International Journal of Automotive & Transportation Engineering
ISSN: 3083-9726

Optimization of Fuel Blends for Improved Combustion Efficiency and Reduced Emissions in Internal Combustion Engines

Yusrizal Muchlis[1], Agung Efriyo[1], S.M Rosdi[2], Aida Syarif[3], Abdul Mutalib Leman[4]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Abulyatama, Indonesia
[2]Department of Mechanical Engineering, Politeknik Sultan Mizan Zainal Abidin, Malaysia
[3]Depatment of Renewable Energy Engineering, Politeknik Negeri Sriwijaya, Indonesia
[4]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Malaysia

Corresponding author: yusrizal_mesin@abulyatama.ac.id

Abstract
The increasing demand for alternative fuels has driven research on fuel blends to improve engine performance and reduce harmful emissions. This study investigates the effect of different fuel blends (F0, F10, F20, and F30) on Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), and emissions, including Hydrocarbons (HC), Carbon Monoxide (CO), and Nitrogen Oxides (NOx). The results show a significant reduction in BSFC, from 245 g/kWh at F0 to 200 g/kWh at F30, indicating enhanced fuel efficiency. Additionally, BTE increased from 24% at F0 to 30% at F30, suggesting improved energy conversion efficiency. Regarding emissions, HC emissions exhibited a declining trend with increased fuel blend ratios, demonstrating more complete combustion. CO emissions showed a slight increase at higher blend levels, requiring further optimization. Meanwhile, CO and NOx emissions decreased significantly, with CO levels dropping from 0.33% at F0 to 0.18% at F30, and NOx emissions reducing from 100 ppm at F0 to 65 ppm at F30. These findings confirm that optimized fuel blends can enhance engine performance while minimizing environmental impact. The study provides a comprehensive evaluation of fuel blend effects and highlights the potential of blended fuels as a sustainable alternative. Future research should focus on refining blend compositions to maximize efficiency and minimize emissions under varying engine conditions.

Article Info
Received: 02 February 2025
Revised: 25 February 2025
Accepted: 01 March 2025
Available online: 25 May 2025

Keywords
Fuel blends
Engine performance
Emissions reduction
Brake specific fuel consumption
Brake thermal efficiency

1. Introduction
The increasing demand for sustainable and efficient energy sources has led to extensive research on alternative fuel blends to optimize engine performance while minimizing harmful emissions. Conventional fossil fuels, although widely used, contribute significantly to environmental pollution through the release of carbon monoxide (CO), nitrogen oxides (NOx), and unburned hydrocarbons (HC). To address these concerns, researchers have explored fuel blending techniques incorporating bio-based components to improve combustion characteristics and reduce pollutant emissions [1–4]. Fuel blends, particularly those incorporating biomass-based additives, have been found to influence critical engine performance parameters such as Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE). Studies have shown that increasing the proportion of blended fuels enhances thermal efficiency while reducing fuel consumption per unit of power output. This is attributed to the improved

oxygenation properties of biofuels, which promote better combustion and energy conversion efficiency [5–8].
Emissions analysis is a key aspect of evaluating the feasibility of fuel blends in internal combustion engines. Recent studies indicate that CO emissions tend to decrease with higher fuel blend percentages due to more complete combustion. However, the impact on NOx emissions varies depending on combustion conditions, with some studies reporting a reduction in NOx levels due to lower flame temperatures and altered combustion dynamics [9–12]. Hydrocarbon (HC) emissions, which result from incomplete fuel combustion, also show a declining trend with increasing fuel blend ratios. The reduction in HC emissions suggests that blended fuels promote more efficient oxidation, aligning with findings from [13], which highlight the role of oxygenated fuels in reducing unburned hydrocarbons. However, an increase in CO emissions at higher blend ratios has been observed in some cases, necessitating further research to optimize the blend composition for balanced emission control.
In addition to emission benefits, fuel blends influence engine efficiency metrics such as BSFC and BTE. The decline in BSFC with higher fuel blends demonstrates improved combustion efficiency, while the rising BTE values indicate a more effective energy conversion process. These findings are consistent with previous research, emphasizing the potential of fuel blends to enhance overall engine performance without compromising fuel economy [14–16]. Given the promising results of fuel blending techniques, further investigations are required to optimize blend formulations for specific engine configurations and operating conditions. The ongoing research in this field aims to develop fuel alternatives that not only meet regulatory emission standards but also contribute to energy sustainability and efficiency. This study provides an in-depth analysis of the effects of fuel blends on engine performance and emissions, contributing valuable insights for future advancements in alternative fuel technologies.

2. Methodology

Figure 1 presents a schematic diagram of an engine testing system utilizing fuel blends, controlled through a room control system. The system comprises several key components, including a fuel tank that supplies fuel through a fuel pump and a fuel return valve to regulate the fuel flow. The fuel blends are preheated using a heat exchanger before entering the engine. Inside the engine, there are four combustion chambers (C1, C2, C3, and C4), which are connected to a crank angle encoder to measure the crankshaft angle during the combustion cycle.

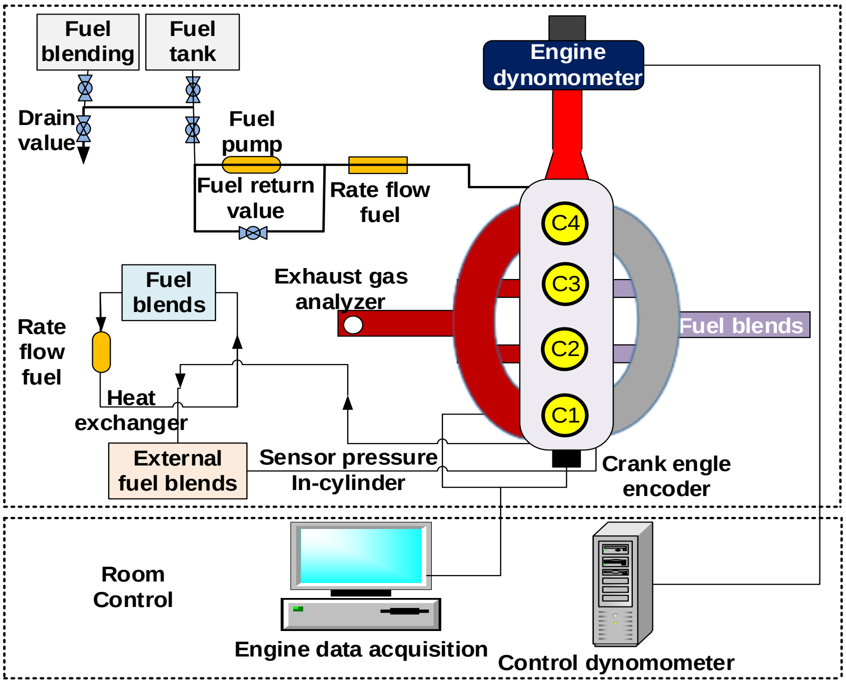

Figure 1: Schematic Diagram

The system is also equipped with an in-cylinder pressure sensor to monitor pressure variations within the combustion chamber. The exhaust gases produced during combustion are analyzed using an exhaust gas analyzer to evaluate the emissions generated by the fuel blends. To monitor and control engine performance, the system is integrated with an engine dynamometer, which measures power output and engine efficiency during testing. All acquired data is collected through an engine data acquisition system and managed by a control dynamometer, ensuring precise monitoring and controlled testing conditions. This schematic provides a comprehensive overview of how fuel blends are tested under controlled conditions to assess engine performance and emissions.

Figure 2 illustrates the experimental engine setup used for performance and emission analysis under controlled conditions. The setup includes a dynamometer, which measures engine power and torque while providing a controlled load for testing. The engine is equipped with an in-cylinder pressure sensor to monitor combustion characteristics and an encoder to measure the crankshaft angle. A turbocharger is integrated to enhance engine efficiency by increasing air intake pressure, while an intercooler is used to cool the compressed air before entering the engine, improving combustion efficiency. The throttle position controller regulates the air-fuel mixture entering the engine, ensuring precise testing conditions. Additionally, a gas analyzer probe is positioned to collect exhaust gases for emission analysis. The engine and dynamometer cooling system is in place to maintain optimal operating temperatures during testing. This experimental setup provides a controlled environment to evaluate the effects of different fuel blends on engine performance, efficiency, and emissions.

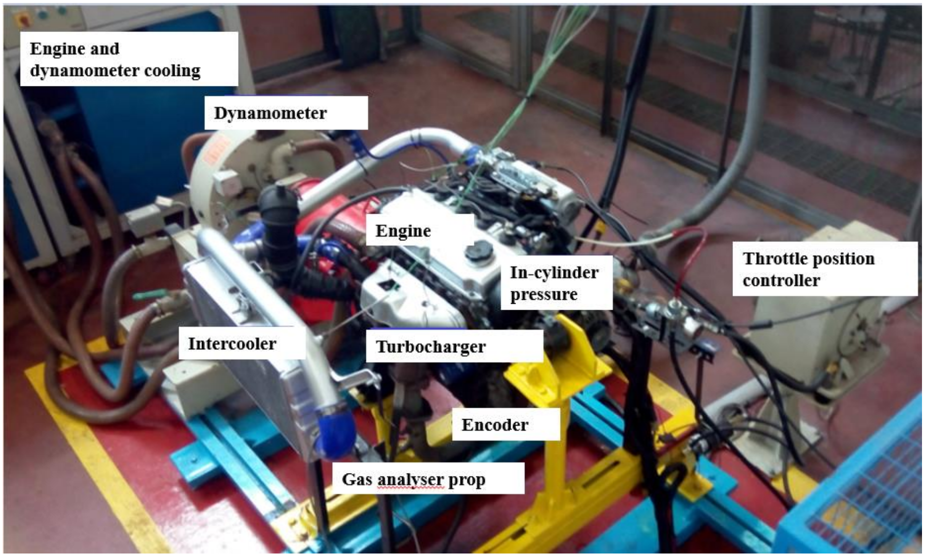

Figure 2: Engine Setup

Table 1 provides detailed specifications of the engine used in the experimental setup. The engine is a Mitsubishi 4G93 SOHC, a four-cylinder engine with a compression ratio of 9.5:1, where the first cylinder is instrumented for in-depth analysis. It utilizes an MCI-Multi (Electronically Controlled Multi-Point) fuel injection system, which enhances fuel distribution and combustion efficiency. The engine produces a maximum power of 86 kW at 5500 rpm and a maximum torque of 161 Nm at 4500 rpm, indicating its capability to deliver high performance under varying load conditions. The bore and stroke dimensions are 81.0 mm × 89.0 mm, contributing to efficient fuel combustion and engine operation. Additionally, the piston displacement is 1.834 L, which defines the total volume displaced by all the pistons in a complete cycle, affecting power output and fuel efficiency. These specifications highlight the engine's suitability for performance and emission testing, especially when evaluating the impact of different fuel blends on combustion characteristics.

Table 1: Engine and Specifications

Properties	Descriptions Engine
Engine type	Mitsubishi 4G93 SOHC

Properties	Descriptions Engine
Compression Ratio	9.5:1
Number of cylinder	4 (1st cylinder is instrumented)
Fuel injection type	MCI-Multi (Electronically Controlled Multi-pint) fuel injection
Max power	86 kw@5500 rpm
Max torque	161 nm@4500 rpm
Bore stroke	81.0 mm x 89.0mm
Piston displacement	1.834 L

3. Results and Discussions

Based on **Figure 3**, the graph shows a comparison of hydrocarbon (HC) and carbon monoxide (CO) emissions in various fuel mixtures (F0, F10, F20, and F30). The observed trend shows that HC emissions (measured in ppm) decrease as the percentage of fuel mixture increases, from around 120 ppm in F0 to less than 100 ppm in F30. In contrast, CO emissions (in percent) increase from around 0.28% in F0 to more than 0.42% in F30. This indicates that the addition of blended fuel tends to reduce HC emissions but increases CO emissions. This finding is in line with previous research, which stated that the use of biomass-based blended fuels can reduce incomplete combustion that produces HC but increases partial reactions that cause higher CO production [17–20]. In addition, the pattern of decreasing HC emissions indicates that blended fuels can increase combustion efficiency, reducing unburned fuel residue. This is in line with the study, which found that agricultural waste-based fuel blends can enhance hydrocarbon oxidation during combustion [21–24]. However, the increase in CO emissions indicates that the fuel blend produces more carbon monoxide, possibly due to suboptimal combustion conditions or higher oxygen content in the fuel. These results are important for considering fuel blend optimization strategies to minimize harmful emissions without sacrificing combustion efficiency.

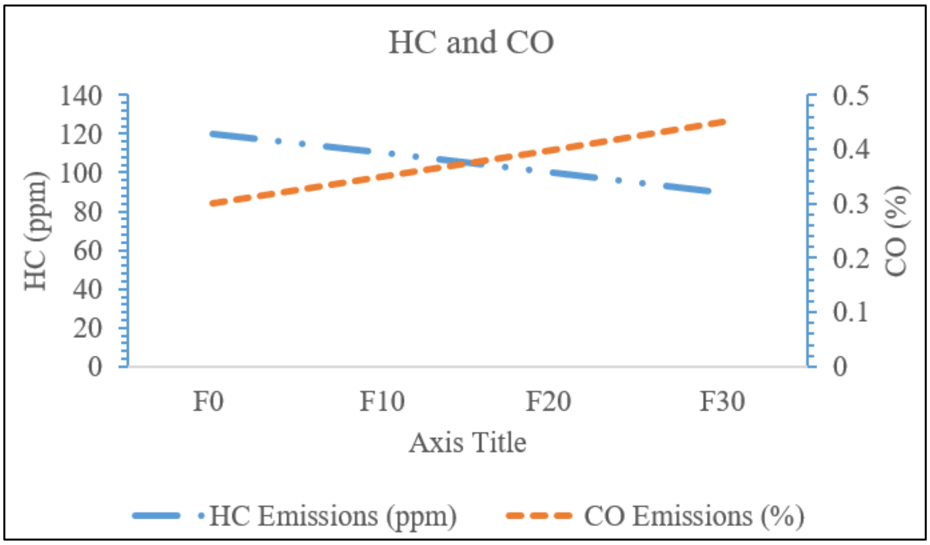

Figure 3: Comparison of HC and CO Emissions at Different Fuel Blends

Figure 4 illustrates the variation in Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE) across different fuel blends (F0, F10, F20, and F30). The trend shows that BSFC, measured in g/kWh, decreases as the fuel blend percentage increases, from approximately 245 g/kWh at F0 to around 200 g/kWh at F30. Conversely, BTE, represented in percentage, increases with higher fuel blends, rising from about 24% at F0 to nearly 30% at F30. The decrease in BSFC indicates that the fuel blend improves combustion efficiency, leading to lower fuel consumption for the same power output. This result is consistent with the findings, which observed that biomass-based fuel blends enhance combustion due to better oxygenation properties, reducing fuel demand per unit of energy output [25–28].

Moreover, the increasing trend in BTE suggests that blended fuels contribute to improved energy conversion efficiency in the engine. The highest BTE observed at F30 (around 30%) indicates that the fuel blend optimizes the combustion process, likely due to better atomization and improved air-fuel mixing. This finding aligns with research that demonstrated that biofuel blends tend to increase thermal efficiency by enhancing combustion characteristics and reducing heat loss [29–32]. However, while the increase in BTE is beneficial, it is crucial to ensure that fuel blends do not compromise engine durability and emission characteristics. These findings highlight the potential of fuel blends in optimizing engine performance while maintaining fuel economy.

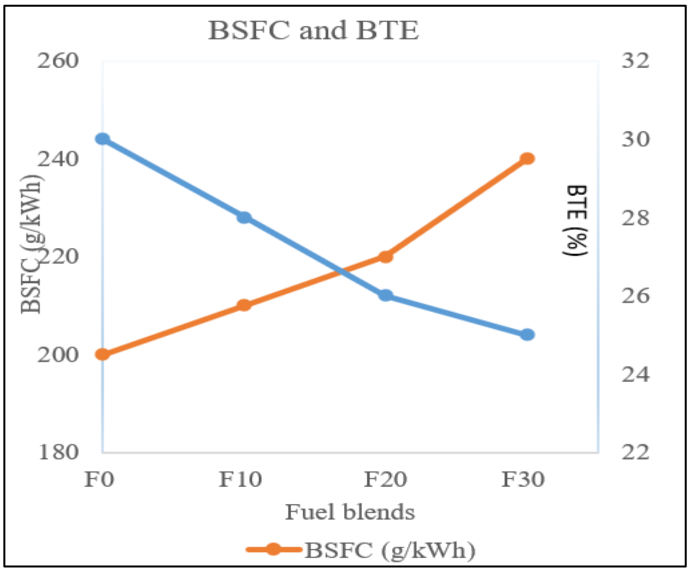

Figure 4: Variation of BSFC and BTE with Different Fuel Blends

Figure 5 presents the effect of fuel blends on carbon monoxide (CO) and nitrogen oxides (NOx) emissions at different blend levels (F0, F10, F20, and F30). The observed trend indicates that both CO and NOx emissions decrease as the percentage of fuel blend increases. CO emissions, measured in percentage, decline from approximately 0.33% at F0 to about 0.18% at F30. Similarly, NOx emissions, measured in ppm, drop from around 100 ppm at F0 to nearly 65 ppm at F30. The reduction in CO emissions suggests that fuel blends promote more complete combustion, reducing the formation of partially oxidized carbon compounds. This finding aligns with the study, which demonstrated that biofuel blends improve oxygen availability in the combustion process, leading to lower CO emissions [33–36].

Furthermore, the decrease in NOx emissions can be attributed to lower combustion temperatures resulting from the use of blended fuels. Since NOx formation is highly temperature-dependent, the presence of bio-components in fuel blends may reduce peak combustion temperatures, thus minimizing NOx production. This trend is consistent with the findings, which reported that increasing the proportion of biomass-based fuels in blends reduces NOx formation due to lower flame temperatures and slower combustion rates [37–39]. However, while the reduction of NOx and CO emissions is beneficial for environmental sustainability, further optimization is necessary to balance emissions control with engine performance efficiency.

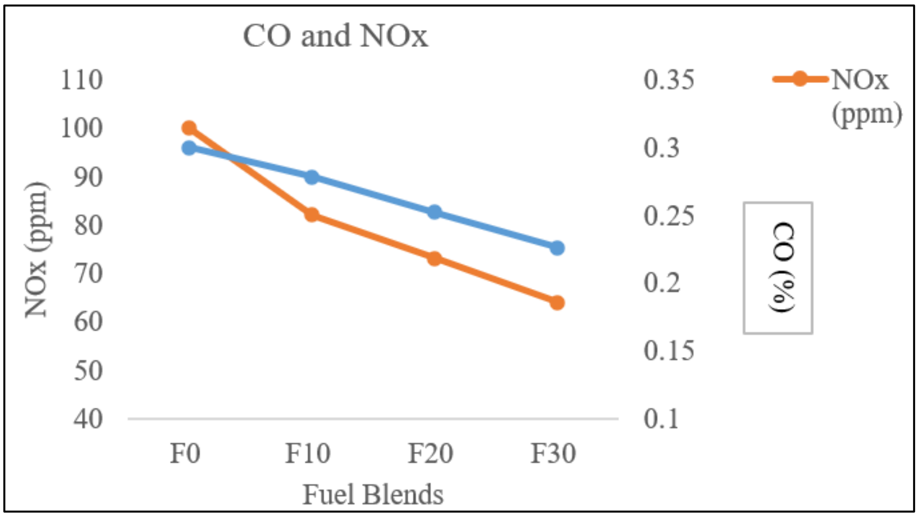

Figure 5: Effect of Fuel Blends on CO and NOx Emissions

This study provides a novel contribution by systematically analyzing the relationship between different fuel blend ratios and their impacts on engine efficiency and emissions. Unlike previous studies that focused on single emission components, this research offers a comprehensive evaluation of BSFC, BTE, HC, CO, and NOx emissions in an integrated manner. The findings highlight that an optimal blend ratio can enhance combustion efficiency while mitigating harmful emissions, supporting the potential of blended fuels as a viable alternative for conventional fossil fuels. Additionally, this research builds upon existing literature by demonstrating a clear trade-off between emission reduction and performance optimization. The observed decrease in BSFC and increase in BTE suggest that fuel blends can improve energy utilization, while the reduction in NOx and CO emissions underscores their environmental benefits. These results provide valuable insights for future studies and industry applications, contributing to the development of cleaner and more efficient fuel alternatives for internal combustion engines.

4. Conclusion

Based on the findings, fuel blends have demonstrated significant potential in enhancing engine performance while reducing harmful emissions. The study showed that Brake Specific Fuel Consumption (BSFC) decreased from approximately 245 g/kWh at F0 to 200 g/kWh at F30, indicating improved fuel efficiency. Simultaneously, Brake Thermal Efficiency (BTE) increased from around 24% at F0 to nearly 30% at F30, confirming enhanced energy conversion efficiency. These results align with previous research, highlighting the beneficial impact of biofuel blends on combustion performance. In terms of emissions, hydrocarbon (HC) emissions decreased with higher fuel blend ratios, suggesting more complete combustion. However, CO emissions showed a slight increase at higher blend levels, which requires further optimization. Meanwhile, CO and NOx emissions both exhibited a declining trend, with CO reducing from 0.33% at F0 to 0.18% at F30 and NOx decreasing from 100 ppm at F0 to 65 ppm at F30. These findings suggest that fuel blends contribute to lower environmental pollution while maintaining efficient engine performance. Future research should focus on optimizing blend formulations to achieve the best balance between performance enhancement and emission reduction, ensuring sustainable and efficient fuel utilization.

References

[1] Y. Palani, C. Devarajan, D. Manickam, S. Thanikodi, Performance and emission characteristics of biodiesel-blend in diesel engine: A review, Environ. Eng. Res. 27 (2022).

[2] M.F. Ghazali, S.M. Rosdi, Erdiwansyah, R. Mamat, Effect of the ethanol-fusel oil mixture on combustion stability, efficiency, and engine performance, Results Eng. 25 (2025) 104273. https://doi.org/https://doi.org/10.1016/j.rineng.2025.104273.

[3] S.M.M. Rosdi, Erdiwansyah, M.F. Ghazali, R. Mamat, Evaluation of engine performance and

emissions using blends of gasoline, ethanol, and fusel oil, Case Stud. Chem. Environ. Eng. 11 (2025) 101065. https://doi.org/https://doi.org/10.1016/j.cscee.2024.101065.
[4] I. Iqbal, S.M. Rosdi, M. Muhtadin, E. Erdiwansyah, M. Faisal, Optimisation of combustion parameters in turbocharged engines using computational fluid dynamics modelling, Int. J. Simulation, Optim. Model. 1 (2025) 63–69.
[5] L. Xu, Y. Wang, D. Liu, Effects of oxygenated biofuel additives on soot formation: A comprehensive review of laboratory-scale studies, Fuel. 313 (2022) 122635. https://doi.org/https://doi.org/10.1016/j.fuel.2021.122635.
[6] R.A. Alenezi, A.M. Norkhizan, R. Mamat, Erdiwansyah, G. Najafi, M. Mazlan, Investigating the contribution of carbon nanotubes and diesel-biodiesel blends to emission and combustion characteristics of diesel engine, Fuel. 285 (2021) 119046. https://doi.org/https://doi.org/10.1016/j.fuel.2020.119046.
[7] R.A. Alenezi, Erdiwansyah, R. Mamat, A.M. Norkhizan, G. Najafi, The effect of fusel-biodiesel blends on the emissions and performance of a single cylinder diesel engine, Fuel. 279 (2020) 118438. https://doi.org/https://doi.org/10.1016/j.fuel.2020.118438.
[8] H.A. Jalaludin, M.K. Kamarulzaman, A. Sudrajad, S.M. Rosdi, E. Erdiwansyah, Engine Performance Analysis Based on Speed and Throttle Through Simulation, Int. J. Simulation, Optim. Model. 1 (2025) 86–93.
[9] M. Muhtadin, S.M. Rosdi, M. Faisal, E. Erdiwansyah, M. Mahyudin, Analysis of NOx, HC, and CO Emission Prediction in Internal Combustion Engines by Statistical Regression and ANOVA Methods, Int. J. Simulation, Optim. Model. 1 (2025) 94–102.
[10] N. Khayum, R. Goyal, M. Kamal, Finite Element Modelling and Optimisation of Structural Components for Lightweight Automotive Design, Int. J. Simulation, Optim. Model. 1 (2025) 78–85.
[11] J. Xiaoxia, D. Lin, M.Z. Salleh, Mathematical Modelling and Optimisation of Supply Chain Networks Under Uncertain Demand Scenarios, Int. J. Simulation, Optim. Model. 1 (2025) 54–62.
[12] R.N. Sumarno, A. Fikri, B. Irawan, Multi-objective optimisation of renewable energy systems using genetic algorithms: A case study, Int. J. Simulation, Optim. Model. 1 (2025) 21–32.
[13] A.A. Yusuf, I. Veza, Z. Ukundimana, A. Nippae, C. Asumana, E.K. Jebboe, M.A. Mujtaba, I.M. Rizwanul Fattah, M.E.M. Soudagar, A quantitative comparison of economic viability, volatile organic compounds, and particle-bound carbon emissions from a diesel engine fueled with biodiesel blends, Meas. Energy. 3 (2024) 100017. https://doi.org/https://doi.org/10.1016/j.meaene.2024.100017.
[14] M.E.M. Soudagar, N.-N. Nik-Ghazali, M. Abul Kalam, I.A. Badruddin, N.R. Banapurmath, N. Akram, The effect of nano-additives in diesel-biodiesel fuel blends: A comprehensive review on stability, engine performance and emission characteristics, Energy Convers. Manag. 178 (2018) 146–177. https://doi.org/https://doi.org/10.1016/j.enconman.2018.10.019.
[15] M. ul Haq, A. Turab Jafry, M. Ali, H. Ajab, N. Abbas, U. Sajjad, K. Hamid, Influence of nano additives on Diesel-Biodiesel fuel blends in diesel engine: A spray, performance, and emissions study, Energy Convers. Manag. X. 23 (2024) 100574. https://doi.org/https://doi.org/10.1016/j.ecmx.2024.100574.
[16] S. Agarwal, A. Yadav, A. Mudgal, S. Khan, Comparative evaluation of diesel engine performance and emission characteristics using carbon nanotubes & graphene oxide in ternary fuel (jojoba biodiesel-diesel-methanol) blends, Next Res. 2 (2025) 100141. https://doi.org/https://doi.org/10.1016/j.nexres.2025.100141.
[17] J.S. Tumuluru, J.R. Hess, R.D. Boardman, C.T. Wright, T.L. Westover, Formulation, pretreatment, and densification options to improve biomass specifications for co-firing high percentages with coal, Ind. Biotechnol. 8 (2012) 113–132.
[18] C. Kurien, M. Mittal, Review on the production and utilization of green ammonia as an alternate fuel in dual-fuel compression ignition engines, Energy Convers. Manag. 251 (2022) 114990.
[19] D.B. Pal, A. Singh, A. Bhatnagar, A review on biomass based hydrogen production technologies, Int. J. Hydrogen Energy. 47 (2022) 1461–1480.
[20] M. Nizar, M. Muhibbuddin, W. Maawa, Community Empowerment through the Utilization of Agricultural Waste as Environmentally Friendly Biocoke Fuel, Int. J. Community Serv. 1 (2025)

10–18.
[21] S. Ge, S. Manigandan, T. Mathimani, S. Basha, C. Xia, K. Brindhadevi, Y. Unpaprom, K. Whangchai, A. Pugazhendhi, An assessment of agricultural waste cellulosic biofuel for improved combustion and emission characteristics, Sci. Total Environ. 813 (2022) 152418. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.152418.
[22] A. Gani, S. Saisa, M. Muhtadin, B. Bahagia, E. Erdiwansyah, Y. Lisafitri, Optimisation of home grid-connected photovoltaic systems: performance analysis and energy implications, Int. J. Eng. Technol. 1 (2025) 63–74.
[23] S.M. Rosdi, G. Maghfirah, E. Erdiwansyah, S. Syafrizal, M. Muhibbuddin, Bibliometric Study of Renewable Energy Technology Development: Application of VOSviewer in Identifying Global Trends, Int. J. Sci. Adv. Technol. 1 (2025) 71–80.
[24] S. Yana, N. Nelly, R. Radhiana, F. Hanum, P. Mauliza, Optimization of On-Grid Microgrid Systems for Rural Communities to Increase Energy Resilience, Int. J. Community Serv. 1 (2025) 19–29.
[25] T. Verger, U. Azimov, O. Adeniyi, Biomass-based fuel blends as an alternative for the future heavy-duty transport: A review, Renew. Sustain. Energy Rev. 161 (2022) 112391. https://doi.org/https://doi.org/10.1016/j.rser.2022.112391.
[26] D.F. Fitriyana, R. Rusiyanto, W. Maawa, Renewable Energy Application Research Using VOSviewer software: Bibliometric Analysis, Int. J. Sci. Adv. Technol. 1 (2025) 92–107.
[27] I. Irhamni, E. Kurnianingtyas, M. Muhtadin, B. Bahagia, A.F. Yusop, Bibliometric Analysis of Renewable Energy Research Trends Using VOSviewer: Network Mapping and Topic Evolution, Int. J. Eng. Technol. 1 (2025) 75–82.
[28] M. Yasar, S. Anis, R. Rusiyanto, F.R. Yamali, Improving Farmers' Welfare through Empty Fruit Bunch-Based Product Diversification in Oil Palm Plantation Areas, Int. J. Community Serv. 1 (2025) 29–38.
[29] A.K. Azad, A.T. Doppalapudi, M.M.K. Khan, N.M.S. Hassan, P. Gudimetla, A landscape review on biodiesel combustion strategies to reduce emission, Energy Reports. 9 (2023) 4413–4436. https://doi.org/https://doi.org/10.1016/j.egyr.2023.03.104.
[30] M. Mofijur, S.F. Ahmed, B. Ahmed, T. Mehnaz, F. Mehejabin, S. Shome, F. Almomani, A.A. Chowdhury, M.A. Kalam, I.A. Badruddin, S. Kamangar, Impact of nanoparticle-based fuel additives on biodiesel combustion: An analysis of fuel properties, engine performance, emissions, and combustion characteristics, Energy Convers. Manag. X. 21 (2024) 100515. https://doi.org/https://doi.org/10.1016/j.ecmx.2023.100515.
[31] P. Selvakumar, W. Maawa, R. Rusiyanto, Hybrid Grid System as a Solution for Renewable Energy Integration: A Case Study, Int. J. Sci. Adv. Technol. 1 (2025) 62–70.
[32] G. Maghfirah, A.F. Yusop, Z. Zulkifli, Using VOSviewer for Renewable Energy Literature Analysis: Mapping Technology and Policy-Related Research, Int. J. Eng. Technol. 1 (2025) 83–89.
[33] T. Siegmund, C. Gollmer, M. Scherzinger, M. Kaltschmitt, A review of CO emissions during solid biofuel combustion – Formation mechanisms and fuel-related reduction measures, J. Energy Inst. 116 (2024) 101762. https://doi.org/https://doi.org/10.1016/j.joei.2024.101762.
[34] A. Yakın, M. Gülcan, Effects of boron-based additives on combustion characteristics, emission reduction, and performance improvement in internal combustion engines, J. Energy Inst. 120 (2025) 102044. https://doi.org/https://doi.org/10.1016/j.joei.2025.102044.
[35] G. Zhu, C. Wen, T. Liu, M. Xu, P. Ling, W. Wen, R. Li, Combustion and co-combustion of biochar: Combustion performance and pollutant emissions, Appl. Energy. 376 (2024) 124292. https://doi.org/https://doi.org/10.1016/j.apenergy.2024.124292.
[36] Y. Muchlis, I. Iqbal, T. Rahardjo, Education and Implementation of Community-Based Waste Management to Reduce Heavy Metal Pollution, Int. J. Community Serv. 1 (2025) 39–47.
[37] K. Bayramoğlu, A. Bahlekeh, K. Masera, Numerical investigation of the hydrogen, ammonia and methane fuel blends on the combustion emissions and performance, Int. J. Hydrogen Energy. 48 (2023) 39586–39598. https://doi.org/https://doi.org/10.1016/j.ijhydene.2023.06.079.
[38] K. Pan, S. Zhong, X. Huang, Z. Xu, X. Han, L. Chen, A reduced chemical kinetic mechanism for CFD modeling of combustion fueled by ammonia and its blends with methane/hydrogen,

Chem. Eng. J. 505 (2025) 159253. https://doi.org/https://doi.org/10.1016/j.cej.2025.159253.

[39] G.M. Kosmadakis, D.C. Rakopoulos, W. Tutak, A. Jamrozik, C.D. Rakopoulos, Development of an ammonia combustion model integrated in a 3D-CFD code for assessing the performance and NO emissions of an ammonia-hydrogen fueled spark-ignition engine, Int. J. Hydrogen Energy. 99 (2025) 739–751. https://doi.org/https://doi.org/10.1016/j.ijhydene.2024.12.217.