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Published in:
Journal of Environmental Management

DOI:
10.1016/j.jenvman.2024.121116

Publication date:
2024

Journal of Environmental Management 360 (2024) 121116

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Advancing sustainable materials in a circular economy for decarbonisation

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ARTICLE INFO

Keywords:
Decarbonisation
Sustainability
Chemical looping technologies
Oil refineries
Carbon capture and utilisation
Integrated assessment modelling

ABSTRACT

This research paper delves into the intricate interplay between decarbonisation and sustainability, focusing on adopting chemical looping technologies. Deep decarbonisation scenarios necessitate a profound transformation in various sectors to mitigate climate change, and oil refineries, as pivotal players, must adapt to these changes. Employing the BLUES integrated assessment model, we evaluate the evolution of the refining sector in decarbonisation pathways, emphasising its potential for sustainability through repurposing and emissions mitigation. Additionally, we delve into chemical looping technologies, including Solar Thermal Chemical Looping (STCL), Reverse Water Gas Shift Chemical Looping (RWGS-CL), Chemical Looping Reforming (CLR), and Super Dry Reforming (SDR), elucidating their principles and contributions to carbon dioxide (CO_2) conversion. These technologies offer promising routes for CO_2 capture and present opportunities for sustainable carbon loop cycles, potentially revolutionising industries' emissions reduction efforts. In a world of climate change, this research illuminates a sustainable path forward by integrating decarbonisation and innovative CO_2 management strategies.

1. Introduction

In a world facing the ever-pressing challenges of climate change and environmental degradation, the imperative to decarbonise industries and transition towards sustainable practices has become paramount. As nations strive to meet climate targets and reduce greenhouse gas emissions, profound transformations are underway in the energy production and transportation sectors (Zheng et al., 2024; Luo et al., 2023). Two critical themes emerge as focal points among the myriad facets of this transition—the decarbonisation of energy systems and the responsible management of materials in a circular economy. Deep decarbonisation scenarios, predicated on scientific assessments of the urgency of curbing global warming, project a significant decline in the use of fossil fuels in the coming decades (Xiao et al., 2023). This transformation implies that industries traditionally reliant on fossil resources must adapt to ensure their relevance and sustainability in a decarbonised world(Rodrigue, 2020). One such sector facing a transformative challenge is the oil refining industry. The refining sector plays a pivotal role in the energy landscape, producing a spectrum of products vital to modern life, including fuels for transportation, feedstocks for petrochemicals, and various other essential materials. However, it is also a notable source of greenhouse gas emissions. This research paper delves into the refining sector's role in deep decarbonisation pathways, explicitly focusing on Brazil as a case study (Scown, 2022;Adeoye et al., 2017). This study employs the BLUES (Brazilian Land-Use and Energy Systems) model, a national integrated assessment tool designed to investigate the evolution of sectors within Brazil's economy under different mitigation scenarios until 2050. This model provides a comprehensive framework for evaluating strategies to mitigate climate change, considering the dynamics of various economic sectors, socio-cultural factors, and policy contexts over long time horizons (Geyer et al., 2017;Wen et al., 2024). The research within this paper examines not only the broad implications of decarbonisation for the refining sector but also delves into specific strategies that can enhance the sector's resilience in the face of transformative change. These strategies encompass the production of feedstocks for petrochemicals, fuels for aviation and maritime sectors, and biomass co-processing. Repurposing refining assets and considering emissions mitigation within the sector aims to reduce the risks associated with carbon lock-in and asset stranding (Wang et al., 2021; Oladapo et al., 2023b).

Generating waste and emissions of linear lifecycle flow automation enables a circular economy for plastic recycling. Digitalisation is

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https://doi.org/10.1016/j.jenvman.2024.121116
Received 3 February 2024; Received in revised form 15 April 2024; Accepted 6 May 2024
Available online 20 May 2024
0301-4797/

foundational to creating a sustainable solution for plastic trash by improving manufacturing processes. Our planet requires sustainable packaging solutions. A circular economy shrinks harmful activities such as carbon emissions, air pollution, and toxicity exposure (Zhang et al., 2019; Olawale et al., 2023). Parallel to the decarbonisation of energy systems, the transition to a circular economy represents a paradigm shift in materials management. The conventional "take-make-toss" linear approach to materials usage gives way to circular economy principles that prioritise sustainability through the recycling, repurposing, and responsible management of materials (Shang and Luo, 2021; Bachmann et al., 2023a). This transition is crucial as materials sourced for decarbonising technologies often rely on mining and extraction industries, which have significant environmental impacts. While renewable energy technologies are a step toward building circular material flows, the materials required for decarbonising electricity generation and mobility still predominantly come from natural resource extraction (Spišáková et al., 2022; Ncube et al., 2023). Manufacturers of essential clean energy technologies, including wind turbines, photovoltaics, batteries, and electric vehicles, continue to rely on virgin materials rather than waste for production.

Moreover, comprehensive end-of-life management strategies for these materials remain underdeveloped (Luo et al., 2023a; Wang et al., 2024). This paper synthesises progress towards a circular economy for critical materials essential to decarbonising electricity generation and mobility. It focuses on strategies to reduce the environmental impacts of resource extraction, metallurgy, manufacturing, and waste disposal while promoting resource recovery (Sun et al., 2024; Oladapo and Zahedi, 2021). The ultimate aim is to outline pathways for a more sustainable future by analysing the materials needed for the clean energy transition and their impact on the environment and society (Bachmann et al., 2023b; Sun et al., 2024). In the following sections, we delve into the methodology of this study, exploring the use of integrated assessment modelling and downscaling of results to the refinery level, as well as investigating various chemical looping technologies for CO_2 conversion and examining sustainability initiatives in the electric vehicle (EV) industry, with a particular focus on NIO, a prominent EV manufacturer in China (Rahla et al., 2021;Li et al., 2023). Fig. 1 shows the linear lifecycle flow inefficiencies in designing processes that generate waste and emissions and sustainability innovation and solutions for a circular economy's oil, gas, and petrochemical industries. The research presented herein underscores the urgency and complexity of transitioning towards decarbonisation and circular material flow to secure a sustainable future.

The primary purpose of this paper is to provide a comprehensive examination of the challenges and opportunities associated with integrating chemical looping technologies for carbon dioxide (CO_2) conversion in the context of sustainable decarbonisation efforts (Balogun and Oladapo, 2016;Ahmed et al., 2017). We aim to assess the sustainability challenges posed by the transition towards deep decarbonisation, particularly within the context of oil refineries and related industries (Bala et al., 2007; Omigbodun et al., 2019). This includes an exploration of the environmental, economic, and regulatory constraints that necessitate innovative CO2 management strategies. This paper delves into the various chemical looping technologies, with a focus on Solar Thermal Chemical Looping (STCL), Reverse Water Gas Shift Chemical Looping (RWGS-CL), Chemical Looping Reforming (CLR), and Super Dry Reforming (SDR)(Oladapo et al., 2022;Gonçalves et al., 2017). We provide insights into their principles of operation, advantages, and potential applications in CO_2 conversion. The methodology section outlines the integrated assessment modelling for climate change mitigation and introduces the BLUES Model. It describes the representation of the refining sector within the BLUES Model and the future scenarios modelled in this study. We conduct an in-depth analysis of methane-utilising CO_2CL processes, their mechanisms, performance characteristics, and potential for contributing to carbon capture and utilisation (CCU) efforts (Oladapo et al., 2023a,; Sangsiri et al., 2022). The paper presents a set of research questions and objectives to explore the feasibility, challenges, and prospects of integrating chemical looping technologies into the broader framework of decarbonisation. Materials Decarbonisation and Sustainability Program: This program is a new, non-profit entity for advanced research to tackle the complex challenges of meeting decarbonisation goals for building materials.

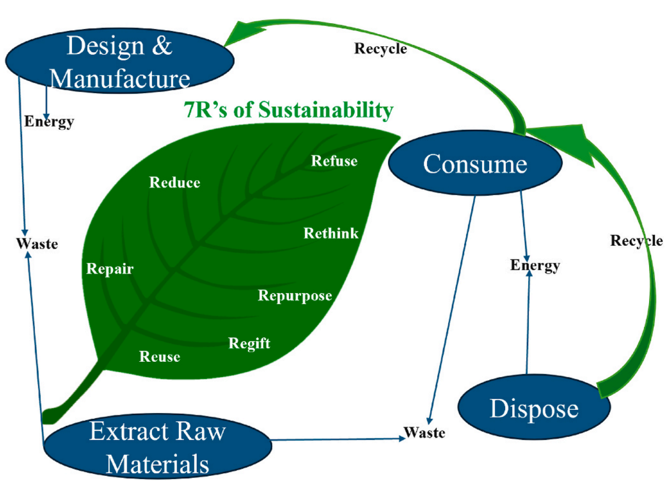

Fig. 1. Linear lifecycle flow inefficiencies in the design of processes generate waste and emissions, as well as sustainability innovation and solutions for a circular economy's oil, gas, and petrochemical industries.

1.1. *Research questions and objectives*

These research questions and objectives guide our investigation and analysis, helping fulfil the broader purpose and scope outlined above. The critical sustainability challenges industries face, particularly oil refineries, in deep decarbonisation are described. Chemical looping technologies, including STCL, RWGS-CL, CLR, and SDR, can be leveraged to address these sustainability challenges and contribute to CO_2 conversion and utilisation. The potential for methane-utilising CO_2CL processes, such as CLR and SDR, to play a role in the performance characteristics of carbon capture and utilisation (CCU) strategies was compared. Evaluate and analyse the environmental, economic, and regulatory factors driving the need for innovative CO_2 management strategies in the transition to deep decarbonisation. Provide a comprehensive overview of chemical looping technologies, highlighting their principles, advantages, and potential applications in CO_2 conversion and mitigation of greenhouse gas emissions. Present the methodology and modelling approach used in the study, including integrating chemical looping technologies within the BLUES Model, and describe the scenarios explored to assess their impact on decarbonisation efforts. Conduct a detailed analysis of methane utilising CO_2CL processes (CLR and SDR), elucidating their mechanisms, performance metrics, and role in advancing CCU strategies. By addressing these research questions and objectives, this paper aims to contribute valuable insights to sustainable decarbonisation, carbon management, and integrating innovative technologies to address the pressing challenges of climate change and greenhouse gas emissions reduction (Fig. 2).

2. Methodology

2.1. *Evaluation of deep decarbonisation*

As the world grapples with the dire consequences of climate change, the need for transformative action to reduce greenhouse gas emissions has never been more apparent. Deep decarbonisation scenarios, informed by scientific assessments and international agreements like the Paris Agreement, outline a trajectory for limiting global warming to 2°C

Fig. 2. Total energies and air liquide innovate to produce renewable, low-carbon hydrogen at Grandpoint zero crude platform.

below pre-industrial levels(Serna-Guerrero et al., 2022; Hertwich, 2021). These scenarios necessitate a substantial shift from fossil fuels, the primary culprit behind carbon dioxide (CO_2) emissions. A profound transition in the energy sector is envisaged in deep decarbonisation scenarios (Luo et al., 2023b; Daly and Bravante, 2021). Fossil fuel-based energy generation gives way to renewables such as wind, solar, and hydropower, accompanied by advancements in energy storage and distribution systems. The electrification of transportation and heating, powered by low-carbon electricity, is a pivotal aspect of these scenarios (Oladapo et al., 2023c;Huntzinger et al., 2009). Furthermore, efforts are intensified to enhance energy efficiency across all sectors, reducing energy demand while meeting the needs of a growing global population (Fig. 3).

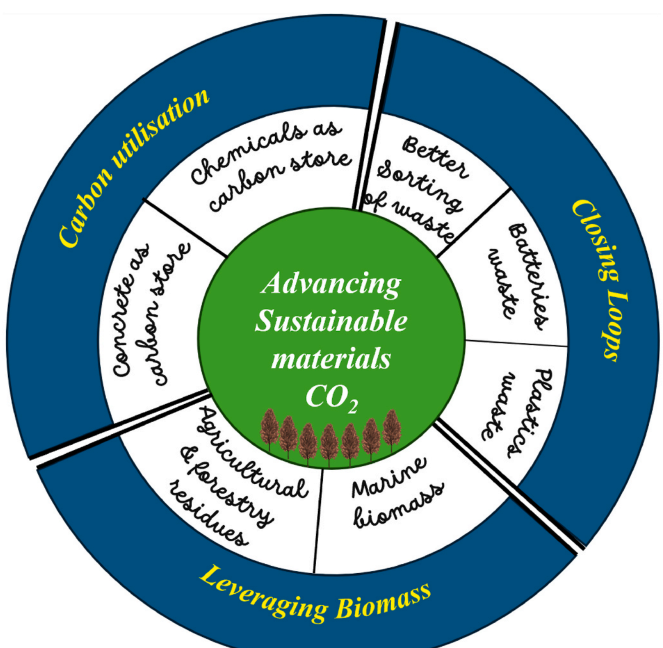

Fig. 3. The circularity of processes and minimising waste are two fundamental economic and zero waste objectives.

2.2. Analysis of oil refineries in Decarbonisation

Oil refineries, integral components of the energy landscape, find themselves at the crossroads of this energy transformation. Traditionally reliant on crude oil as their primary feedstock, these facilities have been engines of economic growth and significant sources of CO_2 emissions. As deep decarbonisation scenarios advocate for significantly reducing fossil fuel use, oil refineries face substantial challenges and opportunities (Oladapo et al., 2018;Jain et al., 2019). One of the fundamental changes expected in the refining sector is the diversification of feedstocks. While crude oil will continue to play a role, the industry will increasingly incorporate alternative feedstocks. In particular, biomass and waste materials can be processed alongside traditional fossil resources(Singh et al., 2014;Balogun et al., 2017). Pyrolysis oils, derived from biomass, can be processed in Fluid Catalytic Cracking (FCC) units.

In contrast, straight vegetable oils can be used in Hydrodesulfurization (HDT) units. This shift to bio-based feedstocks aligns with sustainability goals, reduces carbon emissions, and fosters resource circularity. Historically, decarbonising has been challenging, but the aviation and maritime sectors are a particular focus of attention. Sustainable aviation and marine fuels, produced through advanced refining processes, are essential for reducing emissions in these industries. Oil refineries can play a pivotal role in creating these low-carbon fuels, thereby enabling the decarbonisation of critical transportation modes (Schilling et al., 1981; Rashidi and Yusup, 2016). The concept of biomass co-processing further underscores the role of oil refineries in decarbonisation. It involves the simultaneous processing of fossil and biomass feedstocks to produce fuels with reduced carbon intensity. This strategy enhances the sustainability of refining operations, reduces emissions, and aligns with circular economy principles(Demirbas, 2008; Cui et al., 2023). Beyond feedstock diversification, oil refineries must actively pursue emissions mitigation. Implementing carbon capture and storage (CCS) technologies can significantly reduce emissions from refineries. The captured CO_2 can then be repurposed or stored underground to prevent its release into the atmosphere. An intriguing aspect of oil refinery sustainability in decarbonisation is asset repurposing(Mun and Cho, 2013; Anbar and Akin, 2011)–. Instead of a scenario where assets become stranded due to changing energy demands, refineries can repurpose their infrastructure for activities aligned with decarbonisation goals. For instance, repurposing facilities to produce sustainable chemicals or fuels can ensure their continued relevance and profitability (Carroccio et al., 2002; Mitchell et al., 2010); . The research indicates that adopting these strategies can help oil refineries reduce the risks associated with carbon lock-in, where investments in high-carbon infrastructure become economically stranded as the world transitions to low-carbon energy systems. Refineries can safeguard long-term viability by aligning with decarbonisation targets and sustainability principles (Fig. 4).

The refining sector is a nexus of decarbonisation and sustainability. It faces the dual challenge of reducing emissions while adapting to a changing energy landscape. However, this transformation also offers the sector a unique opportunity to contribute to the decarbonisation agenda through feedstock diversification, sustainable fuel production, emissions mitigation, asset repurposing, and risk reduction (Ali et al., 2023; Alhajiri et al., 2023). The findings of this study emphasise that, with proactive measures, the refining sector can evolve into a resilient and sustainable component of the global energy transition, ensuring energy security and reduced environmental impact.

2.3. Integrated assessment modelling in climate change mitigation

Assessing and evaluating strategies for climate change mitigation requires comprehensive models that can account for the complexities of

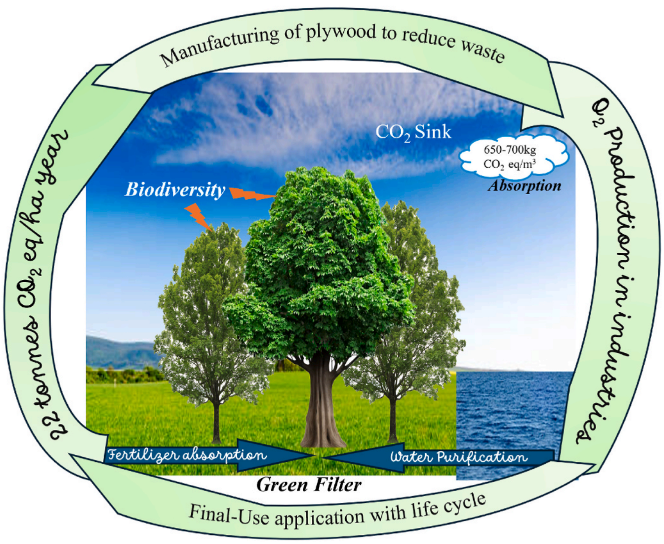

Fig. 4. Poplar, an ally in the fight against climate change, has one of the highest CO_2 absorption rates of all tree species.

various sectors of the economy, technological advancements, policy evolution, and societal changes. Integrated Assessment Models (IAMs) are invaluable tools for this purpose. They provide a framework for understanding how different mitigation strategies impact greenhouse gas emissions, energy systems, and land use(Durmanov et al., 2023; Grasa and Abanades, 2006). These models help formulate scenarios consistent with specific hypotheses, data, and assumptions, aiding in identifying effective strategies for mitigating climate change.

2.4. Introduction to the BLUES model

In this study, the Brazilian Land-Use and Energy Systems (BLUES) model is the primary tool for evaluating the refining sector's role in deep decarbonisation scenarios. BLUES is a national-level Integrated Assessment Model (IAM) specifically tailored to the context of Brazil. IAMs like BLUES are designed to encompass various facets of the energy, land-use, and economic systems, enabling a holistic assessment of long-term climate change mitigation strategies. The BLUES model is characterised by its ability to represent the Brazilian energy system, accounting for the diversity of energy sources, land use patterns, and policy frameworks within the country (Ning Yang et al., 2022; He et al., 2022). Its key strength lies in its capacity to offer insights into how different scenarios affect Brazil energy landscape and emissions trajectories. Detailed information about the BLUES model structure, parameters, and assumptions can be found in this research supplementary materials (SM). This study focuses on the refining sector and its dynamics within the BLUES model. The refining sector, a critical component of the energy value chain, plays a pivotal role in determining the carbon intensity of various end-use fuels and chemicals. BLUES includes representations of the refining sector activities and emissions to assess its impact on decarbonisation pathways (Qian Lv et al., 2020); Daniyan et al., 2023). It is important to note that, in the BLUES model, the refining sector is not characterised by individual refineries but is represented at a regional level, considering the five geographical regions of Brazil. This approach allows for a comprehensive evaluation of the sector's performance across different parts of the country. BLUES considers various feedstock options, including crude oil and biomass, and assesses the potential for emissions reduction within the sector.

2.5. Future scenarios modelled in the study

In this research, we explore three distinct future scenarios to understand how the refining sector may evolve in alignment with deep decarbonisation goals. This scenario assumes Brazil's energy, land use, and agriculture policies continue without significant changes. It is a baseline for assessing the refining sector's performance without substantial decarbonisation efforts. The Nationally Determined Contribution (NDC) Scenario aligns with Brazil's most recent NDC commitments, which target net-zero greenhouse gas emissions by 2050. It includes specific assumptions, such as no illegal deforestation from 2028 onwards, to reflect the country's climate goals. Paris Agreement (PA) Aligned Scenario represents Brazil's contribution to limiting global warming to below 2^oC compared to pre-industrial levels by 2100. It incorporates Brazil's carbon budget and aligns with international efforts to combat climate change. Each scenario provides unique insights into how Brazil's refining sector may adapt and contribute to emissions reduction efforts. The subsequent sections of this research paper will delve into the findings and implications of these scenarios, shedding light on the potential role of the refining sector in achieving deep decarbonisation in Brazil.

3. Result

3.1. Chemical looping for CO_2 conversion

Carbon dioxide (CO_2) conversion technologies are crucial in transitioning towards a more sustainable and low-carbon economy. Chemical looping technologies represent a promising approach to converting CO_2 into valuable products while minimising its release into the atmosphere. This section overviews chemical looping technologies and focuses on Solar Thermal Chemical Looping (STCL). Chemical looping technologies are innovative processes that facilitate the conversion of CO_2 into valuable compounds by employing a solid material known as an oxygen carrier (OC). These technologies operate in two distinct stages: reduction and oxidation. During the reduction stage, the OC selectively captures oxygen from a source, such as air or steam, resulting in an oxygen-deficient material. In the subsequent oxidation stage, the OC releases oxygen through a reaction with a feedstock like CO_2 or hydrocarbons. This release of oxygen forms valuable products, such as carbon monoxide (CO) or hydrogen (H2), depending on the specific chemical looping process (Yan et al., 2021; Olawumi et al., 2023). Chemical looping technologies offer several advantages, including the potential for high-purity product generation, energy efficiency, and the ability to capture CO_2 from various sources, such as industrial processes and power plants. Solar Thermal Chemical Looping (STCL) is a promising approach for solar-driven CO_2 conversion among the different chemical looping technologies (Li et al., 2021).

3.2. Solar Thermal Chemical Looping (STCL)

Solar Thermal Chemical Looping (STCL) is an advanced chemical looping technology that harnesses solar energy to drive the reduction and oxidation reactions within the loop. STCL utilises concentrated solar radiation as a source of high-temperature heat to facilitate the reduction of the oxygen carrier during the reduction phase. This process enables the generation of highly reactive oxygen carriers with minimal energy input. STCL systems consist of high-temperature reactors designed to withstand intense solar radiation. Concentrated sunlight is focused on the reactor, allowing the oxygen carrier to reach the necessary reduction temperature. Clean Energy Production STCL produces valuable products like syngas, a mixture of CO and H_2 from CO_2, which can serve as feedstock for various industrial processes, including Fischer-Trosch synthesis for fuel production (Liu et al., 2021; David et al., 2024). This contributes to the reduction of greenhouse gas emissions and the utilisation of clean energy sources. Efficient Use of Solar Energy STCL optimises solar energy by directly converting it into high-temperature heat for the reduction phase, making it an environmentally friendly and sustainable approach. Potential for Carbon Capture of STCL can be integrated into carbon capture and utilisation (CCU) systems, allowing for the capture of CO_2 from industrial processes and its subsequent conversion into valuable products. STCL is a dynamic and evolving field of research with the potential to play a significant role in addressing climate change and advancing sustainable energy solutions. As the development of STCL continues, it holds promise for contributing to reducing CO_2 emissions and the transition towards a more carbon-neutral future. Fig. 5 describes the advanced sustainable materials from 2005 to the first quarter of 2024 on money spent. The subsequent sections of this research paper will explore various chemical looping processes, including Reverse Water Gas Shift Chemical Looping (RWGS-CL) and other methane-utilising CO_2CL pathways, providing insights into their mechanisms, potential applications, and current research endeavours.

3.3. Reverse Water Gas Shift Chemical Looping (RWGS-CL)

Reverse Water Gas Shift Chemical Looping (RWGS-CL) is a chemical looping process that converts CO_2 into valuable products through a cyclic redox reaction. This section delves into the details of RWGS-CL and its potential applications in sustainable CO_2 conversion. The critical reaction at the heart of RWGS-CL is the reverse water gas shift reaction, which can be represented as follows:

$$\delta CO2 + MOx\text{-}\delta \rightarrow MOx + \delta CO$$

Here, δCO_2 represents a molecule of carbon dioxide, MOx-δ stands for the reduced oxygen carrier (OC), MOx represents the oxidised form of the OC, and δCO signifies a molecule of carbon monoxide (CO). During this reaction, carbon dioxide is reduced to carbon monoxide by the OC, which releases oxygen in the process, converting the OC from its reduced state back to its oxidised form. RWGS-CL has distinctive characteristics that make it an intriguing technology for CO_2 conversion. The utilisation of Hydrogen (H_2) helps RWGS-CL employ H_2 as the reducing agent, which is introduced during the reduction stage of the process. H_2 reacts with the reduced OC to produce water (H_2O) and simultaneously reduces the OC. The formation of Carbon Monoxide (CO), the primary product of RWGS-CL, is carbon monoxide (CO), a valuable feedstock for various industrial processes, including the production of synthetic fuels and chemicals. Lower Temperature Operation Compared to some other chemical looping technologies, RWGS-CL operates at relatively lower temperatures, making it energy-efficient and potentially suitable for a wide range of applications. Flexibility in carbon sources is RWGS-CL's ability to utilise different sources of carbon dioxide, including captured industrial emissions, thereby contributing to carbon capture and utilisation (CCU) efforts.

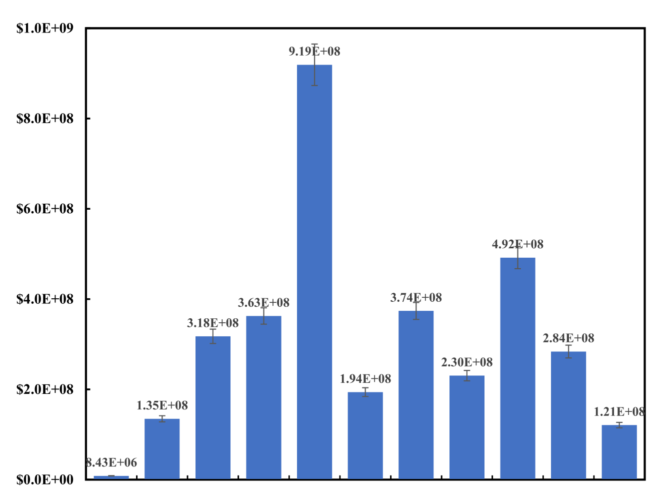

Fig. 5. Advance sustainable materials from 2005 to the first quarter of 2024 on money spend.

3.4. Methane utilising CO_2CL processes

In addition to RWGS-CL, other chemical looping processes use methane (CH_4) as a feedstock for CO_2 conversion. These methane-utilising CO_2CL processes offer unique advantages and opportunities for sustainable carbon management. Chemical Looping Reforming (CLR) is a chemical looping process that involves the reforming of methane (CH_4) with an oxygen carrier (OC). The primary reactions in CLR include the conversion of methane into carbon monoxide (CO) and hydrogen (H_2). The process can be represented as follows:

$$MOx + CH4 \rightarrow MOx\text{-}\delta + \delta CO + \delta H_2$$

In this equation, MOx represents the oxidised OC, MOx-δ means the reduced OC and δCO and δH2 represent the produced carbon monoxide and hydrogen, respectively. CLR is particularly advantageous because it allows for producing valuable syngas, which can serve as a versatile feedstock for various downstream processes, including the synthesis of liquid fuels and chemicals. Moreover, CLR can be integrated into carbon capture and utilisation (CCU) systems, making it a promising technology for mitigating CO_2 emissions while producing valuable products. (Fig. 6)

3.5. Super Dry Reforming (SDR)

Super Dry Reforming (SDR) is another methane-utilising CO_2CL process that combines methane (CH_4) reforming with an oxygen carrier (OC). SDR is characterised by the simultaneous conversion of methane and carbon dioxide into syngas, which consists of carbon monoxide (CO) and hydrogen (H_2) and is represented by the following reaction:

$$MOx + CH_4 + CO_2 \rightarrow MOx\text{-}\delta + \delta CO + \delta H_2$$

Like CLR, SDR offers the advantage of producing syngas with diverse industrial applications. Additionally, SDR has the potential to facilitate carbon capture and utilisation (CCU) efforts, as it allows for the direct conversion of CO_2 into valuable products. These methane-utilising CO_2CL processes present opportunities for sustainable carbon management and producing beneficial chemicals and fuels. Their ability to utilise methane, a potent greenhouse gas, underscores their significance in addressing environmental challenges while contributing to developing a circular carbon economy. The subsequent sections of this research paper will explore the current state of these methane-utilising CO_2CL processes, including their performance, material design considerations, and future directions in advancing their development and

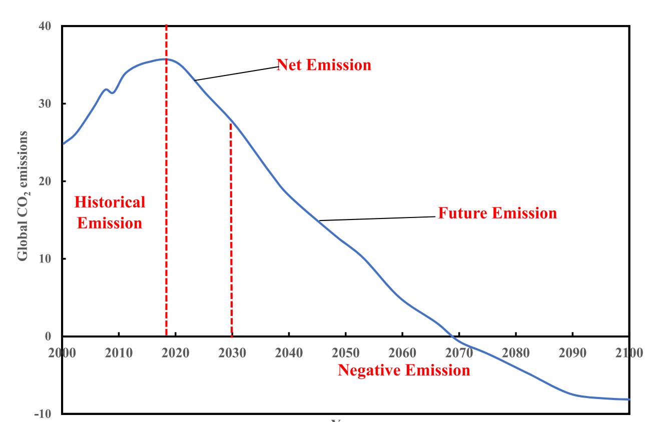

Fig. 6. Slow decarbonisation pathways require significant harmful emissions to stay within the carbon budget of global CO_2 emissions (Gt CO_2 e/year).

application.

4. Conclusion

Integrating chemical looping technologies for CO_2 conversion is a promising avenue in pursuing deep decarbonisation and climate change mitigation. This research paper has illuminated the sustainability challenges faced by industries, particularly oil refineries, in the context of decarbonisation. These challenges span environmental concerns, economic considerations, and evolving regulatory landscapes, necessitating innovative CO_2 management strategies. The exploration of various chemical looping technologies, including Solar Thermal Chemical Looping (STCL), Reverse Water Gas Shift Chemical Looping (RWGS-CL), Chemical Looping Reforming (CLR), and Super Dry Reforming (SDR), has provided valuable insights into their principles and potential applications. These technologies offer novel CO_2 capture and utilisation pathways, presenting opportunities for reducing greenhouse gas emissions and advancing carbon neutrality goals. This paper has highlighted the importance of including chemical looping processes within decarbonisation scenarios through the integrated assessment modelling approach. The findings underscore the significance of refining sector repurposing and the potential for mitigating emissions through innovative CO_2CL strategies.

Moreover, the in-depth analysis of methane utilising CO_2CL processes, such as CLR and SDR, has highlighted their capacity to contribute to carbon capture and utilisation efforts. These processes offer an avenue for CO_2 conversion and facilitate the production of valuable syngas components. This research underscores the crucial role of chemical looping technologies in the broader landscape of sustainability and decarbonisation. As industries navigate the complex terrain of emissions reduction, these technologies promise a more sustainable and environmentally responsible future. By addressing sustainability challenges head-on and leveraging innovative solutions, we can move closer to achieving a carbon-neutral world and combatting the pressing threat of climate change.

CRediT authorship contribution statement

Bankole I Oladapo: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Mattew A. Olawumi:** Conceptualization, Project administration, Software, Validation, Visualization, Writing – review & editing. **Temitope Olumide Olugbade:** Data curation, Formal analysis, Project administration, Resources, Software, Writing – review & editing. **Ting Tin Tin:** Data curation, Formal analysis, Resources, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing for financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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