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Energy Efficiency and CO2 Emissions in the UK universities

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Abstract

Understanding how energy efficiency improvement can mitigate CO2 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 an instrumental role in this vision by adopting energy-saving and CO2 reduction strategies. We investigate how energy efficiency and affluence affect the emissions reduction experience of the UK universities. Using HESA data, a centralized system of reporting energy use and corresponding emissions, we adopt a two-step estimation strategy to first develop efficiency and activity indices for residential and non-residential energy use and emissions, and then to employ a two-step system GMM estimation procedure that captures the environment-economy-energy nexus to analyze the impact of the energy efficiency on CO2 emissions. For 122 UK universities over the period between 2008-09 and 2018-19, econometric results, which are robust to alternative specifications and restricted samples, confirm higher energy efficiency is conducive to lower emissions. However, the less-than-elastic relationship between energy efficiency and emissions implies that the UK universities will not be able to comply with their net-zero objectives unless they increase their investments in renewables and energy-efficient technologies. These findings will draw interests from pro-environment activists, university and government administrators, and policymakers.

Keywords

Emissions, Energy, Index decomposition, University

JEL Classification

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Energy Efficiency and CO2 Emissions in the UK universities[*]

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Abstract

Understanding how energy efficiency improvement can mitigate CO2 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 an instrumental role in this vision by adopting energy-saving and CO2 reduction strategies. We investigate how energy efficiency and affluence affect the emissions reduction experience of the UK universities. Using HESA data, a centralized system of reporting energy use and corresponding emissions, we adopt a two-step estimation strategy to first develop efficiency and activity indices for residential and non-residential energy use and emissions, and then to employ a two-step system GMM estimation procedure that captures the environment-economy-energy nexus to analyze the impact of the energy efficiency on CO2 emissions. For 122 UK universities over the period between 2008-09 and 2018-19, econometric results, which are robust to alternative specifications and restricted samples, confirm higher energy efficiency is conducive to lower emissions. However, the less-than-elastic relationship between energy efficiency and emissions implies that the UK universities will not be able to comply with their net-zero objectives unless they increase their investments in renewables and energy-efficient technologies. These findings will draw interests from pro-environment activists, university and government administrators, and policymakers.

Highlights

- Universities can play a leading role in emissions reductions by setting up examples.
- Higher energy efficiency is conducive to lower emissions in the UK universities.
- Universities may not become net-zero emitters with their current efforts.
- They need to increase investments in renewables and energy-efficient technologies.
- Greater incentives, supervision, and enforcement of policies will be useful in further emissions reduction.

1. Introduction

The 2011 Carbon Plan, replacing 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, including energy efficiency and low carbon heating.

As public educational institutions, the UK universities have the social responsibility to make a commitment to the environment and sustainable development by reducing their CO2 emissions. This backdrop has brought the importance of energy consumption and energy efficiency at the university level to the fore. This paper focuses on this energy-related plan that is included in the 2011 Carbon Plan of the UK to investigate how the universities are keeping up with the objectives set out in this national plan and what are the implications of energy efficiency improvement and affluence on their carbon emissions. Therefore, the objective of this study is to explore the relationship between energy use and CO2 emissions. In doing so, we focus on residential and non-residential energy use and corresponding emissions by the UK universities.

Universities are increasingly adopting greener sources of energy to reduce scope 1 and scope 2 emissions[1] that emerge from their energy consumption for both the residential and non-

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[1] As Ozawa-Meida *et al.* (2013, pp. 185) put in "Scope 1 is direct emissions that occur from sources that are owned or controlled by the organization, for example emissions from combustion in owned or controlled boilers, furnaces, vehicles; Scope 2 accounts for indirect emissions from the generation of purchased electricity, heat or steam consumed by the organization; Scope 3 is all other indirect emissions which are a consequence of the activities of the company, but occur from sources not owned or controlled by the

residential buildings. These types of buildings, and their users, use energy for different purposes which necessarily results in different energy efficiency improvement potentials by building types. In addition, residential and non-residential energy uses generate respective incomes for universities. Income growth from these sources can have differential effects on energy use and efficiency. Therefore, the underlying relationship between energy efficiency, income, and emissions requires to differentiate between energy consumptions by types of buildings.

The practical importance of this study lies in the fact that energy efficiency improvement is cost-effective as an interim measure and can at least partially offset CO2 emissions. Moreover, understanding the effectiveness of efficiency improvement in reducing emissions can then have implications for the need for increased adoption of renewables in achieving the net-zero objective. In this regard, we make a number of contributions. First, this paper joins the limited literature on investigating energy efficiency and emissions at the university level for any country. To the best of our knowledge, this is the first study to use the HESA data to estimate this causal relationship between energy efficiency and CO2 emissions.

We employ a two-step estimation procedure. The first step involves an index decomposition analysis (IDA) to develop an energy efficiency index that reflects the true energy use per unit of economic output (e.g., Boyd and Roop, 2004; Choi and Ang, 2003; Inglesi-Lotz and Pouris, 2012; Zhao *et al.*, 2010), and reveals the changes in relative contributions of these sources in incomes and emissions with changes in energy demand (Boyd *et al.*, 1987; Metcalf, 2008). In the second step, we use a two-step system GMM estimation

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organization. Examples include upstream emissions from the production and transportation of purchased goods, and downstream emissions from the use and disposal of the organization's products and services."

procedure capturing the environment-economy-energy nexus to analyze the impact of the energy efficiency on CO2 emissions.

The remainder of this paper is as follows. Section II provides the background of energy consumption and emissions in UK universities and a brief literature review. Section III discusses the empirical strategy, and describes the HESA data and variables used in this paper. Section IV reports and discusses the regression results. Finally, Section V summarizes and concludes.

2. Background and Literature

2.1.The emissions reduction efforts of the UK

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 of making the UK a "net-zero" emitter requires a combined effort and sustained policy interventions across several sectors – many of which will be complicated, expensive, and time-consuming (CCC, 2019).

2.2.The role of universities in emissions reductions

The universities are important partners of the higher education sector that can produce intellectual and practical leadership in building a sustainable society (Larsen *et al.*, 2013). Sustainable universities are conducive to building a sustainable society. 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). By increasing energy efficiency and reducing emissions, the universities can achieve sustainability and combat climate change. Universities create knowledge, integrate sustainability in education and research programs, and promote environmental issues to the society (Lozano, 2010; Stephens and Graham, 2010; Waas *et al.*, 2010).

Moreover, universities can increase climate and environmental awareness of the future generation, and therefore can contribute to longer-term emission reduction. In the past, universities showed their preferences towards 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).

2.3.Energy consumption and emissions of the UK universities

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, Knuth *et al.* (2007) argue that some large universities may produce emissions like those of small cities. Due to their ability to make independent decisions on resource use, universities also have similar arrangement and execution efforts to increase the energy efficiency like small cities (Kolokotsa *et al.*, 2016).

The growing number of students and staff, and increased research activities lead to increased energy demand in the UK higher education sector (Ward *et al.*, 2008; Bourdeau *et al.*, 2018). In 2017-18, HE providers in England, Wales, and Northern Ireland consumed 6.7 TWh of energy, compared to 6.5 TWh in 2016-17. For the same period, emissions fell from 1.7 MtCO2e to 1.6 MtCO2e (HESA, 2019), implying that the sector is gradually reducing its carbon footprints.

2.4.The emission reduction target of the UK universities

According to the Climate Change Act 2008, each economic sector of the UK including the universities must be committed to reducing emissions (Robinson *et al.*, 2015). The 2011 carbon plan sets s specific emissions reduction target for the UK universities. For example, all new non-domestic university buildings in England were targeted to emit zero carbon from 2019. The universities were also encouraged to set up their overall emissions reduction target (i.e., reduce emissions by 70% by 2020), and increase the use of renewable sources of energy (e.g., using at least 12% of heating energy consumption from renewable sources by 2020).

Moreover, the Higher Education Funding Council for England (HEFCE) encourages higher education institutions to reduce carbon emissions by 34% and 80% (relative to their respective 1990 levels) by 2020 and 2050, respectively (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). Using 20 Russell Group 1 institutions and the University of Southampton as a case study, Robinson *et al.* (2015) found that, although the UK institutions pledged an average emission reduction of 35.6%, their emission-reducing targets are extremely ambitious and almost certainly unachievable by the year of 2020.

3. Methodology and Data

Our empirical strategy is designed in two steps. *First*, we adopt an index decomposition analysis (IDA) approach to measure improvements in energy efficiency in the UK universities for their different economic activities. *Next*, we develop an econometric framework to empirically examine the relationship between energy efficiency and CO2 emissions.

3.1.The Decomposition Indices

Since 1990, studies on energy-related CO2 emissions are extensively using the IDA method (see Ang and Pandiyan, 1997; Choi and Ang, 2001; Stern, 2004; Metcalf, 2008; Ang, 2015; Tajudeen *et al.*, 2018; Eskander and Nitschke 2021; among others). This method decomposes the technological factors into energy mixture (substitution), energy intensity, and other technical effects (Ang and Zhang, 2000), and then can determine which of these fundamental factors is the principal contributor to emissions (Ma and Stern, 2008).

We adopt a Fisher Ideal Index (FII) within the IDA approach to decompose energy intensity. The FII holds many desirable properties including the ability to provide perfect decomposition without unexplained residuals and provides consistency in aggregation and satisfies the basic index theory properties such as the time-reversal and proportionality (Boyd and Roop, 2004).

We define two economic activities as non-residential and residential operations. This classification follows the fact that non-overlapping energy use and corresponding emissions are available for these two types of economic activities. Non-residential operations involve teaching, research and other related activities which are mostly conducted in academic and administrative buildings. On the other hand, residential operations include student accommodations managed and/or operated by the universities. The UK universities generate residential and non-residential incomes by allocating, among others, their total energy use between residential and non-residential operations. On average, universities use 45.86 GWh for non-residential and 11.29 GWh for residential operations to generate £219.9 and £13.93 millions, respectively, resulting in 13.59 kt and 3.056 kt in CO2 emissions (Table 1).

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:

$$e_{it} = \frac{E_{it}}{Y_{it}} = \sum_k \frac{E_{ikt}}{Y_{ikt}} \frac{Y_{ikt}}{Y_{it}} = \sum_k e_{ikt} s_{ikt} \qquad (1)$$

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 (inverse) *efficiency 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 EFF and ACT denote efficiency and activity indices so that

$$\begin{aligned}
&Laspeyres'Index: \quad L_{it}^{EFF} = \frac{\sum_k e_{ikt} s_{ik0}}{\sum_k e_{ik0}\, s_{ik0}}; \qquad L_{it}^{ACT} = \frac{\sum_k e_{ik0} s_{ikt}}{\sum_k e_{ik0}\, s_{ik0}} \\
&Pasche's\ Index: \quad P_{it}^{EFF} = \frac{\sum_k e_{ikt} s_{ikt}}{\sum_k e_{ik0}\, s_{ikt}}; \qquad P_{it}^{ACT} = \frac{\sum_k e_{ikt} s_{ikt}}{\sum_k e_{ikt}\, s_{ik0}} \qquad (2) \\
&Fisher's\ Index: \quad F_{it}^{EFF} = \sqrt{L_{it}^{EFF}\, P_{it}^{EFF}}; \qquad F_{it}^{ACT} = \sqrt{L_{it}^{ACT}\, P_{it}^{ACT}}
\end{aligned}$$

In equation (2), Fisher's ideal indices are the geometric means of respective Laspeyers' and Pasche's indices. Combining equations (1) and (2) provides us the decomposition of the improvements in energy intensity as

$$I_{it} = e_{it}/e_{i0} = F_{it}^{EFF}\, F_{it}^{ACT}, \qquad (3)$$

which shows how energy intensity has changed over time and how efficiency and activity indices contribute to energy intensity improvements. In particular, F_{it}^{EFF} is a measure of inverse energy efficiency so that higher (lower) values of F_{it}^{EFF} correspond to higher (lower) emissions. Similarly, F_{it}^{ACT} measures the activity index so that higher (lower) values of F_{it}^{ACT} correspond to higher (lower) emissions.

3.2.The Econometric Approach

The relationship between energy efficiency and CO2 emissions requires first linking energy efficiency and energy use and then energy use and CO2 emissions according to

$$E_{it} = f(EFF_{it}, Y_{it}, \epsilon_{it}), \qquad (4)$$

$$CO2_{it} = f(E_{it}, Y_{it}, \epsilon_{it}), \qquad (5)$$

where the subscripts i and t denote university and time, respectively.

Following Tajudeen *et al.* (2018), Adetutu *et al.* (2016), and Broadstock and Hunt (2010), equation (4) outlines the relationship between energy use (E_{it}) and energy efficiency (EFF_{it}) controlling for per-capita income (Y_{it}). We define energy efficiency as $EFF_{it} = \frac{1}{F_{it}^{EFF}}\ \forall i, t$.

Next, consistent with Ang (2007), Hamit-Haggar (2012), among others, equation (5) outlines the relationship between CO2 emissions ($CO2_{it}$) and energy use (E_{it}), controlling for per-capita income (Y_{it}).

The coefficient of energy use in equation (5) links equations (4) and (5). To reduce skewness and kurtosis, we convert all the variables in natural log form. Therefore, the link between CO2 emissions, energy use and energy efficiency in the reduced form is:

$$\ln CO2_{it} = \beta_0 + \beta_1 \ln CO2_{it-1} + \beta_2 \ln Y_{it} + \beta_3 \ln EFF_{it} + \beta_4 \ln F_{it}^{ACT} + \delta_i + \delta_t + \epsilon_{it}. \quad (6)$$

The Estimated coefficients of equation (6) can be interpreted as partial elasticities of emissions with respect to respective explanatory variables. Our main interest is in the coefficients of energy efficiency variable $\ln EFF_{it}$ that shows the relationship between emissions and energy efficiency. One can expect that $\hat{\beta}_3 < 0$.

In the vector of controls, we include lagged dependent variable $\ln CO2_{it-1}$ since emissions are almost always autoregressive in nature. Consistent with existing literature, logged activity index $\ln F_{it}^{ACT}$ controls for the changes in structural composition of the university. In addition, logged per-capita income controls for any income-induced heterogeneity by university and year. 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 (6) is dynamic in nature as it contains the lagged dependent variable as an explanatory variable. In addition, explanatory variables such as income, energy efficiency and activity are 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).

3.3. Data and variables

We use HESA estate management data, compiled, and maintained by the Higher Education and Statistics Agency (HESA) according to the 1992 Higher and Further Education Act, which is publicly available at https://www.hesa.ac.uk/data-and-analysis. Over 150 higher education institutes in the UK self-report extensive information on students, staff, graduates, finances, business and community interaction, and estates management to this database (HESA, 2019). As part of this scheme, universities also report their carbon emissions and fossil fuel consumption to the HESA. We extract energy, emissions, income, and population data from the HESA database. After excluding those with missing data on variables necessary for our quantitative analysis, the final estimating sample consists of 122 UK universities over 11 fiscal years from 2008-09 to 2018-19. Table A1 appends the list of universities.

Energy received from different sources are used in residential and non-residential buildings, which are separately reported in the HESA database. Majority of energy is used in non-residential buildings that normally operate teaching and research activities (ranging between 1.053 and 275.3 GWh), whereas non-residential buildings use around 19% of total energy on average (ranging between 0 and 76.29 GWh). In total, universities use between 1.575 and 294 GWh of energy, with an average use of 55.43 GWh.

Next, scopes 1 and 2 emissions associated to residential and non-residential use of energy are also reported in the HESA database. Consistent with energy use, non-residential emissions constitute around 72% of total emissions, with non-residential and residential emissions ranging 0.0336-84.68 and 0-21.14 ktCO2e with respective averages of 13.22 and 2.952 ktCO2e. In total, universities emit between 0.454 and 95.05 ktCO2e, with an average annual emission of 16.25 ktCO2e.

Third, HESA database reports total residential and non-residential incomes derived from different sources. In particular, non-residential incomes include teaching, research, and other non-residential incomes, whereas we calculate residential incomes by deducting non-residential incomes from total incomes. Overall, non-residential incomes range between £7 million to £2.4 billion (with a mean value of £214.6 million), which is over 90% of total incomes (range £7.1 million to £2.45 billion, with a mean value of £228 million).

Finally, total population is obtained by adding full-time equivalent number of teaching and research students.

[Table 1]

Table 1 also reports the variables constructed for the decomposition and regression analyses. Decomposition indices reveal that (inverse) efficiency 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 intensity indices, according to Fisher's ideal index method, range between 0.183 and 3.004, with a mean value of 0.823.

For regression analysis, we divide total energy consumption, total CO2 emissions and total incomes by total number of full-time equivalent students and convert them to per-capita terms, all of which are then converted to log form. Annual per-capita energy consumption ranges between 754 to 20,484 kWh with a mean value of 4,336 kWh, whereas per-capita CO2 emissions range between 1.979 and 6,871 kgCO2e (with a mean value of 1,275 kgCO2e). Finally, annual per-capita income ranges between £6,698 and £307,460 with a mean value of £18,705.

4. Results and Discussion

4.1. Energy Intensity Decomposition

Figure 1 plots the three decomposed Fisher indices: (inverse) efficiency index (F_t^{EFF}), activity index (F_t^{ACT}), and intensity index (I_t), according to equations (2) and (3).

[Figure 1]

The value of efficiency index for 2008-09 was close to 1 and it went down to 0.67 in 2018-19. The declining trend in efficiency index implies that the UK universities used lower energy to produce the same level of output throughout the period from 2008-09 to 2018-19. In particular, the figure shows that same level of income generation through educational activities of the universities takes around 67% of energy in 2018-19 compared to the 2008-09 level. In other words, if the educational activities of the universities had remained unchanged, the education related energy consumption in 2018-19 would be 67% of that existed in 2008-09. So, the efficiency index of Figure 2 implies that the UK universities made improvements in energy efficiency implying they have been using less energy to produce the same level of output since 2008-09.

The upward sloping activity index implies that the level of activities related to the energy sector has been rising from 2008-09. This is expected because, due to population growth and other market factors, universities experienced growth in their activities. The activity index increased at a greater pace between 2008-09 to 2012-13 and after that it became almost constant. The value of activity index in 2018-19 is 101.4. This implies that if energy efficiency and energy intensity remained constant at the 2008-09 level, the energy activities in 2018-19 would have increased by 1.4% of the 2008-09 level.

The downward sloping energy intensity index indicates that the UK universities are incurring lower cost of converting energy into output throughout the period from 2008-09 to 2018-19. Using 2008-09 as the base year, the total energy intensity index in 2018-19 is 67% of its 2008-09 level. This indicates that the cost of converting energy into educational output decreases by 33% between 2008-09 and 2018-19.

Figure 2 shows the three Fisher decomposition indices for the universities located in the twelve regions of the UK. Each of the indices of twelve regions of Figure 2 shows qualitatively similar trend of Figure 1. Figures 1-2 indicate that the three Fisher decomposition indices show consistent behavior for all the UK universities and also for their different regional groups. So, the trend of the three Fisher decomposition indices of the UK universities are robust across regions.

[Figure 2]

4.2.Diagnostic tests

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]

[Table 3]

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.

We then carry out the cointegration tests to confirm if the fitted model exhibits 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 model are cointegrated. We can, therefore, implement the GMM estimation procedure.

4.3.Energy efficiency and CO2 emissions

Table 5 reports the regression results using two-step system GMM regression estimation procedures for the overall sample (122 universities), English universities (103 universities) and post-1992 universities (74 universities). Following equation (6), the dependent variable is the log of CO2 emissions per-capita (denoted by $ln\, C_{it}$). 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 $ln\, C_{it}$ by its 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 number of instruments is 20.

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, the two-step system GMM specifications are free from serial correlation.

[Table 4]

All the estimated coefficients exhibit expected directions of relationship with the dependent variable and are statistically significant at least at a 5% level of significance except for per-capita income for the English universities sample. Results are consistent with one-step system GMM regression results reported in the appendix Table A.2.

We identify a statistically significant negative relationship between emissions and energy efficiency (i.e., between $ln\, C_{it}$ and $ln\, EFF_{it}$). Overall efficiency elasticity of emissions is estimated at 56.42%, implying that a 10% increase (decrease) in energy efficiency results in around 5.6% decrease (increase) in emissions. On the other hand, post-1992 universities have slightly higher elasticity (58.81%) than the overall sample, whereas English universities incur slightly lower elasticity (51.46%).

However, this less-than-elastic relationship between energy efficiency and emissions is a clear indication of rebound effect, and therefore justifies the inclusion of control variables. We identify that lagged per-capita emissions ($\ln C_{it-1}$), per-capita income (i.e., $\ln Y_{it}$) and the activity index (i.e., $\ln F_t^{ACT}$) also significantly affect per-capita emissions.

We find that a 10% increase (decrease) in lagged emissions increases (decreases) current emissions by around 1.7%. Estimated coefficients are positive but slightly higher for both the English university and post-1992 university samples. This autoregressive nature of emissions may imply lack of effective actions by the universities to reduce their respective emissions.

Consistent with the existing literature (e.g., Tajudeen *et al.* 2018), our results show positive effects of per-capita income and the activity index on per-capita emissions. We find that a 10% increase (decrease) in per-capita income increases (decreases) per-capita emissions by 3.9%; with the estimated coefficients being higher for both the sub-samples. Finally, we also find that a 10% increase (decrease) in the activity index increases (decreases) per-capita emissions by 9.4%. The effect of the activity index is statistically insignificant for English universities, whereas that effect is considerably higher for post-1992 universities.

4.4.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 in the near future. But, 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 in recent times. Therefore, the formulation and enforcement of sectoral plans policies to curb emissions to ensure a green environment for the future generation are equally important for developed countries.

Reducing emissions is a part and parcel of sustainable development goals and the Paris agreement. Although the UK universities are lagging to achieve their initial targets of emissions reductions, our paper shows some optimistic results. Table 5 reports the reductions in total emissions and efficiency improvement over the last 11 years. Overall, UK universities made consistent progress – their emission level of 2018-19 was 35% lower than that of 2008-09. Over the same period, their efficiency also improved by around 63% (Mention which Table you are referencing to for 35% and 63% numbers, I did not get it as a general reader).

[Table 5]

However, they 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), just 49 out of 154 institutions are on track to meet their emission 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.”

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).

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). This paper joins the limited literature identifying the driving forces of energy efficiency and consequent emissions reduction in the UK higher education sector.

Using a two-step estimation procedure, we investigate the role of energy efficiency in reducing CO2 emissions in the UK universities. While energy intensity has decreased 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 2030.

The less-than-elastic relationship between energy efficiency and emissions 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. Consistent with related literature (e.g., Eskander and Nitschke 2021), 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.

Figures

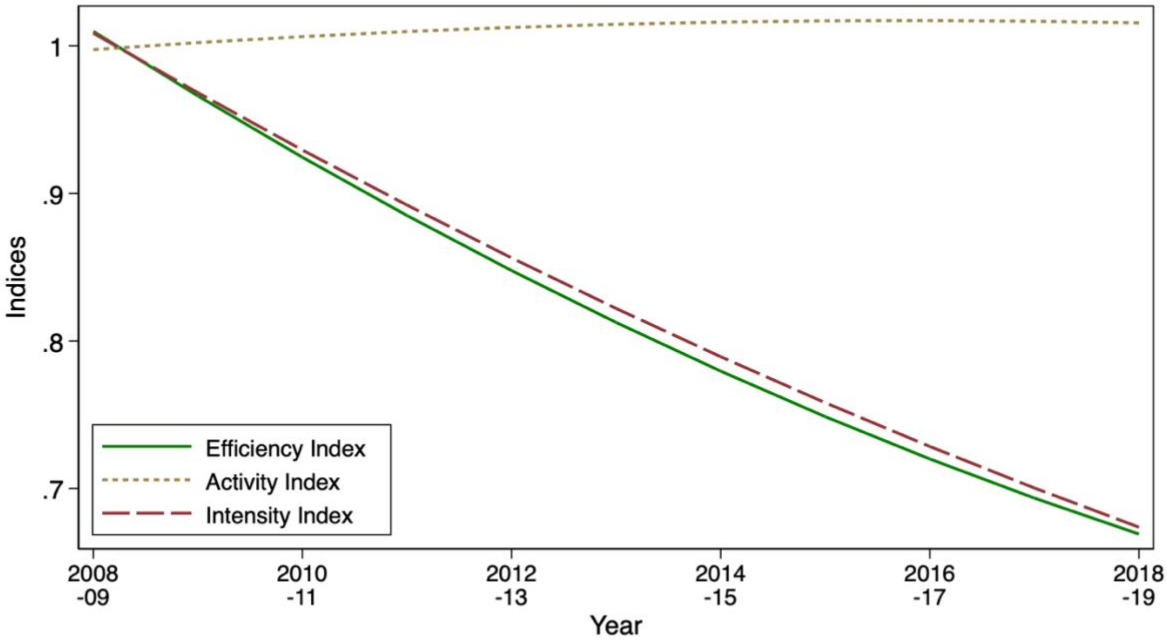

Figure 1. Decomposed Index Values, 2008-09 to 2018-19.

Notes. Indices are derived according to equations (2) and (3) using the HESA (2019) data.

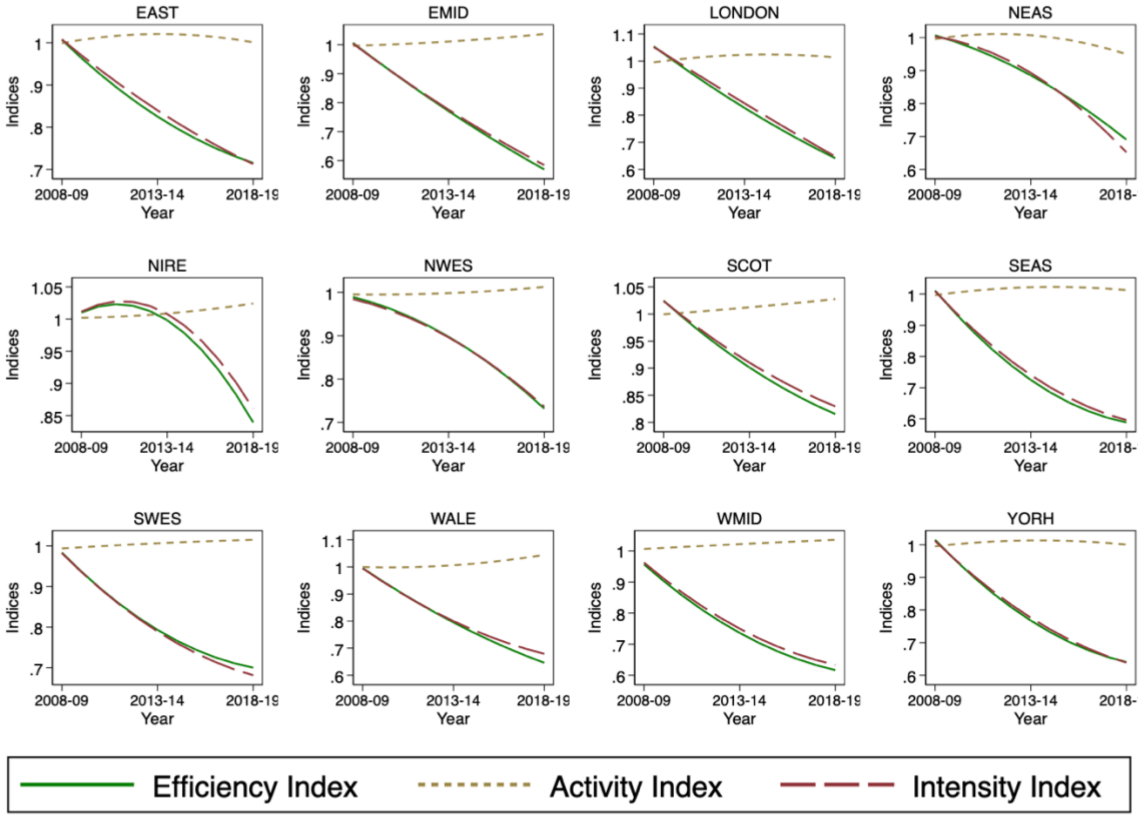

Figure 2. Decomposed indices by UK region, 2008-09 to 2018-19.

Notes. Indices are derived according to equations (2) and (3) using the HESA (2019) data. Twelve administrative regions (NUTS 1 statistical regions), in alphabetic order, are: EAST = East of England; EMID = East Midlands; LONDON = London; NEAS = North East; NIRE = Northern Ireland; NWES = North West; SCOT = Scotland; SEAS = South East; SWES = South West; WALE = Wales; WMID = West Midlands; YORH = Yorkshire and the Humber.

Tables

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)	45.86	50.60	1.053	275.3
Residential energy	Total residential energy use (GWh)	11.29	11.69	0	76.29
Total energy	Total energy use (GWh)	57.15	57.96	1.575	294.0
Non-residential emissions	Total non-residential CO2 emissions (kt CO2e)	13.59	15.25	0.0336	84.68
Residential emissions	Total residential CO2 emissions (kt CO2e)	3.056	3.135	0	21.14
Total emissions	Total CO2 emissions (kt CO2e)	16.64	17.23	0.0420	91.68
Non-residential incomes	Total non-residential incomes (million GBP)	219.9	249.1	7.939	2,444
Residential incomes	Total residential incomes (million GBP)	13.93	12.79	0.0260	79.19
Total incomes	Total incomes (million GBP)	233.8	256.1	8.260	2,450
Teaching student	Number of teaching students, full-time equivalent (thousands)	12.17	6.715	0.515	32.56
Research student	Number of research students, full-time equivalent (thousands)	0.671	0.878	0	4.775
Population	Total number of students, full-time equivalent (thousands)	12.84	7.208	0.665	35.90
Decomposition indices					
L_{it}^{EFF}	Efficiency index, Laspeyres' method	0.827	0.216	0.189	2.912
L_{it}^{ACT}	Activity index, Laspeyres' method	1.016	0.0707	0.792	1.527
P_{it}^{EFF}	Efficiency index, Pasche's method	0.820	0.214	0.178	3.100
P_{it}^{ACT}	Activity index, Pasche's method	1.007	0.0546	0.464	1.326
F_{it}^{EFF}	Efficiency index, Fisher's ideal index method	0.823	0.213	0.183	3.004
F_{it}^{ACT}	Activity index, Fisher's ideal index method	1.011	0.0583	0.644	1.417
I_{it}	Improvement in energy intensity index	0.830	0.210	0.208	3.190
Variables for regression					
ln E_{it}	Natural log of per-capita energy use	8.166	0.628	6.625	9.927
ln C_{it}	Natural log of per-capita CO2 emissions	6.926	0.664	0.683	8.835
ln Y_{it}	Natural log of per-capita income	9.633	0.530	8.810	12.64
ln EFF_{it}	Natural log of energy use efficiency (i.e., inverse of Fisher's use index)	0.228	0.265	-1.100	1.696
ln F_{it}^{ACT}	Natural log of Fisher's activity index	0.00969	0.0566	-0.440	0.349
No. of universities	122				
No. of Obs.	1,342				

Notes. All data comes from HESA estate management data for the years 2008-09 to 2018-19 (HESA, 2019). There are 122 universities in the whole sample, of which 103 are English universities and 74 are post-1992 universities.

Table 2. Unit root test

	Statistic			p-value
Variables	t-bar	t-tilde-bar	z-t-tilde-bar	
$\ln C_{it}$	-0.2630	-0.1870	16.7222	1.000
$\ln Y_{it}$	-0.7710	-0.7202	8.6317	1.000
$\ln EFF_{it}$	-1.1912	-1.0396	3.7847	0.9999
$\ln F_{it}^{ACT}$	-1.4652	-1.2317	0.8695	0.8044

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". There are 122 panels over 11 years. Fixed-N exact critical values are -1.74, -1.67 and -1.64 at 1%, 5% and 10% significance levels.

Table 3. Cointegration test

	Statistic	p-value
Modified Dickey-Fuller t	-10.8479	0
Dickey-Fuller t	-13.5810	0
Augmented Dickey-Fuller t	-5.1404	0
Unadjusted modified Dickey	-11.7197	0
Unadjusted Dickey-Fuller t	-13.8686	0

Notes. Null hypothesis for Kao test for cointegration is "H0: No cointegration" against the alternative hypothesis "Ha: All panels are cointegrated". There are 122 panels over 8 years.

Table 4. Energy efficiency and CO2 emissions

Variables	Entire sample	English universities	Post-1992 universities
ln C_{it-1}	0.1687*	0.1828*	0.2225*
	(0.0944)	(0.1064)	(0.1165)
ln Y_{it}	0.3880**	0.4207	0.6744**
	(0.1882)	(0.3239)	(0.2943)
ln EFF_{it}	-0.5642***	-0.5146***	-0.5881***
	(0.1016)	(0.1423)	(0.1813)
ln F_{it}^{ACT}	0.9422***	0.9999**	0.5838*
	(0.3405)	(0.3991)	(0.3196)
Constant	2.2172	1.4228	-1.3626
	(1.9526)	(3.4693)	(2.8033)
No. of Obs.	1,220	1,030	740
No. of Universities	122	103	74
No. of Years	10	10	10
Year FE	YES	YES	YES
Hansen p	0.148	0.0346	0.513
Hansen df	6	6	6
No. of instruments	20	20	20
AR (1)	-1.520	-1.413	-1.579
AR (2)	0.913	1.040	0.801
AR (3)	-1.168	-0.741	-0.109

Notes: Robust/Corrected standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variable is the log of CO2 emissions per-capita denoted by $ln\, C_{it}$.

All estimations are done by two-step GMM procedure. In Blundell–Bond GMM estimations, 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 $ln\, C_{it}$. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2. Total number of instruments is 20.

Out of a total of 122 universities, there are 103 English universities that are geographically located in England, whereas 74 post-1992 universities are those receiving university status through the Further and Higher Education Act 1992.

Table 5. Average efficiency improvement and aggregate emissions reduction

Year	Total CO2 emissions (GtCO2e)	Emissions reduction (%), from 2008-09 level	Mean efficiency	Efficiency improvement (%), from 2008-09 level
2008-09	2.3409	0	1	0
2009-10	2.3239	0.73	1.0482	4.82
2010-11	2.2875	2.28	1.0995	9.95
2011-12	2.2037	5.86	1.1920	19.20
2012-13	2.1542	7.98	1.1487	14.87
2013-14	2.1302	9.00	1.3246	32.46
2014-15	2.0625	11.89	1.3814	38.14
2015-16	1.9157	18.16	1.4741	47.41
2016-17	1.7801	23.96	1.5158	51.58
2017-18	1.6275	30.48	1.5342	53.42
2018-19	1.5109	35.46	1.6269	62.69

Notes: Emissions are for aggregates for 122 universities in our estimating sample by year. Mean efficiencies are average for 122 universities by year for the efficiency index $EFF_{it} = \frac{1}{F_{it}^{EFF}}$ according to equation (2).

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Appendices

Table A1. List of UK universities

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

Notes. Out of a total of 122 universities, there are 103 English universities that are geographically located in England, whereas 74 post-1992 universities are those receiving university status through the Further and Higher Education Act 1992. Twelve administrative regions (NUTS 1 statistical regions), in alphabetic order, are: EAST = East of England; EMID = East Midlands;

LONDON = London; NEAS = North East; NIRE = Northern Ireland; NWES = North West; SCOT = Scotland; SEAS = South East; SWES = South West; WALE = Wales; WMID = West Midlands; YORH = Yorkshire and the Humber.

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

Variables	Entire sample	English universities	Post-1992 universities
ln C_{it-1}	0.2565**	0.2637**	0.2657***
	(0.1055)	(0.1197)	(0.0993)
ln Y_{it}	0.4908***	0.4941***	0.6151***
	(0.1504)	(0.1768)	(0.2228)
ln EFF_{it}	-0.5247***	-0.4677***	-0.5720***
	(0.1010)	(0.1134)	(0.1383)
ln F_{it}^{ACT}	0.9684***	0.8881***	0.7364***
	(0.2803)	(0.2833)	(0.2684)
Constant	0.5939	0.1553	-1.0714
	(1.7292)	(2.0188)	(2.1807)
No. of Obs.	1,220	1,030	740
No. of Universities	122	103	74
No. of Years	10	10	10
Year FE	YES	YES	YES
Hansen p	0.148	0.0346	0.513
Hansen df	6	6	6
No. of instruments	20	20	20

Notes: Robust/Corrected standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variable is the log of CO2 emissions per-capita denoted by $ln\ C_{it}$.

All estimations are done by one-step GMM procedure. In Blundell–Bond GMM estimations, 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 $ln\ C_{it}$. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2. Total number of instruments is 20.

Out of a total of 122 universities, there are 103 English universities that are geographically located in England, whereas 74 post-1992 universities are those receiving university status through the Further and Higher Education Act 1992.