaya Campus, Jalan Kajang - Puchong, 43000 Kajang, Selangor, Malaysia
[4]Universiti Kuala Lumpur Malaysia France, Institute Section 14, Jalan Damai, Seksyen 14, 43650 Bandar Baru Bangi, Selangor

**Abstract.** This paper presents a comprehensive review of the life cycle assessment (LCA) of biofuel production from waste cooking oil (WCO). It consolidates previous findings on greenhouse gas (GHG) emissions, revealing that WCO-based biofuels can achieve a minimum of 30% reduction compared to conventional diesel. The study also examines the policy landscape influencing WCO biofuel production, highlighting key regulatory drivers and barriers. Recommendations are proposed to stimulate industry growth and support sustainable biofuel adoption. The findings underscore the potential of WCO biofuels as a viable low-carbon alternative in the transition to cleaner energy systems. Finally, the paper concludes with preliminary findings of an inter-university project involving the use of biodiesel derived from WCO in fishing boats in Malaysia.

## 1 Introduction

The power generation and transportation sector's heavy reliance on fossil fuels has translated into its annual contribution of more than 50% of global greenhouse gas emissions [1]. This motivates exploration of biofuels as energy source for both the power generation and transportation sector. The utilization of waste cooking oil (WCO) as a feedstock for biodiesel production is gaining traction due to its low cost and high availability, making it an economically viable alternative to traditional feedstocks like virgin vegetable oils. Studies have shown that biodiesel derived from WCO can significantly reduce greenhouse gas emissions compared to fossil fuels, with reductions reported as high as 97% in carbon emissions when compared to conventional diesel [2]. Furthermore, the recycling of WCO not only mitigates waste disposal issues but also contributes to a circular economy by transforming waste into valuable energy resources.

Despite the advantages, there are notable gaps in the literature regarding the comprehensive lifecycle assessment (LCA) of social impacts and the long-term sustainability of WCO-derived biodiesel. While many studies focus on environmental and economic aspects, the social implications, such as the effects on local communities and employment opportunities in the biofuel sector, remain underexplored. Moreover, the variability in WCO quality and its impact on biodiesel production efficiency is another area that requires further investigation [3]. Addressing these gaps is crucial for developing a holistic understanding of the implications of WCO recycling into biofuels and justifies the need for a comprehensive review paper that synthesizes existing research and identifies future research directions.

## 2 LCA of Biofuel Production from WCO

### 2.1 Overview

The utilization of waste cooking oil (WCO) as a feedstock for biofuel production has garnered significant attention due to its chemical composition, availability, and the logistics involved in its collection and processing. This response synthesizes studies that detail these aspects, including pre-treatment processes, feedstock variability, and environmental considerations. WCO primarily consists of triglycerides, fatty acids, and various contaminants introduced during cooking processes. Triglycerides and fatty acids constitute the bulk of WCO, but the presence of additives from frying can affect its quality [3]. The chemical composition can vary significantly based on the type of food cooked and the duration of use, which influences its suitability for biodiesel production [4]. For example, the fatty acid profile of WCO can include significant amounts of palmitic acid and linoleic acid, which are crucial for biodiesel synthesis [5].The availability of WCO is substantial, with estimates indicating that urban areas can generate millions of litres annually from restaurants, hotels, and households [6]. This makes WCO an economically viable feedstock for biofuel production, as it is often available at a lower cost compared to virgin vegetable oils. The exploitation of WCO not only reduces feedstock costs but also addresses waste management issues, thereby contributing to a circular economy.

Pre-treatment of WCO is essential to enhance its quality for biofuel production. A pre-treatment process involving filtration to remove particulate matter and heating to eliminate water content, which is critical for improving the oil's properties before transesterification was described in [7]. This step is vital as the presence of water can lead to hydrolysis reactions that negatively impact biodiesel yield. The variability in WCO quality poses challenges for consistent biofuel production. Factors such as the type of food cooked, the number of frying cycles, and the storage conditions can lead to significant differences in the oil's physicochemical properties. This variability necessitates robust quality control measures and standardized protocols for assessing WCO before its use as a feedstock.

* Corresponding author: clsiow@mmu.edu.my

The environmental implications of collecting and processing WCO are also noteworthy. While the recycling of WCO into biofuels can mitigate waste disposal issues, the logistics of collection and processing must be managed to minimize environmental impacts. For instance, the collection process should be designed to reduce emissions and energy consumption, as highlighted in studies focusing on reverse logistics management models [8]. Furthermore, the processing of WCO can involve energy-intensive steps that may offset some of the environmental benefits associated with its use as a renewable feedstock.

### 2.2 Common LCA Methodologies

Life Cycle Assessment (LCA) is a critical methodology for evaluating the environmental impacts of biofuel production from waste cooking oil (WCO). Various LCA tools and methodologies have been applied to assess the sustainability of WCO-based biofuels, focusing on different system boundaries and impact categories. The main LCA approaches are:

- Cradle-to-Grave: Entire life cycle of the biofuel, from raw material extraction (cradle) to disposal (grave) is considered. Assess impacts related to resource extraction, production, transportation, use, and end-of-life disposal [9].
- Cradle-to-Gate: Focuses on the life cycle stages up to the point of sale or gate of the production facility. Applied in studies to optimize production processes and assess the sustainability of feedstock logistics [10].
- Well-to-Wheel: Evaluates the entire fuel supply chain, from the extraction of raw materials (well) to the delivery of fuel to the end-user (wheel). Relevant for assessing transportation fuels, including biofuels, as it encompasses all stages of fuel production and use, providing insights into the overall energy efficiency and greenhouse gas emissions associated with biofuel use [11].
- Hybrid LCA: Combine elements of both attributional and consequential LCA. Allows for a more nuanced understanding of the impacts of biofuel production by considering both direct and indirect effects, such as land-use changes and market dynamics. Provides a comprehensive assessment of the sustainability of biofuels [9]

LCA studies of WCO-based biofuels typically assess a range of environmental impact categories, including:

- Greenhouse Gas (GHG) Emissions: Quantifies the total GHG emissions associated with biofuel production and use. Many studies report significant reductions in GHG emissions when using WCO compared to fossil fuels [12].
- Water Footprint: Assesses the total volume of freshwater used throughout the biofuel production process, including water used for feedstock cultivation, processing, and transportation. Essential for understanding the sustainability of biofuels in water-scarce regions [13].
- Energy Use: Evaluates the total energy consumed during the life cycle of biofuel production, including energy inputs for cultivation, processing, and transportation. Highlights the energy efficiency of WCO- derived biodiesel compared to conventional fossil fuels [14].
- Eutrophication and Acidification Potential: Assesses the potential for nutrient runoff and acid deposition resulting from agricultural practices and processing activities associated with biofuel production. Enhance the understanding of the broader ecological impacts of biofuel production systems [15].
- Resource Depletion: Evaluates the consumption of non-renewable resources, such as fossil fuels and minerals, during the biofuel production process. Assesses the long-term sustainability of biofuel systems [16].

### 2.3 Past LCA Studies on Biofuel Production

Environmental performance, emissions reduction potential, and energy balances of biofuels produced from waste cooking oil (WCO) have been extensively studied through Life Cycle Assessment (LCA) methodologies. Utilizing WCO as a biodiesel feedstock consistently resulted in significant reductions in greenhouse gas emissions, especially when combined with optimized production methods and fuel blending [17]. The economic competitiveness of WCO- derived biodiesel heavily relies on subsidies and supportive governmental policies. Without robust financial frameworks, biofuels face challenges competing against conventional fossil fuels [18]. Technological innovations, particularly in non-catalytic and acid-catalysed transesterification processes, have enhanced the efficiency of converting high free fatty acid feedstocks like WCO into biodiesel [19]. Effective supply chain management and logistics optimization are crucial to reducing environmental impacts, minimizing transportation emissions, and enhancing the economic feasibility of WCO biodiesel production.

Several recurring hot spots have been identified in the supply chain of WCO-based biofuels that significantly influence their environmental performance:

- Feedstock Collection and Transportation: The logistics of collecting and transporting WCO can contribute substantially to the overall GHG emissions and energy use in the life cycle. Studies have shown that optimizing collection routes and methods can mitigate these impacts [20]
- Pre-treatment Processes: The pre-treatment of WCO, which often involves filtration and heating, is another critical stage that can affect energy consumption and emissions. Inefficient pre- treatment processes can lead to higher energy demands and associated emissions [20]
- Processing Efficiency: The efficiency of the transesterification process, which converts WCO into biodiesel, is crucial for minimizing environmental impacts. Variability in processing techniques can lead to differences in yield and energy consumption, making this a significant hot spot in the supply chain [21].
- End-of-Life Considerations: The disposal and end-of-life management of WCO-derived biodiesel also present environmental challenges. Studies emphasize the importance of considering the entire life cycle, including potential impacts from waste disposal and emissions during combustion [22].

The energy balance of WCO-based biofuels is generally favourable, with many studies indicating that the energy output from biodiesel production significantly exceeds the energy input required for its production. For instance, the energy return on investment for biodiesel from WCO has been reported to be in the range of 3:1 to 5:1, meaning that for every unit of energy invested in the production process, three to five units of energy are obtained [23]. This favourable energy balance is attributed to the low-cost nature of WCO as a feedstock, which reduces overall energy inputs associated with cultivation and harvesting.

## 3 Biofuel vs Diesel

The general formula for calculating GHG emissions, $G$ (kg$CO_2$) from biofuels (or any fuel) can be expressed as:

$$G = \sum(Ai \times EF_i) \quad (1)$$

Where:

$A_i$ = Activity data for each emission source (in appropriate units, e.g., liters of fuel consumed, hectares of feedstock planted).

$EF_i$ = Emission factor for each source (in units of kg $CO_2$e per unit of activity, e.g., kg $CO_2$e/liter of biodiesel).

The specific emission factor for diesel is often cited as approximately 2.68kg$CO_2$e/liter [24] while the specific emission factor for biofuel derived from WCO has been demonstrated to be approximately 0.38 kg$CO_2$e/kWh [25].

Fig. 1. shows the carbon emission of diesel and biofuel gathered from the literature while Table I summarises the recent studies, highlighting their methodologies, emissions reductions, and relevant findings pertinent to GHG reductions when using biofuel derived from waste cooking oil (WCO) versus conventional diesel. Note that the baseline for the calculation is the quantity of $CO_2$e emission per 1000 kg of combusted fuel. Taking into consideration that the average density of diesel is 0.832 kg/litre, the amount of $CO_2$e emitted by combustion of 1000 kg of diesel is 3221.15 $CO_2$e. Then, the amount of $CO_2$e emission of biofuel is computed by the percentage of GHG reduction in each reference. The evidence comprehensively indicates that biodiesel derived from WCO not only presents significant GHG reductions compared to standard diesel but also highlights the crucial importance of improving production practices and logistical frameworks to optimize environmental benefits. Ongoing advancements in technology and supportive policy will facilitate greater adoption of WCO-based biodiesel, contributing to a sustainable energy future.

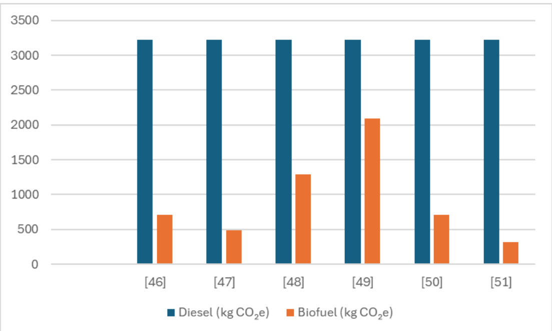


**Fig. 1.** GHG reduction for diesel and biofuel as per literature

**Table 1.** GHG Reduction from the Literature

| Reference | System Boundary | GHG Reduction Compared to Diesel |
|---|---|---|
| [26] | Well-to- Wheel | Up to 78% reduction in GHG emissions |
| [27] | Cradle-to- Grave | 85% GHG reductions with upcycled feedstocks |
| [28] | Well-to- Wheel | GHG reduction of about 40-60% |
| [29] | Cradle-to- Grave | Up to 35% decrease in GHG emissions |
| [30] | Well-to-Wheel | 78% reduction in GHG emissions |
| [31] | Cradle-to Grave | 30% to 90% reduction in GHG emissions |

## 4 Policy Implications and Recommendations

The policy landscape for waste cooking oil (WCO)- based biofuels is shaped by a range of instruments such as carbon credits, subsidies, and mandates designed to foster market development and environmental sustainability. In Brazil, the National Biofuel Policy incentivizes low-carbon fuel production by awarding carbon credits to biofuel producers, enhancing economic feasibility and market participation [32]. Similarly, in the United States, federal subsidies—such as the $0.50 per gallon incentive—help offset higher production costs, making WCO biofuels more competitive with fossil fuels [18]. Key regulatory frameworks such as the U.S. Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS) play pivotal rolesbymandating renewable fuel blends and imposing greenhouse gas (GHG) reduction targets, thereby ensuring consistent demand for WCO-derived fuels [18]. These standards support expanded production capacity and justify infrastructure investments. Policies enabling additional credits for biorefineries that meet GHG benchmarks further stimulate private sector investment.

Effective policies also facilitate the development of logistical infrastructure—pipelines, storage facilities, and distribution systems—which are essential for scaling WCO biofuel deployment. Without these, biofuels face increased distribution costs and reduced carbon benefits [18]. Chen et al. emphasize how carbon pricing mechanisms and fuel mandates can stabilize biofuel pricing, improving both producer confidence and market entry [33]. Carbon credit systems enhance the financial attractiveness of biofuels, making them more appealing for investors. The scalability of WCO biofuels also depends on cost-reduction through innovation, often driven by robust policy support. Research and development initiatives, encouraged through government funding, can improve process efficiency and carbon reduction performance [33]. Yang et al. highlight that subsidies for WCO collection are crucial to securing an adequate feedstock supply [18], while Julio et al. stress that blending mandates—like Brazil's RenovaBio—can create long-term demand for WCO fuels [34].

Advanced strategies such as localized WCO collection and integrated biorefinery models improve sustainability and economic viability. Feo et al. propose multi-criteria decision analysis (MCDA) as a tool for optimizing recycling pathways and product diversification into biolubricants and biosurfactants [35]. Regional collaboration among governments, industry, and academia strengthens infrastructure planning and innovation. Life Cycle Assessment (LCA) is essential for evaluating environmental trade-offs in WCO valorisation strategies, while environmental trade standards can enhance sustainability and global acceptance of WCO biofuels [36]. Global leading palm oil producers such as Indonesia and Malaysia should amplify their efforts to tap on the potential of WCO to fuel their power generation and transportation needs [37].

## 5 Decarbonisation of Malaysia's Fishery Sector: Initial Study

Consistent with the backdrop of this paper, the authors who are researchers from Multimedia University (MMU), Universiti Teknologi PETRONAS (UTP), Universiti Tenaga Nasional (UNITEN) and Universiti Kuala Lumpur (UNIKL) are currently exploring the use of biodiesel derived from WCO to fuel the fishing boats in Pangkor Island, Malaysia. At present, the biodiesel was already successfully produced and meets the Fatty Acid Methyl Ester (FAME) criteria as per ASTM D671. Based on preliminary lifecyle impact assessment analysis, the biodiesel emits 30% less Global Warming Potential (GWP) compared with conventional diesel but requires 15% more water use for production [38]. The biodiesel will next be subjected to characterization tests, running on actual engines in the lab.

## 6 Conclusions

A comprehensive review of the lifecycle assessment of biofuel production from waste cooking oil was presented. Past efforts to quantify the greenhouse gas emissions of biofuel against diesel were consolidated and a minimum of 30% reduction was found. The implications of policies on the production of WCO-based biofuel were discussed with recommendations being put forward to catalyse such industry. The paper concludes with preliminary findings of a case study involving the use of biodiesel derived from WCO in fishing boats in Malaysia.

## 7 Acknowledgement

This work is supported by Joint Research Collaboration Grant with the Grant Number: MMUE/230063.

## References

1. X. Wang, X. Dong, Z. Zhang, Y. Wang, Transportation carbon reduction technologies: A review of fundamentals, application, and performance, Journal of Traffic and Transportation Engineering (English Edition), **11(6)**, 1340–1377, (2024)
2. S. Hadavi, B. Dizayi, H. Li, and A. S. Tomlin, Emissions From a HGV Using Used Cooking Oil as a Fuel Under Real World Driving Conditions, 1-11, (2015)
3. K. Maqsood and M. Alsaady, Optimization Using Response Surface Methodology for Producing Biodiesel From Waste Cooking Oil Using Fishbone Catalyst, Materwiss Werksttech, 53(10), 1242-1248, (2022)
4. O. Awogbemi, E. I. Onuh, and F. L. Inambao, Comparative Study of Properties and Fatty Acid Composition of Some Neat Vegetable Oils and Waste Cooking Oils, International Journal of Low- Carbon Technologies, 14(3), 417-425, (2019)
5. P. A. Nur Oktadina, A. Syarif, M. Yerizam, and A. Medi, The Characterization of Used Cooking Oil as a Raw Material to Produce Biofuel Using CoMo/Bottom Ash With Catalytic Cracking Process, Journal of Mechanical Civil and Industrial Engineering, 37-42, (2023)
6. A. Nurfitriyah, A. Assari, F. S. Pamungkas, A. Elliyanti, A. H. Darmawan, and H. Juwono, Catalytic Co-Cracking of Used Cooking Oil Methyl Ester and Polystyrene Waste for Gasoline- Rich Biofuel Over Mesoporous Al-MCM-41 Catalyst, Iptek Journal of Proceedings Series, 6, 388-393, (2021)
7. M. S. Khan, H. Farah, N. Iqbal, T. Noor, M. Z. Bin Amjad, and S. S. Ejaz Bukhari, A $TiO_2$ Composite With Graphitic Carbon Nitride as a Photocatalyst for Biodiesel Production From Waste Cooking Oil, 11, 37575-37583, RSC Adv (2021)
8. H. Zhang, U. A. Öztürk, D. Zhou, Y. Qiu, and Q. Wu, How to Increase the Recovery Rate for Waste Cooking Oil-to-Biofuel Conversion: A Comparison of Recycling Modes in China and Japan,Ecol Indic, 51, 146-150, (2015).
9. A. I. Osman, N. Mehta, A. M. Elgarahy, A. Al- Hinai, A. H. Al-Muhtaseb, and D. W. Rooney, Conversion of Biomass to Biofuels and Life Cycle Assessment: A Review, Environ Chem Lett. 19, 4075–4118, (2021)
10. V. Russo, L. Di Paola, V. Piemonte, A. Basile, M. De Falco, and A. Giuliani, Are Biofuels Sustainable? An LCA/multivariate Perspective on Feedstocks and Processes, Asia-Pacific Journal of Chemical Engineering, 11(5), 650-663, (2016)
11. E. Martin, M. Chester, and S. E. Vergara, Attributional and Consequential Life-Cycle Assessment in Biofuels: A Review of Recent Literature in the Context of System Boundaries, Current Sustainable/Renewable Energy Reports, 2, 82-89, (2015)
12. D. Rathor, A. Nizami, A. Singh, and D. Pant, Key Issues in Estimating Energy and Greenhouse Gas Savings of Biofuels: Challenges and Perspectives, Biofuel Research Journal, 3(2), 380-393, (2016)
13. G. Gopal, M. Dhanorkar, S. P. Kale, and Y. Patil, Life Cycle Assessment of Anaerobic Digestion Systems, Management of Environmental Quality an International Journal, 391-414, (2019)
14. E. M. Miyasato and B. J. Cardinale, Impacts of Fungal Disease on Algal Biofuel Systems: Using Life Cycle Assessment to Compare Control Strategies, Environ Sci Technol, 57(6), 2602–2610, (2023)
15. O. V Tryboi, Efficient Biomass Value Chains for Heat Production From Energy Crops in Ukraine, Energetika, 64(2), 84-92, (2018)
16. D. R. Shonnard et al., A Review of Environmental Life Cycle Assessments of Liquid Transportation Biofuels in the Pan American Region, Environ Manage, 56, 1356–1376, (2015)
17. A. Eladeb, Magnesium Oxide (MgO) as a Sustainable Catalyst for Biodiesel Production From Waste Cooking Oil: A Comparative Study With KOH, Engineering Technology & Applied Science Research, 14(2), 13751-13756, (2024)

18. R. Yang, W. Tang, and J. Zhang, Implications of Government Subsidies for Waste Cooking Oil Considering Asymmetric Information, Kybernetes, 50(2), 588-615, (2020)
19. M. Ali, M. Shahid, W. Saeed, S. Imran, and M. A. Kalam, Design, Fabrication, and Operation of a 10 L Biodiesel Production Unit Powered by Conventional and Solar Energy Systems, Sustainability, 15(12), 9734, (2023)
20. R. Rusdianasari, L. Utarina, L. Kalsum, D. Wulandari, and Y. Bow, Environmental Potential Impact on Biofuel Production From Thermal Cracking of Palm Shell Using Life Cycle Assessment, Journal of Ecological Engineering, 23(12), 61–67, (2022)
21. S. Liu, S. Zhou, A. Peng, and W. Li, Investigation of Physiochemical and Rheological Properties of Waste Cooking Oil/SBS/Eva Composite Modified Petroleum Asphalt, J Appl Polym Sci, 137(26), 48828, (2019)
22. D. Quiroz, J. M. Greene, B. J. Limb, and J. C. Quinn, Global Life Cycle and Techno-Economic Assessment of Algal-Based Biofuels, Environ Sci Technol, 57(31), 11541–11551, (2023)
23. M. R. Giraldi-Díaz, L. De Medina-Salas, E. Castillo-González, and M. De la Cruz-Benavides, Environmental Impact Associated With the Supply Chain and Production of Biodiesel From Jatropha Curcas L. Through Life Cycle Analysis, Sustainability, 10(5), 1451, (2018)
24. J. Chocholac, R. Hruska, S. Machalik, D. Sommerauerova, and P. Sohajek, Framework for Greenhouse Gas Emissions Calculations in the Context of Road Freight Transport for the Automotive Industry, Sustainability, 13(7), 1-28, (2021)
25. P. Thanatrakolsri and D. Sirithian, Evaluation of Greenhouse Gas Emissions and Mitigation Measures at Thammasat University's Lampang Campus in Thailand, Environ Health Insights, 18 (2024)
26. M. Kareem and A. Saleh, Engine Performance with Diesel-Biodiesel Blends Fuel and Emission Characteristics, Engineering and Technology Journal, 38(5), 779–788 (2020)
27. A. Mata et al., A Review of Grease Trap Waste Management in the US and the Upcycle as Feedstocks for Alternative Diesel Fuels," Environments, 11(8), 159 (2024)
28. M. A. Qamar, R. Liaquat, U. Jamil, R. Mansoor, and S. Azam, Techno-spatial assessment of waste cooking oil for biodiesel production in Pakistan, SN Appl Sci, 2(5), 901 (2020)
29. M. Niekurzak, Determining the Unit Values of the Allocation of Greenhouse Gas Emissions for the Production of Biofuels in the Life Cycle, Energies (Basel), 14(24), 8394 (2021)
30. M. M. Roy, M. S. Islam, and M. N. Alam, Biodiesel from Crude Tall Oil and Its NOx and Aldehydes Emissions in a Diesel Engine Fueled by Biodiesel-Diesel Blends with Water Emulsions, Processes, 9(1**)**, 126, (2021)
31. S. Cassiers et al., Emission Measurement of Buses Fueled with Biodiesel Blends during On-Road Testing, Energies (Basel), 13(20), 5267 (2020)
32. C. H. Ribeiro and M. P. da Cunha, The Economic and Environmental Impacts of Brazilian National Biofuel Policy, Biofuels Bioproducts and Biorefining, 16, 413-434, (2021)
33. X. Chen, M. Khanna, and S. Yeh, Stimulating Learning-by-Doing in Advanced Biofuels: Effectiveness of Alternative Policies, Environmental Research Letters, 7, 045907, (2012)
34. A. A. Vitoriano Julio, T. S. Milessi, D. M. Yepes Maya, E. E. Silva Lora, and J. C. Escobar Palácio, Assessment of the sustainability and Economic Potential of Hydrotreated Vegetable Oils to complement Diesel and Biodiesel Blends in Brazil, Biofuels Bioproducts and Biorefining, 17(2), 312-323, (2022)
35. G. De Feo, C. Ferrara, L. Giordano, and L. S. Ossèo, Assessment of Three Recycling Pathways for Waste Cooking Oil as Feedstock in the Production of Biodiesel, Biolubricant, and Biosurfactant: A Multi-Criteria Decision Analysis Approach, Recycling, 8(4), 64, (2023)
36. I. Thushari and S. Babel, Comparative Study of the Environmental Impacts of Used Cooking Oil Valorization Options in Thailand, J Environ Manage , 310, 114810, (2022)
37. S. C. Lim, I. A. Santo, C.Y. Ho, N. M. . Razali, L.Yusoff, and C. Gomes, Decarbonization of ASEAN: An Engineering Approach, Journal of Engineering Technology and Applied Physics, 7(2), 75–80 (2025)
38. C. L. Siow, I. A. Santo, Y. H. Chai, N. M. Razali, L. Yusoff and R. I. A. Jalal, Decarbonization of Malaysia's Fishery Sector: Utilization of Waste Cooking Oil-Derived Biodiesel in Marine Engines,109-113, (2025)