Eco-efficiency and financial sustainability in UK universities: strategic pathways to a carbon-neutral higher education sector

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Abstract

Purpose – The purpose of this study is to assess the eco-efficiency of universities in the UK and investigate the impact of critical financial indicators on environmental performance. This is particularly relevant in the context of institutions that are seeking to balance financial sustainability with climate commitments.

Design/methodology/approach – Using data from the entire population of 160 British higher education institutions from 2015 to 2021, a two-stage empirical methodology is implemented. Institutional eco-efficiency is evaluated through Data Envelopment Analysis during the initial phase. Quantile regression analysis is used in the second stage to examine the impact of financial indicators, such as profitability, liquidity and operational cash flow, on eco-efficiency across various performance quantiles.

Findings – The findings of this study suggest that universities in Wales consistently exhibit increased eco-efficiency, which is attributed to their investment in low-carbon initiatives and their implementation of comprehensive sustainability strategies. Conversely, institutions situated in densely urbanized regions, such as London, operate less efficiently because of restricted space for green infrastructure and elevated emissions. The results of quantile regression indicate that eco-efficiency is positively correlated with liquidity and operational cash flow, particularly among institutions that perform better. This underscores the critical role of sound financial management in the pursuit of environmental objectives.

Research limitations/implications – This study is limited to higher education institutions in the UK and does not consider the differences in funding structures, environmental policies or regulatory environments that

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exist across different countries. Furthermore, comparative analyses across various higher education systems could be investigated in future research.

Practical implications – The results of this study indicate that financial resilience is a critical factor in the enhancement of environmental performance in higher education. To facilitate sustainable institutional transformation, university leaders and policymakers are encouraged to integrate financial management with environmental strategy.

Originality/value – This study conceptualizes eco-efficiency as a resource-based capability, thereby extending the Natural Resource-Based View to the higher education context. This study contributes to the literature on sustainable higher education by providing innovative insights into the ways in which financial performance can influence environmental outcomes in universities, both theoretically and practically.

Keywords Eco-efficiency, Financial sustainability, Higher education institutions, Environmental performance, University governance, Sustainability strategy, UK universities

Paper type Research paper

1. Introduction

Eco-efficiency is a philosophy that organizations are encouraged to adopt, as it allows them to achieve financial and environmental benefits simultaneously (Heikkurinen *et al.*, 2019). Primarily, it creates a harmonious equilibrium between the ecological and financial components of contemporary society. This approach emphasizes the optimization of energy and natural resource utilization, with the objective of reducing waste by producing goods and services with the least amount of energy and natural resource input. This is accomplished by using sophisticated technologies and methodologies (Calvo *et al.*, 2022; Sun and Zhou, 2023). The implementation of comprehensive and integrated eco-efficiency ideas and practices by businesses may result in significant economic and social benefits (Sun and Zhou, 2023; WBCSD, 2000). Organizations have demonstrated an increasing propensity to mitigate pollution since the Kyoto Protocol was implemented in 1997 (Doğan *et al.*, 2022; Quinn *et al.*, 2023). Corporations, financial markets and governments have implemented strategies to mitigate the effects of climate change, as evidenced by the Chicago Climate Exchange (Hoque and Sabbaghi, 2011). Companies have supplanted conventional compliance strategies with pledges to environmental responsibility as part of their ongoing adaptation process to satisfy the expectations of public investors. In addition, Tong and Jian (2021) note that there is no empirical evidence to suggest that ethical portfolios are associated with a decline in performance. Additionally, investors frequently prioritize social objectives over personal financial gains (Ragazou *et al.*, 2024). Gao *et al.* (2020) propose that investors' portfolios may be enhanced by making responsible investments in emerging countries (Gao *et al.*, 2020). In addition, these advantages are increased on days that are distinguished by elevated levels of air pollution (Gao *et al.*, 2020).

By using a variety of strategies, including operational practices, community engagement, research and instruction, universities are instrumental in the advancement of sustainable development in higher education (Lozano *et al.*, 2013). The term "universities" will be used in this research endeavor to encompass all higher education institutions (HEIs), including colleges, universities, technical schools, community colleges and law schools. The university is in a unique position to incorporate sustainable practices into its community and to empower and equip students, faculty and visitors to effect change, as it functions as a reliable institution that functions analogous to a miniature society (Dinh *et al.*, 2024). To achieve these objectives, universities may implement a variety of strategies, with top-down and bottom-up methodology being the most prevalent. The administration, students and professors have either individually or collectively endorsed these techniques (Frizon and Eugénio, 2022; Odell *et al.*, 2020; Pereira *et al.*, 2021).

Despite the necessity of promoting and advancing sustainability at the university level, it is crucial to recognize the associated obstacles (Larrán Jorge *et al.* (2016). Generally, universities that prioritize sustainability are indispensable for sustainable development because of their capacity to initiate and influence change, their prominence in society and the education of the next generation. However, universities should be cognizant of the importance of monitoring their sustainability progress (Frizon and Eugénio, 2022). In particular, the absence of specific committees and offices that are dedicated to the pursuit of sustainability and progress monitoring at certain universities presents a challenge in terms of conducting research and implementing sustainable practices (Taimur and Onuki, 2022). The challenge of calculating eco-efficiency is, therefore, presented to universities. However, eco-efficiency is still a relatively novel concept in the academic community, and there are virtually no universities worldwide that have implemented a measurement system. In addition, universities encounter an additional obstacle in the form of financing, which may serve as an incentive for them to refrain from advocating for sustainable development on their campuses (Mgaiwa and Ishengoma, 2023; Serafini *et al.*, 2022).

This study aims to examine the correlation between specific financial indicators and eco-efficiency outcomes in the UK higher education sector. Additionally, it will assess the eco-efficiency of British universities using a performance-based methodology, as one of the first UK-wide analyses to do so, informed by these theoretical and contextual considerations. Few studies have conducted a comprehensive UK-wide assessment that explicitly incorporates eco-efficiency with financial performance, even though previous research has applied efficiency and benchmarking methods in higher education, with a concentration on estates management, energy use or research productivity. Therefore, this investigation contributes to the growing body of research by integrating quantile regression and Data Envelopment Analysis (DEA) within the Natural Resource-Based View (NRBV) framework to encompass both the financial and environmental aspects of sustainability.

The objective is to examine the potential impact of financial ratios – including the return on assets (ROA), quick ratio, current ratio and operational cash flow ratio – on the environmental performance of universities and to develop a robust eco-efficiency index by incorporating both environmental and financial inputs and outputs. The objectives of this study are guided by two interrelated hypotheses: the first hypotheses posit that financial performance has a significant impact on institutional eco-efficiency, while the second hypotheses posit that the magnitude and direction of this relationship vary across performance levels, reflecting distributional heterogeneity.

The theoretical underpinnings of this investigation are derived from the NRBV, which posits that organizations attain a sustainable competitive edge by strategically deploying internal capabilities and resources that are valuable, rare, inimitable and non-substitutable. In this context, eco-efficiency functions as a proxy for environmental performance, which is associated with institutional capability and financial fortitude. This study empirically addresses a significant research void in the literature by assessing the environmental efficacy of HEIs in the UK and investigating the potential impact of their financial health on sustainability performance. This study makes a unique contribution to the comprehension of eco-efficiency in the higher education sector by integrating a comprehensive data set that encompasses the entire population of British universities over a six-year period. Additionally, it broadens the theoretical scope of NRBV in the context of academic institutions.

Five sections comprise the current investigation. Section 2 offers a comprehensive examination of the theoretical underpinnings of eco-efficiency and the current state of research regarding the correlation between financial metrics and eco-efficiency in UK higher education. The results of this study are presented in Section 4, while an overview of the materials and procedures used is provided in Section 3. The results, theoretical and practical implications, limitations and prospective research proposals are all addressed in Section 5. Finally, Section 6 concludes with implications for policy, institutional leadership and future research opportunities.

2. Theoretical background

2.1 *The theoretical basis of eco-efficiency*

The Resource-Based View (RBV) has been extensively implemented in service innovation research, and this includes HEIs (Kleinschmidt *et al.*, 2007; Terziovski, 2010). It postulates that the potential of an organization to achieve a competitive advantage is contingent upon its capacity to leverage valuable, rare, inimitable and non-substitutable resources (Barney, 1991; Peteraf and Barney, 2003). The NRBV builds upon this by incorporating sustainability into strategic management and expanding the RBV to consider the environmental impact of organizational activities (Buchinsky, 1995; Hart and Dowell, 2011).

Three strategic capabilities – sustainable development, pollution prevention and product stewardship – are identified by the NRBV as enabling firms to minimize environmental damage and generate long-term value. It underscores the potential of proactive environmental strategies to improve competitiveness, particularly when they result in energy and raw material cost reductions (Benkraiem *et al.*, 2023). Additionally, recent research indicates that the implementation of green services and process innovations enhances performance, reduces emissions and facilitates strategic differentiation. This investigation broadens the scope of NRBV by establishing a connection between it and eco-efficiency as a quantifiable capability for sustainable competitive advantage.

Eco-efficiency is a concept that seeks to decouple resource use from environmental degradation by balancing economic performance with environmental protection (Zhao and Li, 2023; Aoki-Suzuki *et al.*, 2023). It ensures that companies are held accountable for their environmental impacts and promotes resource-efficient operations that generate financial and ecological benefits. The concept was initially introduced by Schaltegger and Sturm in 1989 and later gained popularity through the World Business Council for Sustainable Development (WBCSD, 2000; Schmidheiny, 1992). The WBCSD defines eco-efficiency as the provision of commodities and services that are competitively priced and meet human requirements, while simultaneously reducing ecological impacts and resource intensity throughout the product life cycle.

Despite its widespread recognition, eco-efficiency is still not fully integrated into traditional accounting systems, which frequently lack mechanisms to record environmental performance (Nath and Ramanathan, 2016; Saha and Guha, 2019). Even though the United Nations has promoted frameworks such as life-cycle assessments and ISAR standards, which have increased awareness, measurement tools are still inconsistently applied (Heikkurinen *et al.*, 2019). Eco-efficiency is typically measured by the ratio of economic value to environmental impact; higher ratios suggest more eco-efficient environmental performance. Conversely, the inverse (eco-intensity) may also be used. Nevertheless, the adaptability of measurement methodologies presents obstacles to standardization and comparability across sectors and institutions.

This study establishes a theoretical framework for assessing the impact of financial and operational inputs on the environmental performance of universities by combining NRBV with eco-efficiency. This framework emphasizes the strategic importance of eco-efficiency as a sustainability indicator and a source of institutional advantage in the transition to net-zero objectives.

2.2 The role of eco-efficiency in higher education in the UK

Universities are essential in society beyond education and research, as they function as centers for the dissemination of knowledge and public engagement on scientific and cultural matters (Serafini *et al.*, 2022). HEIs are increasingly anticipated to prioritize environmental sustainability in addition to fulfilling their obligations to society and students (Lozano *et al.*, 2013b). This is demonstrated through interdisciplinary research, sustainability-focused academic programs and awareness-raising initiatives, including public events and conferences. Additionally, universities are accountable for their environmental impact as significant consumers of energy, water, paper and other resources, as well as producers of pollution and emissions (Chin *et al.*, 2022).

Numerous HEIs have implemented sustainability policies and initiated carbon neutrality initiatives to serve as role models. Nevertheless, the scope of carbon accounting is still restricted. The STARS Reporting Tool, a self-reporting framework that standardizes emissions data and supports sustainability benchmarking, is used by more than 1,000 HEIs in the USA (Chernozhukov and Hansen, 2008; Zarghami and Fatourehchi, 2020). While STARS provides transparency, it is predominantly used for marketing purposes by numerous institutions, rather than for transformative sustainability action.

In comparison to countries such as Germany, UK universities are comparatively advanced in reporting institutional emissions in Europe (Genus and Theobald, 2015; Townsend and Barrett, 2015). HEIs have been motivated to disclose emissions and implement climate strategies as a result of the UK Government's net-zero target for 2050 (HM Government, 2023). However, institutional responses are inconsistent: some have advanced sustainability strategies, while others are still in the process of developing them. Infrastructure, procurement, finance, internal capabilities and travel comprise the primary focus areas. Institutions are integrating environmental considerations into operations and decision-making by implementing low-carbon travel policies, sustainable procurement practices and emissions reporting (Genus and Theobald, 2015; Di Stasio *et al.*, 2016; Kirchherr *et al.*, 2023; Mion *et al.*, 2023).

Major investment and public–private partnerships are required to ensure that facilities are energy-efficient and climate-resilient. Internal skills, governance tools and collaboration with government bodies, including the Department for Education and the Department for Transport, are also critical factors in success (HM Government, 2023; Department for Transport, 2021; Department of Education, 2022; Hassani-Nezhad *et al.*, 2021). It is imperative to incorporate sustainability into professional training and align it with long-term investment strategies. Universities must evaluate the environmental impact of their investments, including pensions and endowments, and leverage public and private finance, including green bonds (Leal Filho *et al.*, 2023; HM Government, 2023).

Beyond policy frameworks, a significant body of literature has implemented DEA and associated benchmarking methodologies in HEIs. Abbott and Doucouliagos (2003) and Johnes (2006) assessed efficiency by using inputs such as student enrolments, staff FTEs and research income, while Sarrico *et al.* (2010) investigated institutional boundaries and performance (Doucouliagos and Laroche, 2003; Johnes and Jill, 2006; Sarrico *et al.*, 2010). Most studies that have examined sustainability have prioritized productivity or resource consumption over eco-efficiency in a comprehensive sense (Lozano *et al.*, 2013). However, this approach has been extended to estates management and energy use. Furthermore, although undesirable outputs are frequently acknowledged in eco-efficiency research, they have been infrequently explicitly incorporated into higher education DEA models. In contrast to multi-criteria decision-making methodologies such as TOPSIS or PROMETHEE, which produce rankings based on weighted preference configurations, DEA establishes a non-parametric efficiency frontier, thereby allowing universities to be evaluated relative to their highest-performing counterparts – an approach extensively endorsed in frontier efficiency literature.

This research extends and augments these research strands. Unlike previous applications that focused on productivity and estates indicators, our specification incorporates CO_2 emissions as an undesirable output and incorporates financial ratios – return on assets, quick ratio, current ratio and operational cash flow ratio – into the second-stage quantile regression to capture the role of financial resilience in eco-efficiency. Financial resilience is explicitly linked to environmental performance in a UK-wide context through this approach, which is based on the NRBV. By adopting this perspective, this study contributes to literature by connecting contemporary debates on sustainability finance with benchmarking traditions in higher education.

Finance continues to be the most critical enabler of net-zero transitions, supporting infrastructure retrofits, sustainability training and emissions reduction initiatives. HEIs can align their operations with national climate targets by adopting investment-led strategies and expanding access to green finance. With an economic impact of £95.00bn, 815,000 jobs and over 1.7 million students, UK universities are critical promoters of sustainable development (HM Government, 2023). By introducing an eco-efficiency index, the current study contributes to this endeavor by enabling institutions to identify financial indicators that are most influential in attaining net-zero objectives and to measure their environmental imprint.

3. Materials and methods

This study's methodological design is predicated on a two-stage analytical framework that is consistent with its dual research objectives. In the initial stage, DEA is implemented to evaluate the eco-efficiency of universities by comparing numerous inputs and outputs without presuming a predetermined functional form. DEA is particularly well-suited for the assessment of performance efficiency in intricate institutional environments, such as higher education, where the input–output relationships are multivariate and nonlinear. The relationship between financial indicators and eco-efficiency scores is investigated in the second stage through the application of quantile regression analysis at various locations in the conditional distribution. Quantile regression, in contrast to conventional least squares regression, which concentrates on average effects, captures heterogeneous effects at different performance levels. This methodological combination enables a thorough comprehension of the financial determinants that influence eco-efficiency and the measurement of eco-efficiency, thereby directly addressing the core research questions of this study.

3.1 Data

This study examines a balanced panel data set that includes all 160 recognized universities in the UK from the academic year 2015/2016–2020/2021. This ensures temporal comparability and mitigates sampling bias by consistently observing each institution over the course of six academic years. The generalizability and validity of the findings are further enhanced by the fact that the sample is representative of the entire population of UK HEIs. The universities are distributed geographically as follows: There are 38 locations in London, 22 in the Southeast, 18 in Scotland, 13 in the North West and 11 in the South West, Yorkshire and the Humber, East Midlands and East of England. Wales and the West Midlands each have ten universities, while the remaining institutions are in the Northeast and Northern Ireland (Table 1). The data set was obtained from the Higher Education Statistics Agency (HESA), the official organization responsible for the collection and dissemination of comprehensive data on the financial, environmental and institutional performance of higher education

Table 1. Regional distribution of the studied population

Period	Time period	Academic years
Period 1		2015/2016
Period 2		2016/2017
Period 3		2017/2018
Period 4		2018/2019
Period 5		2019/2020
Period 6		2020/2021
	Research population	
Country of HE provider	Region of HE provider	Number of universities per region
England	London	38
	South East	22
	North West	13
	South West	11
	Yorkshire and the Humber	11
	East Midlands	11
	East of England	11
	West Midlands	10
	North East	8
Scotland	Scotland	11
Wales	Wales	10
Northern Ireland	Northern Ireland	8

providers in the UK. This assessment of eco-efficiency across the UK sector is both robust and representative because of the incorporation of the entire university population.

The data set, which spans six academic years from 2015/2016–2020/2021, is composed of a balanced cohort of 160 universities, as previously mentioned. The period of 2015–2021 was deliberately chosen. In 2015, the United Nations Sustainable Development Goals (SDGs) were adopted, which served as a critical external framework for UK universities to enhance their sustainability strategies and reporting. In addition, the COVID-19 pandemic years (2020–2021) are included in the period, which had a substantial impact on the financial and environmental performance of higher education. To illustrate, lockdowns decreased emissions associated with travel, while concurrently increasing the need for digital infrastructure and impacting institutional finances. By incorporating both the SDG implementation era and the pandemic shock, this study can offer a more contextually grounded and comprehensive evaluation of the eco-efficiency trajectories in UK universities. Missing values (<3% of observations) were imputed using the mean of adjacent years, as per established benchmarking practice. All financial variables were derived from audited HESA data sets (Table 2).

A cross-sectional data set that is appropriate for the two-stage analysis was generated by averaging the annual observations of each institution over this period to guarantee consistency and comparability. In the initial phase, the DEA methodology was used to estimate an eco-efficiency index. The DEA model's input–output configuration was customized to account for the financial and environmental aspects of university operations, using the extant literature as a guide. Specifically, the inputs consisted of gross domestic product (GDP) per capita (non-discretionary contextual input) (GDP), total income, total assets, and total academic staff. The sole undesirable output was CO_2 emissions from energy consumption.

Table 2. Definition and measurement of variables

Variables	Symbols	Variable types	Operationalization	Source
Eco-efficiency	Eco*Eff*	Dependent	By implementing technology advancements and refining processes, it enhances the value of the product or service while simultaneously reducing resource consumption and minimizing environmental impact throughout its lifespan. Eco-efficiency is applicable to all aspects of business, including procurement, manufacturing, advertising and distribution (Schaltegger and Sturm, 1989; Schaltegger and Wagner, 2005; WBCSD, 2000)	DEA
GDP per capita (non-discretionary contextual input)	GDP	Independent	GDP per capita (non-discretionary contextual input) (GDP) is a measure of the total value of goods and services produced and bought by consumers in a country over a given time period, such as a quarter or a year (OECD, 2022)	Office for national statistics
Total income	Tot_*Inc*	Independent	Total revenue refers to the whole income generated by a firm or organization through the sale of its goods or services (HESA, 2023)	Higher education statistics agency (HESA)
Total academic staff	Tot_*staff*	Independent	The entire academic staff (HESA, 2023)	Higher education statistics agency (HESA)
CO2 from the energy consumption of the academic institutions	CO2_*emm*	Independent	Total CO_2 emissions from institutional energy consumption (Scopes 1 and 2, HESA data)	Higher education statistics agency (HESA)
Current assets	*Curr_Ass*	Independent	Assets that are used, replaced or converted to currency by a company within a typical operational cycle (typically less than 12 months) are occasionally referred to as short-term assets. These assets are distinguished from long-term assets, which are those that a company uses for a period exceeding one year. As they can be converted into cash more easily than long-term assets, current assets are referred to as liquid Assets (HESA, 2023)	Higher education statistics agency (HESA)
Current liabilities	Curr_*Liab*	Independent	Current liabilities are the short-term financial obligations of a company that are due within a year or within a typical operational cycle (HESA, 2023)	Higher education statistics agency (HESA)

(*continued*)

Table 2. Continued

Variables	Symbols	Variable types	Operationalization	Source
Current ratio	Current ratio	Independent	The discrepancy between a company's current assets and its current expenses. This demonstrates a company's capacity to satisfy its current liabilities with its current assets (HESA, 2023)	$Current\ ratio = \frac{Current\ Assets}{Current\ Liabilities}$
Quick ratio	Quick ratio	Independent	The ratio of current liabilities to current assets that are either in cash or very near to it. It illustrates a company's ability to promptly satisfy its current obligations (HESA, 2023)	Higher education statistics agency (HESA)
Return on assets	ROA	Independent	Profitability ratio: the ratio that indicates the potential profit that a business can generate from its assets. In other words, the ROA metric evaluates the efficiency of a company's management in generating revenue from the assets or financial resources that are listed on its balance sheet (HESA, 2023)	Higher education statistics agency (HESA)
Operating cash flow ratio	OCFR	Independent	It is a measurement that quantifies the frequency with which a business can satisfy its current liabilities with cash that is generated during the same period. A figure that exceeds 1 suggests that a business has generated greater financial resources in a specific time frame than was required to satisfy its current liabilities (HESA, 2023)	Higher education statistics agency (HESA)

In the quantile regression analysis, the eco-efficiency scores obtained from DEA were the dependent variable in the second stage. The financial variables of ROA, quick ratio, current ratio and OCFR – explanatory variables – were chosen for their theoretical relevance to financial resilience and sustainability, as well as their empirical support in prior literature. The current ratio was determined internally by using current assets and current liabilities, while the remaining financial indicators were obtained directly from the HESA, the official statistical entity for UK HEIs.

This variable configuration directly supports the second research question of this study, which determines the impact of institutional financial performance on eco-efficiency outcomes. The analysis incorporates performance-specific effects across the eco-efficiency distribution by using quantile regression, providing a nuanced understanding of how internal financial characteristics influence environmental sustainability within the higher education sector.

Financial ratios were computed using audited HESA financial data sets. In accordance with the established benchmarking practice of HEIs, missing values were imputed using the mean of adjacent years. This guaranteed the balanced panel's completeness without the introduction of systematic bias.

3.2 Data envelopment analysis

Charnes *et al.* (1978) were the first to develop DEA, a linear programming-based decision-making method that is used to compare the relative efficacy of a group of comparable units (Charnes *et al.*, 1978). DEA is a nonparametric technique that is used to evaluate the efficacy of decision-making units (DMUs) and determine production boundaries. The frontier is constructed by using piecewise linear technology based on the observed inputs and outputs. The relative effectiveness of DMUj, where j = 1, 2,…, n, is determined by comparing the ratio of outputs to inputs. The weighted total of outputs divided by the weighted sum of inputs (1) represents the efficiency ratio for the combined multiple inputs (i = 1,…, m) and outputs (k = 1,…, s):

$$\text{Efficiency} = max \frac{\sum_{k=1}^{s} u_k y_{kj0}}{\sum_{i=1}^{m} v_i x_{ij0}} \tag{1}$$

$$\frac{\sum_{k=1}^{s} u_k y_{kj0}}{\sum_{i=1}^{m} v_i x_{ij0}} \leq 1, \; j = 1, \ldots, n$$

$$v_{i \geq} \varepsilon, \; i = 1, 2, \ldots, \text{ m}$$

$$u_{r \geq} \varepsilon, \; r = 1, 2, \ldots, \text{ s}$$

However, the issue is with the weights (uk and vi). Specifically, each DMU is given a best set of weights and these weights' values might differ from one DMU to another. The weights are determined via linear programming, and the optimal set of weights is given to each DMU, with values that may differ from one DMU to the next. When we think about output orientation, the model is linearized, which results in equation (2):

$$max \sum_{i=1}^{m} v_i x_{ij0} \quad (2)$$

Subject to:

$$\sum_{r=1}^{s} u_r y_{rj0} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj0} - \sum_{i=1}^{m} v_i x_{ij0} \leq 0$$

$$v_{i \geq} \varepsilon, i = 1, 2, \ldots, \text{ m}$$

$$u_{r \geq} \varepsilon, r = 1, 2, \ldots, \text{ s}$$

The DEA method has been predominantly dependent on two basic models. The original Charnes, Cooper and Rhodes model establishes an efficiency frontier under the assumption of constant returns to scale (Charnes *et al.*, 1978). In contrast, the Banker, Charnes and Cooper model incorporates VRS by incorporating a convexity constraint, which enables the assessment of efficiency across institutions of varying sizes (Banker *et al.*, 1984). The most frequently used DEA models in the literature are Charnes, Cooper and Rhodes and Banker, Charnes and Cooper models. DEA uses an envelopment form of linear programming to construct a frontier from efficient DMUs and assess the distance of each unit from this benchmark (Pascoe, 2025). A DMU is considered entirely efficient when its score is equal to 1, while scores below 1 suggest inefficiency.

The selection of DEA over alternative frontier or multi-criteria methodologies was deliberate. The DEA is particularly well-suited for HEIs because of its ability to accommodate a variety of heterogeneous inputs and outputs, including undesirable outputs like CO_2 emissions, without imposing a predetermined functional form. DEA does not impose restrictive distributional assumptions, which may not be applicable to non-profit, multi-mission universities, in contrast to parametric approaches like Stochastic Frontier Analysis. DEA offers a benchmarking frontier that enables each institution to be evaluated in relation to its most efficient counterparts, in contrast to multi-criteria decision-making methods such as TOPSIS or PROMETHEE. This comparison based on frontiers is particularly beneficial in the context of higher education, where the efficacy of the system is contingent upon the joint optimization of financial, academic and environmental factors.

This study uses an output-oriented DEA model to assess the eco-efficiency of UK universities from 2015/2016 to 2020/2021. The analysis uses an output-oriented BCC model under VRS, capturing the heterogeneity in size, mission and resource endowments among UK HEIs. The model uses a combination of monetary and non-monetary inputs, including the number of academic staff, total income, total assets and GDP per capita (non-discretionary contextual input). The emission of CO_2 from institutional energy use is the singular undesirable output. Even though GDP per capita (non-discretionary contextual input) is not directly under the control of individual universities, it was included as a non-discretionary input to reflect the macroeconomic context and regional funding environment in which universities operate. Prior research on the efficacy of higher education

(Sarrico *et al.*, 2010) has shown that environmental variables external to the institution, such as regional economic capacity, can significantly influence resource availability and operational constraints. In this respect, GDP per capita (non-discretionary contextual input) serves as a contextual input, which is in accordance with the eco-efficiency literature that enables the incorporation of non-discretionary factors. To ensure robustness, we conducted sensitivity analyses that excluded GDP per capita (non-discretionary contextual input). The results are not unduly influenced by this specification, as the aggregate classification of universities and mean efficiency scores remained highly correlated ($r > 0.85$), verifying that this specification does not affect the results. This method is consistent with previous DEA studies that incorporate environmental or contextual factors as non-discretionary variables to reflect macroeconomic conditions that affect the availability of institutional resources.

The results of the efficiency scores were calculated to benchmark institutions, and they are summarized in Table A1 (Appendix 1). Furthermore, ArcGIS software was used to illustrate the spatial distribution of eco-efficiency (Figure 1).

3.3 Quantile regression analysis

Koenker and Bassett (1978) introduced quantile regression, which offers a comprehensive framework for investigating the impact of financial variables on eco-efficiency at various locations in its conditional distribution. Quantile regression is particularly effective when linearity assumptions are violated and captures heterogeneity in relationships, in contrast to OLS, which estimates mean effects and assumes homoscedasticity (Koenker and Hallock, 2001; Buchinsky, 1995). This method is particularly well-suited for the analysis of the impact of financial indicators, such as the ROA, current ratio and operational cash flow ratio, on eco-efficiency, particularly in situations where extreme values or asymmetrical distributions are present. DEA scores that assume the boundary value of 1 were preserved without modification, as quantile regression inherently accounts for bounded dependent variables; the robustness of this approach was further confirmed through the fractional logit specification.

Quantile regression has been implemented in financial and corporate social responsibility contexts in previous research (Oware *et al.*, 2021). Subsequently, advanced versions have integrated endogeneity and fixed effects (Chernozhukov and Hansen, 2008; Harding and Lamarche, 2009). Nevertheless, the distributional results presented in Table A1 substantiate the notion that eco-efficiency is regarded as an exogenous variable in this study. So, to investigate the distributional impacts of financial performance on eco-efficiency, quantile regression is used. Fractional response models, such as beta regression, are a prevalent substitute for DEA scores, as they have a bounded range of 0–1. Nevertheless, we use quantile regression to analyze the distributional heterogeneity across the conditional efficiency distribution, thereby capturing the determinants of eco-efficiency at various performance levels. A fractional logit specification was also estimated to confirm robustness, and the results were consistent with those from quantile regression, thereby corroborating the validity of the chosen approach. All quantile regression estimates were obtained through 999 bootstrap replications, using a fixed seed (set seed 12,345) to guarantee complete reproducibility. DEA scores of exactly 1 were preserved without modification, as quantile regression accounts for boundary values and robustness was additionally validated through the fractional logit analysis. The formal model specification is presented in the following section:

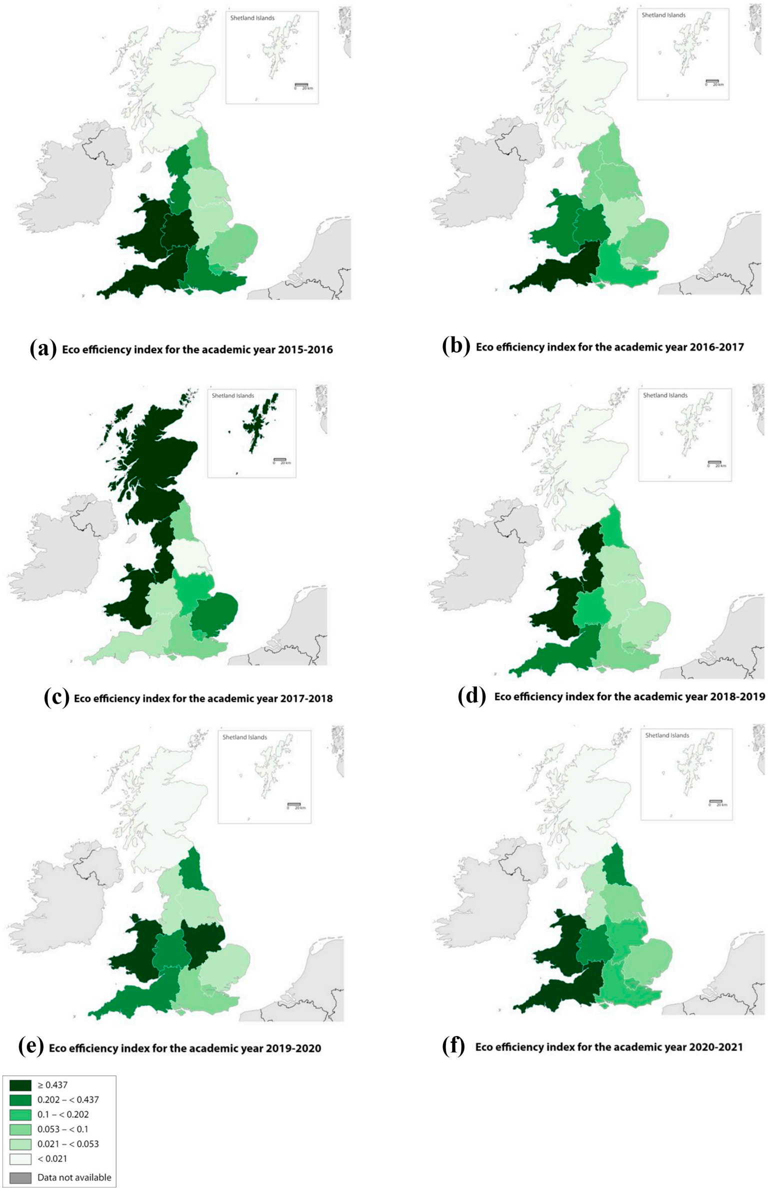

Figure 1. Spatial distribution of eco-efficiency scores for UK universities, 2015/2016–2020/2021. Panels (a)–(f) correspond to the academic years 2015/2016, 2016/2017, 2017/2018, 2018/2019, 2019/2020 and 2020/2021, correspondingly. Eco-efficiency values are represented by data envelopment analysis scores, which range from 0 (indicating the lowest efficiency) to 1 (signifying frontier efficiency). Color categories represent the natural breakpoints (Jenks) classification applied to the distribution of eco-efficiency scores in each year

$$Y_t = x_t\beta + u_t \tag{3}$$

where is the estimated coefficient, ut is the residual term, xt is the independent variable and Yt is the dependent variable. Consequently, the objective of a quantile regression model is to estimate for various conditional quantile functions. If the conditional mean of μ(X) = X'β, then the ordinary least squares (OLS) approach that is used to estimate β minimizes $\sum_{t=1}^{n}(\Upsilon_t - \mu)2$ that is based on:

$$\min_{\beta\epsilon R}\sum_{t=1}^{n}\left(Y_t - X^{'}\beta\right)^2 \tag{4}$$

An estimation of the median function, or the second quantile or 50th percentile, is obtained by addressing the linear specification of equation (4). To represent the other quantile values, we used the symbol “”. The conditional quantile function may, thus, be written as follows:

$$Q_Y(\tau|X) = X^{'}\beta(\tau) \tag{5}$$

Then to estimate the conditional quantile functions, or $\widehat{\beta}(\tau)$, we should find the solution to the following equation:

$$\min_{\beta\epsilon R}\sum_{t=1}^{n}\rho_\tau\left(Y_t - X^{'}\beta\right) \tag{6}$$

where the weighting function of ρ_τ has the following expression for every $\tau\epsilon$ (0, 1):

$$\rho_\tau(u_i) = \begin{cases} t_u if u_i \geq 0 \\ (1-\tau)u_i if u_i < 0 \end{cases} \tag{7}$$

where:

$$u_i = Y_t - X^{'}\beta$$

The issue of the weighted minimization can be solved by combining equations (6) and (7), which helps in obtaining the $\widehat{\beta}(\tau)$ as well:

$$\min_{\beta\epsilon R}\left[\tau\sum_{Y_t \geq X^{'}\beta}|\Upsilon_{t-}X^{'}\beta| + (1-\tau)\sum_{Y_t < X^{'}\beta}|\Upsilon_{t-}X^{'}\beta|\right] \tag{8}$$

Finally, to accommodate readers, a framework has been established (Figure 2), which demonstrates the methodological framework that was implemented during the investigation. In the initial stage of the DEA model, financial performance indicators (ROA, quick ratio, current ratio and OCFR) are used to calculate an eco-efficiency score for each university. The second stage involves the application of quantile regression to evaluate the impact of these financial indicators on eco-efficiency across a variety of quantiles, thereby enabling a more detailed comprehension of performance-specific effects.

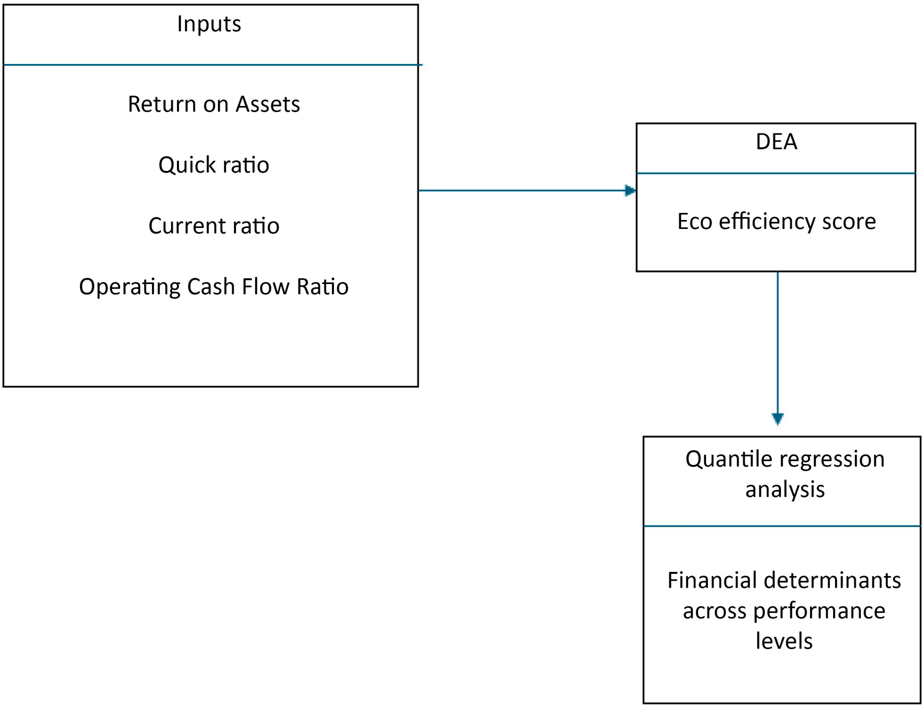

Figure 2. Conceptual framework of the two-stage analytical model
Source: Authors' elaboration

4. Results

The empirical results of the two-stage analysis are presented in Section 4. The DEA approach was used to evaluate the eco-efficiency of UK universities in the initial stage, with input–output combinations that encompassed both financial and environmental aspects. Institution-level DEA scores for each academic year from 2015/2016 to 2020/2021 are presented in Appendix 1. Spatial distributions of eco-efficiency levels are visualized through regional mapping to facilitate interpretation, emphasizing significant geographic patterns. Universities in Wales exhibit the greatest overall eco-efficiency scores, as demonstrated. To contextualize the second-stage analysis, the descriptive statistics for the primary variables used in the quantile regression are as summarized in Table 3. The use of a distribution-sensitive estimation technique is justified by the degree of variation in eco-efficiency and financial indicators across institutions, as evidenced by these statistics.

The analysis demonstrates distinct regional contrasts in terms of eco-efficiency. Supported by proactive decarbonization commitments, early renewable investment and integrated governance structures, Welsh universities consistently outperform the sector. In contrast, institutions situated in London exhibit substantially lower eco-efficiency, which is likely because of infrastructural and spatial constraints in congested urban settings, despite having access to more financial resources. Scottish universities are situated in a middle ground, with supportive regional frameworks but inconsistent institutional responses. These discrepancies emphasize the influence of financial capacity, governance arrangements and policy integration on the results of eco-efficiency. Eco-efficiency scores also exhibit quantifiable progress throughout the study period at the sector level.

Table 3. Descriptive statistics of main variables

Variable	Mean	SD	Minimum	Maximum
Eco-efficiency score	0.213	0.261	0.001	1.000
ROA	0.047	0.032	−0.015	0.128
Quick ratio	1.425	0.563	0.634	3.204
Current ratio	1.733	0.705	0.912	3.978
OCFR	1.268	0.411	0.502	2.985

Quantile regression is applied in the next phase to analyze the financial determinants affecting this environmental performance. Multicollinearity is not an issue, as correlation diagnostics indicate negligible pairwise connections and all variance inflation factor values are much below the specified threshold of 5 (Appendix 2, Table A2). Table 4 underscores a negative correlation between the current ratio and return on assets, suggesting that entities with more liquidity often own significant non-current assets, like student housing, labs or digital infrastructure.

Additionally, it is important to note that universities situated in the metropolitan region of London, where most of them are located, are experiencing a decline in their environmental sustainability. Carbon emissions continue to be excessively high, despite some encouraging accomplishments. To ensure robust inference, bootstrapped standard errors were approximated using 999 replications in STATA (Table 5). We replicate the results of the median regression at q = 0.50 because the quantile-based coefficients vary across the distribution. Dissimilarities are observed in the OLS coefficients for the upper and lower quantiles. The slope coefficients at different locations along the distribution are captured by the quantile estimates. The quick ratio is statistically significant at the median quantile (q = 0.50), underscoring the significance of short-term liquidity in promoting eco-efficiency. The OCFR approaches significance at the upper quantile (q = 0.75), indicating that universities with stronger cash flow positions are better positioned to improve eco-efficiency. Conversely, the current ratio and ROA do not exhibit consistent or statistically significant effects across quantiles.

4.1 Robustness checks

A series of diagnostic procedures were conducted to assess the robustness of the quantile regression findings. Initially, an identical set of explanatory variables was used to estimate the OLS regression. The OLS results, reflecting average effects, demonstrate reduced explanatory capacity and conceal the heterogeneity across different performance levels revealed by quantile regression, thereby confirming the suitability of the distributional approach. Secondly, to mitigate the effects of heteroskedasticity and outliers, bootstrapped

Table 4. Correlation coefficients between the independent variables in the model

Description	Eco*Eff*	ROA	Quick ratio	Current ratio	Oper_*Rat*
Eco*Eff*	1.000	0.004	0.061	−0.007	0.055
ROA	0.004	1.000	0.020	−0.006	0.004
Quick ratio	0.061	0.020	1.000	−0.003	−0.008
Current ratio	−0.007	−0.006	−0.003	1.000	0.109
Oper_*Rat*	0.055	0.004	−0.008	0.109	1.000

Table 5. Estimation results of quantile regression analysis

Quantile	Variable	Coef.	Bootstrapped SE	*t*-statistics	*p*-value
q25	ROA	0.000	0.000	0.860	0.390
	Quick ratio	0.001	0.001	0.974	0.330
	Current ratio	0.000	0.000	0.873	0.383
	OCFR	−0.000	0.000	−0.117	0.907
	Constant	0.021	0.003	6.665	<0.001
q50	ROA	−0.000	0.000	−0.018	0.986
	Quick ratio	0.003	0.001	2.017	0.044
	Current ratio	0.000	0.000	0.647	0.518
	OCFR	0.000	0.000	0.171	0.864
	Constant	0.055	0.005	11.551	<0.001
q75	ROA	−0.000	0.000	−0.200	0.841
	Quick ratio	0.009	0.006	1.442	0.149
	Current ratio	−0.000	0.000	−0.074	0.941
	OCFR	0.002	0.001	1.947	0.052
	Constant	0.163	0.022	7.320	<0.001

standard errors were computed with 1,000 replications. The estimated effects were further corroborated by the observation that the majority of the quantile coefficients retained their statistical significance throughout the bootstrapping process. Finally, multicollinearity was evaluated using variance inflation factors, all of which remained well below standard thresholds, as detailed in Appendix 2 (Table A2).

5. Discussion

This study examined the relationship between financial performance and eco-efficiency in UK HEIs, revealing significant discrepancies in both environmental performance and financial-health alignment across the sector. The findings suggest that the eco-efficiency of UK universities is inconsistently distributed, with Welsh institutions consistently outperforming their counterparts in other regions, as evidenced by a two-stage DEA–quantile regression approach. This regional advantage is likely the outcome of a combination of proactive climate strategies, targeted public financing and integrated institutional governance structures that emphasizing sustainability.

In contrast, universities in densely populated metropolitan areas, particularly in London, exhibited lower eco-efficiency scores, despite frequently having access to greater financial resources. This suggests that the relationship between financial capacity and environmental outcomes may be moderated by operational scope, infrastructure limitations and spatial constraints.

The quantile regression analysis suggests that the influence of financial indicators is not consistent. The quick ratio is a statistically significant predictor of eco-efficiency at the median quantile (q = 0.50), underscoring the importance of short-term liquidity in the support of sustainability investments. The OCFR approaches significance at the upper quantile (q = 0.75), indicating that institutions with a greater internal cash generation capacity are more suited to improve eco-efficiency. In contrast, the ROA and the current ratio do not demonstrate statistically significant effects across the distribution, suggesting that profitability and general solvency are not reliable drivers of eco-efficiency in this context.

These findings underscore the importance of understanding eco-efficiency as a financial and managerial phenomenon that is incorporated into the strategic architecture of universities, in addition to serving as an environmental metric. The results offer a nuanced perspective on the sustainability capacity of institutions, which is influenced by internal financial management, external governance conditions and geographic constraints.

5.1 Theoretical implications

By operationalizing eco-efficiency as a strategic capability within the framework of the NRBV, this study contributes to the theoretical advancement of sustainability and strategic management in higher education (Swindell *et al.*, 2024; Tian and Liu, 2024; Zeng *et al.*, 2024). Although NRBV has been extensively implemented in corporate sustainability research, its application to publicly funded, non-profit institutions is still restricted. The relevance of NRBV to public-sector organizational behavior is reinforced by the empirical demonstration that the capacity of universities to achieve superior environmental outcomes is conditioned by internal financial attributes.

Additionally, quantile regression contributes to the theoretical comprehension of institutional heterogeneity. Unlike conventional mean-based models, quantile methods demonstrate that the intensity and direction of financial influences on eco-efficiency vary across the performance distribution. This corroborates the notion that sustainability capacities are context-specific and path-dependent, rather than unconditionally responsive to financial inputs. This distinction is especially evident in higher education, where institutions exhibit substantial differences in their mission, structure and resource endowments (Abo-Khalil, 2024; Frizon and Eugénio, 2022; Vergani, 2024).

Finally, the incorporation of quantile regression and DEA introduces a methodological innovation in the evaluation of university performance. Although DEA is frequently used for efficiency benchmarking, its integration with distribution-sensitive regression modeling offers more comprehensive insights into the systemic and conditional nature of sustainability outcomes. This methodological contribution is applicable to other research domains that are concerned with the multidimensional performance of public institutions (Drăgan *et al.*, 2014; Ragazou *et al.*, 2024; Shin *et al.*, 2023).

5.2 Practical implications

The practical implications of this research are multifaceted and highly germane to institutional leaders, policymakers and funding agencies. The results emphasize the significance of university administrators' alignment of financial planning with sustainability objectives. The eco-efficiency index developed in this study functions as a diagnostic tool to identify institutional strengths and shortcomings, facilitate evidence-based decision-making and inform resource allocation.

The findings suggest that environmental performance is significantly improved by financial health, particularly liquidity and capital flow. This understanding encourages a transition from the classification of sustainability as a cost center to its recognition as a strategic investment area. Senior leadership and finance teams must collaborate with sustainability officers to incorporate environmental considerations into capital investment, infrastructure modernization and risk management processes.

The results offer estates and facilities managers immediate guidance from an operational standpoint. Institutions with greater liquidity are better equipped to prioritize energy-efficient retrofits, renewable energy integration and digital infrastructure upgrades. Conversely, those with lower eco-efficiency levels may achieve impact through low-cost interventions, such as optimized heating and cooling schedules, improved energy management systems or behavioral programs that reduce consumption. Liquidity can be strategically deployed to integrate sustainability into ongoing operations and investment decisions for mid-range performers. University leaders and estates teams can convert financial resilience into quantifiable sustainability outcomes by customizing actions to institutional capacity.

The significance of differentiated support frameworks is also underscored by the quantile regression analysis. National and regional governments, as well as research funding councils, can use eco-efficiency metrics to develop performance-linked incentives, green finance instruments and capacity-building programs. For instance, institutions with lower eco-efficiency scores may necessitate targeted technical assistance, whereas high-performing institutions could capitalize on innovation funding and advanced financing mechanisms to expand their best practices. It is critically important to note that the analysis of devolved nations (e.g. Wales, Scotland and London) is exclusively based on the DEA–quantile regression estimates presented here. Consequently, it should be interpreted as indicative of structural factors rather than as prescriptive judgments about specific administrations.

In general, the research supports a systems-thinking approach to sustainability in higher education. Eco-efficiency should be regarded as a fundamental aspect of institutional governance, reputation and long-term resilience, rather than a peripheral reporting exercise. In an educational landscape that is becoming increasingly competitive, universities that transparently monitor and disseminate their eco-efficiency performance are more likely to establish public trust and a strategic advantage, because of the increasing expectations of students, staff, funders and civil society.

Consequently, the investigation suggests a multi-tiered framework for universities with varying levels of eco-efficiency. By stabilizing financial resilience and addressing infrastructural inefficiencies, low-performing institutions should establish the foundations of sustainability. High-performing universities should prioritize innovation, sectoral leadership and the adoption of advanced green financing instruments, such as sustainability-linked bonds or green revolving funds, while mid-range performers should strategically deploy liquidity to embed sustainability into their operations. This distinction guarantees that the practical implications of eco-efficiency are in accordance with the diverse capacities and starting positions of universities.

5.3 Limitations and future research

This study presents several limitations that offer avenues for future research, notwithstanding its contributions. Initially, the analysis is limited to universities within the UK, thereby restricting the generalizability of the findings to other national contexts. Cross-country comparative analyses may examine whether the financial determinants affecting eco-efficiency differ among higher education systems with distinct regulatory and funding structures.

Second, the qualitative dimensions of sustainability governance – such as leadership dedication, organizational culture and institutional values – are not captured in secondary data, even though such data offer extensive national coverage. Future research may use mixed method approaches to investigate how these intangible factors interact with financial indicators to influence eco-efficiency outcomes.

Third, a notable limitation relates to the extent of the emissions boundary. The environmental indicator used in this study considers exclusively Scope 1 CO_2 emissions, as Scope 3 emissions (such as travel, procurement, commuting and waste) are not consistently reported by UK universities and therefore are not captured. As a result, the estimates of eco-efficiency may be understated. Future research would benefit from the integration of comprehensive carbon accounting frameworks once standardized Scope 3 reporting is implemented.

Fourth, while DEA provides a comprehensive non-parametric framework for efficiency assessment, it remains vulnerable to outliers and relies on the assumption of stable input–output relationships. Future research could assess the robustness of eco-efficiency estimates through the application of alternative frontier methodologies, such as fuzzy-logic multi-criteria decision-making models or Stochastic Frontier Analysis.

Ultimately, future research may investigate the temporal progression of eco-efficiency by using panel quantile regression or time-series clustering techniques to identify trajectory patterns in the environmental and financial alignment of universities. Such an approach would enhance the understanding of how institutional sustainability performance evolves over time and responds to policy disruptions or fluctuations in funding.

6. Conclusions

The eco-efficiency of 160 universities in the UK was evaluated over a six-year academic period, and the impact of key financial indicators on environmental performance was investigated. Using a two-stage DEA–quantile regression methodology, we offered a nuanced and empirically supported comprehension of the relationship between sustainability outcomes and financial resilience in higher education.

The results indicate that there are substantial discrepancies in eco-efficiency among institutions, with operational cash flow and liquidity being more closely associated with enhanced environmental performance at higher performance levels. Internal financial capabilities and governance structures are critical drivers of eco-efficiency, as indicated by this discovery, and they serve to complement rather than replace external policy mandates. In theory, this study expands the NRBV by conceptualizing eco-efficiency as a dynamic capability that is rooted in institutional resource configurations. In a methodological sense, it integrates DEA and quantile regression to capture distributional heterogeneity in performance.

The eco-efficiency index provides a benchmarking tool for university leaders, policymakers and funding agencies in the context of practice and policy. The quantile analysis underscores the necessity of context-sensitive interventions that align with institutional capacity. Financial planning and environmental strategy are integrated to improve long-term sustainability, as the study promotes a systems-thinking approach. Future research could address these limitations by conducting longitudinal analyses, qualitative explorations of governance practices and cross-national comparisons, as well as by addressing the UK-only focus and reliance on secondary data.

In conclusion, universities should adopt eco-efficiency as a strategic imperative, rather than solely an operational measure, considering the increasing demand for meaningful climate action from stakeholders, regulatory pressure and climate uncertainty.

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Appendix 1

Table A1. Eco-efficiency of British universities

DMUs	Eco*Eff* Academic year 2015/2016	Eco*Eff* Academic year 2016/2017	Eco*Eff* Academic year 2017/2018	Eco*Eff* Academic year 2018/2019	Eco*Eff* Academic year 2019/2020	Eco*Eff* Academic year 2020/2021
University_1	0.1035	0.143	0.039	0.509	0.032	0.044
University_2	0.4110	0.400	0.393	1.000	0.256	0.547
University_3	0.0168	0.023	0.014	0.007	0.055	0.016
University_4	0.0065	0.007	0.081	0.847	0.013	0.034
University_5	0.3108	0.312	0.029	0.707	0.223	1.000
University_6	0.0222	0.035	0.274	0.228	0.013	0.009
University_7	0.0128	0.022	0.029	1.000	0.134	0.005
University_8	0.0278	0.044	0.052	0.079	0.020	0.024
University_9	0.0125	0.013	0.285	0.798	0.023	0.003
University_10	0.0197	0.030	0.012	0.106	0.095	0.010
University_11	0.0550	0.081	0.023	0.235	0.024	0.032
University_12	0.0253	0.036	0.102	0.105	0.051	0.007
University_13	0.0344	0.045	0.025	0.202	0.121	0.275
University_14	0.1031	0.116	0.313	0.084	1.000	0.094
University_15	0.8385	0.963	0.135	0.128	0.196	1.000
University_16	0.0736	0.099	1.000	0.777	0.506	0.021
University_17	0.0041	0.008	0.085	0.090	0.032	0.033
University_18	0.0125	0.011	0.011	0.012	0.014	0.027
University_19	0.6892	0.795	0.008	0.079	0.116	0.020
University_20	0.0288	0.038	0.924	0.150	0.060	0.109
University_21	0.0679	0.103	0.136	0.139	0.033	0.015
University_22	0.0298	0.047	0.114	0.053	0.090	0.031
University_23	0.0792	0.077	0.049	0.099	0.061	0.025
University_24	0.0078	0.010	0.075	0.121	0.148	0.097
University_25	0.7720	1.000	0.010	0.051	0.006	0.008
University_26	0.0478	0.046	1.000	0.091	0.003	0.002
University_27	0.1019	0.100	0.043	0.621	0.216	0.336
University_28	0.0551	0.068	0.115	0.091	1.000	0.130

(*continued*)

Table A1. Continued

DMUs	Eco*Eff* Academic year 2015/2016	Eco*Eff* Academic year 2016/2017	Eco*Eff* Academic year 2017/2018	Eco*Eff* Academic year 2018/2019	Eco*Eff* Academic year 2019/2020	Eco*Eff* Academic year 2020/2021
University_29	0.0031	0.005	0.087	0.040	0.389	0.096
University_30	0.0521	0.053	0.005	0.011	0.108	0.869
University_31	0.4625	0.531	0.053	0.025	0.199	0.016
University_32	0.0017	0.353	0.544	0.229	0.016	0.082
University_33	0.2565	0.052	0.394	0.048	0.006	0.004
University_34	0.0346	0.209	0.057	0.083	0.020	0.039
University_35	0.0752	0.034	0.240	0.096	0.152	0.018
University_36	0.0236	0.004	0.037	0.108	0.051	0.004
University_37	0.0252	0.036	0.005	0.002	0.087	0.006
University_38	0.1158	0.010	0.034	0.072	0.012	0.027
University_39	0.0335	0.014	0.009	0.041	0.107	0.005
University_40	0.0386	0.054	0.015	0.012	0.013	0.011
University_41	0.0751	0.076	0.050	0.158	0.032	0.059
University_42	0.0111	0.036	0.076	0.030	0.352	0.056
University_43	0.0078	0.116	0.048	0.102	0.045	0.061
University_44	0.1001	0.089	0.116	0.079	0.024	0.004
University_45	0.0389	0.020	0.110	0.232	1.000	0.023
University_46	0.0094	0.175	0.018	0.057	0.101	0.048
University_47	0.0397	0.070	0.183	0.027	0.003	0.039
University_48	0.1102	0.020	0.078	0.318	0.044	1.000
University_49	0.0126	0.051	0.016	0.040	0.051	0.197
University_50	0.1241	0.005	0.050	0.186	0.019	0.005
University_51	0.0227	0.006	0.007	0.005	0.005	0.002
University_52	0.0198	0.046	0.007	0.003	0.038	0.023
University_53	0.0323	0.004	0.044	0.216	0.109	0.065
University_54	0.0238	0.051	0.005	0.005	0.023	0.003
University_55	0.0870	0.077	0.046	0.032	1.000	0.010
University_56	0.1856	1.000	0.076	0.376	1.000	0.026

(*continued*)

Table A1. Continued

DMUs	Eco*Eff* Academic year 2015/2016	Eco*Eff* Academic year 2016/2017	Eco*Eff* Academic year 2017/2018	Eco*Eff* Academic year 2018/2019	Eco*Eff* Academic year 2019/2020	Eco*Eff* Academic year 2020/2021
University_57	1.0000	0.019	1.000	1.000	0.465	0.019
University_58	0.0224	0.276	0.020	0.008	0.317	0.035
University_59	0.1423	0.021	0.279	1.000	0.013	0.007
University_60	0.0297	0.006	0.023	0.021	0.036	0.012
University_61	0.0341	0.006	0.006	0.014	0.266	1.000
University_62	0.0230	0.055	0.007	0.004	0.113	0.025
University_63	0.0273	0.047	0.057	0.011	0.037	0.027
University_64	0.0739	0.043	0.048	0.036	0.004	0.109
University_65	0.0194	0.182	0.029	0.027	0.103	0.023
University_66	0.3224	0.022	0.210	0.528	1.000	0.003
University_67	0.0187	0.049	0.024	0.019	0.033	0.028
University_68	0.0604	0.100	0.054	0.419	0.054	0.027
University_69	0.0107	0.051	0.108	0.011	0.312	0.001
University_70	0.0099	0.239	0.063	0.030	0.356	0.514
University_71	0.1353	0.145	0.022	0.023	0.287	0.576
University_72	0.0661	0.029	0.165	0.262	0.458	0.024
University_73	0.0320	0.012	0.030	0.022	0.029	0.021
University_74	0.1563	0.011	0.013	0.047	0.256	0.621
University_75	0.0352	0.107	0.011	0.081	0.465	0.157
University_76	0.1528	0.562	0.126	0.090	0.058	0.024
University_77	0.4572	0.024	0.642	0.472	1.000	0.006
University_78	0.0166	0.022	0.027	0.113	0.077	0.488
University_79	0.0127	0.010	0.013	0.099	0.180	0.042
University_80	0.0081	0.011	0.031	0.344	0.992	0.028
University_81	0.0369	0.078	0.012	0.004	0.098	1.000
University_82	0.0383	0.009	0.086	0.099	0.061	0.047
University_83	0.0080	0.250	0.013	0.001	1.000	0.198
University_84	0.0298	0.017	0.280	0.122	0.099	1.000

(*continued*)

Table A1. Continued

DMUs	Eco*Eff* Academic year 2015/2016	Eco*Eff* Academic year 2016/2017	Eco*Eff* Academic year 2017/2018	Eco*Eff* Academic year 2018/2019	Eco*Eff* Academic year 2019/2020	Eco*Eff* Academic year 2020/2021
University_85	0.0232	0.009	0.017	0.053	0.203	0.018
University_86	0.0115	0.205	0.010	0.009	0.168	0.144
University_87	0.1263	0.020	0.219	0.086	0.124	0.023
University_88	0.7649	0.728	0.008	0.005	0.664	0.417
University_89	0.0569	0.074	0.924	0.456	0.165	0.043
University_90	0.0949	0.087	0.073	0.605	0.366	0.480
University_91	0.0329	0.038	0.157	0.216	0.017	0.046
University_92	0.0474	0.050	0.027	0.412	0.605	0.032
University_93	0.0234	0.044	0.080	0.073	0.027	0.094
University_94	0.0779	0.072	0.174	0.580	0.243	0.147
University_95	1.0000	1.000	1.000	1.000	0.144	0.018
University_96	0.0588	0.090	1.000	0.152	0.086	0.141
University_97	0.0150	0.020	0.086	0.014	0.066	0.086
University_98	0.3583	0.348	0.022	0.462	0.238	0.044
University_99	0.0527	0.067	0.340	0.142	0.686	0.015
University_100	0.0134	0.020	0.077	0.029	0.410	0.076
University_101	1.0000	1.000	0.017	1.000	0.023	0.082
University_102	0.0219	0.019	1.000	0.330	0.071	0.306
University_103	0.0535	0.079	0.017	0.115	0.050	0.304
University_104	1.0000	1.000	0.080	0.396	0.008	0.378
University_105	0.0357	0.061	1.000	0.045	0.127	0.163
University_106	0.1179	0.027	0.061	0.100	0.036	0.116
University_107	0.0727	0.825	0.028	0.077	0.012	0.144
University_108	0.0689	0.026	1.000	0.121	0.045	0.009
University_109	0.0761	0.035	0.027	0.134	0.040	0.065
University_110	0.1107	1.000	0.033	0.334	0.985	0.011
University_111	0.3109	0.046	1.000	0.167	1.000	0.141
University_112	0.0245	0.126	0.047	0.139	0.142	0.054

(continued)

Table A1. Continued

DMUs	Eco*Eff* Academic year 2015/2016	Eco*Eff* Academic year 2016/2017	Eco*Eff* Academic year 2017/2018	Eco*Eff* Academic year 2018/2019	Eco*Eff* Academic year 2019/2020	Eco*Eff* Academic year 2020/2021
University_113	0.8342	0.291	0.172	0.410	0.005	0.004
University_114	0.1210	0.212	0.249	0.340	0.105	0.823
University_115	0.0875	0.015	0.227	0.022	0.024	0.171
University_116	0.1693	0.125	0.016	0.215	0.422	0.009
University_117	0.0329	0.279	0.144	0.059	0.342	0.008
University_118	0.1342	0.029	0.290	0.068	0.099	0.031
University_119	0.2581	0.079	0.029	0.115	0.014	0.018
University_120	0.2851	0.323	0.079	0.494	0.021	0.019
University_121	0.1194	0.110	0.333	0.327	0.120	0.069
University_122	0.4851	0.328	0.105	0.656	0.121	0.027
University_123	0.2068	0.218	0.299	0.141	0.539	0.013
University_124	1.0000	0.418	0.220	0.327	0.033	0.126
University_125	0.0896	0.299	0.378	0.048	0.054	0.179
University_126	0.2670	0.073	0.387	0.662	0.042	0.019
University_127	0.0835	0.275	0.076	0.955	0.231	0.233
University_128	0.5331	0.116	0.331	0.098	0.447	0.004
University_129	0.1017	0.197	0.112	0.459	0.112	0.016
University_130	0.0071	0.221	0.211	0.007	0.037	0.015
University_131	0.0479	0.017	0.289	0.049	0.012	0.045
University_132	0.0183	0.011	0.020	0.268	0.468	1.000
University_133	0.0507	0.091	0.011	0.043	0.058	0.009
University_134	0.1922	0.134	0.108	0.169	0.169	0.011
University_135	0.0047	0.004	0.142	0.011	0.031	0.036
University_136	0.6217	0.796	0.004	0.493	0.793	0.920
University_137	0.0389	0.047	0.789	0.202	0.320	0.371
University_138	1.0000	0.447	0.054	0.644	0.768	0.890
University_139	0.0195	0.024	0.471	0.095	0.115	0.134
University_140	0.0316	0.043	0.027	0.052	0.052	0.060

(*continued*)

Table A1. Continued

DMUs	Eco*Eff* Academic year 2015/2016	Eco*Eff* Academic year 2016/2017	Eco*Eff* Academic year 2017/2018	Eco*Eff* Academic year 2018/2019	Eco*Eff* Academic year 2019/2020	Eco*Eff* Academic year 2020/2021
University_141	0.0371	0.055	0.048	0.108	0.124	0.143
University_142	0.0432	0.057	0.103	0.248	0.283	0.329
University_143	0.0267	0.042	0.049	0.151	0.172	0.200
University_144	0.0841	0.121	0.042	0.210	0.239	0.278
University_145	0.0056	0.005	0.131	0.015	0.017	0.020
University_146	0.0515	0.073	0.005	0.352	0.401	0.465
University_147	0.1099	0.025	0.087	0.025	0.028	0.033
University_148	0.0718	0.274	0.024	0.103	0.118	0.137
University_149	0.6223	0.210	0.309	1.000	1.000	1.000
University_150	0.0907	0.011	0.221	0.020	0.022	0.026
University_151	0.3062	1.000	0.013	0.300	0.342	0.396
University_152	0.0100	0.004	0.770	0.007	0.008	0.009
University_153	0.0258	0.042	0.004	0.013	0.015	0.018
University_154	0.0801	0.018	0.067	0.061	0.069	0.080
University_155	0.1769	0.109	0.021	0.056	0.064	0.074
University_156	0.9556	0.022	0.149	0.437	0.498	0.578
University_157	0.3536	0.202	0.020	0.166	0.189	0.219
University_158	0.0293	0.037	0.208	0.021	0.023	0.027
University_159	0.0085	0.008	0.035	0.017	0.020	0.023
University_160	0.0231	0.035	0.008	0.025	0.028	0.033

Appendix 2

Table A2. Variance inflation factors for the independent variables

Variable	VIF	1/VIF
ROA	1.42	0.704
Quick ratio	1.19	0.838
Current ratio	1.27	0.784
OCFR	1.31	0.762
Mean VIF	1.30	

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