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Charles, V., & Emrouznejad, A. (2024). DEA-based index systems for addressing the United Nations' SDGs. *Environmental Science & Policy*, *162*, Article 103950. https://doi.org/10.1016/j.envsci.2024.103950

Published in:
Environmental Science & Policy

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

DEA-based index systems for addressing the United Nations' SDGs

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Abstract

The Sustainable Development Goals (SDGs) represent a global commitment to tackling pressing challenges such as poverty, inequality, and environmental degradation by 2030. This special issue focuses on applying Data Envelopment Analysis (DEA) as a tool for measuring and benchmarking progress towards these goals across various sectors. DEA, known for its capacity to handle multiple dimensions of performance, offers a comprehensive framework for assessing the efficiency of different systems in achieving sustainability targets. The 16 papers included in this issue are organised into three thematic sections: Sustainable Efficiency in Resource Management, Environmental and Energy Efficiency for Sustainability, and Governance, Policy, and Social Dimensions of SDG Implementation. Each section explores the application of DEA to key areas such as water management, energy use, waste management, public transport, and governance, providing insights into how DEA-based index systems can drive progress toward achieving the SDGs. The issue also sets a future research agenda, highlighting the need for expanding DEA applications across underrepresented regions and sectors, addressing data challenges, and incorporating dynamic and behavioural factors into DEA models. This collection of papers provides valuable contributions to academics, policymakers, and practitioners working to advance global sustainability efforts.

Keywords: Sustainable Development Goals (SDGs), Data Envelopment Analysis (DEA), Sustainability Measurement, Benchmarking, Multi-Dimensional Analysis, Composite Indices.

1. Introduction

The 2030 Agenda for Sustainable Development, adopted by all United Nations (UN) member states in 2015, established the Sustainable Development Goals (SDGs) (see Figure 1) as part of a broader commitment to global development. The SDGs, which encompass 17 goals and 169 targets, build upon the earlier and significantly narrower UN Millennium Development Goals (MDGs) (2000-2015). These goals aim to tackle global challenges such as poverty, inequality, environmental degradation, and climate change, with the overarching goal of achieving sustainable development by 2030 (United Nations General Assembly, 2015). Each nation bears the responsibility of implementing the SDGs domestically while also contributing

to global efforts; however, the UN highlights that private entities, civil society organisations, and other non-governmental stakeholders have significant roles in achieving these Global Goals. Achieving sustainable development, however, is a complex and evolving task that requires a comprehensive, multi-faceted approach.

One of the first steps towards assessing the potential of meeting the SDGs by 2030 is developing methods and tools to monitor and evaluate progress (Cristóbal et al., 2021; Nhamo et al., 2020). The challenge lies in quantifying sustainability across various dimensions—economic, environmental, and social—simultaneously. This complexity stems from the fact that sustainable development requires balancing these often-competing dimensions in a way that promotes overall well-being and resource conservation for future generations (Galán-Martín et al., 2016).

Figure 1. Sustainable Development Goals. (Source: https://sdgs.un.org/goals)

1.1 DEA as a Prescriptive Analytics Tool

Data Envelopment Analysis (DEA), an optimisation-based, data-driven management science technique (Charles et al., 2020, 2021), has emerged as a promising method for addressing the multifaceted challenge of measuring progress toward the SDGs. DEA is particularly well-suited for sustainability assessments because it considers multiple performance metrics simultaneously and offers a framework for evaluating the relative efficiency of decision-making units (DMUs). For example, DEA has been widely applied in assessing eco-efficiency across various fields, including studies focused on NetZero targets (Emrouznejad et al., 2023). In the context of the SDGs, DEA can be employed to develop composite indicators that capture the economic, social, and environmental dimensions of sustainability in a holistic manner (Zakari et al., 2022).

As a prescriptive analytics tool (Charles et al., 2022), DEA empowers organisations to not only assess but also enhance their operational performance. Prescriptive analytics goes beyond analysing historical data (descriptive analytics) and predicting future trends (predictive analytics); it provides actionable recommendations based on data-driven insights. DEA helps

decision-makers by identifying inefficiencies and providing insights into best practices across various sectors, regions, or countries. By classifying inputs and outputs, DEA enables comparisons between DMUs with diverse resource allocations and performance metrics. DEA's capacity to handle a large number of variables makes it particularly useful for constructing sustainability indices, which must account for diverse and non-uniform data across the SDG dimensions.

One of DEA's standout features is, indeed, its capability for index development, allowing organisations to create comprehensive performance benchmarks tailored to their specific contexts. By comparing DMUs against their peers, DEA facilitates the identification of operational strategies that can drive improvement. This benchmarking process enables decision-makers to allocate resources effectively and prioritise interventions based on a clear understanding of performance dynamics.

Moreover, DEA's multi-dimensional approach supports nuanced assessments that guide organisations in making informed, data-driven decisions. By translating complex performance metrics into actionable insights, DEA empowers organisations to foster continuous improvement and achieve their strategic objectives. In a nutshell, DEA emerges as an essential prescriptive analytics tool, providing a roadmap for sustainable growth and operational excellence.

While studies utilising DEA to examine sustainability are emerging (Chuai et al., 2021; Xu & Yao, 2022), there remains a need for more comprehensive research that integrates multiple dimensions of sustainability—economic, social, and environmental—into composite indicators. Most existing research focuses on specific dimensions of the SDGs, such as food supply/SDG2 (Lucas et al., 2021), health/SDG3 (Habib & Shahwan, 2020), energy/SDG7 (Zakari et al., 2022), or CO2 emissions/SDG13 (De Castro Camioto et al., 2014). Developing DEA-based composite indices that capture the interplay between these dimensions is crucial for creating an integrated framework for sustainable development.

1.2 Relevance and Impact of DEA-based Composite Indices

DEA-based composite indicators can significantly aid the transition toward sustainable development by identifying the most efficient pathways for progress. These indicators can pinpoint the primary sources of inefficiency and establish goals for improvement. Furthermore, integrating the three pillars of sustainability into a unified index system offers a more nuanced understanding of resource allocation and performance evaluation. This, in turn, provides governments and organisations with actionable insights to better design policies and optimise resource use, ultimately improving the efficiency of SDG-related efforts.

However, developing composite indices without explicitly linking them to the SDGs can lead to suboptimal results or even unintended consequences, promoting unsustainable practices. By utilising DEA-based indices, which reflect a careful integration of sustainability goals, decision-makers are better positioned to design policies that not only benchmark progress but also drive sustainable transformation.

The scope of this Special Issue is timely and vital for the global challenge of sustainable development. It focuses on research that explores the potential of DEA-based index systems to measure and benchmark SDG progress across various contexts, offering valuable contributions to academics, policymakers, practitioners, and NGOs alike. The papers in this issue inform strategies aimed at improving the efficiency of current SDG policies, engaging in best practices, and guiding the allocation of resources—all with the ultimate aim of achieving sustainable development.

2. The Papers in This Special Issue

This special issue brings together diverse research on the application of DEA to assess progress towards the United Nations' SDGs. The 16 papers are organised into three thematic sections based on their focus, methodologies, and contributions. This classification not only underscores the versatility of DEA across different sectors and challenges but also allows for a clearer understanding of how DEA-based assessments can drive sustainable progress across a wide range of disciplines, from resource management to governance and social policy.

The first section, *Sustainable Efficiency in Resource Management*, encompasses papers that evaluate the efficiency of resource use in sectors such as energy, waste management, and water resources. These papers address critical global challenges by employing DEA models to measure and improve sustainability outcomes, particularly in the context of SDGs related to clean energy (SDG 7), water (SDG 6), and environmental sustainability (SDG 13). Each paper in this section emphasises the need for better resource management and showcases DEA as a powerful tool for guiding policy interventions, optimising resource use, and reducing environmental impacts.

The second section, *Environmental and Energy Efficiency for Sustainability*, focuses on the integration of DEA models with environmental and energy efficiency objectives. The papers explore how DEA can be applied to assess the environmental performance of various industries, such as refrigeration, tourism, and public transportation. These studies contribute to global discussions on SDG 13 (Climate Action) and SDG 9 (Industry, Innovation, and Infrastructure) by offering policy recommendations aimed at improving energy efficiency and fostering sustainable practices. The use of innovative hybrid models and incorporation of external factors like built environment considerations highlight the role of DEA in promoting sustainable urban development and energy transitions.

The third section, *Governance, Policy, and Social Dimensions of SDG Implementation*, explores how DEA can be applied to governance structures, educational efficiency, and policymaking. These papers examine the social dimensions of sustainability, focusing on the intersection of political factors, public governance, and education with SDGs like quality education (SDG 4), gender equality (SDG 5), and sustainable cities (SDG 11). By applying DEA to evaluate public services, governance efficiency, and educational outcomes, these studies provide valuable insights for policymakers and governments seeking to align their practices with the broader sustainability agenda. They also emphasise the need for transparency, standardisation, and policy innovation in achieving sustainable development goals.

2.1 Sustainable Efficiency in Resource Management

In “Green Economic Efficiency and Productivity for Sustainable Development of China: A Ray Epsilon-Based Measure Model Analysis”, Renbian Mo, Hongyun Huang, Jiacheng Zhang, Ying Liu, and Xin Zhao address the urgent challenge of improving China’s green economic efficiency (GEE) and green total factor productivity (GTFP) in the face of high energy consumption and pollution. By employing a Ray epsilon-based measure (REBM) model that accounts for both desirable and undesirable outputs, the authors present a robust methodology for assessing regional disparities in GEE across China. The paper’s spatial econometric analysis reveals that while coastal urban areas perform better, China still faces substantial challenges in energy conservation and emissions reduction. This study is crucial for policymakers, as it highlights the need for targeted interventions to improve the GEE, especially in inland areas. Furthermore, the dynamic evolution of GTFP provides valuable insights into the impact of technical progress on sustainable development, making this research instrumental for China’s ongoing efforts to meet its sustainability goals.

In “Eco-Efficiency Approach in Sustainable Waste Management: An Uncertainty Analysis for Chile”, Ramon Sala-Garrido, Manuel Mocholi-Arce, Alexandros Maziotis, and Maria Molinos-Senante tackle the critical issue of municipal waste management in Chile, where data uncertainty and inefficiencies hinder progress towards a circular economy. The authors apply a DEA tolerance method to account for uncertainty and evaluate eco-efficiency in waste management across Chilean municipalities. By creating a composite indicator that includes operational costs, recycling rates, and non-valorised waste, the study reveals a significant gap in municipal performance. The average eco-efficiency score of just 0.18 suggests that substantial improvements are needed. This paper underscores the importance of adopting more sustainable waste management strategies to achieve circular economy goals and offers a blueprint for municipalities to improve their eco-efficiency under conditions of data uncertainty, making it highly relevant for policymakers and local governments.

In “Energy Efficiency Evaluation of Wastewater Treatment Plants: A Methodological Proposal for Its Benchmarking”, Ramon Sala-Garrido, Manuel Mocholi-Arce, Alexandros Maziotis, and Maria Molinos-Senante propose a novel DEA-based approach to assess the energy efficiency (EE) of wastewater treatment plants (WWTPs). The authors introduce a common-weight DEA model (DEA-CSW) that overcomes the limitations of traditional models by allowing for the benchmarking of energy performance under uniform conditions. Using a sample of 108 WWTPs in Catalonia, Spain, their findings show that these facilities could save up to 62.8% of their current energy use, which translates into substantial greenhouse gas emission reductions. This stricter evaluation method offers critical insights for policymakers, helping them identify high-performing WWTPs and prioritise interventions for those with the greatest potential for improvement. The study provides a comprehensive framework for utility operators and regulators to enhance the energy efficiency of WWTPs, thereby contributing to broader environmental goals, including SDG 6 (Clean Water and Sanitation) and SDG 7 (Affordable and Clean Energy), as well as SDG 13 (Climate Action).

In “A Metafrontier Network DEA Approach for Water Usage Efficiency Assessment in the Light of SDG Target 6.4”, Sebastián Lozano and María M. Borrego-Marín address the critical issue of water usage efficiency, focusing on 126 countries and their progress towards SDG Target

6.4, which aims to ensure sustainable water management. The authors employ a metafrontier network DEA approach, which distinguishes between water withdrawal and water productivity stages, to assess countries' efficiency in using water resources. Their results highlight significant inefficiencies, particularly in Central Asia, and provide valuable benchmarks for improving water management practices. Additionally, the study emphasises the importance of sharing best practices between regions, as countries with higher water usage efficiency, such as those in Australia and Western Europe, can offer valuable insights and technologies to help countries with lower efficiency, particularly in agriculture, reduce water stress and improve sustainability. This paper is particularly important for international development agencies and governments seeking to address water scarcity and improve resource management in line with global sustainability targets.

In "Effectiveness and Efficiency of Urban Water Access in the Democratic Republic of Congo: A Panel Directional Approach", Jeannine Mwaku, Sergio Perelman, Barnabe Walheer, and Mbangala Mapapa conduct a performance evaluation of water access in the Democratic Republic of Congo (DRC), a country paradoxically rich in water resources but with a large portion of its population lacking access to safe drinking water. The authors apply a directional DEA approach to evaluate the efficiency and effectiveness of urban water distribution across 11 provinces. The study's findings reveal inefficiencies primarily due to resource constraints and technological stagnation, which have significant implications for public policy in the DRC. Moreover, the results emphasise the need for substantial investments in infrastructure and the adoption of better practices from well-performing regions to close the efficiency gap and improve service delivery. This paper is critical in highlighting the need for improved governance and investment in infrastructure to meet the SDG target of universal water access (SDG 6), echoing global calls for increased public funds and resource efficiency in achieving sustainable water management.

2.2 Environmental and Energy Efficiency for Sustainability

In "G20 Countries' Progress on the 7th SDG Under Circular Economy DEA Model", Jessica Suárez Campoli, Paulo Nocera Alves Junior, Tatiana Kimura Kodama, Marcelo Seido Nagano, and Heloisa Lee Burnquist explore the efficiency and productivity of G20 nations in achieving SDG 7 (Affordable and Clean Energy) through a DEA model framed within the principles of a circular economy. Their analysis reveals that emerging economies such as South Africa, Brazil, India, and China perform better in terms of energy efficiency than many developed countries. The authors suggest that developed nations must enhance their technological innovation and policy frameworks to improve energy efficiency. This study has significant implications for global energy policy, particularly in promoting international cooperation to share best practices and technologies for achieving energy sustainability.

In "Exploring Energy and Tourism Economy Growth Nexus with DEA-Based Index Systems: The Case of Sustainable Development of Tourism Destinations", Dongdong Wu, Wei Liu, Youyang Ren, and Hui Li examine the complex relationship between energy use, environmental pollution, and economic growth in tourism destinations in China's Yangtze River Delta. The authors develop a DEA-based index system to assess the efficiency of tourism economies in balancing growth with environmental sustainability. Their findings indicate a positive trend toward more integrated development between tourism and environmental systems, yet

highlight the persistent challenges of decoupling tourism growth from carbon emissions. This paper is particularly important for regional policymakers and tourism managers looking to promote sustainable tourism that aligns with SDGs 8 (Decent Work and Economic Growth) and 13 (Climate Action).

In "Sustainable Refrigeration Technology Selection: An Innovative DEA-TOPSIS Hybrid Model", Behrouz Arabi, Mehdi Toloo, Zaoli Yang, Peihao Zhang, and Bing Xu propose a hybrid DEA-TOPSIS model to evaluate and select sustainable refrigeration technologies in the UK, focusing on their carbon and energy efficiency. The authors demonstrate that by 2035, CO2-based refrigeration technologies will surpass HFO-based technologies in both environmental and economic performance. The paper highlights the need for targeted taxation, tighter regulations on fugitive emissions, and innovative business models to support the transition to low-carbon refrigeration. This research provides a decision-making framework that aligns with the UK's net-zero policies and contributes to the SDGs related to climate action (SDG 13) and sustainable industry (SDG 9). This paper is particularly valuable for policymakers and industry leaders seeking to make informed technology choices that reduce environmental impacts while ensuring economic viability.

In "Analyzing Efficiency and Built Environment Factors for Achieving Convenient Access to Public Transport: A Europe-Wide DEA Application", Georgios Georgiadis, Aristomenis Kopsacheilis, Ioannis Marios Andreadis, and Ioannis Politis evaluate the efficiency of public transport systems in 22 European cities, focusing on achieving SDG 11.2.1, which measures convenient access to public transport. Their DEA analysis, which incorporates built environment factors, reveals significant inefficiencies in lower-density cities, and the paper offers practical solutions for improving access to public transportation. Notably, the study highlights how urban planning decisions—such as increasing population densities and reducing car-related infrastructure—can enhance public transport efficiency by shortening walking distances to transport stops. This research is particularly relevant for urban planners and policymakers seeking to improve public transportation infrastructure and support sustainable urban development.

2.3 Governance, Policy, and Social Dimensions of SDG Implementation

In "Political Factors and Efficiency in the Responsible Production of Municipal Solid Waste Services: A Dynamic DEA with a Network Structure Approach", Tadeu Junior de Castro Gonçalves, Alexandro Barbosa, Pedro Simões, and Severino Cesário de Lima examine how political cycles and contextual factors influence the efficiency of municipal solid waste services in Brazil. Using a dynamic DEA model, the authors show that efficiency fluctuates with political cycles, with lower efficiency observed during election years. The study highlights the strategic use of resources during electoral periods, where increases in inputs like labour and vehicles are often misaligned with outputs, leading to inefficiencies. This paper provides critical insights into how political factors affect public service delivery, particularly in developing countries, and offers valuable recommendations for policymakers to stabilise and improve waste management efficiency in line with SDGs 11 (Sustainable Cities and Communities) and 12 (Responsible Consumption and Production). The findings also suggest the need for more transparent budgeting and stricter regulations during election periods to curb political opportunism and ensure sustainable service provision.

In “From Outcomes to Practices: Measuring the Commitment to Sustainability of Organizations”, Matteo Mura, Mariolina Longo, Filippo Boccali, Franco Visani, and Sara Zanni introduce a DEA-based index to assess organisational commitment to sustainability by evaluating the relationship between resources and sustainability practices. The authors highlight the importance of focusing on practices rather than outcomes to drive long-term sustainability. The study also underscores the need for standardised sustainability metrics across industries, which can help policymakers design more effective regulations and incentive structures, fostering greater corporate alignment with the SDGs. This paper’s innovative approach to measuring organisational sustainability has practical implications for corporate governance and policymaking, particularly in aligning business practices with the SDGs.

In “Assessing Provincial Environment Governance Efficiency in China: A Multi-Agents Participation Perspective”, Rui Yang, Lin Li, Junyang Chen, Meng Li, Ahtam Anwar, Huan Lu, and Yingwen Chen develop a nested leader-follower game network DEA model to assess environmental governance efficiency (EGE) across Chinese provinces. Their analysis focuses on the roles of central and local governments, enterprises, and the public, revealing significant regional disparities in governance efficiency. While the eastern provinces perform better due to higher levels of technological innovation and environmental awareness, the middle and western provinces lag behind. The study underscores the importance of improving coordination between governance agents and tailoring environmental policies to the unique characteristics of each region. By identifying the weak links in governance, the authors provide critical insights into how China can improve its environmental governance efficiency, particularly in achieving SDG 13 (Climate Action).

In “Efficiency Analysis of Engineering Classes: A DEA Approach Encompassing Active Learning and Expositive Classes Towards Quality Education”, Paulo Nocera Alves Junior, Paul Leger, and Isotilia Costa Melo apply a DEA model to evaluate the relative efficiency of active versus passive learning methods in engineering education. Their findings highlight that active learning approaches consistently outperform passive methods, particularly in the later stages of education, where students tend to adapt more efficiently. This has significant implications for improving retention rates and fostering a more inclusive educational environment. The study recommends investing in teacher training and innovative pedagogical techniques to enhance classroom efficiency, especially in the early years of higher education, which is critical for reducing dropout rates. This research not only contributes to SDG 4 (Quality Education) but also aligns with SDG 5 (Gender Equality) and SDG 8 (Decent Work and Economic Growth) by advocating for more inclusive policies that extend access to education for diverse age groups, support gender equity, and improve student outcomes.

In “Developing a Sustainable Development Goals Index for OECD Countries: An Effectiveness-Based Hierarchical Data Envelopment Analysis”, Yongli Guo, Ming-Miin Yu, and Kok Fong See propose a hierarchical DEA model to assess the performance of OECD countries in meeting SDG targets. The study emphasises the importance of using objective weighting schemes to improve the comparability of SDG indices across countries, as opposed to subjective weights often used in other models. This approach offers a more accurate and nuanced view of a country’s progress toward SDGs by accounting for the unique prioritisation of different goals.

Notably, the study reveals significant changes in rankings, such as Iceland and Austria, demonstrating the potential of the H-DEA model to highlight specific areas for improvement. This research is valuable for national governments and international organisations seeking to benchmark progress and identify targeted strategies for enhancing SDG performance. Moreover, it offers policymakers insights into resource allocation optimisation, especially in relation to high-impact goals like SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 16 (Peace, Justice, and Strong Institutions).

In "An Optimization Model Based DEA-MARCOS Approach for Assessing EU Countries Towards Achieving Sustainable Development Goals", Abhijit Saha, Arunodaya Raj Mishra, Pratibha Rani, Muahmmet Deveci, Bijoy Krishna Debnath, Norziana Jamil, and Moamin A. Mahmoud present a hybrid DEA-MARCOS model to evaluate EU countries' progress towards the SDGs. Their results highlight Austria as the top performer, showcasing its steady and equitable advancement across multiple sustainability metrics. By integrating DEA and MARCOS, the study avoids the bias of focusing on isolated goals, providing a balanced and comprehensive evaluation of each country's progress. This paper has significant implications for regional policymakers and international bodies in designing strategies to achieve sustainable development, offering insights into the areas where countries can prioritise their resources for optimal SDG achievement.

In "A Hybrid Multi-Attribute Decision-Making and Data Envelopment Analysis Model with Heterogeneous Attributes: The Case of Sustainable Development Goals", Mehdi Soltanifar, Madjid Tavana, Francisco J. Santos-Arteaga, and Hamid Sharafi propose an integrated multi-attribute decision-making (MADM) and DEA framework for assessing the performance of European countries in meeting the SDGs. The study introduces a novel way to handle heterogeneous attributes, offering a flexible approach to strategic decision-making. One of the key strengths of this method is its ability to reduce reliance on expert-assigned weights, minimising the impact of subjective judgments and enhancing the objectivity of the rankings. This paper contributes to improving the analytical tools available for evaluating complex, multidimensional sustainability challenges, providing policymakers with a robust framework for identifying performance gaps and prioritising interventions to achieve the SDGs more effectively.

3. Future Research Agenda

The collection of papers in this special issue presents a solid foundation for understanding how Data Envelopment Analysis (DEA) and related methodologies can address various global challenges, particularly in advancing Sustainable Development Goals (SDGs), providing critical insights for academics, policymakers, and practitioners. However, numerous opportunities remain for future research to enhance the scope, applicability, and impact of DEA in these contexts.

One of the most promising avenues for future research lies in expanding DEA applications to underrepresented regions and sectors, particularly in developing countries. Several papers in this issue, such as those on water management in the Democratic Republic of Congo or environmental governance in China, highlight the need for DEA models that consider local socio-economic and environmental conditions. Future research could explore how DEA can be adapted to account for regional disparities and offer more context-specific

insights, particularly for countries facing challenges in meeting their SDG targets due to resource constraints, governance issues, or infrastructural limitations.

Another key direction for future work is the integration of multiple dimensions within DEA models, particularly those related to economic, environmental, and social sustainability. While several studies in this issue, such as the ones on refrigeration technologies and EU countries' SDG performance, have begun to incorporate multi-dimensional factors, future research could take this further by including more comprehensive sets of indicators aligned with the SDGs. This would allow for a more holistic understanding of how different dimensions of sustainability interact and contribute to overall performance. Such models could be especially useful for policymakers seeking to balance environmental goals with economic and social considerations.

Addressing data availability and quality remains a significant challenge in DEA research, particularly in sectors or regions with limited access to reliable data. Several papers in this issue, including those on wastewater treatment and municipal waste services, underscore the importance of robust and comprehensive datasets for accurate efficiency assessments. Future research should explore the development of DEA models that can work with incomplete or imprecise data, possibly through fuzzy logic or stochastic approaches. Such advancements would enable the broader application of DEA in real-world contexts where data limitations are a persistent issue.

Incorporating dynamic and network DEA models into future research would also be a valuable contribution, particularly for evaluating long-term efficiency and multi-stage processes. Several studies in this issue, such as those on municipal solid waste services and public transportation systems, highlight the need to account for the interdependencies between different stages of production or service delivery. Dynamic DEA models that capture changes over time, as well as network models that evaluate complex, multi-layered processes, could offer more detailed insights into the factors driving efficiency. These models could be especially useful for sectors such as education and infrastructure, where improvements tend to unfold gradually.

Behavioural and institutional factors also represent an important, yet underexplored, area for future DEA research. While the studies in this issue primarily focus on technical efficiency, several, such as the one on political cycles in waste management, hint at the significant role that institutional governance and stakeholder behaviour play in influencing outcomes. Future research could investigate how these non-technical factors, such as organisational behaviour, governance quality, and political stability, affect efficiency and how DEA models can incorporate these variables. This would be particularly relevant for public sector applications, where institutional dynamics often shape the effectiveness of service delivery.

Enhancing the policy relevance and impact of DEA models is another critical area for future exploration. Many studies in this issue offer valuable policy insights but translating these into practical actions remains a challenge. Future research could focus on developing decision-support tools that make DEA results more accessible and actionable for policymakers. By providing clearer guidelines on resource allocation, policy adjustments, and strategic planning, these tools could help bridge the gap between academic research and real-world policymaking.

Methodological innovations in DEA also hold significant potential for future research. While several papers in this issue propose hybrid models that integrate DEA with other techniques, such as TOPSIS or hierarchical analysis, future research could explore the

integration of machine learning techniques into DEA models. Machine learning could offer new ways to handle large, complex datasets and reveal hidden patterns in efficiency performance. Additionally, the development of intertemporal DEA models that account for long-term trends and the inclusion of network-based approaches could further refine the accuracy and applicability of DEA.

Finally, future research could benefit from a cross-sectoral approach, examining how improvements in one area (such as education) might positively impact other areas (such as economic growth and social equity). The interconnected nature of the SDGs presents a unique opportunity for interdisciplinary research that combines insights from economics, environmental science, public administration, and education to create more comprehensive DEA models that address multiple SDGs simultaneously. This approach could offer valuable insights for policymakers and international organisations working on global sustainability challenges.

In conclusion, the papers in this special issue provide a solid foundation for the application of DEA in advancing sustainable development. However, future research must expand the geographical and sectoral scope, integrate more dimensions into the analysis, address data limitations, and incorporate dynamic and behavioural factors. These advancements will be crucial for ensuring that DEA continues to play a pivotal role in supporting global efforts to achieve the SDGs.

The many academics and researchers who contributed papers and the experts within the field who reviewed the papers have made this Special Issue on *"DEA-based index systems for addressing the United Nations' SDGs"* of Environmental Science and Policy possible. We extend our gratitude to all of them, as well as to the Editors-in-Chief for their support. We wish you, our readers, informative reading!

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