Environmental Pollution and Carbon Accountability: Will Energy Efficiency Budgeting and Banks Portfolios Carbon Footprint Facilitate United Kingdom's 2050 Net-Zero Emissions?

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ABSTRACT

The energy and financial sectors have been incorporated into the quest to solve climate change, with increasing recognition of the direct impacts that financial institutions' lending and investment practices have on environmental sustainability. This study applies Quantile Autoregressive Distribution Lags (QARDL) Model to examine the dynamic impact of energy efficiency budgeting on carbon dioxide emissions, controlling carbon footprint of banks' portfolios in United Kingdom. First, an in-depth descriptive statistics analysis of data for various variables are conducted. The study then uses Quantile Augmented Dickey-Fuller to test for stationarity, then proceeds to perform Quantile Cointegration test and closely followed by Quantile Autoregressive Distributed Lags (QARDL) estimation to examine the impact of energy efficiency budgeting and carbon footprint of banks' portfolios on carbon dioxide emissions. The empirical results validate the findings of stationarity for each variable. There is evidence of first-order differential integration I (1) among variables. There is a cointegration link between the three variables and that they have a more prolonged and stabled relationship. The results showed that energy efficiency budgeting has a reducing effect on carbon dioxide emissions. Its effectiveness varies across different emission quantiles, there is the need for a flexible budgeting approach. Policymakers should develop mechanisms to adjust budget allocations based on current emission levels, potentially increasing budget during periods when the impact is likely to be strongest. However, carbon footprint of banks portfolios promote rise in carbon dioxide reduction. The central bank of UK should implement mandatory carbon screening tools for bank portfolios. These mechanisms would help banks understand and manage their immediate carbon impact. Banks should be required to develop comprehensive carbon accounting systems that track both direct and indirect emissions from their investments.

Keywords: United Kingdom; Energy Efficiency Budgeting; CO_2 Emissions; Carbon Footprint of Banks Portfolios; Quantile ADF; Quantile Cointegration Relations Processes; Quantile Autoregressive Distributed Lags.

INTRODUCTION

The financial sector has been incorporated into the quest to solve climate change, with increasing recognition of the direct impacts that financial institutions' lending and investment practices have on environmental sustainability. Reducing carbon is a national commitment in the United Kingdom, so one area in need of critical research is to understand the carbon implications of banking activities. Banks and financial institutions provide capital for any economic activity, from an industrial project to corporate expansion. All these financial flows have traditionally been decoupled from their environmental impacts.

In the UK, listed companies on the stock exchange are required to disclose and report Scope 1 and Scope 2 emissions for the current and last year (Singh et al., 2015). Regulatory frameworks are also very instrumental in driving carbon accountability. The EU's Sustainable Finance Disclosure Regulation and the UK's Prudential Regulation Authority have both developed environmental disclosure rules for financial institutions, among others, as claimed by (Loorbach et al., 2020).

One of the recent research studies by World Wide Fund for Nature (2021) assessed the emission attributed to the global investments of 10 asset managers and 15 British banks. They stated that their investments generate 805 million tonnes of carbon per year. In short, if the sector were a country, it would be ranked 9th globally by carbon emissions and is on par with other carbon intensive industries such as oil and gas, coal, aviation, and transport. The report addressed traditional mortgages, lending in industries such as information technology, energy, industry, and mortgages. Although UK banks have committed to themselves that their lending and investing portfolios should achieve net-zero emissions by 2050, the amount of emissions of carbon associated with their current funding and investments is nearly double Britain's overall domestic carbon emissions annually.

The investigation also notes that 60 biggest banks in worldwide have contributed £2.7 trillion to high-emissions industries including fossil fuels since the 2015 Paris Agreement. In order to prevent the worst effects of climate change, it is accompanied by a greater focus on keeping global temperature increases to 1.5 degrees Celsius over pre-industrial levels. To achieve this, carbon emissions must decrease by 45% from 2010 levels to 2030 and reach net zero by 2050. Advocates are calling for the UK government to implement regulatory legislation which might include required reporting procedures that would allow the UK banking sector to lead the net zero transitions as international commerce changes to more sustainable investing. The carbon footprints of financial organizations' loan portfolios are measured, as shown in Table 1.

Table 1: Approaches to Quantifying Carbon Footprint of Financial Institutions loans

Approach	Description	Strength	Weakness
IMF Carbon Footprint of Bank Loans Indicator	Banking sector's carbon intensity weighted by sectoral share of bank loans	Underlying loans by industry data generally available	Focus on broad sectors
Guan and others (2017)	Individual bank's portfolio carbon intensity weighted by shares of loans in all sectors	Provides bank-level exposure metric	Intensive data requirements (individual bank's sectoral exposures)
Boermans and Galema (2019)	Individual pension fund's portfolio carbon intensity weighted by shares of companies in the portfolio	Provides fund-level exposure metric	Intensive data requirements (individual funds' sectoral exposures)
Vermeulen and others (2021)	Ratio of average emissions intensity in each global industry to the global average	Emissions intensities keep track of embodied emissions (indirect exposures)	Hard to interpret the indicator as an absolute measure of risk exposure
Faiella and Lavecchia (2020)	Emissions per unit of loans in each sector	Required data generally available	Hard to interpret for sectors with low credit balances
Hirvonen, Karhu, and Tolkki (2021)	Banking sector's carbon intensity weighted by individual exposures' bank loans	Provides granular exposure metrics for financial institutions	Data requirements are high

Source: IMF staff compilation.

(https://www.elibrary.imf.org/display/book/9798400217296/CH007.xml#RCH007tab01)

In order to achieve carbon neutrality by 2050 and further, the European Union (EU) has identified energy efficiency (EE) as one of its primary tools (Koutsandreas et al., 2021, Rubino, 2017). In some areas, Energy Efficiency could cut energy demand and greenhouse gas emissions in half between 2020 and 2050, and it might contribute 44% of the worldwide emission reductions required in 2040 (IEA, 2018). The European Green Deal and its related financing sources have had a major impact on energy efficiency budgets across Europe. According to Webb et al. (2017), energy efficiency projects in the UK have received a capital investment of £356 million.

The likelihood of success in a single city like Edinburgh, where economical mitigation investments in housing, public and commercial buildings, transportation, industry, and waste sectors up to 2030 are estimated to be nearly £4 billion, makes this sum insignificant (Williamson et al., 2020). One of the main financing sources for household energy efficiency upgrades is the Energy Company Obligation (ECO) program. Department for Business, Energy and Industrial Strategy (2022) calculated that between 2018 and 2022, the ECO project provided energy efficiency improvements of around £3.2 billion.

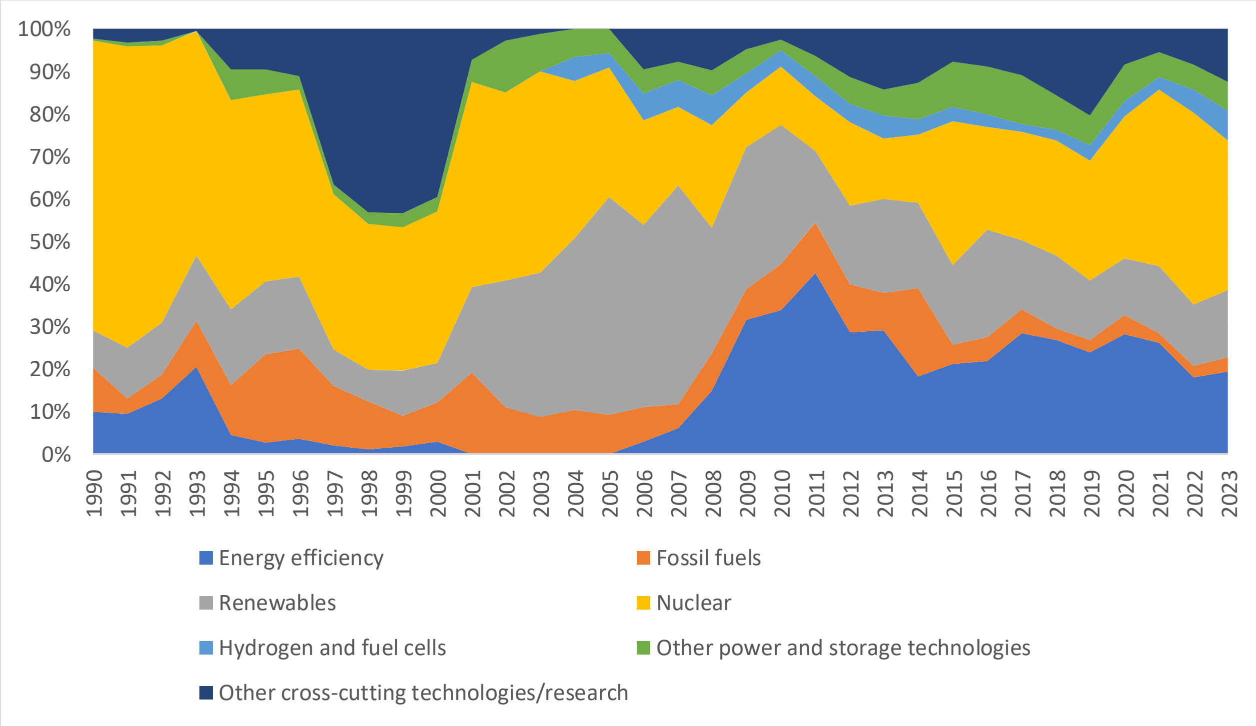


Figure 1: UK Energy Technology, Research and Development expenditure in the energy sector

Source: Authors construction based on data form IEA (2023)

From figure 1, it is obvious that nuclear energy receives the highest budget allocation in the energy sector. This is closely followed by renewable energy and energy efficiency. The least budget allocation is for hydrogen and fuel cells. However, according to Enright (2017), there are multiple areas that improve energy efficiency in the way we extract, transform, consume and return resources to the environment (see figure 2).

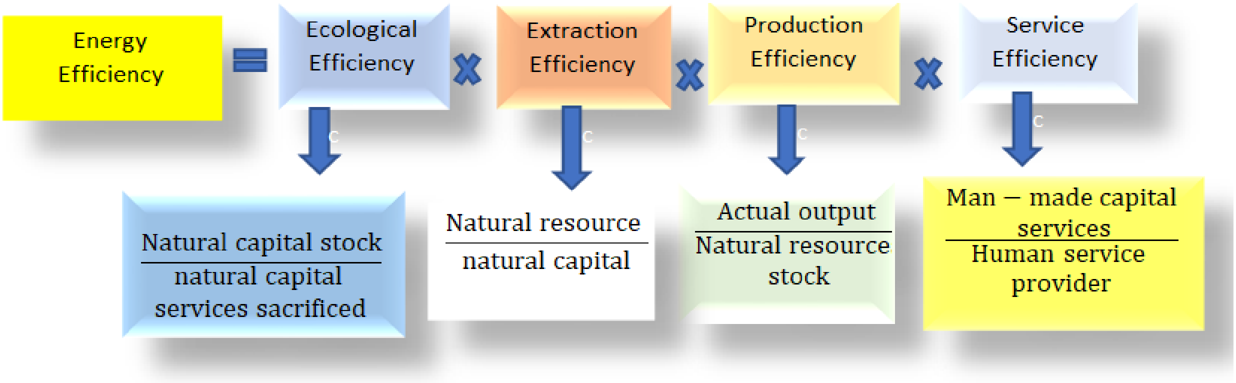


Figure 2: Natural Energy Resources Efficiency Areas.

Source: Authors modification of Enright (2017).

Minimizing resource wastage and utilizing less resources to produce the same results or more with the same input.is reflected in production efficiency. Resource efficiency refers to the extent to which we can extract useful material from nature and minimize waste, energy consumption, and ecological harm. The extent to which the use or exploitation of natural resources results in a loss of natural capital services is known as ecological efficiency. The service efficiency is represented by the number of services provided per unit by the service provider.

The "energy efficiency gap" is a phenomenon that causes the rate of energy efficiency investment to stay comparatively unchanged despite technological developments and the apparent cost-effectiveness of efficiency increases. The term "gap" describes the discrepancy between the actual and perceived levels of investment in technically possible and cost-effective energy efficiency measures (Hirst and Brown, 1990; Jaffe and Stavins, 1994).

A rising amount of research over the past years has attempted to explore the main causes of these gaps, leading to the identifying of several obstacles and market failures that are thought to be responsible for the market's inadequacies. Five interlinked categories can be used to categorize these barriers: a) classical market failures, which include split incentives, transaction costs, and imperfect information; b) institutional, which include conflicting guidelines and a lack of supportive government policy or coordination; c) technical, which include low rates for creativity or insufficient technology; d) motivational, which include bounded rationality or conflicting values; and e) financial, which include hidden costs, access to capital, absence of suitable financing options, customer disparity, fluctuating or artificially low energy prices, and unpredictability (Sorrell et al. 2004).

In addition to addressing limited resources, waste, and the resulting environmental repercussions, a shift to a more responsible and efficient use of energy resources is essential for encouraging creativity and advancement in the direction of a circular economy. Since it enables us to produce greater value while using fewer natural resources, energy resource efficiency entails doing much more with less energy. According to Flachenecker and Rentschler (2018), this shift can prevent negative effects on the environment and, consequently, subsequent generations while promoting sustainable economic development that creates welfare.

The best method to lessen our influence on the environment is obviously to eliminating our demand a resource. Figure 2 shows the resource efficiency hierarchy, which ranks the methods we can use to reduce our negative effects on the environment. The two preventative strategies removal and reduction are at the very top of the hierarchy. We are more obviously pointing to product design as a way to completely eliminate resource required by developing a removal approach. Resourcing comes after reducing. In this step, we look at different sources or materials with a reduced ecological impact after removing or reducing our need for a resource. Remanufacturing is the process of restoring a resource or piece of machinery to its original or improved state. In terms of cost and environmental impact, reuse within the same process is typically preferable than recycling or downcycling into another process. Where recycling is not practical, there may be a chance to recover a portion of the resource. We can at last release waste back into the ecosystem.

Although the advantages of increasing resource efficiency may be widely acknowledged, doing so is a difficult undertaking. Businesses encounter a variety of market obstacles and frictions that might deter or even prohibit them from making investments in low-carbon and efficient technologies.

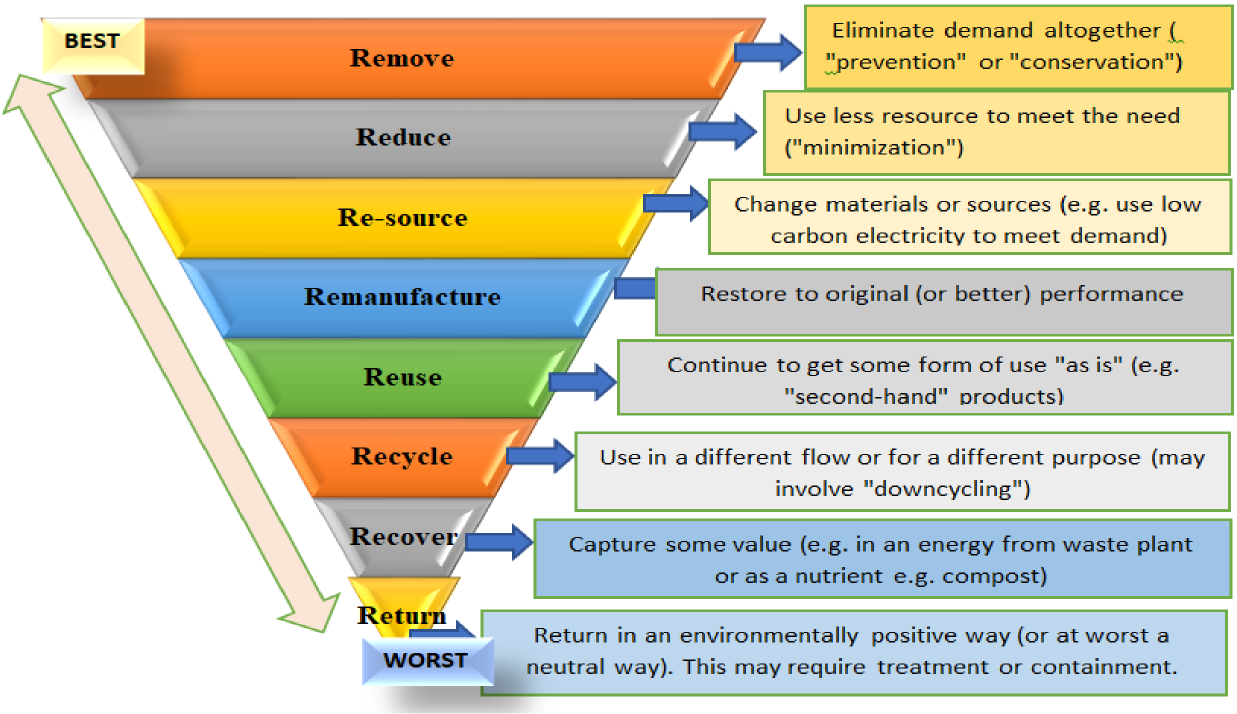


Figure 3: Resource efficiency hierarchy showing, eight natural resource efficiency methods

Source: Authors modification of Enright (2017).

The primary objective of this study is to examining the effects energy efficiency financing and carbon footprint of bank loans on environmental quality in United Kingdom. There are three key areas that make up the contribution of this work. This study is groundbreaking in the field of sustainable development studies in UK. This study takes a different approach than previous ones by using Quantile Autoregressive Distribution Lags (QARDL) methods to analyzing the environmental impacts of energy efficiency financing and carbon footprint of bank loans concurrently. The application of QARDL methods is relatively novel in this field. These methods allow for a nuanced analysis of data across different scales and quantiles, capturing both local variations and long-term trends that might be missed by other techniques.

Second, with the UK focus offers an opportunity to examine country-specific determinants, policies, and historical backgrounds leading energy efficiency finance and carbon intensity of bank lending and environmental implications. Such specificity can offer immediate insights useful for policy-making within the UK as well as industry practices within it. This can help UK construct more realistic policies which will facilitate it to become closer to its 2050 Net-zero emission target.

Through presenting empirical evidence of the environmental cost linked to bank lending, this contributes to the literature on sustainable finance and carbon transparency. The banks will be enhanced in regards to meeting regulators and being more sustainability-focused due to the practical implications potentially drawn from the results. Finally, the report provides valuable policy recommendations to policymakers and scholars based on an examination of the research findings. In academia, almost all studies that we read on resource and energy efficiency are cross-sectional. The current study adds to literature by separating UK and look at how their energy and resource efficiency relate to their environment. There are five sections that make up this study: an introduction, literature review, methodology, data presentation and analysis and finally, conclusions and policy implications.

LITERATURE REVIEW

This study combines and builds upon emerging research in sustainable finance, carbon accounting, and environmental economics. We will look at the primary theoretical and empirical underpinnings.

Theoretical foundation

Corporate carbon disclosure and accountability

Public communication about carbon emissions and other environmental sustainability-related activities is ideally expected of businesses (Hahn and Lülfs, 2014). Because managing carbon and reports are utilized to regulate and evaluate company threats and commercial opportunities linked with global warming, investors demand businesses to compile and submit information on their carbon emissions (Lash and Wellingtong 2007). Therefore, by releasing sustainable reports, organizations expect to fill stakeholder wishes to develop strong ties so that the long term prosperity of the company is accomplished.

The voluntary disclosure theory, on the other hand, serves as the foundation for businesses' disclosure of carbon emission data; it emphasizes that businesses will willingly divulge information if doing so will benefit them (Clarkson et al., 2008). As a way to show external investors that they care about the environment, businesses with a strong environmental history will be motivated to publicly share their environmental accomplishments. Conversely, businesses with negative environmental profiles like excessive carbon emissions tend to keep quiet (Lee et al., 2023). One way to lessen knowledge asymmetry between the business and external stakeholders is through openness of carbon emissions. in response to environmental challenges, businesses can enhance efficiency, minimize operational expenses, and lower both current and potential environmental compliance costs, all of which will boost the value of the company (Matsumura et al., 2014).

According to Christi (2015), by revealing carbon emissions, the business has addressed its concern about mitigating the harm they contributed to the environment and promoting environmental sustainability. Businesses that reveal carbon emissions will see a boost in their worth; this suggests that the company is attempting to legitimize its operations in the public's eyes by disclosing carbon emissions (Pratiwi and Sari 2016). The legitimacy argument, which discloses a business's carbon emissions, is also frequently used to clarify the environmental disclosure (Syabilla, Wijayanti, and Fahria, 2021). This theory serves as a means of encouraging businesses to voluntarily reveal their carbon footprint, ensuring that their business practices align with environmental principles and standards (Anggraini and Handayani, 2021).

Sustainability in Finance and Environmental Economics

The importance of scholarly research on the connection between sustainable development and financial systems has grown. By suggesting that financial processes are essential in attempting to tackle global environmental concerns, Stern (2008) popularized the economic analysis of climate change. A comprehensive framework demonstrating how financial institutions may play a crucial role in the shift to a low-carbon economy has now been developed by Campiglio et al. (2018).

Sustainable finance has developed alongside policy proposals as it has grown evident that they are not feasible and finished despite creative financing from private sector that enable a diverse pool of prospective financiers to take advantage of significant growth, though uncertain and unsafe, opportunities. According to Krauss et al. (2016), ecological finance is an approach to finance and investing that emphasizes strategic planning, long-term making choices, and lasting value creation. Long-term-oriented financial decision-making that incorporates factors related to the environment, society, and governance (ESG) is another way to define sustainable finance.

In order to increase long-term investments in environmentally friendly endeavors and projects, the European Commission (EC, 2023) defined sustainable finance as the process of taking ESG factors into account in evaluating financial industry choice of investments. The European Commission provided instances of environmental factors such as climate change adaptation and mitigation, as well as environmental concerns more generally, such as protecting biodiversity, minimizing pollution, and sustainable economy. Social considerations covered issues of human rights, employment practices, disparities, inclusivity, and personnel development, their societies, and their expertise. In order to guarantee that social and environmental factors are taken into account when making investment decisions, the European Commission maintained that the governance of both public and private institutions including managerial structures, relations with workers, and executive compensation was essential.

Whenever financial institutions offer financial support for businesses that are linked to illicit activities (such as hydraulic fracturing, arctic drilling, coal-fired power plants), they expose themselves to environmental and social risks. These risks include business practices, sectors, projects, and nations that are whether directly or indirectly, or purportedly or truthfully, linked to adverse social and ecological effects (Krauss et al., 2016). Financial institutions must put in place a framework for doing credit and operational risk evaluations that include social and environmental concerns as well as metrics of ESG success and danger if they are to behave responsibly in regard to such risks.

Empirical foundations

Carbon footprint of bank loans and environmental quality

In order to achieve the objectives established in the 2015 Paris Agreement, which include limiting the rise in global temperatures to less than 2℃ over the historical average and accelerating investments in low-carbon technologies for sustainable development, greenhouse gas (GHG) emissions must be significantly reduced. The financial system must assist by directing financing for a move to a low-carbon economy and by significantly supporting climate financing, which the International Finance Corporation estimates will increase from seven percent of overall support in 2017 to thirty percent in 2030 (IFC 2018).

According to Semieniuk et al. (2021), international banks still fund the fossil fuel sector despite their climate pledges. Innovative approaches to measuring carbon exposure in financial portfolios were developed by Battiston et al. (2017). The actions of financial regulators in promoting carbon accountability were examined by Robins et al. (2020). Carbon-intensive investments have been linked to systemic financial risk, according to Carney (2015). Agyemang et al. (2024) examined the dynamic effects of environmental taxes, bank loan carbon footprints, and environmental protection spending on carbon dioxide emissions in Turkey. They found that Bank loans have both short and long-term increasing effect on carbon emissions.

Company credit rating is a key moderator in the association between the business carbon emissions and new bank loans, according to Ding et al. (2023) empirical investigation of the effect of firm carbon emissions on the obtaining of new bank loans and its mechanism of action. Takahashi and Shino (2023) looked into bank lending practices in relation to loan amounts, which they believe have a greater influence on business investment choices. Iyke-Ofoedu et al. (2023) investigate how bank loans and fossil fuel subsidies affect Tunisia's ecological footprint. According to the study, there is a 0.15% rise in carbon dioxide emissions for every 1% rise in CFBL.

In order to determine if financial institutions' lending practices help mitigate the risk of global warming, Othman (2023) looks at the correlation between the magnitude of Carbon Footprints of Bank Loans and CO_2 emissions released by advanced economies. The study's conclusions show that there is an inverse relationship between CO_2 emissions and the severity of bank loan carbon footprints in industrialized nations. Furthermore, the study by Ntarmah (2022) looks at how bank funding, economic development, and carbon emissions relate to each other in sub-Saharan Africa between 1990 and 2018. The findings demonstrate that bank lending raises economic growth and carbon emissions in Sub-Saharan Africa.

Energy efficiency budgeting and environmental quality

EU member states are required by the Energy Efficiency Directive to allocate specified funds for energy efficiency upgrades. Countries with mandated energy-efficiency budgeting programs saved 30% more energy than those lacking such mandates, according to research by Bertoldi and Mosconi (2020). However, there are not many academic studies on energy efficiency budgeting. Below is a discussion of a few similar studies on the topic.

The asymmetrical impact of nuclear energy R&D budgets on CO_2 emissions is examined by Huang et al. (2024) in the top ten economies with the largest nuclear energy R&D budgets (the United States, South Korea, Russia, China, France, Japan, Canada, the United Kingdom, Germany, and India). Estimates show that in the majority of the economies examined, spending on nuclear energy R&D lowers CO_2 emissions. According to the findings, increasing funding for nuclear energy research and development should be prioritized in order to hasten the development of better and more effective nuclear technologies and so reduce CO_2 emissions. By examining panel data from 1990 to 2020, Li et al. (2022) examined the interactions among economic development, green finance, renewable energy utilization, natural resource rent, energy innovation, urbanization, and environmental pollution. According to the study's findings, green finance, the use of renewable energy, and the encouragement of energy innovation are all efficient ways to reduce environmental pollution.

Weng et al. (2023) assessed the direct and indirect effects of clean energy investment on carbon emissions. They discovered that domestic carbon emissions are reduced by about 0.05 percent for every 1% growth in domestic clean energy investment. Li and Li (2020) looked into how economic expansion and energy investment affected the decrease of carbon emissions. The findings show that the rise in China's provincial CO_2 is caused by both economic expansion and energy investment. According to Ma et al. (2021), energy investments, technical innovation, the usage of renewable energy, research and development spending, and carbon emission taxes all reduce carbon dioxide emissions and help China's carbon-abatement program.

Proposed hypothesis and conceptual framework

Based on the literature we have discussed above, we propose the following hypothesis. First, we propose hypothesis (H_1) that carbon footprint of bank loan portfolios promote rise in carbon dioxide emitted from fossil fuel and industry. Secondly, hypothesis (H_2) is that energy efficiency budgeting has a reducing effect on carbon dioxide emissions.

Based on Johnson (2022) “how to find joy in climate action”, figure 4 provides a schematic representation of a proposed conceptual framework for energy efficiency budgeting, carbon footprint of bank portfolios and carbon dioxide emissions. The aim of the framework is to demonstrate the interplay, linkages and what Energy efficiency budgeting, carbon dioxide emissions and bank loan portfolios offer to achieve environmental quality and UK net-zero emissions.

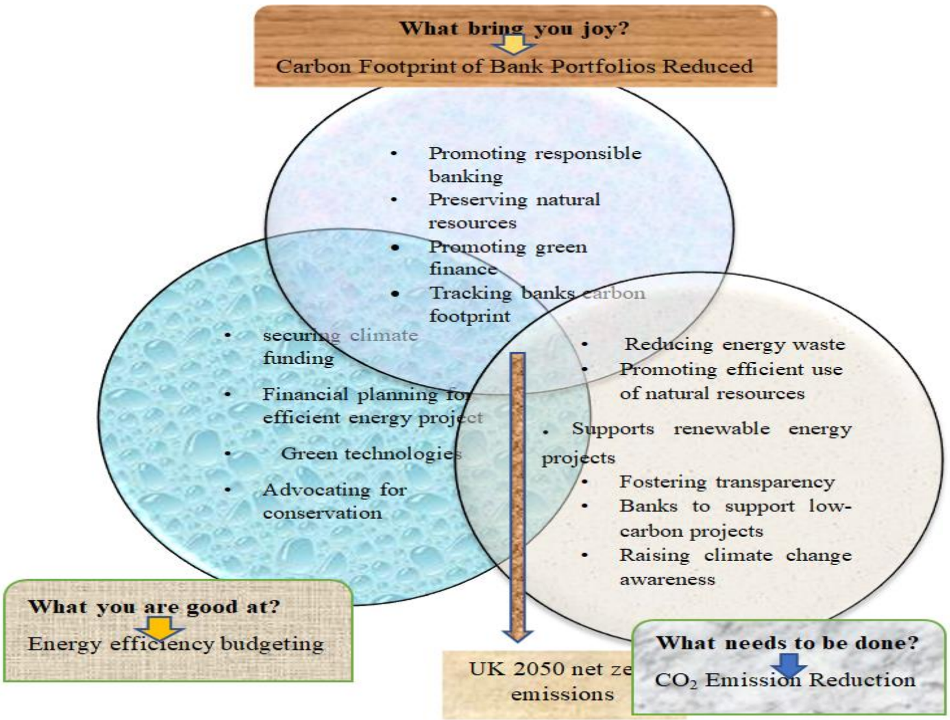


Figure 4: Conceptual framework (United Kingdom’s climate action venn diagram)

Source: Authors construction and modification of Johnson (2022).

(https://www.ted.com/talks/ayana_elizabeth_johnson_how_to_find_joy_in_climate_action)

What bring you joy circle defines activities and tasks which give UK climate satisfaction. Doing what they love is vital in sustaining long-term motivation and engagement. What are you good at circle represents their strengths, expertise, and skills that will enable them to achieve the 2050 Net-Zero emissions. What is to be done circle identifies immediate actions and activity that needs to be undertaken to combat climate change for net-zero emissions. Intersections parts define how all circles relate with one another. The core of the framework lies in the "UK 2050 Net-Zero emission.". Individuals and institutions will discover the most successful and fruitful way of engaging in fulfilling the UK's net zero target through greater energy efficiency and enhanced banking mechanisms.

Gaps in the literature

After scouring the environmental studies literature, we came up with a list of key gaps in our understanding. To start, we found that there are no studies on the impact of energy efficiency budgeting and carbon footprint of banks portfolios on carbon dioxide emissions in UK. The subject matter has been examined by writers separately with regard to their impact on the environment. As a result, we are the first to do this study to look at all of these factors and their effects at the same time. Thirdly, we observed that most studies relied on classical methods like, Ordinary Least Squares, VECM, FMOLS, etc.; so, we employed a number of novel econometric approaches, including: Quantile Autoregressive Distribution Lags (QARDL), quantile ADF and Quantile Cointegration.

METHODOLOGY

Research Design:

The study focuses on regression research design using quantitative research approaches for empirical analysis of the relationship among environmental pollution, energy efficiency budgeting and carbon footprint of bank portfolios. The research uses measurements of central tendency and dispersion, such as standard deviation, mean, and percentage frequencies, in descriptive statistics. Quantitative data and text-based explanations are presented via graphs and tables.

To determine the effects of independent variables on the dependent variable, this study specifically use Quantile Autoregressive Distributed Lag (QARDL) Model, which has the capacity to capture the effects of carbon footprint of bank loans and energy efficiency budgeting at different time quantiles and periods. QARDL allows for investigation of how covariates impact the dependent variable not just at the mean, but at extreme quantiles. It can also identify if high or low values of a variable react differently to changes in another variable, which is often crucial in economics and finance.

Data Sources and Description

To achieve the objectives of the study, time series data are sourced from International Monetary Fund (IMF) and International Energy Agency (IEA) databases from 1995- 2022. All data have been converted into their natural logarithm for easily statistical computation and analysis. Variables have been described below.

i. Carbon footprint of bank loan (CFBP): this serves as control variable for the study and it refers to the contribution of banks to climate change risk captured in a cross-nationally comparable manner. The carbon intensity of banks' domestic lending portfolio increases with a higher ratio. This data is sourced from International Monetary Fund (IMF) database.

ii. Carbon dioxide emissions (CO_2E). This data is also sourced from International Monetary Fund (IMF) database and measures amount of CO_2 emitted into the atmosphere as a result of burning fuel directly per million US dollars of output is represented by CO_2 emissions intensity. This is used as the dependent variable and a proxy for environmental pollution.

iii. Energy efficiency budgeting (EEB): this is the amount of fund governments allocate to energy sector for energy efficiency projects, energy technology and research and development. This is measured in millions of US dollars (2023 prices and exchange rates) and it is used as independent variable for the study. This data is sourced from the International Energy Agency (IEA) database

Empirical Analysis Procedures and Model Specification.

In the case of time series variables, the order of integration is significant to be checked prior to applying the Quantile Autoregressive Distributed Lag (QARDL) model. Tests for stationarity are therefore conducted to examine the regression equation for the hypothesis $H_0{:}\rho = 0$ (there is a unit roots). This study used Quantile ADF unit root test which is estimated as follows:

Given that, $Q_{\Delta y_t}(\tau | y_{t-1}, \Delta y_{t-1}, \dots, \Delta y_{t-p})$ is τ_{th} quantile of y_t conditional on the previous set of information, k is lag order, $\text{⍰}_0(\tau)$ is the quantile-specific intercept and as stated by Tsong and Lee (2011), the extent to which each quantile is affected by the variable of concern can be captured by its estimated values. $\phi_k(\tau)$ coefficients on the lagged differences, $\beta_1(\tau)$ rate of average reversion of the quantile-specific error term ε_t within every quantile. Then Quantile ADF unit root test is estimated as:

$$Q_{\Delta y_t}(\tau | y_{t-1}, \Delta y_{t-1}, \dots, \Delta y_{t-p}) = \text{⍰}_0(\tau) + \beta_1(\tau) y_{t-1} + \sum_{k=1}^{k} \phi_k(\tau)\Delta y_{t-k} + \varepsilon_t(\tau) \tag{1}$$

$$Q\Delta y_t = y_t - y_{t-1} \tag{2}$$

then becomes the first differential order.

Next, we estimate Quantile Autoregressive Distributed Lag (QARDL). Cho et al. (2015) presented the QARDL model and expanded the linear ARDL model to take locational asymmetry into consideration. The QARDL model for a given quantile τ $(where\ 0 < \tau < 1)$ may be stated as:

$$y_t = \alpha(\tau) + \sum_{i=1}^{p} \Upsilon_i(\tau) y_{t-i} + \sum_{j=0}^{q} \sum_{k=1}^{K} \zeta_{j,k}(\tau) \delta_{k.t-j} + \varepsilon_t(\tau) \qquad 3$$

Where y_t is the dependent variable at time t, $\alpha(\tau)$ is the intercept term for quantile τ, $\Upsilon_i(\tau)$ is the autoregressive coefficients for quantile τ , $\zeta_{j,k}(\tau)$ are the distributed lag coefficients for the $k-th$ independent variable at lag j for quantile τ, $\delta_{k.t-j}$ is the $k-th$ independent variable at time $t-j$ and $\varepsilon_t(\tau)$ is the error term for quantile τ, which satisfies the condition that the $\tau-t$h quantile of $\varepsilon_t(\tau)$ conditional on the information set is zero. The key quantile regression constraint on the error term is:

$$\text{Quant}_\tau(\varepsilon_t(\tau))|\ \Omega_{t-1} = 0 \tag{4}$$

If the variables are cointegrated, the QARDL model can be expressed in error correction form:

$$\Delta y_t = \alpha(\tau) + \acute{\omega}(\tau)(y_{t-i} - \phi((\tau)X_{t-1}) + \sum_{i=1}^{p-1} \Upsilon_i(\tau)\Delta y_{t-i} + \sum_{j=0}^{q-1} \sum_{k=1}^{K} \zeta_{j,k}(\tau)\Delta\delta_{k.t-j} + \varepsilon_t(\tau) \tag{5}$$

Δ is the first difference operator, $\acute{\omega}(\tau)$ is the speed of adjustment coefficient for quantile τ, $\phi(\tau)$ is a $K \times 1$ vector of long-run coefficients for quantile τ and $\Upsilon_i(\tau)$, $\zeta_{j,k}(\tau)$ are short-run dynamics coefficients for quantile τ. Figure 5 graphically illustrate the study analysis procedures

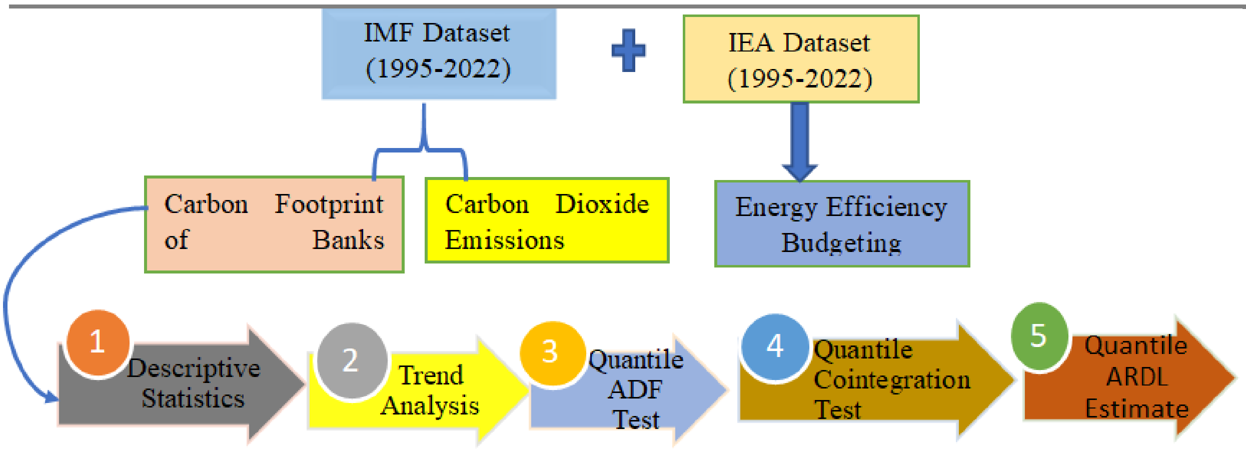


Figure 5: empirical analysis procedures chart

Source: Authors construction

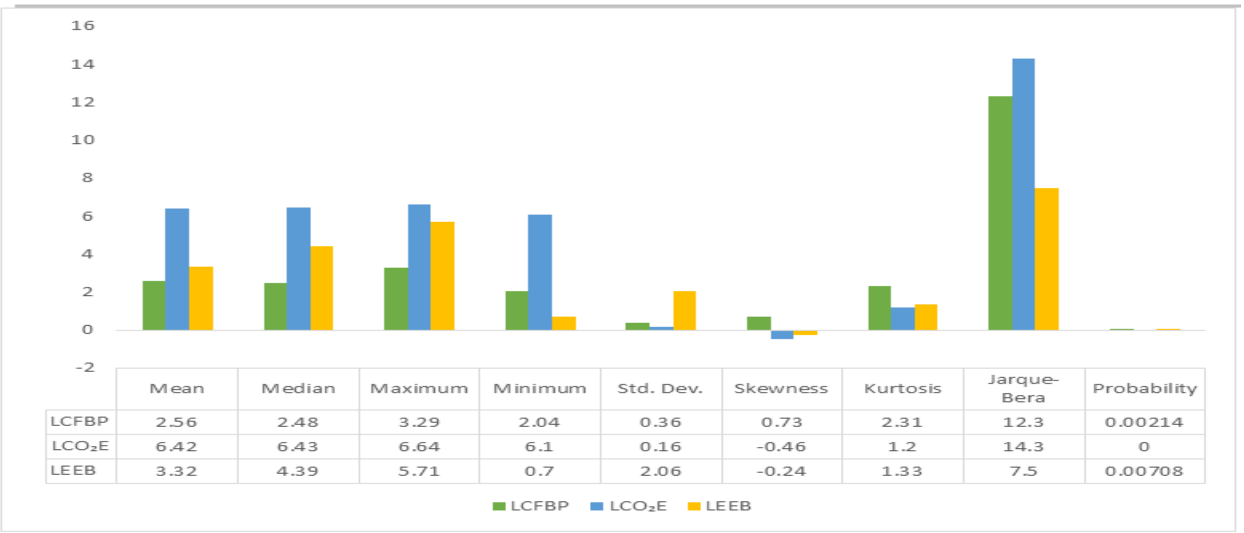
Empirical Analysis

Descriptive Statistics Analysis

From figure 6, starting with Carbon Footprint of Banks Portfolios (LCFBP), we see that it has a mean of 2.56 and a median of 2.48. These very close measures of central tendency, combined with a fairly low standard deviation of 0.36, tell us that bank carbon footprints tend to cluster around these central values. The skewness is positive (0.73), which indicates that the distribution is right-tailed slightly, that is., very few banks have significantly larger carbon footprints than the average bank. The difference between the minimum (2.04) and maximum (3.29) value is relatively small, which means that banks have relatively consistent carbon footprint practices.

For Carbon Emissions (LCO_2E), the values at the center are greater with a mean of 6.42 and median of 6.43. What is noteworthy here is the very low standard deviation of 0.16, that is, total carbon emissions are very concentrated around these center values. The negative skewness (-0.46) shows a very negligible left tail in the distribution. The proximity of minimum (6.10) and maximum (6.64) values also supports the observation that carbon emissions have been very stable over the period.

Energy Efficiency Budgeting (LEEB) shows the most variability among the three measures. With a mean of 3.32 and median of 4.39, there is a notable difference between these central tendency measures.



	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
LCFBP	2.56	2.48	3.29	2.04	0.36	0.73	2.31	12.3	0.00214
LCO_2E	6.42	6.43	6.64	6.1	0.16	-0.46	1.2	14.3	0
LEEB	3.32	4.39	5.71	0.7	2.06	-0.24	1.33	7.5	0.00708

Figure 6: Descriptive statistics graph

The large standard deviation of 2.06 indicates substantial variation in budgeting practices. The range is particularly wide, from a minimum of 0.70 to a maximum of 5.71. The negative skewness (-0.24) indicates a slight left tail in the distribution.

Jarque-Bera test statistics and associated probabilities (all < 0.05) confirm that none of these are normally distributed. This is particularly crucial for LEEB ($p = 0.00708$) and LCFBP ($p = 0.00214$), which confirm that these variables have distributions that are far from normality. The three variables have platykurtic distributions (kurtosis < 3), which are lighter-tailed and have lesser extreme values than a normal distribution, according to the kurtosis values. The kurtosis of 1.33 in LEEB, which indicates that while having the biggest standard deviation, its extreme values are widely dispersed rather than bundled together in the tails.

Trend Analysis

The trends illustrated in figure 7 tracks three significant environmental indicators in the UK from between 1995 and 2023; carbon dioxide emissions (LCO2), carbon footprint of banks (LCFBP), and energy efficiency budgeting (LEEB). Starting with carbon dioxide emissions (orange line), we see a very stable trend hovering around most of the time with a very slow decline becoming apparent only after 2010. This stability shows that in spite of all green efforts, sudden reductions in overall emissions have been hard to achieve in UK. The declining trend in recent years may be the combined impact of several carbon cut policies and technological improvements.

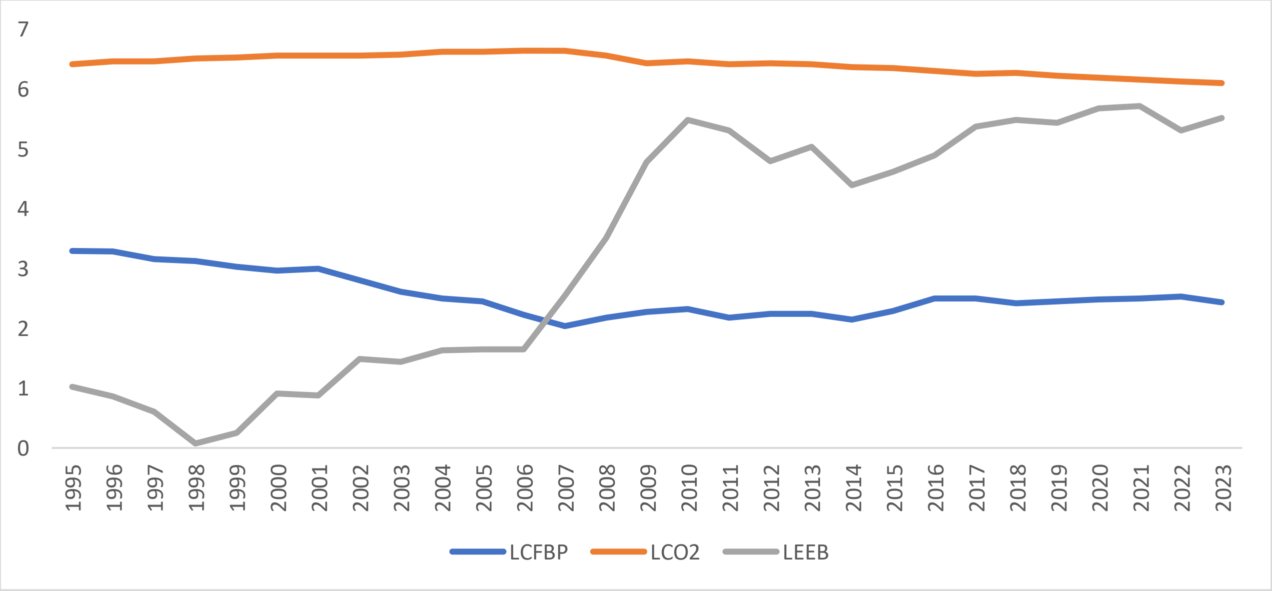


Figure 7: Trend analysis graph of variables under study

The trend of banks' portfolios' carbon footprint (blue line) is quite interesting. It began in 1995 at about 3.5 units and has steadily decreased since then, stabilizing in 2008. This may be a sign of the banking sector's growing adherence to sustainable practices and environmental issues, which may be prompted by both corporate social responsibility programs and regulatory pressure. Possibly the most dramatic change is seen the energy efficiency budgeting (grey line). The sharp spike in 2008-2010 is particularly noteworthy since it occurs in the time of the global financial crisis. The coincidence suggests that the crisis may have triggered a fundamental rethink on the use of resources, with a much greater premium on energy efficiency. This may have been due to cost-containment pressures as well as increased regulatory focus on sustainable banking practices.

Bank carbon footprints and CO_2 emissions have decreased somewhat, despite the massive rise in energy efficiency budgeting since 2008. This may indicate that even if financial investments in energy efficiency have increased significantly it has proven difficult to convert these investments into comparable reductions in carbon emissions. This trend is generating important questions regarding the effectiveness of financial investments in energy efficiency and suggests that other factors perhaps technological constraints, structural economic features, or implementation challenges are constraining the impact of such investments on real emission savings.

Unit Root Test

Figure 8 and 9 show Quantile Augmented Dickey Fuller (QADF) test statistics across different quantiles (0.2 to 0.8 on the x-axis) for each variable. The three colored horizontal lines represent critical values at different significance levels (red for 1%, blue for 5%, and green for 10%). When the black line (test statistic) falls below these colored lines, we can reject the null hypothesis of a unit root at that particular quantile.

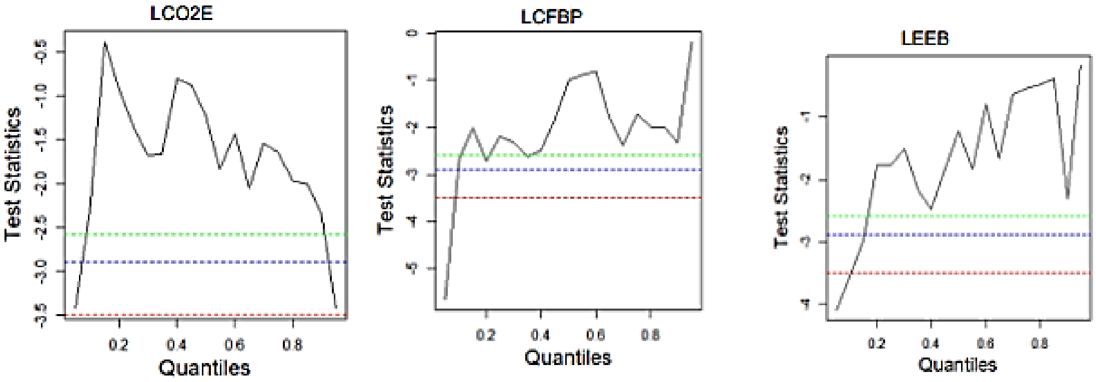


Figure: 8 Quantile Augmented Dickey Fuller (QADF) Test graph at Level

At level (see figure 8), Carbon Dioxide Emissions (LCO_2E) shows a clear downward trend in the test statistics across quantiles. The black line stays consistently below all critical value lines (particularly from quantile 0.4 onwards), and drops dramatically towards higher quantiles. This suggests that CO_2 emissions are stationary at level across most quantiles, but particularly so at higher quantiles. This means that any shocks to emission levels tend to be temporary rather than permanent, especially when emission levels are high.

LCFBP has more variability in test statistics. The sequence of test statistics fluctuates above and below critical values with quantiles showing different behavior. There are some instances in which it crosses below critical values (0.6-0.8), revealing that the stationarity of bank portfolio carbon footprints differs according to their magnitude. Energy Efficiency Budgeting (LEEB) presents an interesting pattern where the test statistics are increasing in general across quantiles, with great volatility. There are points where the line cuts below the critical values, particularly in the middle quantiles, but crosses above them at higher quantiles. This suggests that budgeting for energy efficiency may be non-stationary at some quantiles and not others, meaning that shocks to energy efficiency budgeting persistence are heterogeneous in their dependence on the size of the budget.

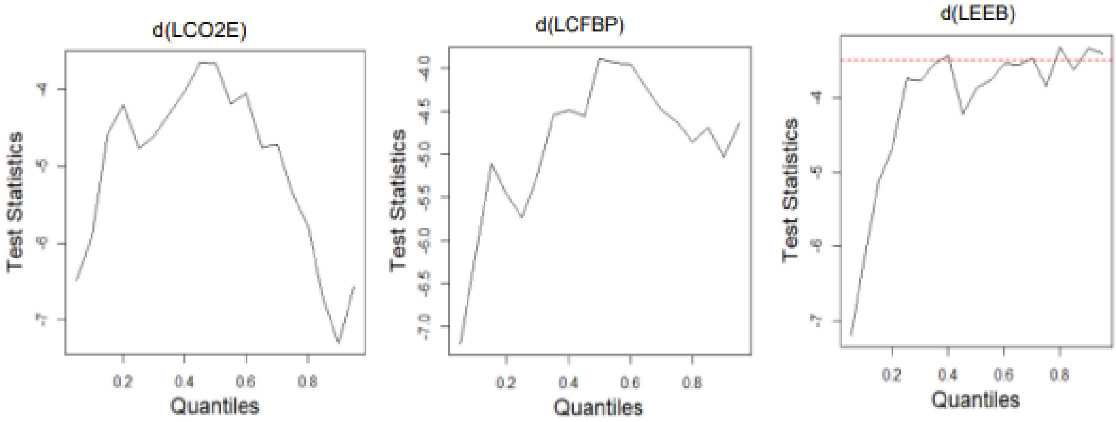


Figure 9: Quantile Augmented Dickey Fuller (QADF) Test graph at first difference

The first differential order, LCO_2E graph (see figure 9) shows a very distinct inverted U-shaped pattern among quantiles. From around -7 at low quantiles, the test statistic rises to the point of -4 in higher quantiles around the range 0.5, and then goes down further to around -7 at more advanced quantiles. This pattern indicates that following the taking of first differences, CO_2 emissions exhibit strong stationarity at high and low quantiles and slightly lower (but nonetheless statistically significant) stationarity at middle levels. This implies that changes in level of emissions are more stable and predictable at very high and very low levels of change.

For Bank Portfolio Carbon Footprint (LCFBP), the graph is similarly but more intensely patterned. The test statistic starts at about -7, rises to about -4 at the middle quantiles, then levels off to about -5 at the top quantiles. This U-pattern, though not as symmetric as the plot for emissions, implies that the changes in bank portfolio carbon footprints become stationary following first differencing. Greater stationarity for lower quantiles means that the minor portfolio movements could be more controlled and predictable than greater portfolio movements.

For Energy Efficiency Budgeting (LEEB), the trend is most pronounced in the graph. It starts at a very low point (around -7) and increases sharply, then plateaus near -4 for the majority of the upper quantiles. The trend is a sign that when first differenced, energy efficiency budgeting always shows that the series becomes stationary in all quantiles after differencing.

Quantile Cointegration Analysis

The Cointegrating Relation Quantile Processes describes how the long-run equilibrium relations between such financial and environmental variables change across the distribution, not just averaging over relations. Figure 10 displays different quantiles (0.1-0.9), tracking relations between energy efficiency budgeting, bank portfolio carbon footprint, and carbon dioxide emissions over the years 1995-2022.

The highest line (pink, labeled 0.8) starts at around 7 on the y-axis and slopes downward steadily over time, suggesting a worsening relationship at this quantile. This might be read as that the most powerful relationships between these variables have moderated over time. The most dramatic change is reflected by the black line (0.9 quantile). It starts around 5.5 and falls steeply between 2000-2008 to a trough of around zero. This suggests a radical structural change in the relationship at the upper quantile. The 0.3 and below quantiles crosses over the negative territory. This suggests that there is a long-run disequilibrium of the cointegrating relation at different levels of the distribution. The green line (0.4 quantile) is always negative over time, implying a persistent negative relationship between the quantile and the variable. The dates of some significant changes (specifically around 2006-2008) overlap with the global financial crisis, which probably affected bank portfolios and energy investments.

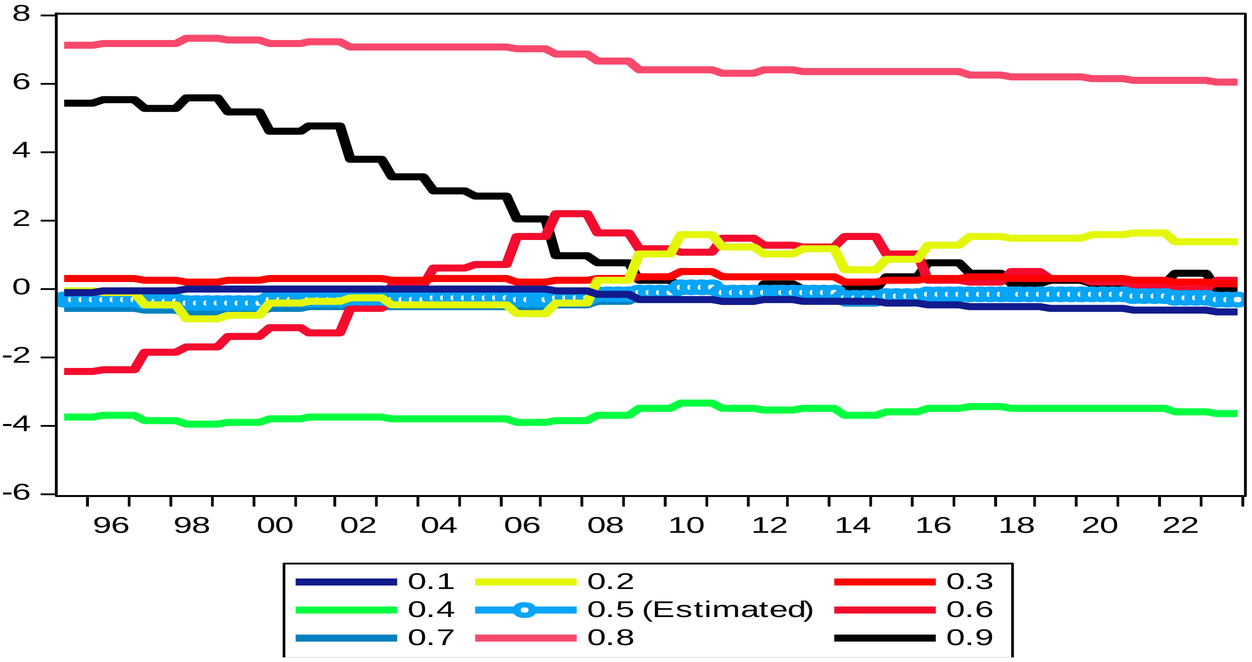


Figure 10: Cointegrating Relation Quantile Processes.

Source: Authors construction from Eviews

The middle quantile (0.5, "Estimated") is showing fairly stable pattern hovering around zero, which validates that the median relationship between the variables is quite consistent throughout the time span. This means that in normal or average scenarios, there is a constant long-run equilibrium relationship between energy efficiency budgeting, banks' carbon footprints, and overall emissions. The 0.5 quantile, or median, is marked as "Estimated" because it is a primary point of reference in quantile regression analysis. It is estimated by a specific statistical procedure that tells us about the central tendency of the cointegrating relationship between variables (energy efficiency budgeting, carbon footprint of banks, and carbon emissions).

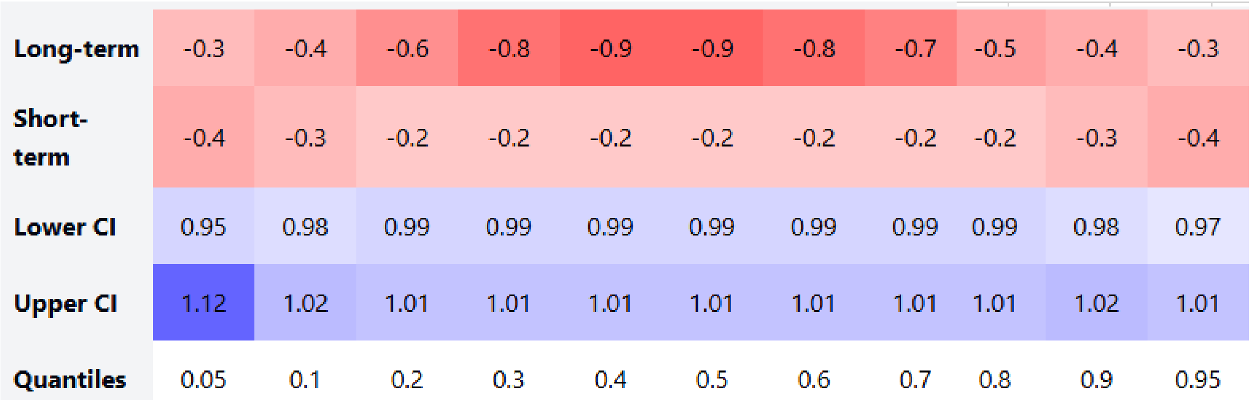
The convergence of several quantile processes toward the middle range in recent years (post-2015) might indicate that differences in the relationship between these variables are becoming less extreme across different segments of the distribution, possibly due to more standardized environmental policies or practices in the UK banking and energy sector. This analysis suggests that while there are persistent differences in how energy efficiency budgeting relates to carbon emissions across different quantiles, there's evidence of some stabilization in recent years, particularly in the middle range of the distribution.

This could be valuable information for policymakers and financial institutions working on carbon reduction strategies. The persistence of separation between some quantiles (like 0.8 remaining high and 0.4 remaining low) suggests that there continue to be structural differences in how these relationships manifest at different intensity levels in the UK economy.

Quantile Autoregressive Distributed Lag (QARDL) Estimates

The impact of Energy Efficiency Budgeting on Carbon Dioxide Emissions is thoroughly examined by QARDL regression heatmap graph, which encompasses many quantiles and time spans, it is illustrated in figure 11. In the view of long-run effects, we notice the strongest negative impacts, represented by the deep pink shades. The coefficients range from -0.3 to -0.9, with the strongest impacts (-0.9) at the median quantiles (0.4-0.5). This deeper color in the middle quantiles means that budgeting for energy efficiency has its biggest long-run impact on emission reduction when the emissions are at or close to their average levels.

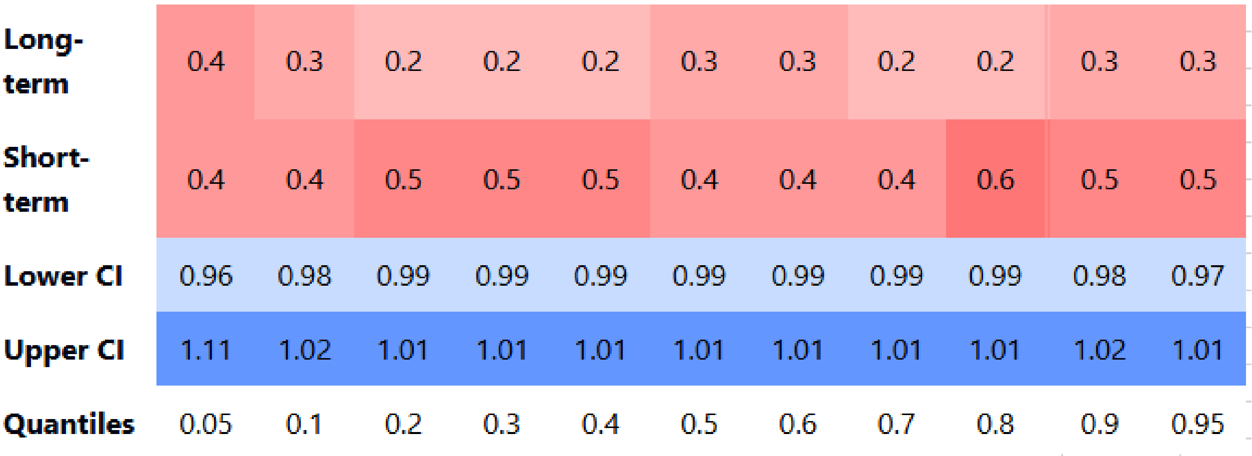
Short-term impacts are mostly in the light pink colors, which signifies the smallest negative coefficients (-0.2 to -0.4). This lighter color indicates that while energy efficiency budgeting still reduces emissions in the Short-term, the effect is less strong than for longer time horizons. Somewhat darker pink in the tails (-0.3 and -0.4 at quantiles 0.05 to 0.1 and 0.9-0.95) suggest relatively stronger Short-term effects at very low or very high levels of emissions. The confidence intervals (CI) displayed in light dark blue are consistently small (between 0.95 and 1.12), reflecting high statistical precision in these estimates. The fact that the confidence intervals do not include zero establishes the proof that the adverse effects are statistically significant at all quantiles.



Long-term	-0.3	-0.4	-0.6	-0.8	-0.9	-0.9	-0.8	-0.7	-0.5	-0.4	-0.3
Short-term	-0.4	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.4
Lower CI	0.95	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.97
Upper CI	1.12	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01
Quantiles	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95

Figure 11: QARDL Regression (LCO$_2$E-dependent and Energy Efficiency Budgeting-independent)

Similar to (Huang et al. 2024; Weng et al. 2023), we can deduce that, the negative coefficients across all the time horizons indicate that Energy Efficiency Budgeting consistently reduces CO$_2$ emissions and that its effect becomes more pronounced in longer time horizons, meaning that energy efficiency budgeting yield increasing returns over time. The dark pink in the long-run row (-0.9) compared to the light pink in the short-run row (-0.2) evidently plot this trend. Again, the efficacy of energy efficiency budgeting is very sensitive to levels of emissions, with particularly strong long-term effects in median emission periods. This means that energy efficiency budgeting is a powerful tool for lowering emissions, with impacts becoming increasingly effective rather than decreasing over time. The color scale well demonstrates that the effect is rising in depth from short-term (light pink) to long-term (dark pink), and the equal negative values for all time horizons and quantiles confirm that energy efficiency budgeting is a solid and sound measure of emission reduction.



Long-term	0.4	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.3
Short-term	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.6	0.5	0.5
Lower CI	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.97
Upper CI	1.11	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01
Quantiles	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95

Figure 12: QARDL Regression (LCO_2E-dependent and Carbon Footprint of Banks Portfolios-independent)

The impact of carbon footprint of bank portfolios on carbon dioxide emissions is examined in detail with the assistance of QARDL regression heatmaps graph, spanning a broad range of quantiles and time periods, it is depicted in figure 12. The color in the heatmap indicates the relative size and direction of the impacts of carbon footprint of bank portfolio on CO_2 emissions. Short-term impacts are the most robust and positively significant, varying from 0.4 to 0.6(dark pink). This is to say that banks portfolios carbon footprint most explicitly and significantly weighs on emissions in short term. It is even greater at higher quantiles (0.8-0.9), which indicates that the regions or periods with already substantial emissions are most sensitive to banks portfolios composition in the short term.

Long-term effects have the weakest magnitude, as their coefficients vary between 0.2 and 0.3(mostly light pink). A weaker long-run positive effect would be read to mean that other factors over the long term tend to drive levels of emissions to some extent lessening the relative direct influence of bank portfolios. The narrow confidence intervals (Lower CI and Upper CI) between 0.96-1.11 suggests high statistical reliability in these estimates. The fact that neither CI includes zero confirms that the effects are statistically significant across all quantiles.

This analysis suggests bank portfolio decisions have a significant but differential contribution to determining CO_2 emissions, with most effects in the short-run and diminishing as the time horizon grows. This is pertinent to climate policy and regulation, as it suggests changes in bank portfolio allocation can be a potent tool for short-run emission reduction. Likewise, Agyemang et al. (2024) also found that carbon footprint of bank loans has short and long-term increasing effect on carbon emissions. Also, Iyke-Ofoedu et al, (2023) found that, carbon footprint of bank loans exacerbates ecological footprint.

Stability and Robustness checks

The Breusch-Pagan-Godfrey test suggests an F-statistic of 2.033957 and a p-value of 0.1310 (see table 2). The null hypothesis of this test is the constant variance of errors or homoskedasticity. Since the p-value of 0.1410 is greater than the usual significance value of 0.05, we cannot reject the null hypothesis. It suggests there is no evidence for heteroskedasticity in the QARDL estimation. The error variance appears to be quite consistent across all observations, which is in favor of one of the key requirements for standard errors and coefficient estimates to be reliable.

Serial correlation, or autocorrelation, occurs when the error terms in the model are correlated with each other over time intervals. The Breusch-Godfrey test show F-statistic of 2.226327 with a probability of 0.1328. As we have a p-value of 0.1128, which is larger than 0.05, we cannot reject the null hypothesis. This result shows that the model has successfully detected the dynamic relationships in the data without losing systematic patterns in the residuals.

Table 2: Breusch-Pagan-Godfrey Heteroskedasticity and Breusch-Godfrey Serial Correlation Test

Heteroskedasticity Test: Breusch-Pagan-Godfrey				
F-statistic	2.033957	Prob.	0.1310	
Breusch-Godfrey Serial Correlation LM Test:				
F-statistic	2.226327	Prob.	0.1128	

CUSUM tests are observations of the model residuals for unusual patterns that can be interpreted as structural breaks or parameter instability. The idea is that: if model parameters are stable over time, the cumulative sum of residuals should wander randomly around zero within predictable bounds. If there is a structural break, that is, policy change or economic shock that altered fundamentally the relations being studied, the CUSUM statistics would go outside of these limits and stay there. In figure 13, the solid blue line represents the cumulative sum of the standardized residuals, and the dashed orange lines represent the critical bounds at the 5% significance level.

The CUSUM statistic is well within the critical bounds throughout the entire sample period. The line fluctuates around zero and registers some movement but never approaches the critical boundaries. This pattern suggests that the underlying relationships in the model, how energy efficiency budgeting and carbon footprint of bank loans affect UK carbon emissions are stable across study periods.

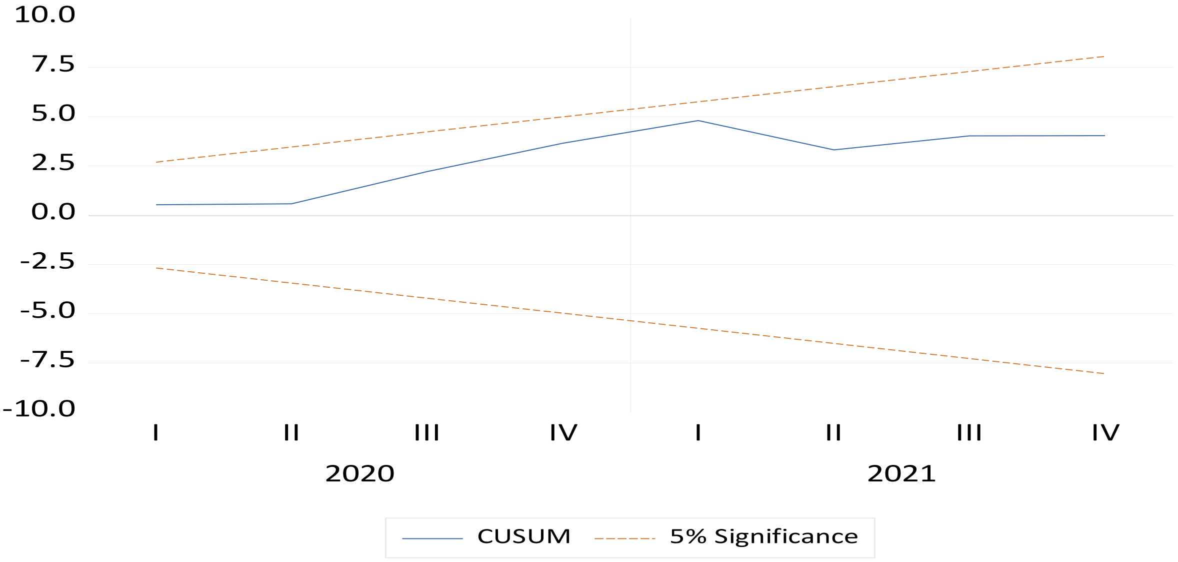


Figure 13: Cumulative Sum of Residuals (Cusum) Test

CONCLUSION AND POLICY RECOMMENDATION

The study demonstrates that energy efficiency budgeting is a highly effective method of reducing CO_2 emissions, whose impact intensifies with time. The evidence confirms that there is a consistent negative relationship between emission levels and budgeting policies, where coefficients range from -0.2 in the short term to -0.9 in the long term. Of most important consideration is the determination of the optimal levels of reduction during times of middle period emissions, which suggests that these programs operate best during typical operating periods relative to when in a state of maximum stages of emissions. Having uniformly negative coefficients across all horizons tells us that efficiency in energy budgeting must be an element of large-scale climate policy regimes as a definite supply of carbon reductions as complementary interventions to other reduction programs.

The results show that bank portfolio carbon footprints increase CO_2 emissions, as highlighted by a positive strong short-run effect which diminishes over time gradually. The short-run effects show the highest positive coefficients (0.4-0.6) with particular prominence during high-emission periods. This reveals that the banking portfolio decisions have their most significant impact on emissions as soon as they are made. The medium-term effect still exhibits a moderate positive influence (0.3-0.5), while long-term effects show smaller coefficients (0.2-0.3), implying that other phenomena like technological advancement and policy change begin to take over the direct function of bank portfolios in the longer term. We then make the following recommendation.

With the evidence that energy efficiency budgeting benefits increase with time to a coefficient of up to -0.9 in long-term effects, UK policymakers ought to invest in long-term, multi-year energy efficiency budgeting programs rather than short-term ones. This will provide the maximum return on investment and capture of the greater long-term gains. Since the analysis shows peak effectiveness in median emission periods (-0.9 coefficient at 0.4-0.5 quantiles), the UK government should give priority to implementing substantial energy efficiency interventions during periods of average emission levels rather than anticipating extreme emission events.

The non-uniform performance at different quantiles of emissions implies the importance of a flexible budgeting scheme. Policymakers must work to implement flexible mechanisms to allocate budgets in proportion to existing emission levels, where possible raising investments during phases where the effect will most likely be the greatest. Considering the increasingly stronger effects of the passage of time, design sound monitoring frameworks to monitor the short-run and long-run consequences of energy efficiency investments. This would maximize budget allocation and express program value to stakeholders.

As the short-run positive impact of banks' portfolio decisions on CO_2 emissions is that powerful, the UK central bank should implement mandatory carbon screening devices for bank portfolios. Banks could understand and manage their short-run carbon footprint through these devices, especially since the analysis shows coefficients of up to 0.6 during peak-emission periods. Banks should be required to develop inclusive carbon accounting systems that track direct and indirect emissions from investments.

Since the analysis shows varying impacts over time horizons, UK government through other stakeholders should design a graduated transition plan for portfolios. This would involve increasingly stringent carbon reduction targets over time, acknowledging the strong short-term effects (0.4-0.6) while having flexibility in the moderate medium-term effects (0.3-0.5). The model must account for natural time-dilution of portfolio impacts, as reflected in the lower long-term coefficients (0.2-0.3). Application of carbon-adjusted capital requirements that account for differential impact of portfolio decisions based on emission levels will be helpful. Banks whose portfolios are strongly skewed towards high-emission sectors must face higher capital requirements, particularly given the stronger effects (0.6) observed at higher emission quantiles (0.8-0.9).

The UK central bank should develop compulsory disclosure requirements that reflect short-term and longer-term carbon consequences of portfolio decisions. The requirements should be particularly strict for short-term portfolio shifts, as they have disproportionate impacts on emissions. The reporting framework should reflect the trend seen for diminishing impacts over time. Regulators can design a regulatory incentive scheme that incentivizes banks to pre-decarbonize their portfolios and rewards the declining long-term coefficients. This could include green assets being accorded preferential treatment in capital computations, with incentives skewed more toward short-term portfolio adjustments where the impact is strongest.

Limitations of the study are that, the study is focused on United Kingdom and that we cannot make generalization that the study findings apply to other countries. Also, apart from carbon footprint of banks loan and energy efficiency budgeting other factors such as economic growth, government expenditure, etc can affect carbon emissions. Therefore, future studied should consider such factors.

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