Energy efficiency and CO2 emissions: Evidence from the UK universities[1]

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Abstract

Understanding how energy efficiency improvement can mitigate CO_2 emissions is critical for global climate change policies to ensure environmental sustainability and a low carbon future. Being the catalyst for training future generations, universities can play a leading role in this vision by adopting energy-saving and emissions reduction strategies. Using HESA data, a centralized system of reporting energy use and corresponding emissions, we adopt a two-step system GMM estimation procedure to estimate the effect of energy efficiency on CO_2 emissions for 119 UK universities over the period between 2008-09 and 2018-19. Results confirm that higher energy efficiency is conducive to lower emissions. However, the less-than-elastic relationship between energy efficiency and emissions implies that energy efficiency improvement alone cannot enable the UK universities to comply with their net-zero objectives unless they increasingly adopt renewable energy sources. Despite this, universities were able to avoid 2.21 gtCO2e emissions over the sample period due to energy efficiency improvements. Our results are robust to alternative specifications.

Keywords: Emissions; Energy; Fisher Index; University.

JEL Classifications: Q41, Q42

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1. Introduction

The Climate Change Act 2008 mandated each economic sector of the UK to actively commit to reducing emissions (Robinson *et al.*, 2015), whereas the 2011 carbon plan sets specific emissions reduction targets including the requirement for all new non-residential buildings in England to emit zero carbon from 2019. To keep up with these national strategies, the UK universities were encouraged to reduce their overall emissions and increase the use of renewable energy sources (e.g., using at least 12% of heating energy consumption from renewable sources by 2020). The Higher Education Funding Council for England (HEFCE) encourages higher education institutions to reduce carbon emissions by 34% and 80% by 2020 and 2050, respectively, relative to their respective 1990 levels (HEFCE, 2010). Under the HEFCE requirements, the UK universities need to set individual reduction targets for 2020 against a 2005 baseline for their direct and indirect emissions (Ozawa-Meida *et al.*, 2013). However, despite pledging an average emissions reduction of 35.6%, UK universities could not achieve their extremely ambitious targets set for 2020 (Robinson *et al.*, 2015).

Against this backdrop, the main objective of this paper is to investigate how the UK universities are keeping up with the energy-related objectives set out in the 2011 Carbon Plan[2], and the consequent effects of energy efficiency improvement on their carbon emissions, by focusing on their respective residential and non-residential energy use. While the UK has phased out coals and set up the long-term energy-related objective of increasing the adoption of renewables, energy efficiency improvement is a short-term yet cost-effective measure. In fact, especially for the universities who have structural limitations towards achieving many

[2] Following up on the 2008 Climate Change Act, the 2011 Carbon Plan (which replaces the 2009 Low Carbon Transition Plan) sets out the guideline for decarbonizing the UK within its energy policy framework. The original 50% emissions reduction target from its 1990 level has been revised for the country to become carbon neutral by 2050, while maintaining energy security and minimizing costs of consumption. There were five sectoral plans covering measures to be taken over the years which include low carbon buildings, energy efficiency, and low carbon heating.

energy-related goals, understanding the effectiveness of efficiency improvement and consequent emissions reduction is extremely important for the adoption of renewable energy and achieving the target of net-zero emissions.

Following existing literature, we hypothesize that universities with greater energy efficiency will have lower CO2 emissions, controlling for economic activities and infrastructural attributes. Using the Higher Education and Statistics Agency (HESA) estate management data from 2008-09 to 2018-19 for 119 UK universities, we used Fisher's ideal index method to calculate energy efficiency and then adopted a two-step system GMM estimation procedure to estimate the relationship between energy efficiency and CO2 emissions for the UK universities.

We make two novel contributions to related academic and policy literature. First, this paper joins the limited literature on university level energy use, energy efficiency and CO2 emissions for any country. To the best of our knowledge, this is the first robust econometric investigation into the aforementioned relationship using the HESA estate management data. Next, the UK universities have pledged to comply with national climate and energy targets. Our investigation identifies their overall progress towards becoming net-zero emitters by 2050 through energy efficiency improvement.

Although we identify significant but less-than-elastic relationship between energy efficiency and emissions, the 119 UK universities were able to avoid 2.21 gtCO2e emissions between 2008-09 and 2018-19 due to energy efficiency improvements. These results inform several important policy implications. First, significant but less-than-elastic relationship between energy efficiency and emissions implies that factors other than energy efficiency are also important in determining total energy consumption and consequent CO2 emissions. Especially for the UK universities who are publicly subsidized and have structural limitations for increasing energy efficiency, achieving net-zero status will be difficult without considerable increase in the adoption of renewables. Next, energy efficient practices in universities provide virtue signals to students, who may adopt similar practices in their life, which can have longer-term beneficial effects. There are also immediate benefits as we identify that the UK universities were able to avoid emissions due to energy efficiency improvements. Therefore, the government should consider providing price incentives such as subsidies to universities to adopt superior technology to reduce emissions.

The remainder of this paper is as follows. Section 2 provides the background of energy consumption and emissions in UK universities and a brief literature review. Section 3 discusses the empirical strategy and describes the data and variables. Section 4 reports and discusses the regression results. Finally, Section 5 summarizes and concludes.

2. Background and Literature

Economic growth has triggered increased energy consumption and CO2 emissions that challenged environmental quality in almost all the countries (Stigson *et al.*, 2009). To tackle the problem, countries are enacting laws and policies that provide necessary guidelines and regulations for achieving energy efficiency and thereby reducing consequent emissions (see Eskander and Fankhauser, 2020; Eskander *et al.*, 2021; Eskander and Fankhauser, 2021). Under the Kyoto commitments, the UK government has enacted the world's first carbon-related regulation act, the *Climate Change Act 2008*, to tackle the challenges of climate change. In June 2019, the UK parliament passed legislation to reduce net emissions by 100% relative to 1990 levels by 2050 (Shepheard, 2020). However, this technically feasible yet highly challenging ambition requires a combined effort and sustained policy interventions across several sectors – many of which will be complicated, expensive, and time-consuming (CCC, 2019). Therefore, interim measures such as energy efficiency improvement are important and relatively cheaper options that the universities can adopt to achieve environmental sustainability in the short run.

A sustainable university is "*a higher educational institution, that addresses, involves and promotes, on a regional or a global level, the minimization of negative environmental, economic, societal, and health effects generated in the use of their resources in order to fulfill its functions of teaching, research, outreach and partnership, and stewardship in ways to help society make the transition to sustainable lifestyles*" (Velazquez *et al.*, 2006, p. 812). In the past, universities showed their preferences for a cleaner environment through participation in various environmental sustainability declarations such as the Talloires, Halifax, and Kyoto Declarations (Evangelinos *et al.*, 2009). In this context, universities can work as role models in controlling emissions and promoting sustainability (see Clarke and Kouri, 2009 and Geng *et al.*, 2013). Increased energy efficiency and reduced emissions can enable universities to achieve environmental sustainability. They can also integrate sustainability in curriculum and research programs (Lozano, 2010; Stephens and Graham, 2010; Waas *et al.*, 2010), and can thereby contribute to longer-term emissions reduction by increasing environmental awareness of the future generation.

The UK education sector was responsible for around 1.12 MtCO2e emissions in 2018 (Altan, 2010; DUKES, 2019), most of which were attributed to the universities with energy-intensive research programs. In fact, some large universities may produce emissions like those of small cities (Knuth *et al.*, 2007). Due to their ability to make independent decisions on resource use, universities can also have similar arrangements and execution efforts to increase energy efficiency as small cities (Kolokotsa *et al.*, 2016). Therefore, it is important to investigate the role of energy efficiency in reducing emissions at UK universities.

Despite this, literature on energy consumption and consequent emissions is limited for the UK universities. Altan (2010) provided a detailed qualitative assessment of internal and external interventions determining carbon emissions at higher education institutions in the UK. External interventions include the Carbon Trust Higher Education Carbon Management (HECM) program launched in 2005 that offered different technical supports to universities to reduce their carbon emissions. Universities were also qualified to join the 2006 'Partnerships for renewables' program by the Carbon Trust Enterprises. Moreover, there were different initiatives by the Higher Education Funding Council of England (HEFCE) to increase sustainability at the university level. Under these programs, universities adopted different management, technical and non-technical interventions to increase energy efficiency.

Among the limited quantitative investigations, Eskander and Nitschke (2021) adopted an extended Kaya identity framework to decouple the changes in total carbon emissions with a special focus on different energy sources. Ozawa-Meida *et al.* (2013) provided a qualitative assessment of consumption-based carbon footprint of De Montfort University, whereas Robinson *et al.* (2015) evaluated the carbon management plans for the UK Russell group universities on three performance indicators. Wadud *et al.* (2019), on the other hand, identified the presence of economies of scale: UK universities become more energy efficient as they grow.

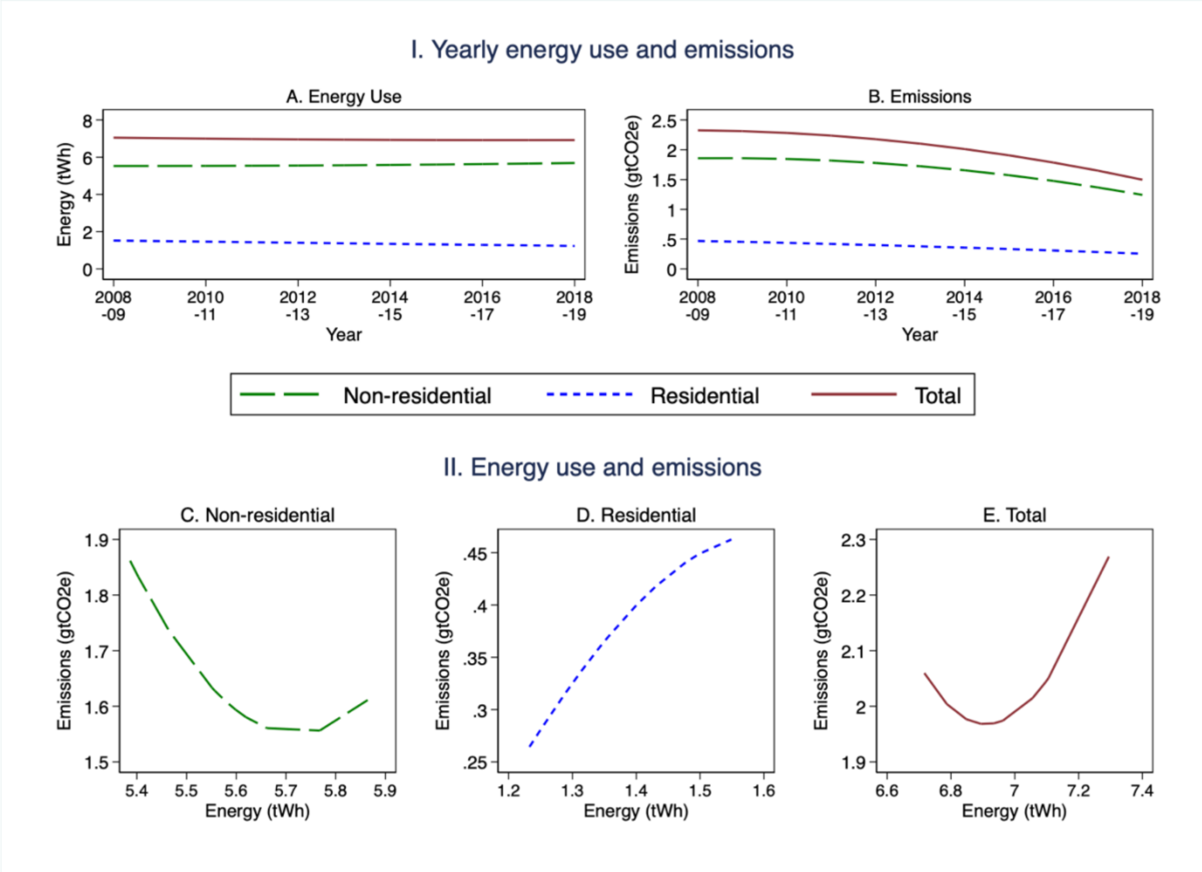

Figure 1. Total annual energy use and emissions, 2008-09 to 2018-19.
Notes. Values are derived for 119 universities using the HESA (2019) data.

Figure 1 provides some stylized facts in this context. Panels A and B, respectively, show the energy use and consequent emissions in the UK universities. Overall, non-residential and total energy uses have increased over the period from 2008-09 to 2018-19, whereas residential energy use went down over the same period (Panel A). On the other hand, emissions went down for both the sectors (Panel B). Panels C-E then plot emissions (gtCO2e) against energy use (tWh). Non-residential emissions decrease with increased energy use except for very large users (Panel C). However, residential emissions are always increasing for all energy use levels (Panel D). Altogether, total emissions decrease with increased energy use for smaller users but then increase for larger users.

3. Methodology and Data

3.1. Estimation strategy

Based on the overall energy use and emissions scenario provided in Figure 1, we set our primary objective of this paper to investigate the relationship between CO2 emissions and energy efficiency for the UK universities. This can be established through the interlinkage between energy use, energy efficiency, and CO2 emissions. First, total energy use depends on the level of energy efficiency (EFF), controlling for, among others, economic activities (ACT) (e.g., Tajudeen *et al.* 2018; Adetutu *et al.* 2016; Broadstock and Hunt 2010). Next, there is a positive relationship between energy use and CO2 emissions (C_{it}), controlling for economic activities among others (Ang 2007; Hamit-Haggar 2012). Moreover, CO2 emissions are autoregressive, i.e., past emissions affect current emissions. Therefore, for university i in year t, the reduced form relationship between energy efficiency and CO2 emissions becomes:

$$C_{it} = f(C_{it-1}, EFF_{it}, ACT_{it}). \qquad (1)$$

For empirical specification, we divide total CO2 emissions by total number of full-time equivalent students (N_{it}) and convert them to per-capita terms (i.e., kgCO2e per-capita), which are then converted to log form. We also convert efficiency and activity indices in natural log form. We estimate the link between per-capita CO2 emissions and energy efficiency for university i in year t according to:

$$\ln c_{it} = \beta_0 + \beta_1 \ln c_{it-1} + \beta_2 \ln EFF_{it} + \beta_3 \ln ACT_{it} + \beta_4 GIA_{it} + \delta_i + \delta_t + \epsilon_{it}, \quad (2)$$

where $c_{it} = C_{it}/N_{it}$ denotes per-capita emissions (kgCO2e). The Estimated coefficients $\hat{\beta}_1, \hat{\beta}_2\ and\ \hat{\beta}_3$ can be interpreted as partial elasticities of emissions with respect to respective explanatory variables, whereas $\hat{\beta}_4$ as semi-elasticity with respect to gross internal area. Our main interest is in the coefficient of energy efficiency variable $\ln EFF_{it}$ that shows the relationship between emissions and energy efficiency. We expect that $\hat{\beta}_2 < 0$.

We control for past emissions $\ln c_{it-1}$ since emissions are almost always autoregressive in nature. On the other hand, logged activity index $\ln ACT_{it}$ controls for the changes in structural composition of the university, whereas gross internal area (GIA_{it}) controls for physical growth of the university. The model is completed by a full set of university and year fixed effects (δ_i and δ_t) and the idiosyncratic error term ϵ_{it}. The university effect δ_i controls for time-invariant factors such as different socio-economic contexts and resource endowments, whereas the year fixed effect δ_t controls for inter-temporal trends that are uniform across universities.

Equation (2) is dynamic in nature as it contains the lagged dependent variable as an explanatory variable. In addition, explanatory variables such as energy efficiency and economic activity can be endogenous. Therefore, our empirical strategy needs to address university heterogeneity, short run time effects, and any possible endogeneity between the dependent and explanatory variables. In this situation, OLS may produce inconsistent estimates (Greene 2010), whereas an instrumental variables approach requires additional information to obtain consistent estimates. We instead consider a generalized method of moment (GMM) estimation procedure that controls for any potential endogeneity that may arise from explanatory variables. We implement a two-step system GMM estimation procedure introduced by Arellano and Bover (1995) and Blundell and Bond (1998; 2000).

As an alternative measure, we estimate the link between per-m^2 CO2 emissions and energy efficiency for university i in year t according to:

$$\ln g_{it} = \gamma_0 + \gamma_1 \ln g_{it-1} + \gamma_2 \ln EFF_{it} + \gamma_3 \ln ACT_{it} + \gamma_4 N_{it} + \delta_i + \delta_t + \epsilon_{it}, \quad (3)$$

where $g_{it} = C_{it}/GIA_{it}$ and N_{it} denote per-m^2 CO2 emissions (kgCO2e) and total population, respectively, in university i in year t. Here, we divide total CO2 emissions by gross internal area and convert them to per-m^2 terms (i.e., kgCO2e per-m^2), which are then converted to log form. All other variables follow their respective definitions in equation (2). As before, our main interest is in the coefficient of energy efficiency variable $\ln EFF_{it}$ and we expect that $\hat{\gamma}_2 < 0$.

3.2. Data and variables

3.2.1. HESA data

We use HESA estate management data, available at https://www.hesa.ac.uk/data-and-analysis, which is compiled and maintained by the Higher Education and Statistics Agency (HESA) according to the 1992 Higher and Further Education Act. Over 150 UK universities self-report extensive information on students, staff, graduates, finances, business and community interaction, and estates management to this database (HESA, 2019). Universities also report their energy consumption and carbon emissions to the HESA. We extract energy use, emissions, income, and population data from the HESA database. After excluding those with missing data on variables necessary for our analysis, the final estimating sample consists of 119 UK universities over 11 years from 2008-09 to 2018-19. Table A1 appends the list of universities.

Due to the availability of non-overlapping data on energy use and corresponding emissions, we consider both non-residential and residential operations that generate incomes for the universities. In this way, we identify energy used in buildings or spaces used for these respective operations. Non-residential operations are conducted in academic and administrative buildings and usually involve teaching, research, and other related activities. On the other hand, residential operations include student accommodations managed and/or operated by the universities. Overall, as Table 1 reports, non-residential incomes range between £13.4 million and £2.4 billion (with a mean value of £225 million), which is over 90% of total incomes (range £14.3 million to £2.45 billion, with a mean value of £239.3 million).

Table 1. Variable description and summary statistics

Variables	Description	(1) Mean	(2) S.D.	(3) Minimum	(4) Maximum
Original variables					
Non-residential energy	Total non-residential energy use (gigawatt-hour - GWh)	46.95	50.77	1.053	275.3
Residential energy	Total residential energy use (GWh)	11.56	11.70	0	76.29
Total energy	Total energy use (GWh)	58.51	58.04	1.575	294.0
Non-residential emissions	Total non-residential CO2 emissions (kt CO2e)	13.91	15.31	0.0336	84.68
Residential emissions	Total residential CO2 emissions (kt CO2e)	3.128	3.140	0	21.14
Total emissions	Total CO2 emissions (kt CO2e)	17.03	17.27	0.0420	91.68
Non-residential incomes	Total non-residential incomes (million GBP)	225.0	250.1	13.38	2,444
Residential incomes	Total residential incomes (million GBP)	14.26	12.78	0.0260	79.19
Total incomes	Total incomes (million GBP)	239.3	256.9	14.30	2,450
Teaching student	Number of teaching students, full-time equivalent (thousands)	12.45	6.562	0.515	32.56
Research student	Number of research students, full-time equivalent (thousands)	0.687	0.883	0	4.775
Decomposed indices					
L_{it}^{E}	Energy use index, Laspeyres' method	0.826	0.213	0.189	2.912
L_{it}^{ACT}	Activity index, Laspeyres' method	1.017	0.0712	0.792	1.527
P_{it}^{E}	Energy use index, Pasche's method	0.819	0.211	0.178	3.100
P_{it}^{ACT}	Activity index, Pasche's method	1.008	0.0548	0.464	1.326
F_{it}^{E}	Energy use index, Fisher's ideal index method	0.822	0.210	0.183	3.004
F_{it}^{ACT}	Activity index, Fisher's ideal index method	1.012	0.0586	0.644	1.417
Variables for regression					
$\ln c_{it}$	Natural log of per-capita CO2 emissions	6.925	0.664	0.683	8.835
$\ln g_{it}$	Natural log of per-m2 CO2 emissions	4.260	0.388	-2.272	6.158
$\ln EFF_{it}$	Natural log of energy use efficiency (i.e., inverse of Fisher's energy use index)	0.229	0.263	-1.100	1.696
$\ln ACT_{it}$	Natural log of Fisher's activity index	0.0103	0.0569	-0.440	0.349
GIA_{it}	Total gross internal area ('000 m^2)	208.1	163.1	17.29	888.0
N_{it}	Total number of students, full-time equivalent (thousands)	13.14	7.050	0.665	35.90
No. of universities	119				
No. of Obs.	1,309				

Notes. All data comes from HESA estate management data for the years 2008-09 to 2018-19 (HESA, 2019). There are 119 universities in the whole sample, of which 71 are post-1992 universities and 23 are Russell group universities.

The UK universities generate incomes by allocating, among others, their total energy use between residential and non-residential operations. In total, universities annually use 1.575-294 GWh of energy, with an average use of 58.51 GWh. HESA database reports residential and non-residential energy use separately: non-residential buildings use most energy (ranging 1.053-275.3 GWh), whereas residential buildings use less than 20% of total energy (ranging 0-76.29 GWh).

Similarly, HESA database also reports scopes 1 and 2 emissions associated with residential and non-residential energy uses. Consistent with energy use, non-residential emissions constitute around 72% of total emissions. Annual emissions range 0.0336-84.68 for non-residential and 0-21.14 ktCO2e for residential energy use with respective averages of 13.91 and 3.128 ktCO2e. In total, universities annually emit between 0.042 and 91.68 ktCO2e, with an average annual emission of 17.03 ktCO2e (Table 1).

3.2.2. Efficiency and activity indices

We consolidate non-residential and residential incomes, energy use and emissions into two indices representing energy efficiency and economic activities. Let E_{ikt} and Y_{ikt} denote the energy consumption and income for university i from activity k in year t, respectively, where $k = non - residential, residential$. The energy intensity is defined as the ratio of energy use and income:

$$e_{it} = \frac{E_{it}}{Y_{it}} = \sum_k \frac{E_{ikt}}{Y_{ikt}} \frac{Y_{ikt}}{Y_{it}} = \sum_k e_{ikt} s_{ikt} \tag{4}$$

where $e_{ikt} = E_{ikt}/Y_{ikt}$ denotes energy intensity for university i from activity k in year t, and $s_{ikt} = Y_{ikt}/Y_{it}$ denotes the share of income for university i from activity k in year t.

Improvements in energy intensity over time from the base year level can be expressed as $I_{it} = e_{it}/e_{i0}$ $\forall i, t$. Since income, energy use and emissions from non-residential and residential operations do not overlap, we can use Laspeyers', Pasche's, and Fisher's indices to decompose I_{it} into an *energy use index* (i.e., energy intensity to energy efficiency change holding the economic activity constant) and an *activity index* (i.e., energy intensity to structural changes in economic operations holding efficiency within a sector constant). Let the superscripts E and ACT denote efficiency and activity indices so that

$$
\begin{aligned}
&Laspeyres'Index: \quad L_{it}^{E} = \frac{\sum_k e_{ikt} s_{ik0}}{\sum_k e_{ik0}\, s_{ik0}}; \qquad L_{it}^{ACT} = \frac{\sum_k e_{ik0} s_{ikt}}{\sum_k e_{ik0}\, s_{ik0}} \\
&Pasche's\ Index: \quad P_{it}^{E} = \frac{\sum_k e_{ikt} s_{ikt}}{\sum_k e_{ik0}\, s_{ikt}}; \qquad P_{it}^{ACT} = \frac{\sum_k e_{ikt} s_{ikt}}{\sum_k e_{ikt}\, s_{ik0}} \qquad (5) \\
&Fisher's\ Index: \quad F_{it}^{E} = \sqrt{L_{it}^{E}\ P_{it}^{E}}; \qquad F_{it}^{ACT} = \sqrt{L_{it}^{ACT}\ P_{it}^{ACT}}
\end{aligned}
$$

In equation (5), Fisher's ideal indices are the geometric means of respective Laspeyers' and Pasche's indices. Here, F_{it}^{E} and F_{it}^{ACT} are energy use and economic activity indices. In particular, F_{it}^{E} refers to an inverse energy efficiency (EFF_{it}) and F_{it}^{ACT} denotes a measure of weighted economic activities (ACT_{it}) so that $EFF_{it} = 1/F_{it}^{E}$ and $ACT_{it} = F_{it}^{ACT}$.

Decomposed indices reveal that energy use indices have wider ranges and larger standard deviations than activity indices, implying that efficiency improvement is very important for improving energy intensity. Overall, decomposed energy use indices, according to Fisher's ideal index method, range 0.183–3.004 with a mean value of 0.822; whereas the activity indices range 0.644–1.417 with a mean value of 1.012 (Table 1).

4. Results and Discussion

4.1.Diagnostic tests and preliminary results

Table 1 also reports the summary statistics, whereas appendix Figure A1 shows the density functions, for variables constructed for regression analyses. As expected, conversion of variables to natural logarithm terms greatly reduces skewness and kurtosis.

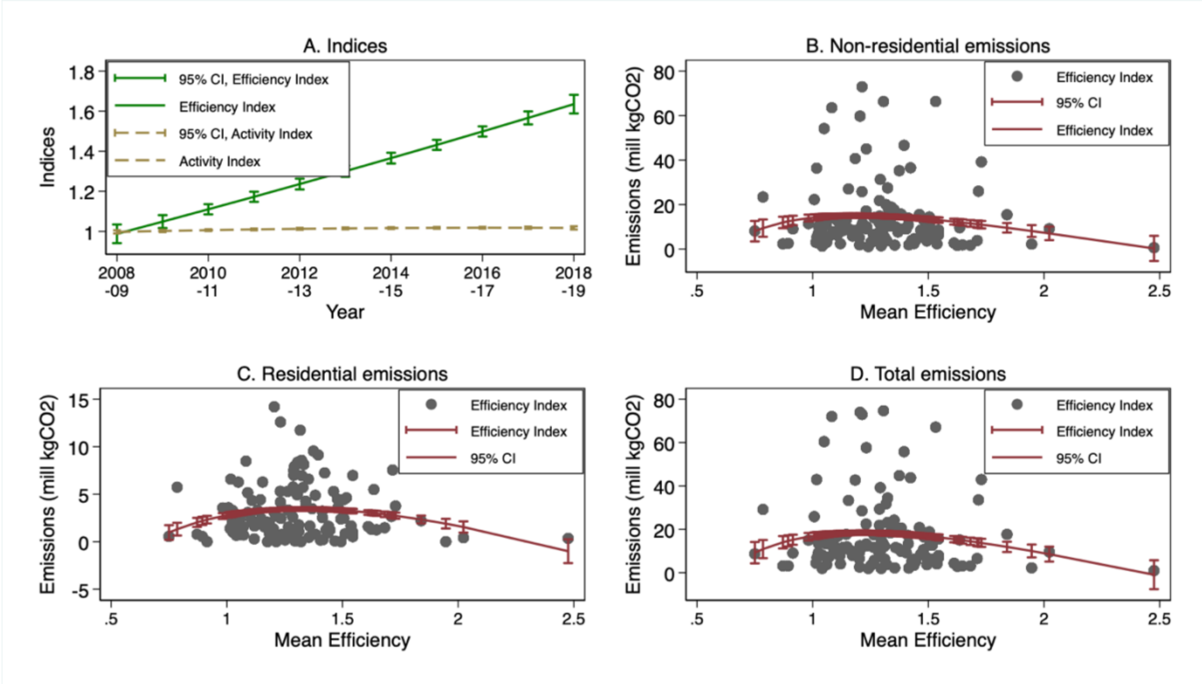

Figure 2. Indices for energy efficiency and activity, 2008-09 to 2018-19.
Notes. Indices are derived according to equations (4) and (5) using the HESA (2019) data.

Figure 2A plots the efficiency index (EFF_{it}) and activity index (ACT_{it}) over time. While the UK universities experienced a continuously increased energy efficiency, from close to 1 in 2008-09 to around 1.6 in 2018-19, activity index roughly remains constant. Panels B-D, respectively then plot non-residential, residential, and total emissions against mean efficiency for 119 university over 11 years. Apparently, total emissions are lower for more energy efficient universities.

We use the Im-Pesaran-Shin unit-root test and the Kao cointegration test for model diagnostics. Tables 2 and 3 report the test results. In both cases, statistically significant (insignificant) test statistics imply the rejection (non-rejection) of respective null hypothesis.

Table 2. Unit root test

Variables	Statistic			p-value
	t-bar	t-tilde-bar	z-t-tilde-bar	
Whole sample				
ln c_{it}	-0.2437	-0.1703	16.7665	1
ln g_{it}	0.2227	0.2223	22.6501	1
ln EFF_{it}	-1.1866	-1.0348	3.8093	0.9999
ln ACT_{it}	-1.474	-1.2405	0.7262	0.7661
GIA_{it}	-1.4548	-0.9576	4.9671	1
N_{it}	-0.9233	-0.7701	7.7762	1
No. of panels	119			
No. of periods	11			
Post-1992 universities				
ln c_{it}	-0.4846	-0.3555	10.807	1
ln g_{it}	0.1682	0.157	16.7389	1
ln EFF_{it}	-1.4779	-1.2786	0.1201	0.5478
ln ACT_{it}	-1.3907	-1.163	1.459	0.9277
GIA_{it}	-1.3205	-1.0639	2.6063	0.9954
N_{it}	-1.1467	-0.9779	3.6018	0.9998
No. of panels	71			
No. of periods	11			
Russell group universities				
ln c_{it}	0.3107	0.3104	10.5379	1
ln g_{it}	0.277	0.3136	10.5591	1
ln EFF_{it}	-0.5927	-0.5245	5.0374	1
ln ACT_{it}	-1.3753	-1.1814	0.7092	0.7609
GIA_{it}	-0.5807	-0.531	4.9947	1
N_{it}	-0.112	-0.0422	8.2148	1
No. of panels	23			
No. of periods	11			

Notes. Null hypothesis for Im-Pesaran-Shin unit-root test is “H0: All panels contain unit roots” against the alternative hypothesis “Ha: Some panels are stationary”. Fixed-N exact critical values are -1.74, -1.67 and -1.64 at 1%, 5% and 10% significance levels.

The panel unit root test results in Table 2 show that the test statistics are statistically insignificant for all the variables used in regression analysis. Therefore, we do not reject the null hypothesis of the presence of unit roots.

Table 3. Cointegration test

	Statistic	p-value	Statistic	p-value
Whole sample				
Modified Dickey-Fuller t	-12.5657	0	-12.9716	0
Dickey-Fuller t	-14.3597	0	-14.3473	0
Augmented Dickey-Fuller t	-6.3315	0	-3.5073	0.0002
Unadjusted modified Dickey	-12.1175	0	-11.567	0
Unadjusted Dickey-Fuller t	-14.2279	0	-13.9488	0
No. of panels	119			
No. of periods	8			
Post-1992 universities				
Modified Dickey-Fuller t	-0.7139	0.2376	-4.0859	0
Dickey-Fuller t	-8.3456	0	-13.1813	0
Augmented Dickey-Fuller t	-0.4945	0.3105	-1.9411	0.0261
Unadjusted modified Dickey	-13.6356	0	-16.1589	0
Unadjusted Dickey-Fuller t	-15.918	0	-18.8694	0
No. of panels	71			
No. of periods	8			
Russell group universities				
Modified Dickey-Fuller t	-4.7676	0	-5.2712	0
Dickey-Fuller t	-3.2821	0.0005	-3.3742	0.0004
Augmented Dickey-Fuller t	-2.1372	0.0163	-2.6274	0.0043
Unadjusted modified Dickey	-2.1865	0.0144	-2.5082	0.0061
Unadjusted Dickey-Fuller t	-2.3618	0.0091	-2.4405	0.0073
No. of panels	23			
No. of periods	8			

Notes. Null hypothesis for Kao test for cointegration is "H0: No cointegration" against the alternative hypothesis "Ha: All panels are cointegrated".

We then carry out the cointegration tests to confirm if the fitted models exhibit a stable long-run relationship. Statistically significant results for all the tests imply that we reject the null hypothesis of no cointegration (Table 3), and the non-stationary variables in our estimating models are cointegrated. We can, therefore, implement the GMM estimation procedure.

4.2.Main Results

Table 4 reports the regression results using two-step system GMM regression estimation procedure. We append results using one-step system GMM regression estimation procedure in Table A2. Following equations (2) and (3), the dependent variables are the log of CO2 emissions per-capita (denoted by $ln\, c_{it}$) and the log of CO2 emissions per-m^2 (denoted by $ln\, g_{it}$). We use standard errors clustered at university level in all the specifications.

In Blundell–Bond GMM estimations, all explanatory variables are instrumented by their first lag and the share of green energy, whereas we instrument $ln\, c_{it}$ and $ln\, g_{it}$ by their respective second and third lags. The figures reported for the Hansen over-identification test are *p*-values for the null hypothesis of valid instruments with χ^2. Total 20 instruments are used in all estimations.

We conduct the Arellano-Bond tests of AR(1), AR(2), and AR(3) to examine the existence of first, second, and third-order serial correlation, respectively. The statistically insignificant test statistics suggest the non-rejection of the null hypothesis of no serial correlation. Therefore, our GMM specifications are free from serial correlation.

Column (1) in Table 4 reports the results for our main specification according to equation (2). All the estimated coefficients exhibit expected directions of relationship with the dependent variables and are statistically significant.

Table 4. Energy efficiency and CO2 emissions

	(1)	(2)	(3)	(4)
	Equation (2): ln c_{it}		Equation (3): ln g_{it}	
Variables	Main regression	Regression for residuals	Main regression	Regression for residuals
ln c_{it-1}	0.2550**	0.2550**		
	(0.1175)	(0.1175)		
ln g_{it-1}			0.3119	0.3119
			(0.1886)	(0.1886)
ln EFF_{it}	-0.4543***		-0.2348***	
	(0.1395)		(0.0840)	
Residuals (ln EFF_{it})		-0.4543***		-0.2348***
		(0.1395)		(0.0840)
ln ACT_{it}	0.9101**	0.3622	0.2574	-0.0258
	(0.3489)	(0.3159)	(0.2067)	(0.1712)
GIA_{it}	0.0018***	0.0018***		
	(0.0003)	(0.0003)		
N_{it}			0.0248***	0.0248***
			(0.0074)	(0.0074)
Constant	4.6726***	4.8424***	2.8332***	2.3274***
	(0.7961)	(0.8276)	(0.7816)	(0.6718)

No. of Obs.	1,190	1,190	1,190	1,190
No. of Universities	119	119	119	119
No. of Years	10	10	10	10
Year FE	YES	YES	YES	YES
Hansen p	0.372	0.372	0.220	0.220
Hansen df	6	6	6	6
No. of instruments	20	20	20	20
AR (1)	-1.448	-1.448	-1.191	-1.191
AR (2)	1.028	1.028	1.435	1.435
AR (3)	-1.039	-1.039	-1.234	-1.234

Notes: Robust/Corrected standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the log of CO2 emissions per-capita denoted by $\ln c_{it}$ for equation (2) and the log of CO2 emissions per-m^2 denoted by $\ln g_{it}$ for equation (3). All estimations follow two-step system GMM procedure. All explanatory variables were instrumented by their first lag and the share of green energy, whereas we include second and third lags as instruments for $\ln c_{it}$ and $\ln g_{it}$. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2.

We identify a statistically significant negative relationship between per-capita emissions and energy efficiency (i.e., between $ln\, c_{it}$ and $ln\, EFF_{it}$). Overall efficiency elasticity of emissions is estimated at 0.4543, implying that a 10% increase (decrease) in energy efficiency results in around 4.5% decrease (increase) in per-capita emissions.

However, this less-than-elastic relationship indicates the presence of rebound effect, i.e., due to other factors such as population and economic activities, per-capita emissions decrease less than proportionally in response to energy efficiency improvement. This happens despite we control for lagged per-capita emissions $\ln c_{it-1}$ (i.e., feedback), logged activity index $\ln F_t^{ACT}$, and gross internal area GIA_{it}.

Consistent with the existing literature (e.g., Tajudeen *et al.* 2018), our results show positive effects of the activity index on per-capita emissions: we find that a 10% increase (decrease) in the activity index increases (decreases) per-capita emissions by 9.1%. We also find that per-capita emissions increase by 0.18% if GIA increases by 1000m^2. Moreover, lagged per-capita emissions also have significant influence on current per-capita emissions, the estimated elastic is 0.255. Therefore, in absence of these controls, the estimated relationship between energy efficiency and per-capita emissions would have been underestimated.

However, as Wadud *et al.* (2019) find that the UK universities become more energy efficient as they grow, it is possible that efficiency and activity indices are correlated. If this is the case, then the efficiency index would rather capture the effects of activity index on per-capita emissions. As a robustness check, we remove this potential source of multicollinearity by first regressing $\ln EFF_{it}$ on $\ln ACT_{it}$ to retrieve "Residuals ($\ln EFF_{it}$)", which is then used as the main regressor in the regression for residuals in column (2). Overall, results are very similar to those in column (1) except for the coefficient of $\ln ACT_{it}$.

Column (3) in Table 4 reports the results for per-m^2 emissions according to equation (3). Consistent with main results in column (1), we identify a statistically significant negative relationship between per-m^2 emissions and energy efficiency: a 10% increase (decrease) in energy efficiency results in around 2.3% decrease (increase) in per-m^2 emissions. Irrespective of statistical significance, control variables also exhibit expected directions of relationships. Estimated relationship between per-m^2 emissions and energy efficiency holds for the regression for residuals as reported in column (4).

4.3. Avoided emissions through efficiency improvement

Reducing emissions is a part and parcel of sustainable development goals and the Paris agreement. Although the UK universities are behind their initial emissions reduction targets, they have still been able to reduce some emissions. Following Eskander and Fankhauser (2020), we use the statistical relationships estimated through equation (2) to calculate a counterfactual "no efficiency improvement" emissions path, which estimates the level of CO2 emissions in the absence of any energy efficiency improvement. For this, we set the coefficient of $\ln C_{it}$ in the estimated equation (2) equal to zero. We then subtract this expression from the full estimated equation (2) so that $\hat{c}_{it} - \tilde{c}_{it} = \hat{\beta}_2 \ln EFF_{it}$ where $\hat{c}_{it} = \ln\left(\hat{C}_{it}/N_{it}\right)$ and $\tilde{c}_{it} = \ln\left(\tilde{C}_{it}/N_{it}\right)$ and superscripts $\tilde{}$ and $\hat{}$ denote "no efficiency improvement" and estimated values, respectively. Therefore, we can calculate the counterfactual emissions level according to:

$$\ln\left(\frac{\hat{C}_{it}}{\tilde{C}_{it}}\right) = \hat{\beta}_2 \ln EFF_{it} \Longrightarrow \ln\left(\frac{\hat{C}_{it}}{\tilde{C}_{it}}\right) = \ln EFF_{it}^{\hat{\beta}_2} \Longrightarrow \frac{\hat{C}_{it}}{\tilde{C}_{it}} = EFF_{it}^{\hat{\beta}_2} \Longrightarrow C_{it} = \hat{C}_{it} EFF_{it}^{-\hat{\beta}_2},$$

where the last step replaces estimated with observed emissions. Overall "no efficiency improvement" emissions are then calculated by aggregating the university-level emissions estimates over university and time:

$$\tilde{C}_{total} = \sum_i \sum_t \tilde{C}_{it} = \sum_i \sum_t \hat{C}_{it} EFF_{it}^{-\hat{\beta}_2}. \qquad (6)$$

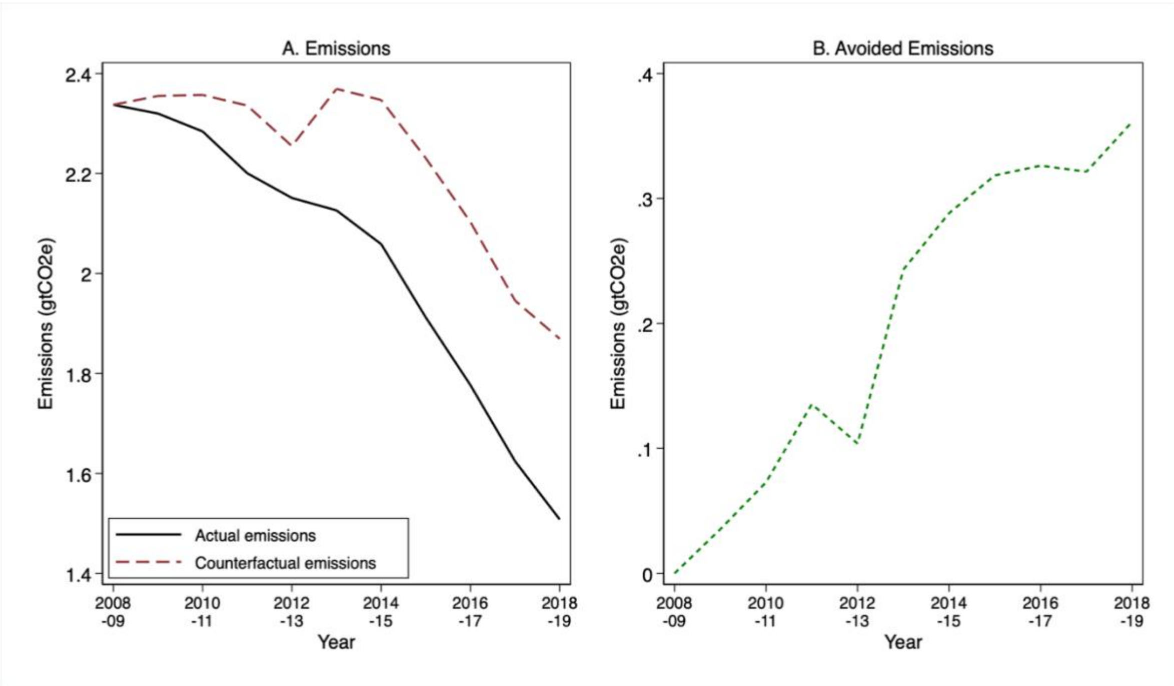

Figure 3. Emissions avoided due to energy efficiency improvement.

Figure 3A plots actual and counterfactual emissions, whereas Figure 3B plots the avoided emissions due to efficiency improvements as the difference between actual and counterfactual emissions. Overall, the UK universities were able to avoid 2.21 gtCO2e emissions over the sample period due to energy efficiency improvements, with annual avoidance ranging from 35.2 ktCO2e in 2008-09 to 361.4 ktCO2e in 2018-19.

4.4. Additional analysis

4.4.1. Results using fixed effect models

For additional robustness check, we consider alternative methods of estimation. Table 5 reports the results from pooled OLS regression and three fixed effect models – with university fixed effect only, with year fixed effect only, and with both university and year fixed effects. Results confirm that the directions of the relationship are consistent with our main specifications in Table 4 for all these alternative cases. However, as expected, the estimated coefficients are slightly different: considerably lower for pooled OLS and year fixed effect estimates, higher for university and two-way fixed effect estimates (except for the post-1992 sample).

Table 5. Fixed effect models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pooled OLS		University FE		Year FE		Two-way FE	
Variables	Eq. (2): $\ln c_{it}$	Eq. (3): $\ln g_{it}$	Eq. (2): $\ln c_{it}$	Eq. (3): $\ln g_{it}$	Eq. (2): $\ln c_{it}$	Eq. (3): $\ln g_{it}$	Eq. (2): $\ln c_{it}$	Eq. (3): $\ln g_{it}$
$\ln c_{it-1}$	0.7979***		0.1208		0.7874***		-0.0105	
	(0.1225)		(0.1350)		(0.1254)		(0.0794)	
$\ln g_{it-1}$		0.6004***		0.2341		0.4983**		-0.0064
		(0.2068)		(0.1962)		(0.2029)		(0.0832)
$\ln EFF_{it}$	-0.2573***	-0.2809***	-0.8026***	-0.7226***	-0.2007***	-0.1452**	-0.5793***	-0.3337***
	(0.0729)	(0.0908)	(0.1026)	(0.1439)	(0.0633)	(0.0668)	(0.0702)	(0.0945)
$\ln ACT_{it}$	0.4020***	0.1145	0.9026***	0.2867	0.3581**	0.0327	0.6712***	0.0753
	(0.1534)	(0.1536)	(0.2284)	(0.3360)	(0.1459)	(0.1206)	(0.1574)	(0.1611)
GIA_{it}	0.0005		0.0001		0.0005*		0.0019	
	(0.0003)		(0.0011)		(0.0003)		(0.0014)	
N_{it}		0.0045**		0.0136		0.0059**		0.0256**
		(0.0022)		(0.0107)		(0.0025)		(0.0111)
Constant	1.3123	1.6635*	6.2371***	3.2279***	1.3640*	2.0494**	6.7236***	4.0078***
	(0.8089)	(0.8855)	(0.7529)	(0.7682)	(0.8219)	(0.8536)	(0.2865)	(0.2425)
No. of Obs.	1,190	1,190	1,190	1,190	1,190	1,190	1,190	1,190
R-squared	0.7807	0.4453	0.8662	0.5768	0.7862	0.4902	0.8864	0.6687
University FE	NO	NO	YES	YES	NO	NO	YES	YES
Year FE	NO	NO	NO	NO	YES	YES	YES	YES

Notes: Robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the log of CO2 emissions per-capita denoted by $\ln c_{it}$ for equation (2) and the log of CO2 emissions per-m^2 denoted by $\ln g_{it}$ for equation (3).

4.4.2. Results for selected university groups

Next, it is possible that post-1992 universities have better emissions reduction experiences due to having newer infrastructures whereas research-intensive Russell group universities may have worse emissions reduction experiences due to having research and teaching related activities that are innately dependent on energy use. We test these possibilities by running separate regressions for 71 post-1992 universities and 23 Russell group universities according to equations (2) and (3).

Table 6. Energy efficiency and CO2 emissions for selected university groups

	(1)	(2)	(3)	(4)
	Post-1992 universities		Russell group universities	
Variables	Eq. (2): $\ln c_{it}$	Eq. (3): $\ln g_{it}$	Eq. (2): $\ln c_{it}$	Eq. (3): $\ln g_{it}$
$\ln c_{it-1}$	0.2962		0.2828	
	(0.1808)		(0.1797)	
$\ln g_{it-1}$		0.2878		0.5400**
		(0.2616)		(0.2062)
$\ln EFF_{it}$	-0.6381**	-0.2815	0.0532	-0.1231
	(0.2448)	(0.1726)	(0.2274)	(0.1525)
$\ln ACT_{it}$	0.7274*	0.1751	1.5302	0.3869
	(0.4329)	(0.3225)	(1.3923)	(0.9810)
GIA_{it}	0.0003		0.0016***	
	(0.0012)		(0.0005)	
N_{it}		0.0073		0.0078
		(0.0076)		(0.0151)
Constant	4.7519***	2.9514***	4.7926***	1.7384**
	(1.3112)	(1.0896)	(1.2440)	(0.6682)
No. of Obs.	710	710	230	230
No. of Universities	71	71	23	23
No. of Years	10	10	10	10
Year FE	YES	YES	YES	YES
Hansen p	0.547	0.466	0.677	0.691
Hansen df	6	6	6	6
No. of instruments	20	20	20	20
AR (1)	-1.445	-1.408	-1.027	-1.084
AR (2)	0.666	1.000	1.040	1.129
AR (3)	-0.316	-1.335	-1.006	-1.138

Notes: Robust/Corrected standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the log of CO2 emissions per-capita denoted by $\ln c_{it}$ for equation (2) and the log of CO2 emissions per-m^2 denoted by $\ln g_{it}$ for equation (3). All estimations follow two-step system GMM procedure. All explanatory variables were instrumented by their first lag and the share of green energy, whereas we include second and third lags as instruments for $\ln c_{it}$ and $\ln g_{it}$. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2. There are 71 post-1992 universities (i.e., those receiving university status through the Further and Higher Education Act 1992) and 23 Russell group universities.

Columns (1) and (2) in Table 6 report the results for per-capita and per-m^2 emissions for the post-1992 universities. Results confirm that these newer universities can lower their per-capita emissions by improving energy efficiency and they actually can benefit more than the older universities. However, such benefits are not realized through infrastructural expansions, as the estimated relationship between per-m^2 emissions and energy efficiency is statistically insignificant.

Results are quite different for the Russell group universities, as reported in columns (3) and (4) in Table 6. These research-intensive universities were not able to significantly reduce their per-capita or per-m^2 emissions, rather the estimated coefficient is positive for the relationship between per-capita emissions and energy efficiency.

4.4.3. Results for different time periods

To check the existence of any time-varying heterogeneity, we run regression models for two split samples, one is for the first half (2008-09 to 2013-14) and the other one is for the second half (2014-15 to 2018-19) of the data. Results (in Table 7) show that the estimated coefficient of $\ln EFF_{it}$ is larger and statistically more significant for more recent years. This evidence shows that UK universities have paid increased attention to emissions reductions in more recent times.

Table 7. Energy efficiency and CO2 emissions for different time periods

	(1)	(2)	(3)	(4)
	Equation (2): $\ln c_{it}$		Equation (3): $\ln g_{it}$	
Variables	2008-09 to 2013-14	2014-15 to 2018-19	2008-09 to 2013-14	2014-15 to 2018-19
$\ln c_{it-1}$	0.2069	0.3548**		
	(0.2318)	(0.1586)		
$\ln g_{it-1}$			0.7841**	0.3170
			(0.3152)	(0.2548)
$\ln EFF_{it}$	-0.3873**	-0.5337**	-0.0317	-0.2618

	(0.1893)	(0.2244)	(0.1564)	(0.1732)
$\ln ACT_{it}$	0.9666*	0.6345**	0.1206	0.1552
	(0.5009)	(0.2973)	(0.5162)	(0.2913)
GIA_{it}	0.0013**	0.0018***		
	(0.0006)	(0.0005)		
N_{it}			0.0145	0.0190**
			(0.0125)	(0.0086)
Constant	5.1853***	4.0233***	0.6223	2.4453**
	(1.5694)	(1.0337)	(1.2291)	(0.9662)
No. of Obs.	595	595	595	595
No. of Universities	119	119	119	119
No. of Years	5	5	5	5
Year FE	YES	YES	YES	YES
Hansen p	0.595	0.626	0.394	0.0820
Hansen df	5	6	5	6
No. of instruments	15	15	15	15
AR (1)	-0.912	-1.498	-1.309	-1.235
AR (2)	0.292	0.456	1.537	1.242
AR (3)	-2.241	1.114	-1.212	0.252

Notes: Robust/Corrected standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the log of CO2 emissions per-capita denoted by $\ln c_{it}$ for equation (2) and the log of CO2 emissions per-m^2 denoted by $\ln g_{it}$ for equation (3). All estimations follow one-step system GMM procedure. All explanatory variables were instrumented by their first lag and the share of green energy, whereas we include second and third lags as instruments for $\ln c_{it}$ and $\ln g_{it}$. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2.

4.5.Discussion and policy implications

According to Kahn and Kotchen (2010), as the economic recovery has been prioritized over environmental sustainability in many countries since the 2008 recession, mostly the developing countries would face the increasing challenge of increased emissions. However, analyzing the emission data of the UK universities, the current paper finds not only the developing countries but also that developed countries like the UK may face the challenge of greater emissions. Therefore, the formulation and enforcement of sectoral plans and policies to curb emissions to ensure a green environment for the future generation are equally important for developed countries.

The UK universities are still far behind achieving net-zero emissions levels – both as individual entities and as sector as a whole. The formerly known Higher Education Funding Council for England developed a carbon reduction strategy in 2011 requiring universities for a

43% reduction in their carbon emissions between 2005 and 2020. According to EM (2020), only 49 out of 154 institutions are on track of meeting their emissions reduction target. EM (2020) also reports that some universities did not have any investment in energy-saving strategies required for energy efficiency improvements. Moreover, several institutions achieved 0% in their emissions reduction and reported no commitment to divesting from fossil fuels. In fact, as EM (2020) puts it, "many universities have slowed down on what was a promising and energetic period of commitment following when the initial targets were set."

Although electricity prices in the UK include carbon taxes, they are still low enough not to provide financial incentives for energy efficiency improvements. However, overall economic incentives also include societal benefits from virtue signalling and being the potential role models in sustainability. Moreover, as Wadud *et al.* (2019) identified, fast growing universities are increasingly becoming energy efficient through, among others, adopting efficient technologies in their newly built buildings, it is imperative to assert that there are greater societal and longer-term economic benefits from investing in energy efficiency.

For speeding up their net-zero ambition by 2050, universities need to increase their adoption of renewable energy sources in addition to energy-efficient technologies. Higher carbon footprints of research-intensive universities require special attention in this regard. By following the carbon-reducing policies, the higher education sector can effectively increase climate and environmental awareness of the other public and private sectors to adopt similar strategies.

The UK Policymakers should seriously consider the importance of the universities to curb emissions because of their long-term impact on human behavior. As Bowen and Learning (2018, p. 26) puts it, "For individuals, the outcomes of higher education are harvested over adult lifetimes averaging fifty to sixty years after graduation from college. For society the impacts may persist through centuries." So, any emission reduction strategy of the universities teaches the students to follow energy saving/emission-reducing strategies over their lifetime. So, universities can also reduce emissions through its long-term impact on future generations.

The post-secondary students are also aware of the leading role of the universities in reducing emissions. The three-year longitudinal analysis conducted in the UK by the National Union of Students (NUS) and Higher Education Academy (HEA) shows that over 80% of the students believe their institutions should actively support sustainable development programs, and over two-thirds of the students believe that sustainable development education should be covered by their courses (Drayson *et al.*, 2014). So, the introduction of sustainable development courses may bring more student enrolment and higher revenue for UK universities. This higher revenue can offset some of the costs related to adopting emission-reduction strategies.

5. Conclusions

In addition to their traditional roles of creating knowledge, universities have their social responsibilities of leading and contributing to the combat against climate change. Their roles are particularly important since they educate future leaders and policymakers, and thus their university-level actions to increase energy efficiency and reduce emissions can have longer-term social benefits (Ceulemans *et al.*, 2015). In this context, reducing carbon emissions has become one of the latest goals of the UK universities (Wadud *et al.*, 2019).

By applying a two-step system GMM estimation procedure, we investigate the role of energy efficiency in reducing CO2 emissions in the UK universities. Our results show that, while energy efficiency has increased from its 2008-09 levels in most universities, their individual progresses are insufficient, and the sector as a whole is not on track for becoming net-zero emitters by 2050. We also find that post-1992 universities are relatively more efficient, but Russell group universities are inefficient in reducing emissions.

Our empirical analysis shows a less-than-elastic relationship between energy efficiency and emissions. This relationship implies that it is practically impossible to become net-zero emitters through efficiency improvement of conventional fossil fuel energy sources especially in presence of persistent population pressure. This implies that the UK universities need to speed up their adoption of renewable energy sources mandated by the 2011 Carbon Plan. Incentivizing individual achievements to universities leading the energy efficiency improvement and renewables adoption may encourage lagging universities to speed up their own actions.

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Appendices

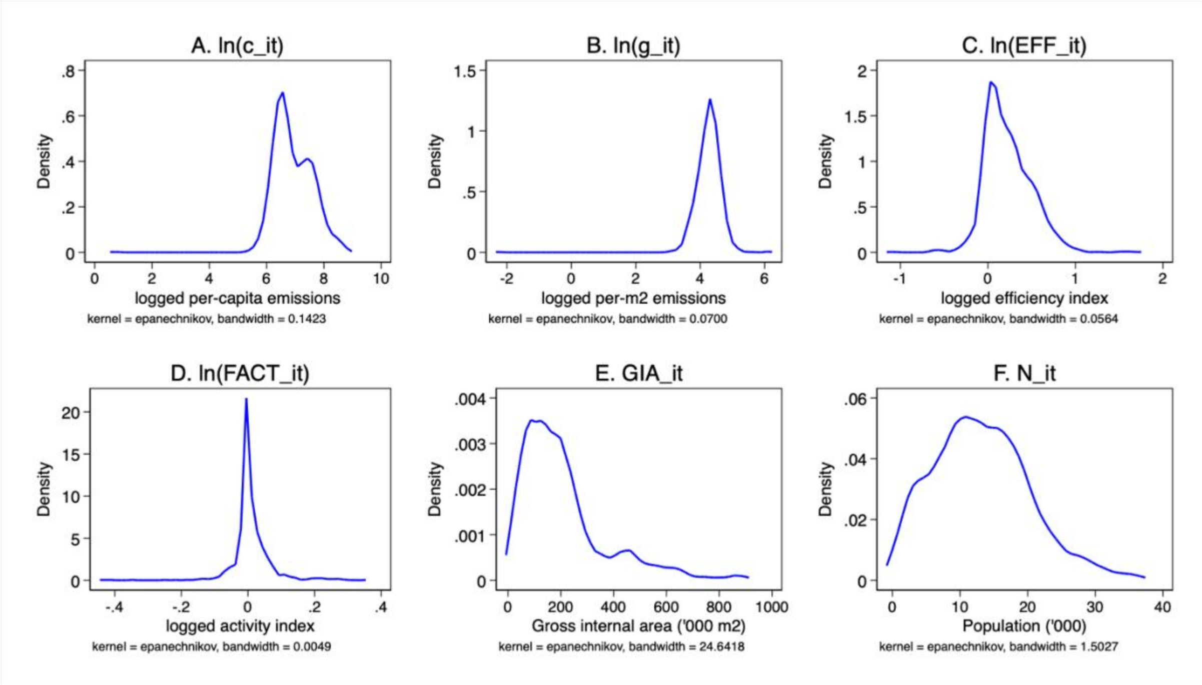

Figure A1: Density functions

Table A1. List of UK universities

Sl. No.	University	England	Post-1992	Sl. No.	University	England	Post-1992
1	Anglia Ruskin U	1	1				
2	AU Bournemouth	1	1	61	U Surrey	1	0
3	Bath Spa U	1	1	62	U Teesside	1	1
4	U C Birmingham	1	1	63	U Warwick	1	0
5	Bournemouth U	1	1	64	UWE Bristol	1	1
6	U Brighton	1	1	65	U Westminster	1	1
7	Brunel U	1	0	66	U Wolverhampton	1	1
8	Bucks NU	1	1	67	U York	1	0
9	Canterbury CCU	1	1	68	Writtle UC	1	1
10	U Northumbria	1	1	69	York SJU	1	1
11	City U	1	0	70	Aston U	1	0
12	Coventry U	1	1	71	Birkbeck C	1	1
13	De Montfort U	1	1	72	Glasgow CU	0	1
14	Goldsmiths	1	1	73	Heriot-Watt U	0	0
15	Imperial College	1	0	74	U Keele	1	0
16	U Winchester	1	1	75	U Lancaster	1	0
17	King's College	1	0	76	LBS	1	1
18	Kingston U	1	1	77	LSHTM	1	0
19	Leeds MU	1	1	78	Edinburgh NU	0	1
20	Leeds TU	1	1	79	U Oxford	1	0
21	Liverpool HU	1	1	80	QMU London	1	0
22	Liverpool JMU	1	1	81	Roehampton U	1	1
23	London MU	1	1	82	SOAS	1	0
24	LSE	1	0	83	St George's	1	1
25	London SBU	1	1	84	U Aberdeen	0	0
26	Loughborough U	1	0	85	UCL	1	0
27	Manchester MU	1	1	86	U Bradford	1	0
28	Middlesex U	1	1	87	U Bristol	1	0
29	Nottingham TU	1	1	88	U Cambridge	1	0
30	Oxford Brookes U	1	1	89	U East Anglia	1	0
31	QMU Edinburgh	0	1	90	U Edinburgh	0	0
32	QU Belfast	0	0	91	U Essex	1	0
33	Robert Gordon U	0	1	92	U Exeter	1	0
34	Royal Holloway	1	1	93	U Glasgow	0	0
35	Sheffield Hallam U	1	1	94	U Leeds	1	0
36	Solent U	1	1	95	U Leicester	1	0
37	Staffordshire U	1	1	96	U Manchester	1	0
38	U Bolton	1	1	97	U Newcastle	1	0
39	U Liverpool	1	0	98	U Plymouth	1	1
40	U Chichester	1	1	99	U Reading	1	0
41	U Northampton	1	1	100	U St Andrews	0	0
42	U Worcester	1	1	101	U Stirling	0	0
43	Birmingham CU	1	1	102	U Strathclyde	0	0
44	UC Lancashire	1	1	103	U Sussex	1	0
45	U Durham	1	0	104	U Ulster	0	0
46	UE London	1	1	105	Bishop GU	1	1
47	U Gloucestershire	1	1	106	Cardiff U	0	0
48	U Greenwich	1	1	107	Cranfield U	1	1
49	U Hertfordshire	1	1	108	Newman U	1	1
50	U Huddersfield	1	1	109	U Cumbria	1	1
51	U Hull	1	0	110	U Chester	1	1
52	U Kent	1	0	111	U Abertay	0	1
53	U Lincoln	1	1	112	U Bath	1	0
54	U Bedfordshire	1	1	113	U Derby	1	1
55	U Nottingham	1	0	114	Cardiff MU	0	1
56	U Portsmouth	1	1	115	Swansea U	0	1
57	U Salford	1	0	116	Aberystwyth U	0	1
58	U Sheffield	1	0	117	Bangor U	0	1
59	U Southampton	1	0	118	Falmouth U	1	1
60	U Sunderland	1	1	119	Harper Adams U	1	1

Notes. Out of a total of 119 universities, there are 71 post-1992 universities (i.e., those receiving university status through the Further and Higher Education Act 1992) and 23 Russell group universities.

Table A2. Energy efficiency and CO2 emissions: One step systems GMM results

	(1)	(2)	(3)	(4)
	Equation (2): $\ln c_{it}$		Equation (3): $\ln g_{it}$	
Variables	Main regression	Regression for residuals	Main regression	Regression for residuals
$\ln c_{it-1}$	0.2546*	0.2546*		
	(0.1448)	(0.1448)		
$\ln g_{it-1}$			0.4333**	0.4333**
			(0.1673)	(0.1673)
$\ln EFF_{it}$	-0.3997***		-0.2382**	
	(0.1414)		(0.0952)	
Residuals ($\ln EFF_{it}$)		-0.3997***		-0.2382**
		(0.1414)		(0.0952)
$\ln ACT_{it}$	0.9013***	0.4192	0.3425	0.0553
	(0.3216)	(0.2815)	(0.2422)	(0.1968)
GIA_{it}	0.0018***	0.0018***		
	(0.0003)	(0.0003)		
N_{it}			0.0223***	0.0223***
			(0.0058)	(0.0058)
Constant	4.6376***	4.8289***	2.2258***	1.8832***
	(0.9325)	(0.9908)	(0.7253)	(0.6126)
No. of Obs.	1,190	1,190	1,190	1,190
No. of Universities	119	119	119	119
No. of Years	10	10	10	10
Year FE	YES	YES	YES	YES
Hansen p	0.372	0.372	0.220	0.220
Hansen df	6	6	6	6
No. of instruments	20	20	20	20
AR (1)	-1.488	-1.488	-1.271	-1.271
AR (2)	1.016	1.016	1.472	1.472
AR (3)	-0.928	-0.928	-1.045	-1.045

Notes: Robust/Corrected standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the log of CO2 emissions per-capita denoted by $\ln c_{it}$ for equation (2) and the log of CO2 emissions per-m^2 denoted by $\ln g_{it}$ for equation (3). All estimations follow one-step system GMM procedure. All explanatory variables were instrumented by their first lag and the share of green energy, whereas we include second and third lags as instruments for $\ln c_{it}$ and $\ln g_{it}$. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2.