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Chonnam National University researchers investigate how biodiesel feedstocks and production pathways affect their life cycle sustainability

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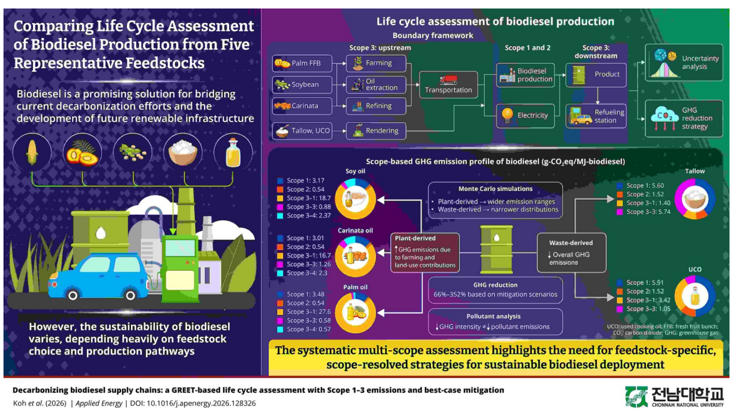
Study provides biofuel producers with a practical, multi-dimensional framework for choosing feedstocks by weighing both climate impact and air pollution together



Biodiesel is a promising bridge technology for enhancing sustainability of the transport industry while renewable energy infrastructure scales up. However, the sustainability of biodiesel varies dramatically with feedstock choice. In a new study, researchers conduct a comprehensive life-cycle assessment of biodiesel production from different feedstocks, revealing significant variability in greenhouse gas emissions, air pollution characteristics, and emission mitigation potential between plant-based and waste-derived feedstocks.

For mitigating climate change and limiting global warming to within 1.5 °C, scaling up global renewable energy capacity is an important goal. However, this effort towards transition to clean energy faces significant resource constraints. To address this challenge, diverse approaches are required like biodiesel, which can serve as a crucial bridge technology for decarbonization of the transportation sector while renewable energy is scaled up.

Biodiesel is compatible with already existing diesel infrastructure and can be deployed quickly without extensive modifications, making it a particularly promising solution.

However, not all biodiesel is equally sustainable. Its environmental impact depends strongly on the feedstock used and the way it is produced. This creates a complex decision-making landscape for policymakers and stakeholders, necessitating comprehensive life-cycle assessments (LCAs) of different biodiesel pathways.

Although previous LCAs have compared biodiesel pathways, most have focused primarily on total greenhouse gas (GHG) emissions and a limited range of feedstocks. They have also rarely examined feedstock-specific mitigation strategies or air-pollution impacts.

To address this gap, a research team led by Professor Boreum Lee along with Mr. Sanghyuk Koh, both from the Department of Environment and Energy Engineering, Chonnam National University, Republic of Korea, presents a comprehensive Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET)-based framework for LCA across five different biodiesel feedstocks.

Their study was made available online on July 01, 2026 and was published in Volume 422 of Applied Energy on November 01, 2026.

The study considered three plant-based feedstocks, namely soy oil, carinata oil, and palm oil, representing diverse agricultural systems, and two waste-derived feedstocks, namely used cooking oil (UCO) and beef tallow.

A Well-to-Tank approach, based on the GREET model, was adopted aiming to capture emissions across the full life cycle. The full life cycle was divided into three categories: Scope 1 that covers direct emissions during biodiesel production, Scope 2 that encompasses indirect emissions from energy use, and Scope 3, which integrates emissions from major upstream and downstream processes.

For plant-based feedstocks, the upstream processes included farming, oil extraction, refining, transportation, and emissions from indirect land use change (ILUC).

In contrast, waste-derived feedstocks included rendering, oil extraction, and refining as upstream processes, while overseas import and long-distance international transport were excluded.

Emissions analysis showed that waste-derived feedstocks consistently demonstrated lower GHG emissions than plant-based oils. This is mainly due to the absence of emissions from upstream agriculture and land use.

Among plant-based options, carinata oil showed the lowest emissions as it avoids ILUC emissions. For plant-based feedstocks, Scope 3 farming processes had the greatest contribution to GHG emissions, while for waste-derived feedstocks Scope 1 and the Scope 3 refining stage were dominant.

"Waste-derived pathways, when paired with renewable energy inputs in processing, can achieve net-negative emissions, meaning they could actually remove more carbon from the atmosphere than they emit with a reduction of up to 346–352 per cent relative to their own baseline (conventional-input) production," says Prof. Lee.

Interestingly, air-pollution analysis showed that low GHG intensity did not necessarily mean uniformly low pollution. For example, carinata oil, despite its lowest plant-based GHG emissions, had the highest volatile organic compound (VOC) and carbon monoxide (CO) levels across all pathways.

These findings highlight the importance of considering air-pollution impacts alongside GHG emissions when evaluating biodiesel sustainability.

Furthermore, Monte Carlo simulation-based uncertainty analysis, aimed at capturing the effect of data variability, showed wider emission ranges for plant-based pathways, compared to much narrower distributions for waste-derived feedstocks.

Importantly, best-case GHG mitigation scenarios revealed emission reduction potentials ranging from 66 per cent to 352 per cent. Waste-derived feedstocks offered the greatest mitigation potential, achieving net-negative GHG emissions through the use of renewable energy in rendering and refining processes.

"Our findings argue against one-size-fits-all biofuel mandates: regions with strong waste-collection infrastructure should prioritize used-oil-based biodiesel, while agricultural regions may benefit more from dedicated energy crops. In the near future, this feedstock-specific, region-aware analysis approach will help policymakers design smarter policies and foster the broader biofuel industry, including aviation and marine fuels, paving the way towards a more sustainable future," concludes Prof. Lee.