The International Journal of Energy & Engineering Sciences, 2024, 9 (2) 115-127
ISSN: 2602-294X - Gaziantep University

A WIDE PERSPECTIVE INVESTIGATION OF THE ROLE OF SUSTAINABLE FUELS IN DECARBONIZING TRANSPORT AND COMPARISON WITH FOSSIL FUELS

Sultan Büşra ARTAŞ[a]*, Hakan TUTUMLU[b], Ali KAHRAMAN[a], Hüseyin YAĞLI[b]

[a] Necmettin Erbakan University, Konya, Turkiye
[b] Gaziantep University, Gaziantep, Turkiye

*Corresponding author: Sultan Büşra ARTAŞ, Engineering Faculty, Department of Mechanical Engineering, Necmettin Erbakan University, 46500, Şehitkamil, Gaziantep, Türkiye. Tel.: +90(342)3172537, sultanbusra.artas@erbakan.edu.tr, htutumlu@gantep.edu.tr, yagli@gantep.edu.tr, akahraman@erbakan.edu.tr.

ABSTRACT

The transition to sustainable fuels has become essential in international initiatives to mitigate climate change and attain carbon neutrality. Sustainable fuels—especially bioenergy and low-emission hydrogen—are vital for decarbonizing high-emission sectors like industry, transportation, and aviation. By offering alternatives where direct electrification and energy efficiency fall short, these fuels enhance energy security and diversification. Under the Net Zero Emissions (NZE) 2050 scenario, need for low-emission fuels like biofuels, and hydrogen is expected to double by 2030 and triple by 2050, highlighting their significance in meeting long-term climate goals. A comparative analysis reveals that biofuels provide a unique advantage over intermittent renewable sources like solar and wind, offering continuous energy production capability. In 2023, biofuel demand reached 2.3 million barrels of oil equivalent per day (mboe/d) and is projected to rise to 3.2 mboe/d by 2035 and 4.1 mboe/d by 2050, driven partly by the growing demand for sustainable aviation fuels (SAF). Although biofuels have a higher carbon footprint than cleaner options like solar and wind, they maintain compatibility with existing fossil fuel infrastructure, making them particularly suitable for the transportation sector. Consequently, the need for fossil fuels is expected to decrease significantly by 2050, with oil demand falling from 78.3 mboe/d in 2030 to 23 mboe/d, while biofuels and hydrogen-based fuels experience a 72% increase over the same period. This study evaluates the current roles, advantages, and disadvantages of sustainable fuels in the energy transition, underscoring the demand for supportive regulatory frameworks, infrastructure investment, and sustainability standards to encourage widespread adoption. Sustainable fuels offer a critical opportunity to reduce carbon emissions in hard-to-decarbonize sectors, playing a pivotal role in transitioning toward a low-carbon global economy.

Keywords: Sustainable fuels, biofuel, Net Zero Emissions (NZE) 2050, decarbonization

1. INTRODUCTION

The transition to alternative fuels from fossil fuels has been an important problem recently, with the need to address pressing issues like global warming, environmental degradation, and the limited nature of fossil fuel resources. As the global population continues to grow and energy demands continue to rise, dependence on fossil fuels, which meet approximately 80% of the world's energy needs, is becoming increasingly

The International Journal of Energy & Engineering Sciences, 2024, 9 (2) 115-127
ISSN: 2602-294X - Gaziantep University

unsustainable [1]. As can be seen from the Figure 1 below, total energy supply will grow increasingly every year.

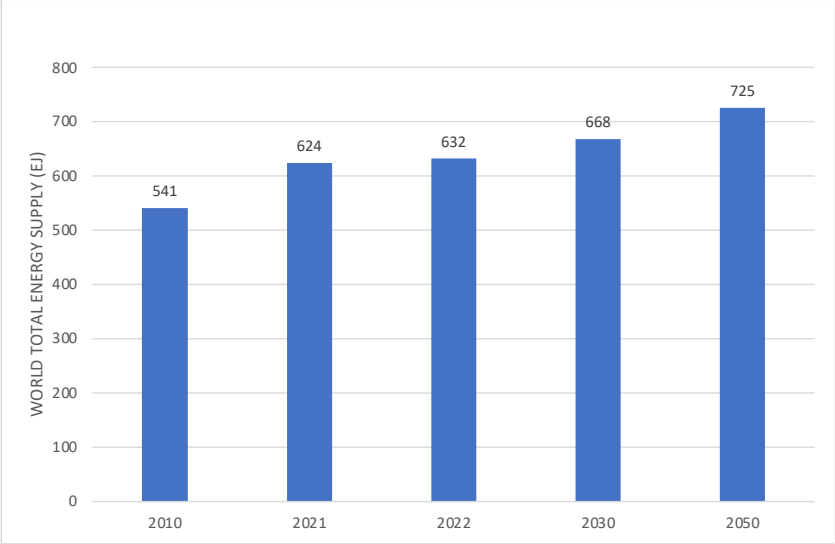

Figure 1. World total energy supply (EJ) through years [2]

As can be seen from following Figure 2, Transport consumption has an important share in total final energy consumption. Fossil fuels also have an important share in transport consumption. The role of sustainable fuels in decarbonising transport is increasingly recognised as an essential part of international efforts to address climate change. One significant source of greenhouse gas (GHG) emissions is the transportation industry, accounting for about one-third of global energy consumption; liquid transport fuels are the main source of energy in this sector [3].

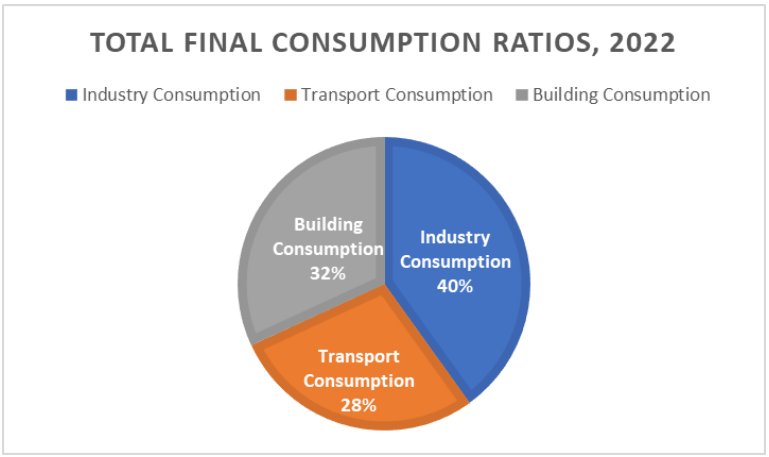

Figure 2. Total final energy consumption ratios in 2022 [2]

As countries strive to meet their climate commitments, switching to sustainable fuels is critical to reduce the carbon footprint and achieve long-term sustainability in transport systems. The transition from fossil fuels to sustainable fuels is a pressing issue in the context of global energy consumption and environmental sustainability. Statistical analyses reveal significant trends and correlations between fossil fuel prices, carbon emissions, and the adoption of renewable sources. For instance, Khaw and Ni

Khaw & Ni [4] demonstrate that in Asian developing countries, rising prices of crude oil and coal correlate positively with an increase in renewable energy capacity. This suggests that as fossil fuel costs escalate, there is a greater impetus for the adoption of alternative sources, highlighting the economic drivers behind the transition to sustainability. Sustainable fuels cover a range of alternatives to traditional fossil fuels, like biofuels, hydrogen and natural gas. Biofuels derived from organic materials have attracted attention due to their potential to notably decrease GHG emissions compared to conventional fuels. For example, biodiesel produced from waste cooking oil provides lower exhaust emissions and offers a more environmentally friendly solution to energy problems [5]. Moreover, advanced biofuels which is able to be integrated into existing infrastructure are especially important for hard-to-decarbonise sectors such as heavy vehicles [6]. The compatibility of these fuels with existing engine technologies is vital for a smooth transition, as this minimises the need for extensive modifications to existing vehicles and fuel infrastructure [7].

Hydrogen fuel stands out as another promising way to decarbonise transport. Hydrogen can fulfil various roles as a clean fuel for fuel cell vehicles, as an energy storage medium and as a tool to facilitate the electrical grid's incorporation of renewable energy [8]. In particular, the development of hydrogen production technologies that minimise CO2 emissions is essential to realise the potential of this fuel in the transport sector [9]. Furthermore, utilising carbon captured in hydrogen production processes can facilitate the transition to a circular economy [8]. The integration of hydrogen into transport systems can contribute significantly to the decarbonisation of various modes of transport, including rail and maritime transport [10].

The use of natural gas, especially compressed natural gas (CNG) and liquefied natural gas (LNG), is also being explored as a transition fuel for decarbonising transport. These fuels have a lower carbon intensity compared to conventional diesel and petrol and offer an attractive option for reducing emissions in both land and maritime transport [11]. The economic performance of natural gas vehicles (NGVs) has been evaluated and it is suggested that they may provide a cost-effective way to reduce emissions while maintaining energy security [12]. However, the long-term sustainability of natural gas remains a controversial issue, especially in light of the requirement to transition to fully renewable sources.

The implementation of sustainable fuels brings some challenges. Policymakers have an significant role in facilitating the transition by creating supportive regulatory frameworks and incentives for the adoption of alternative fuels [13]. The integration of sustainable fuels into transport systems requires significant investments in infrastructure, technology development and public acceptance [14]. Moreover, the socio-economic impacts of the transition to sustainable fuels should be carefully assessed so that the benefits of this transition can be fairly distributed among different communities [15]. In the context of urban mobility, decarbonisation of transport can be framed by two competing approaches, between a paradigm advocating a shift to active transport and public transport and another paradigm promoting clean technologies to preserve motorised mobility [16]. While both approaches have positive

aspects, the integration of sustainable fuels into existing transport systems can offer a pragmatic solution that provides immediate emission reductions while laying the groundwork for long-term behavioural changes in mobility practices. Global pressure for decarbonisation is manifested in various national and international policies aimed at reducing emissions in the transport sector. For example, the European Union has set the goal of becoming the first carbon neutral continent by 2050, and transport is one of the key areas of this goal [17]. Countries such as Sweden have made significant progress in decarbonising their transport sectors through the adoption of low-carbon technologies and fuels [18]. However, the success of these initiatives depends on the co-operation of multiple stakeholders such as governments, industry and civil society to create sustainable transport strategies.

As a result, sustainable fuels play a vital role in decarbonising transport by providing important alternatives to fossil fuels. The transition to these fuels is essential to meet climate goals and ensure a sustainable future for transport. However, this transition requires a concentrated effort from policymakers, industry leaders and communities to overcome challenges related to infrastructure, technology and public acceptance. When the globe advances toward a more sustainable transport system, the integration of sustainable fuels will be a critical component of this transformation.

2. COMPARISON OF FOSSIL FUELS AND BIOFUELS

Biofuels, among other sustainable fuels, have emerged as promising alternatives to fossil fuels. Biofuels are derived from renewable biological materials, like plant biomass, and can significantly reduce greenhouse gas emissions compared to conventional fossil fuels [19]. As an illustration, biodiesel made by transesterifying vegetable or animal lipids has been shown to have a lower carbon footprint compared to petroleum diesel [20]. Additionally, bioethanol obtained through the fermentation of sugars is increasingly being blended with gasoline to decrease dependency on fossil fuels in the transportation sector [21]. The development of these sustainable fuels not only benefits the environment but also offers economic opportunities in rural areas rich in biomass resources [22].

The connection between the cost of fossil fuels and the desire for renewable energy is also noteworthy. Research indicates that as fossil fuel prices increase, there is also a rise in demand for renewable energy sources [4]. This trend suggests that economic factors play an significant role in the transition to sustainable fuels. Furthermore, the volatility of fossil fuel markets, exacerbated by geopolitical tensions and supply chain disruptions, underscores the need for stable and sustainable energy alternatives [23]. As countries strive to ensure energy independence and security, the transition to renewable energy sources is becoming increasingly attractive. The graph below illustrates the Capacity of Biofuels by Year according to IRENA's 2023 Renewable Energy Statistics Report.

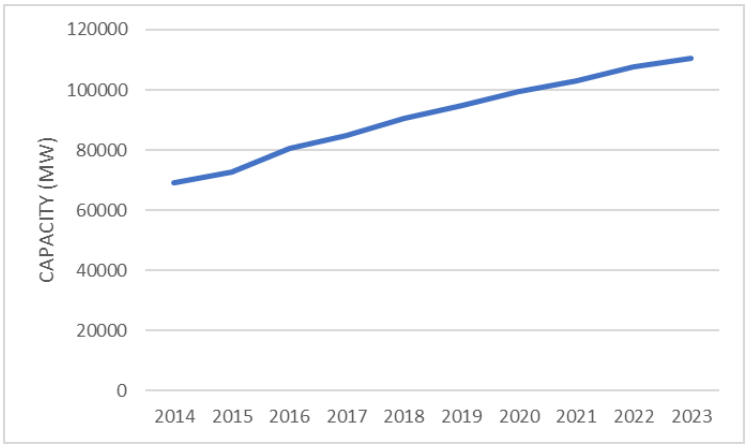

Figure 3. Capacity of biofuels according to years [24]

In the report, biofuels worldwide are examined in three categories: Solid Biofuels and Renewable Waste, Other Solid Biofuels, and Liquid Biofuels. In the Solid Biofuels and Renewable Waste category, key countries with high capacity and production are concentrated in various regions. Europe leads in this category, with countries like the United Kingdom, Sweden, and Germany possessing high capacities. The European Union, in particular, makes the largest contribution, with a total production value of 138,070 GWh as of 2022. In the Other Solid Biofuels category, Asia and North America have the highest capacities. In 2023, the United States recorded a capacity of 10,172 MW and a production value of 38,973 GWh. China and Japan also stand out with high production values, producing 71,600 GWh and 34,483 GWh, respectively. In the Liquid Biofuels category, Italy is notable in Europe, with a production of 3,088 GWh in 2022 [24]. Biofuels differ from other renewable energy sources in several key aspects. Compared to resources like solar and wind energy, the main advantage of biofuels is their ability to provide continuous production capacity. While solar energy loses production capability at night or on cloudy days, and wind energy loses capacity at low wind speeds, biofuels can provide energy under all conditions. This feature makes biofuels a more reliable renewable energy source; however, due to the production processes and raw materials involved, biofuels lag behind cleaner options like solar and wind in terms of carbon footprint.

In terms of capacity, the total capacity (CAP) and production (PROD) values of biofuels fall behind fast-growing sources like solar and wind. Nevertheless, the ability to use biofuels as liquid fuel, especially in the transportation sector, sets this energy source apart from other renewables. Biofuels can work in harmony with fossil fuels and integrate easily with existing infrastructure. However, renewable resources like solar and wind are more often preferred for electricity generation due to their cost-effectiveness and large-scale applicability. In conclusion, biofuels offer the unique advantages of continuous energy production and compatibility with fossil fuel infrastructure, though they fall behind in capacity growth, carbon emissions, and costs compared to solar and wind. In the future, more efficient processes may help bridge this gap. Table 1 below shows the sectoral distribution of global liquid fuel demand (mb/d) according to the IEA's Net Zero Emission (NZE) Scenario.

Table 1. Global liquids demand by net zero emission scenario (mb/d) [25, 26]

	2030	2035	2050
Road Transport	31.9	20.1	2.3
Aviation and shipping	9.3	7.0	1.8
Industry and petrochemicals	19.7	18.2	13.1
Building and power	6.6	3.6	0.4
Other sectors	10.8	8.9	5.3
World Oil Demand	78.3	57.8	23.0
Liquid biofuels and low emissions hydrogen based fuels	6.7	8.8	11.5
World Liquid Demand	85.0	66.6	34.5

The evaluation is as follows:

1. Road Transport: 31.9 mb/d in 2030, decreasing to 20.1 mb/d in 2035 and 2.3 mb/d in 2050. This decrease shows that the transition to alternative energy sources and electrification in road transport should increase rapidly in order to achieve zero emission targets.
2. Aviation and Maritime Transport: Demand falls from 9.3 mb/d in 2030 to 7.0 mb/d in 2035 and 1.8 mb/d in 2050. As these sectors are among the most challenging sectors for carbon mitigation, a lower demand target has been set.
3. World Oil Demand: Total oil demand falls from 78.3 mb/d in 2030 to 57.8 mb/d in 2035 and 23.0 mb/d in 2050. In the NZE scenario, global oil demand is projected to decline significantly.
4. Liquid Biofuels and Low Emission Hydrogen Based Fuels: Demand increases from 6.7 mb/d in 2030 to 11.5 mb/d in 2050. Biofuels and low-emission hydrogen-based fuels stand out as low-carbon alternatives to fossil fuels.
5. World Liquid Fuel Demand: Total liquid fuel demand decreases from 85.0 mb/d in 2030 to 34.5 mb/d in 2050. This decrease indicates that fossil fuels will be replaced by alternative energy sources in line with zero emission targets.

Oil and biofuel demand show significant differences in the process of a sustainable energy transition. In 2030, oil demand is at a very high level, while by 2035, this demand decreases by 26 per cent. This downward trend accelerates further in 2050, representing a reduction of up to 70 per cent. This dramatic decline in oil demand demonstrates the need to rapidly reduce the use of fossil fuels in order to achieve zero emission targets. In contrast, the demand for biofuels and low-emission hydrogen-based fuels is increasing. In contrast to oil demand, this continuously increasing demand indicates that biofuels and low-carbon alternatives are beginning to replace fossil fuels. In the period 2030-2050, the demand for biofuels and hydrogen increases by approximately 72 per cent, while the demand for oil decreases by 70 per cent. This shows how low-carbon fuels such as biofuels and hydrogen will play a critical role in the process of replacing oil in achieving zero emission targets.

The International Journal of Energy & Engineering Sciences, 2024, 9 (2) 115-127
ISSN: 2602-294X - Gaziantep University

In terms of emissions, oil causes high carbon emissions, while biofuels and low emission hydrogen-based fuels offer a lower carbon footprint. In the NZE scenario, the deployment of biofuels and hydrogen fuels offers a strategic approach to achieving sustainable energy targets. By 2050, while oil demand is greatly reduced, biofuels are an important alternative in sectors where decarbonisation is difficult, like industry and transport. In conclusion, the rapid decline of fossil fuels and increase in biofuels in the NZE scenario emphasises the importance of biofuels and low-carbon alternatives in the transition to a sustainable energy future.

According to another evaluation, Figure 4 below shows the distribution of average annual investments in fuel supply between 2030 and 2050 by type under different Net Zero Emission scenarios.

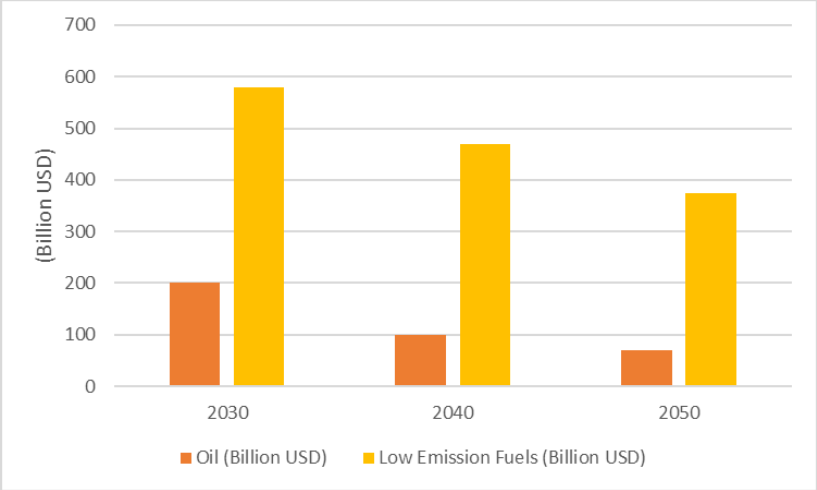

Figure 4. Average annual investments in fuel supply under the net zero emission scenario [25, 26]

A. Increasing weight of investment in low emission fuels:

o In the NZE scenario, investment in low emission fuels remains very high for all three years (2030, 2040 and 2050). This investment peaks in 2030 (USD 580 billion) and then gradually declines, but is still as high as USD 375 billion in 2050, indicating that low emission fuels will play a key role in future energy strategies.

o This indicates that the transition to sustainable energy will accelerate and the use of low emission fuels (hydrogen, bioenergy, etc.) will replace fossil fuels.

B. Declining Investment in Oil:

- Oil investments show a rapid decline from 2030 onwards: USD 200 billion in 2030, falling to USD 100 billion in 2040 and USD 70 billion in 2050. This suggests that the role of oil in energy supply will decline and the need for renewable energy and low-emission fuels will increase.
- This reduction reflects the fact that the Net Zero Emissions (NZE) scenario is based on limiting fossil fuel investments to reduce carbon emissions. Limiting the use of fossil fuels such as oil is an important step to reduce carbon emissions.

C. Shifting Investments in Energy Transition to Renewable Energy:

- Investment in low emission fuels is several times the size of investment in oil. This indicates that the energy sector will make a significant transition towards low-carbon energy sources and that future energy infrastructure will be built on renewable resources and low-emission technologies.
- This transition can be considered as an important step in the fight against climate change. These investments in low-carbon technologies are part of efforts to limit the global temperature rise.

D. Peak in 2030 and Declining Low Emission Fuel Investments Afterwards:

- Investment in low-emission fuels peaks at USD 580 billion in 2030 and declines slightly in 2040 and 2050. This decline may imply that investments until 2030 will be concentrated on building and developing infrastructure, while in 2040 and 2050 this infrastructure can be utilised more efficiently.
- In this case, the decline in investment in low-emission fuels after 2030 can perhaps be attributed to the more established infrastructure of renewable energy systems.

Besides biofuels, advances in technology are also facilitating the development of other sustainable fuel options. For example, hydrogen fuel, produced by electrolysis or reforming processes, has attracted attention as a clean energy carrier that can be utilized in fuel cells to produce electricity where water is the only by-product [27]. Hydrogen has great potential to decarbonise various sectors such as transport and industry, especially as production and storage technologies continue to improve [28].

3. GENERAL OVERVIEW AND ASSESSMENT

The future of sustainable fuels is also closely linked to the concept of circular economy, which emphasises the importance of resource efficiency and waste reduction [29]. By using waste materials and by-products from various industries as feedstock for biofuel production, it is possible to create a more sustainable energy system that maximises resource use while minimising environmental impact.

Despite promising developments in sustainable fuels, some challenges remain. The economic viability of biofuels and other renewable energy sources is often hampered by high production costs and competition with established fossil fuel markets [30]. Moreover, the infrastructure required for the widespread adoption of sustainable fuels, such as fuelling stations for biofuels and hydrogen, is still inadequate in many regions [31]. Policymakers play a critical role in facilitating this transition by implementing supportive regulations, incentivising research and development, and increasing public awareness of the benefits of sustainable fuels [32].

In conclusion, the comparison between fossil fuels and sustainable fuels reveals a complex picture shaped by environmental, economic and technological factors. Although fossil fuels have historically fuelled global development, their negative impacts on the environment and their finite nature necessitate a transition to sustainable alternatives. Advances in biofuels, hydrogen production and circular economy principles offer promising pathways to a more sustainable energy future. Going forward, continuing to invest in research, infrastructure and policies that

support the transition to sustainable fuels is critical to ensure energy security and environmental protection for future generations.

Sustainable aviation fuels (SAF) are attracting increasing attention. SAF has a lower carbon intensity compared to conventional fossil jet fuels and offers a significant opportunity to decarbonise the aviation sector. Expectations are for SAF to meet around 2 per cent of global aviation energy demand by 2030, which could reach 10 per cent by 2050. However, in order for SAF to be used on a large scale, many conditions need to be fulfilled, such as reducing production costs, developing infrastructure and providing regulatory support [25, 26].

In this context, integrating sustainable fuels into the future energy system offers an important contribution towards reducing carbon emissions. Accelerating the adoption of sustainable fuels is considered as a strategic step that will contribute to the sustainable energy transition and the achievement of net zero targets.

Demand for liquid biofuels increased by 7% in 2023, reaching 2.3 million barrels of oil equivalent per day (mboe/g). This demand may increase to 3.2 mboe/g by 2035 and 4.1 mboe/g by 2050. Especially the increase in the demand for sustainable aviation fuels (SAF) supports this growth [25, 26].

Biogas and biomethane demand could double to 90 billion cubic metres equivalent (bcme) by 2035. In all scenarios, the share of biomethane in total biogas demand is expected to increase, driven by CO2 pricing, political support and economies of scale [25, 26].

Low-emission hydrogen production also has an important place in the sustainable energy transition and is expected to account for a significant share of global hydrogen production in 2024 [25, 26].

The GHG intensity, best available technologies and CO_2 removal potential', values of selected biofuel production pathways under typical conditions are as follows:

- Corn Bioethanol: Typical GHG intensity is about 45 gCO_2-eq/MJ, which can be reduced to 20 gCO_2-eq/MJ when using low emission energy sources. With CO_2 capture and storage, negative emissions of up to -20 gCO_2-eq/MJ can be achieved [25, 26].
- Sugar Cane Bioethanol: Typical GHG intensity of about 20 gCO_2-eq/MJ [25, 26]. Renewable Diesel/SAF from Vegetable Oil (HVO/HEFA): The typical GHG intensity of these fuels produced from vegetable oils or waste oils ranges between 33-55 gCO_2-eq/MJ. It can be reduced to 10-15 gCO_2-eq/MJ levels with low emission energy sources [25], [26].
- Renewable Diesel/SAF from Waste Oil (HVO/HEFA): Typical emission intensity is about 10 gCO_2-eq/MJ and exhibits lower carbon intensity [25, 26].

It shows how the GHG intensities of sustainable fuel production pathways can vary with typical, best available technologies and CO_2 capture potential.

4. CONCLUSIONS

In the World Energy Outlook 2024 report, sustainable fuels especially sources such as bioenergy and low-emission hydrogen are presented as critical components of the global energy transition. These sustainable fuels stand out as options that can play an important role in reducing fossil fuels in some challenging sectors (for example, industrial production, transportation and aviation). Low-emission hydrogen has the potential to decrease carbon emissions, especially by using it in energy-intensive sectors. Sustainable fuels are critical in the energy transition and play an important role in reducing carbon emissions. These fuels increase energy security and diversity by providing alternatives to fossil fuels, especially in sectors such as industry and transportation, where direct electrification and energy efficiency are limited. Under the Net Zero Emissions 2050 Scenario (NZE), by 2030 and 2050, the demand for low-emission fuels like hydrogen, liquid biofuels, biogas, and hydrogen-based fuels should have doubled. In order for sustainable fuels to become fully widespread, it is of great importance to develop a common understanding of fuels to be considered "sustainable". The development of common sustainability standards and policies can support broader progress towards reducing carbon emissions by increasing the investment attractiveness of sustainable fuels.

REFERENCES

[1] Baydar, C., Yağlı, H., Ata, S., Koç, Y., Koç, A., & Kocaman, E. (2024). Scrutinizing effect of temperature and pressure variation of a double-pressure dual-cycle geothermal power plant turbines on the temperature profile and heat gain of the heat exchangers. Energy Conversion and Management, 322, 119104. https://doi.org/10.1016/j.enconman.2024.119104

[2] International Energy Agency, 2023. World Energy Outlook. (Accessed in: 25 October 2024) https://www.iea.org/reports/world-energy-outlook-2023

[3] Love, J. (2022). Microbial pathways for advanced biofuel production. Biochemical Society Transactions, 50(2), 987-1001. https://doi.org/10.1042/bst20210764

[4] Khaw, K. and Ni, T. (2021). Fossil fuel price, carbon dioxide emission, and renewable energy capacity: evidence from asian developing countries. International Journal of Banking and Finance, 16. https://doi.org/10.32890/ijbf2021.16.1.5

[5] Kolakoti, A., Setiyo, M., & Waluyo, B. (2021). Biodiesel production from waste cooking oil: characterization, modeling and optimization. Mechanical Engineering for Society and Industry, 1(1), 22-30. https://doi.org/10.31603/mesi.5320

[6] King, R. and Tingas, E. (2021). Potential for carbon-neutral advanced biofuels in uk road transport. Journal of Energy Engineering, 147(4). https://doi.org/10.1061/(asce)ey.1943-7897.0000775

[7] Chiavola, O. (2024). High pressure injection pump operating with renewable diesel fuels.. https://doi.org/10.20944/preprints202402.1319.v1

[8] Kwok, J. (2021). Towards a hydrogen economy – a sustainable pathway for global energy transition. Hkie Transactions, 28(2), 102-107. https://doi.org/10.33430/v28n2thie-2020-0046

[9] Abánades, A., Rathnam, R., Geißler, T., Heinzel, A., Mehravaran, K., Müller, G., … & Wetzel, T. (2016). Development of methane decarbonisation based on liquid metal technology for co2-free production of hydrogen. International Journal of Hydrogen Energy, 41(19), 8159-8167. https://doi.org/10.1016/j.ijhydene.2015.11.164

[10] Harrison, T., Midgley, W., Goodall, R., & Ward, C. (2021). Development and control of a rail vehicle model to reduce energy consumption and carbon dioxide emissions. Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail and Rapid Transit, 235(10), 1237-1248. https://doi.org/10.1177/0954409721993632

[11] Warguła, Ł., Kukla, M., Lijewski, P., Dobrzyński, M., & Markiewicz, F. (2020). Impact of compressed natural gas (cng) fuel systems in small engine wood chippers on exhaust emissions and fuel consumption. Energies, 13(24), 6709. https://doi.org/10.3390/en13246709

[12] Hagos, D. and Ahlgren, E. (2018). Economic performance evaluation of natural gas vehicles and their fuel infrastructures. E3s Web of Conferences, 51, 01008. https://doi.org/10.1051/e3sconf/20185101008

[13] Dyrhauge, H. (2021). Discourses about eu transport decarbonisation: towards a paradigm shift?. The International Spectator, 56(3), 71-86. https://doi.org/10.1080/03932729.2021.1962665

[14] Etukudoh, E. (2024). A review of sustainable transportation solutions: innovations, challenges, and future directions. World Journal of Advanced Research and Reviews, 21(1), 1440-1452. https://doi.org/10.30574/wjarr.2024.21.1.0173

[15] Caetano, T., Merven, B., Hartley, F., & Ahjum, F. (2017). Decarbonisation and the transport sector: a socio-economic analysis of transport sector futures in south africa. Journal of Energy in Southern Africa, 28(4). https://doi.org/10.17159/2413-3051/2017/v28i4a2945

[16] Colombo, C. (2023). Understanding the policy integration challenges of sustainable urban mobility in the context of rapid decarbonisation. European Journal of Risk Regulation, 14(3), 583-606. https://doi.org/10.1017/err.2023.62

[17] Dickason, X. (2023). Decarbonising transport in the european union. Australian and New Zealand Journal of European Studies, 15(1), 102-108. https://doi.org/10.30722/anzjes.vol15.iss1.17371

[18] Mellquist, A., Pirie, J., Smith, A., Stenning, J., Vanacore, E., & Williander, M. (2017). Decarbonising the swedish road transport sector. International Journal of Energy Production and Management, 2(3), 251-262. https://doi.org/10.2495/eq-v2-n3-251-262

[19] Ramli, N., Rahman, R., & Illias, R. (2019). Enhancement of isobutanol and 3-methyl-1-butanol production yields in saccharomyces cerevisiae without genetic modification. Journal of Energy and Safety Technology (Jest), 1(2-2). https://doi.org/10.11113/jest.v1n2-2.26

[20] Parveen, S., Sharma, R., Bais, R., & Saini, R. (2022). Study on biodiesel production from datura innoxia and datura metel seed oils from western rajasthan, india. Ecology Environment and Conservation, 28(04), 1857-1862. https://doi.org/10.53550/eec.2022.v28i04.031

[21] Menezes, F., Cruz, G., Lopes, M., Nelson, D., Martins, T., & Laia, M. (2019). Evaluation of endoglucanase and β-glucosidase production by bacteria and yeasts isolated from an eucalyptus plantation in the cerrado of minas gerais. Ambiente E Agua - An Interdisciplinary Journal of Applied Science, 14(4), 1. https://doi.org/10.4136/ambi-agua.2324

[22] Lin, R. and Ren, J. (2020). Renewable energy and sustainable development. Renewable Energy and Sustainable Development, 6(1), 3. https://doi.org/10.21622/resd.2020.06.1.003

[23] Barke, A., Bley, T., Thies, C., Weckenborg, C., & Spengler, T. (2022). Are sustainable aviation fuels a viable option for decarbonizing air transport in europe? an environmental and economic sustainability assessment. Applied Sciences, 12(2), 597. https://doi.org/10.3390/app12020597

[24] International Renewable Energy Agency, 2024. Renewable Energy Statistics 2024. (Accessed in: 25 October 2024) https://www.irena.org/Publications/2024/Jul/Renewable-energy-statistics-2024

[25] International Energy Agency, 2024. World Energy Outlook. (Accessed in: 25 October 2024) https://www.iea.org/reports/world-energy-outlook-2024

[26] International Energy Agency, 2024.Towards Common Criteria for Sustainable Fuels. (Accessed in: 25 October 2024) https://www.iea.org/reports/towards-common-criteria-for-sustainable-fuels

[27] Al-Mahadin, A. and Mustafa, M. (2018). Utilizing fuel cell technology for dubai roads and transport authority (rta).. https://doi.org/10.1109/icaset.2018.8376784

[28] Srivastava, R., Nouseen, S., Chattopadhyay, J., Woi, P., Son, D., & Bastakoti, B. (2020). Recent advances in electrochemical water splitting and reduction of co2 into green fuels on 2d phosphorene-based catalyst. Energy Technology, 9(1). https://doi.org/10.1002/ente.202000741

[29] Hasheminasab, H., Zolfani, S., Zavadskas, E., Kharrazi, M., & Škare, M. (2021). A circular economy model for fossil fuel sustainable decisions based on madm techniques. Economic Research-Ekonomska Istraživanja, 35(1), 564-582. https://doi.org/10.1080/1331677x.2021.1926305

[30] Lamb, J., Hjelme, D., & Lien, K. (2019). Carbohydrate yield and biomethane potential from enzymatically hydrolysed <i>saccharina

latissima</i> and its industrial potential. Advances in Microbiology, 09(04), 359-371. https://doi.org/10.4236/aim.2019.94021

[31] Tambunan, H., Sitanggang, R., Mafruddin, M., Prasetyawan, O., Kensianesi, K., Istiqomah, I., … & Tanbar, F. (2023). Initial location selection of electric vehicles charging infrastructure in urban city through clustering algorithm. International Journal of Electrical and Computer Engineering (Ijece), 13(3), 3266. https://doi.org/10.11591/ijece.v13i3.pp3266-3280

[32] Bergman, N. (2018). Impacts of the fossil fuel divestment movement: effects on finance, policy and public discourse. Sustainability, 10(7), 2529. https://doi.org/10.3390/su10072529