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Energy use and CO2 emissions in the UK universities: An extended Kaya identity analysis

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ABSTRACT

We investigate the progress of the UK universities in greening their energy sources in line with the UK's goal of becoming a net-zero economy by 2050. Using the HESA estate management data for 116 universities over 2012-13 to 2018–19, we employ a Log Mean Divisa Index decomposition method within an extended Kaya identity framework to decouple the changes in total carbon emissions from a range of variables, with a special focus on the impact of different energy sources on energy use and carbon efficiency measures. Overall, between 2012-13 and 2018–19, universities have reduced emissions by 29% although their energy consumption remained mostly stable, implying that these reductions mostly stemmed from reductions in emission coefficient effect (which measures carbon efficiency of energy generation) by 24% and energy intensity effect by 25%. Consistently, estimated correlation coefficients confirm that emission coefficient, intensity, and affluence effects are major contributors behind the annual change in total emissions, with estimated correlation coefficients being 0.42, 0.66, and −0.24, respectively. The share of renewable energy sources was reduced by 2.2%, which is a major reason, in addition to increased number of students, behind the sector's overall failure achieve the 2020 goal of reducing emissions by 43% from the 2005 level. Finally, our results also expose considerable regional variations in mitigating and worsening factors behind emissions that calls for stronger coordination and supervision by policymakers.

1. Introduction

Limiting the global temperature increase to 1.5 °C as has been pledged in Paris (UNEP, 2019) requires each country to adopt more enhanced actions. The United Kingdom, one of the Annex I countries, reduced its GHG emissions from 600 mt CO2e in 1990 to 364.1 mt CO2e in 2018, and recently pledged to become a net-zero emitter by 2050 (Climate Change Act 2008 (2050 Target Amendment) Order 2019, 2019). Successful achievement of this ambitious target requires each economic sector to cleaning their production systems by reducing their own emissions through increased energy efficiency and uptake of renewable energy sources. Sectoral assessments of adoption of such strategies and their respective contributions in emissions reduction are important for policy implementation and effectiveness. Against this backdrop, our objective is to investigate how increasing energy efficiency and adopting renewable energy sources can help UK Higher Education (UKHE) sector reduce its emissions.

In 2010, the UKHE sector pledged to reducing its emissions by 43% by 2020 from its 2005 level (HEFCE, 2010). Specific actions include establishing energy performance indicators, encouraging the adoption of greener technologies, and embedding sustainability in university curricula to create awareness in students and staff. Despite these concerted efforts, nearly 70% of universities are likely to fail the 2020 emission reduction target (Lightfoot, 2019).

Understanding the reasons behind their relative failures in achieving targeted levels of emissions reduction in the last decade and accordingly guiding their future activities in the right direction, universities need to investigate the link between their use of different energy sources and the

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associated emissions. We make a number of contributions to this pursuit. First, this is the first research on the UKHE sector using a panel dataset investigating the changes that occurred since the introduction of emissions reduction targets and by analyzing which actions contributed to the observed emissions reduction. While the literature on energy use and sustainability at the university level is growing (e.g., Findler et al., 2019; Wadud, Royston, and Selby, 2019), but quantitative investigations into the state of overall progress in reducing carbon emissions through sourcing greener energy in the higher education sectors are still scarce mostly due to the lack of comprehensive and homogenous data. Moreover, most quantitative studies investigate the carbon emissions or energy usages for individual universities (e.g., Ozawa-Meida et al., 2013; Escobedo et al., 2014; Larsen et al., 2013; Sreedharan et al., 2016; Mendoza-Flores, Quintero-Ramírez, and Ortiz, 2019; Clabeaux et al., 2020; Gui, Gou, and Zhang, 2020) or even buildings (e.g., Amber, Aslam, and Hussain, 2015).

Next, we adopt an extended Kaya identity approach (e.g., Ma and Stern, 2008; Wang, Chen, and Zou, 2005; Ma, Cai, and Cai, 2018; Wang et al., 2020) where we explicitly include the share of renewables in the energy mix and their respective carbon emissions. By employing the Log Mean Divisa Index (LMDI I) decomposition method, we identify several important factors driving the changes in energy use, and their influence on total carbon emissions.

Finally, we exploit the availability of continuous data on the sector's energy and emissions performance that was compiled and maintained by the Higher Education and Statistics Agency (HESA). From 2012-13 to 2018–19, the HESA database provides, among others, the different energy sources used and their respective carbon emissions, student numbers, and income figures for over 160 participating higher education institutes or universities, of which 116 were suitable for our investigation.[1]

Our results identify that emissions reduction in the UK universities have mainly stemmed from gains in the carbon efficiency of energy generation from natural gas and grid electricity, and the reduction of energy intensity of economic activities. On the other hand, carbon-neutral renewable sources played a minor role in this process, mainly because of their low shares in total energy use.

These findings have important policy implications for the UKHE sector and its contribution to the national climate struggle. First, the UK universities are behind the national target of adopting at least 12% of heat from renewable sources by 2020. Although the total share of renewable and green energy are above this target level, carbon-neutral renewable sources only constitute less than 1% in the sector's energy mix. The UKHE sector needs to increase its investment in renewables for complying with the national goal of net-carbon neutrality by 2050. Next, although universities benefit from reduced energy intensity and emission coefficient and increased income, most of them failed to meet their respective targets mainly because of their inability to increase the share of renewable energy. In addition to improved energy efficiency, increased use of renewable energy can reduce the rebound effects from increased population and can further reduce emissions. Finally, strong regional variations in the effect of income on emissions reduction reinforce the need for increased supports and guidelines from the government. Especially the lower-income universities with lower shares of renewables can benefit from supervision from the government, which can in turn increase the overall contribution of the sector towards the net-zero transition of the UK economy.

2. Literature review

The topic of sustainability generally and the role of universities in the transition towards a greener economy specifically are important in political and academic discourses. However, the landscape of sustainability reports of universities is heterogenous, patchy, and discontinuous (Sassen, Dienes, and Wedemeier, 2018), resulting in quantitative investigations remain relatively scarce.

In absence of quality panel data, most related studies focused on either cross-sectional or time-series data analysis. Fetcher (2009) and Wadud, Royston, and Selby (2019) are among the few notable exceptions. By controlling for gross building area, number of full-time equivalent students, and several climate indicators, Fetcher (2009) investigated the variations in GHG emissions of 238 US universities. Findings show that carbon efficiency was negatively correlated with size and research intensity of an institute. Wadud, Royston, and Selby (2019) connected energy efficiency changes with the changes in income, space, and population using the HESA data set for 144 UK universities from the years 2002-03 to 2014–15. The results suggest that the institutes' growth over time correlates positively with efficiency gains due to economies of scale.

In related research, Klein-Banai and Theis (2013) further suggest that research orientation represented by larger areas used as laboratories makes it more difficult to reduce GHG emissions and support Fetcher (2009) that size generally has a negative impact on carbon efficiency. They also identify that universities with larger residential facilities produce more emissions due to continuous energy use during night-times and weekends. Applying a similar regression analysis, Wang (2016) finds similar results for primary and secondary education institutes in Taiwan.

Index decomposition analysis (IDA) methods, such as Kaya identity, are heavily used in the investigation of national, regional, and sectoral changes in carbon emissions to decouple these from economic or population growth. This procedure distributes change in a dependent variable on several predefined factors consistently (Ang and Wang, 2015). Based on the IPAT identity, which models the environmental impact of population, affluence, and technology (Commoner, 1972; Ehrlich and Holdren, 1972), Kaya identity models carbon emissions as a function of energy consumption. Especially in recent years when GHG emissions entered the center of public and scientific attention while data availability increased, such IDA methods gained increased attention (see Ang (2015) for a comprehensive review until 2013). Since then, a broad range of topics was covered, and the methodology was refined to serve different research purposes.

To analyze the carbon emission contribution of different types of fossil fuels and especially renewables as carbon-neutral energy sources, Ma and Stern (2008) and Wang, Chen, and Zou (2005) extended the identity and employed the LMDI decomposition methodology. O'Mahony (2013) employs this extension to analyze country-level data of Ireland from 1990 to 2010. He shows that income and population growth are the main drivers of carbon emission growth and are counteracted by energy intensity and substitution between different types of fossil fuels. The impact of the penetration of renewables grew only in the final years and reflects the increased importance of renewables in the energy mix. In related research, Cicea et al. (2014) further include an index of the environmental efficiency of environmental investments and analyzed the performance of several European countries from 1990 to 2008.

For China during 1995–2011, Xu, He, and Long (2014) extended the Kaya identity by distinguishing industrial sectors and regions to investigate their energy consumption and carbon emissions. Their results suggest that the energy intensity of different types of industry is responsible for the differences in carbon emissions.

3. Energy and emissions in the UK higher education sector

The UKHE sector uses energy from different sources (Table A1), with natural gas and grid electricity being the most common sources. On average, universities use 22.804 kWh and 21.689 kWh of energy produced by natural gas and grid electricity. Renewable sources play a

[1] Earlier rounds of the HESA database from 2008-09 to 2011-12 do not provide the breakdown of all energy sources and their corresponding emissions.

relatively minor role in the energy mix of UKHE sector. The largest source of renewables is steam and hot water with mean usage of 1.799 kWh and a range of 0–90.246 kWh. Other renewables, i.e., biomass (0.213 kWh average), onsite photovoltaic (0.061 kWh), onsite wind (0.057 kWh) and other onsite renewables (0.023 kWh), are even scarcely used.

Universities exhibit large variations in their energy sources: except for grid electricity, no other sources are commonly used by all universities. Unsurprisingly, majority of CO2 emissions are originated from their use of natural gas and grid electricity (Table A2). On average, energy from grid electricity and natural gas are responsible for 8.379 kg CO2 and 5.931 kg CO2 emissions. Compressed natural gas and steam and hot water are the third and fourth largest sources of carbon emission, with 0.392 kg CO2 and 0.370 kg CO2 average emissions. The emissions of oils and fuels for transportation contribute with small numbers, which was expected due to their small share in the energy mix.

Renewables are divided into carbon-emitting and carbon-neutral sources. Biofuels and Biomass are burned in the generation process and are distinguished from other fuels only due to their non-fossil characteristics. The use of photovoltaic, wind, and other renewables does not produce any carbon emissions.

Fig. 1 depicts the annual changes in carbon emission per kWh of different energy sources for UK HEIs. While the emissions from energy generated from natural gas fluctuated strongly and stabilized in the second half of the study period, the respective value for grid electricity increased constantly to settle on a low emission level, marginally below natural gas. Emissions from oil remain high and roughly unchanged, whereas the renewables produce low emissions that decreased over time.

During the study period, the UKHE sector experienced increased income and student numbers. Fig. 2 exhibits ratios of energy and emissions to income and population for different categories of energy. Panel A plots energy/£, i.e., the ratio of energy consumption (kWh) and income, and shows that income slightly decoupled from energy consumption, especially for natural gas and grid electricity. Similarly, Panel B shows that energy per-capita from natural gas and grid electricity decreased over the study period. In both cases, oil and renewables remain roughly unchanged at their respective levels.

Panels C and D depict the carbon intensities of income and population for by the respective energy source. Emission per-£ from grid electricity has starkly decreased while that from gas has decreased at a lower rate. On the other hand, per-capita emissions show a similar pattern for grid electricity and natural gas. Both oil and renewables show very low values for the whole period because of their relatively smaller shares in total energy mix.

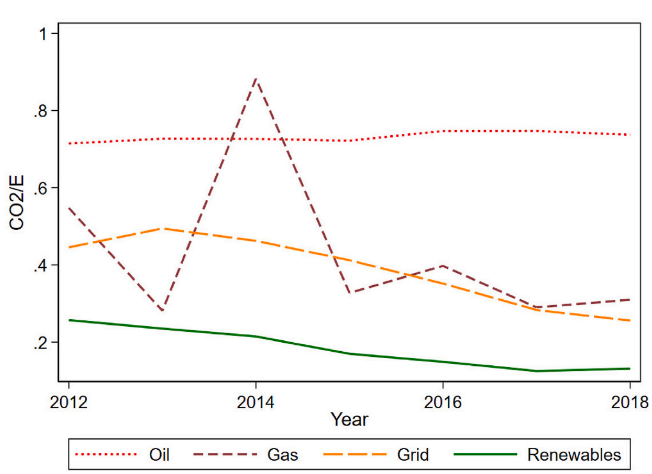

Fig. 1. Carbon emissions (kg CO2e) relative to energy use (kWh). Source: Author's own calculation using HESA data, based on stata software.

4. Data and method

A. Extended Kaya Identity

Index decomposition analysis is used to distribute change in a dependent variable "in a consistent manner to a set of pre-defined factors" (Ang and Wang, 2015). If the variable of interest is the total CO2 emissions, which depends on various macroeconomic and energy-related variables, the Kaya identity, first introduced by Kaya (1990) and later formalized by Zhang and Ang (2001), can be the most important technique to illustrate this connection (Ang, 2015). It is a specification of the IPAT approach that describes the impact of human activity on nature to explicitly model the effects of energy consumption on carbon emissions.

In the Kaya identity, total CO2 emissions are expressed by

$$C = \sum_i C_i = \sum_i \left(\frac{C}{TEC}\right)\left(\frac{TEC}{Y}\right)\left(\frac{Y}{P}\right)P = \sum_i F \times I \times G \times P \tag{1}$$

where TEC, C, Y, and P denote total energy consumption of all fuel types, total CO2 emissions, income, and population, respectively. These variables are then combined to define $F = C/E$ as the carbon intensity of energy use, $I = TEC/Y$ as energy intensity of economic activity, and $G = Y/P$ as per-capita income or affluence.

This approach, however valuable, is not suitable for investigating the effects of shifts in the composition of energy sources. Increased penetration of renewables may not be analyzed if the dependent variable is total CO2 emissions because those are theoretically equal to zero for renewable energy sources.

To specifically address the effects of switching from fossil fuels to renewables, Ma and Stern (2008) and Wang, Chen, and Zou (2005) extended the original Kaya identity by decomposing the carbon intensity of energy use F into two components to account for possible shifts by increasing the share of renewables according to

$$F = \left(\frac{C}{FFC}\right)\left(\frac{FFC}{TEC}\right) \tag{2}$$

where FFC denotes total use of energy from all fossil fuel sources. This extended Kaya identity has since been extensively used for investigating the effects of renewable energy sources on carbon emissions (e.g. O'Mahony, 2013, Lin and Raza, 2019; Lin and Ouyang, 2014).

For UK universities, we define Y as total income received by a university in a given year from all sources, and S as the number of full-time equivalent students. We then integrate them into the extended Kaya identity according to

$$\begin{aligned} C &= \sum_i \left(\frac{C_i}{FFC_i}\right)\left(\frac{FFC_i}{FFC}\right)\left(\frac{FFC}{TEC}\right)\left(\frac{TEC}{Y}\right)\left(\frac{Y}{S}\right)S \\ &= \sum_i CIF_i \times SFF_i \times SFF \times I \times G \times S \end{aligned} \tag{3}$$

where $CIF = C/FFC$ denotes the carbon intensity of fossil fuel type i, $SFF_i = FFC_i/FFC$ the share of fossil fuel type i in total fossil fuel consumption, $SFF = FFC/TEC$ the share of all fossil fuel types in total energy consumption, $I = TEC/Y$ the aggregate energy intensity of all sources, and $G = Y/S$ the income per student. We do not include time and university subscripts for notational simplicity.

We decompose the observed change in C into different effects according to (3), which can be done using either the additive or multiplicative method (Ang, 2005). While the first deconstructs the differences in absolute changes into different changes linked with it, the latter measures the changes in the ratio (Ang and Liu, 2001). We adopt the multiplicative method, which is more suitable since it allows us to compare the progress of UK universities towards their pledged target of reducing emissions by 43% from their 2005 levels. Also, the multiplicative method is neutral to the size of the university, therefore mostly reducing the biases that might arise from different sizes of

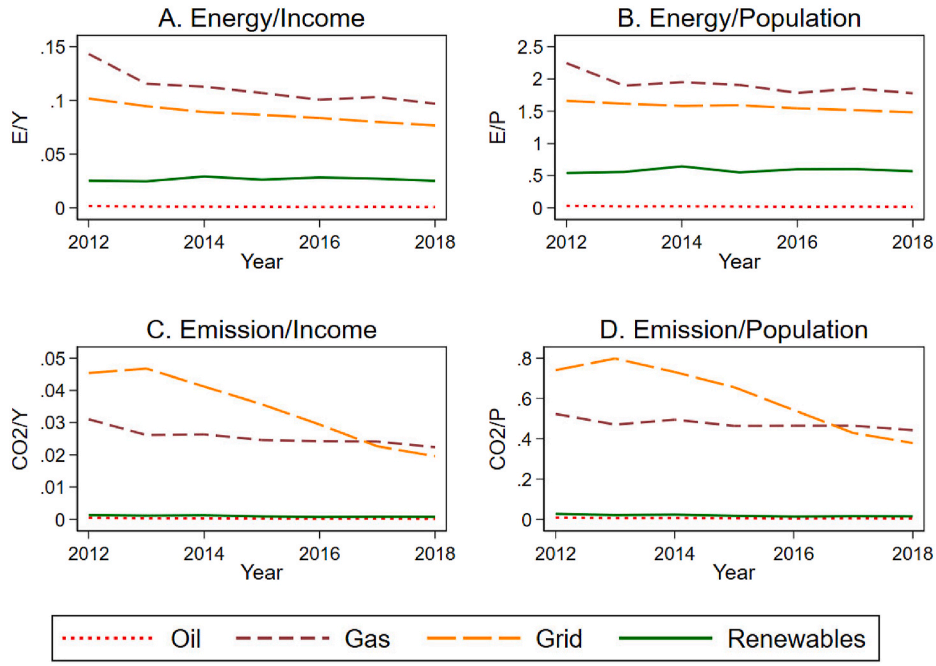

Fig. 2. Emission-energy situation: ***A.*** *energy intensity of economic activity (kWh/£),* ***B.*** *energy consumption per student (kWh/FTE),* ***C.*** *carbon intensity of economic activity (kg CO2e/£),* ***D.*** *CO2 emissions per student (kg CO2e/FTE).*
Source: Author's own calculation using HESA data, based on stata software.

population and income.

Finally, following O'Mahony (2013), the decomposition of an observed change in carbon emission C is associated to the six components on the right-hand side of equation (3), which are termed as the emission coefficient effect (C_{emc}), the fossil fuel substitution effect (C_{ffse}), the renewable energy penetration effect (C_{repe}), the intensity effect (C_{int}), the affluence effect (C_{ypc}), and the population effect (C_{pop}), so that the index of annual change in total CO2 emissions (C_{tot}) can be expressed in the multiplicative form as

$$C_{tot} = C_t / C_0 = C_{emc} \times C_{ffse} \times C_{repe} \times C_{int} \times C_{ypc} \times C_{pop} \tag{4}$$

We then employ the Log Mean Divisia Index (LMDI I) method for decomposing these indices. The approach, LMDI I, provides perfect decomposition, consistent aggregation, and allows for path-dependency and zero values (Ang, 2004, 2015). Specific formulae used for decomposition are:

$$\begin{aligned}
C_{emc} &= \exp\left(\sum_i w_i \ln\left(\frac{CIF_{it}}{CIF_{i0}}\right)\right) \\
C_{ffse} &= \exp\left(\sum_i w_i \ln\left(\frac{SFF_{it}}{SFF_{i0}}\right)\right) \\
C_{repe} &= \exp\left(\sum_i w_i \ln\left(\frac{SFF_t}{SFF_0}\right)\right) \\
C_{int} &= \exp\left(\sum_i w_i \ln\left(\frac{I_t}{I_0}\right)\right) \\
C_{ypc} &= \exp\left(\sum_i w_i \ln\left(\frac{G_t}{G_0}\right)\right) \\
C_{pop} &= \exp\left(\sum_i w_i \ln\left(\frac{S_t}{S_0}\right)\right)
\end{aligned} \tag{5}$$

where $w_i = \frac{C_{it} - C_{i0}}{\ln C_{it} - \ln C_{i0}} \Big/ \frac{C_t - C_0}{\ln C_t - \ln C_0}$. We add a small positive number (i.e., 10^{-6}) with each energy sources i to avoid missing observations.

B. HESA Data

The dataset used in this study is compiled and maintained by the Higher Education and Statistics Agency (HESA) according to the 1992 Higher and Further Education Act. It is a collection of self-reported statistics of all Higher Education Institutes in the UK that offer certified courses of tertiary education. The dataset comprises extensive information on students, staff, graduates, finances, business and community interaction, and estates management. Data on estate management has been collected since 2001–02, and has been extended to Scotland, Wales, and Northern Ireland since 2008–09. Only since 2012-13 the dataset includes disaggregated information on scopes 1, 2 and 3 carbon emissions associated to respective energy sources. These extensions of gathered statistics were part of the efforts that followed the Climate Change Act of 2008, in which the parliament obliged the government to ensure that the UK fulfills all Kyoto Protocol requirements.

Gradually, the dataset was refined and extended to different universities, till most of them report their energy use disaggregated into different fuel types and corresponding carbon emissions. This data is comprehensively available from the fiscal year of 2012–13, which therefore serves as the starting period in this investigation. The last period is 2018–19, however, reporting for this year was voluntary because of the ongoing COVID-19 pandemic.[2]

More than 160 universities reported their carbon emissions and fossil fuel consumption to the HESA. We exclude universities that did not provide data for all years, and those focusing on specialized training instead of conventional tertiary education (e.g., the Liverpool Institute of Performing Arts teaches a very limited set of music, theatre, and dance-related courses). In addition, to avoid double reporting, universities with sub-structures (e.g., University of London) such as colleges

[2] Estate management data are traditionally reported with one-year lag.

Table 1
Energy sources and CO2 emissions.

Variables	Description	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019
E_1	Energy from oil and others	0.291 (0.626)	0.211 (0.499)	0.270 (0.702)	0.203 (0.464)	0.153 (0.366)	0.178 (0.419)	0.168 (0.419)
E_2	Energy from gas	28.157 (26.425)	23.929 (22.984)	24.585 (23.941)	24.427 (25.050)	23.759 (23.531)	25.116 (24.973)	24.656 (24.958)
E_3	Energy from grid electricity	22.193 (24.305)	21.703 (24.173)	21.178 (23.094)	21.785 (25.156)	21.562 (25.117)	21.766 (25.978)	21.634 (25.291)
E_4	Energy from renewable sources	8.038 (18.870)	8.146 (18.422)	9.802 (22.837)	8.376 (19.088)	9.350 (20.771)	9.532 (21.376)	8.987 (21.051)
E_B	Total brown energy consumption	50.641 (49.340)	45.843 (45.912)	46.033 (45.764)	46.415 (48.878)	45.474 (47.061)	47.061 (49.536)	46.459 (48.746)
E	Total energy consumption	58.680 (59.946)	53.989 (56.653)	55.835 (58.954)	54.791 (57.429)	54.823 (58.017)	56.592 (60.638)	55.446 (59.251)
C_1	Emissions from oil and other energy	0.076 (0.161)	0.055 (0.129)	0.071 (0.187)	0.054 (0.125)	0.041 (0.098)	0.048 (0.112)	0.043 (0.107)
C_2	Emissions from gas energy	6.587 (7.106)	5.980 (6.986)	6.369 (7.611)	6.029 (6.882)	6.431 (7.998)	6.567 (7.938)	6.318 (7.734)
C_3	Emissions from grid electricity	9.887 (10.827)	10.727 (11.948)	9.788 (10.674)	8.977 (10.365)	7.580 (8.830)	6.161 (7.354)	5.530 (6.464)
C_4	Emissions from renewable sources	0.569 (2.358)	0.426 (1.725)	0.454 (1.688)	0.360 (1.330)	0.258 (0.879)	0.290 (0.918)	0.270 (0.836)
C_B	Total emissions from brown energy	16.550 (17.063)	16.762 (17.757)	16.229 (16.960)	15.060 (16.039)	14.052 (15.389)	12.776 (14.143)	11.891 (13.184)
C	Total CO2 emissions	17.119 (17.973)	17.188 (18.404)	16.682 (17.616)	15.420 (16.511)	14.310 (15.654)	13.066 (14.436)	12.162 (13.447)

Notes. Standard deviations are shown in parentheses. All data comes from the Higher Education and Statistics Agency (HESA) dataset for the fiscal years 2012-13 to 2018–19. All monetary values are expressed in GBP. Energy units are expressed in kWh, whereas emission units are in kg CO2e.
Source: Author's own calculation using HESA data, based on stata software

that provide their separate data are also excluded.

Altogether, we confine to 116 universities for 2012-13 to 2018-19 from London and the Southeast of England (36), Rest of England (63), and Rest of the UK (17). Table A4 appends the list of universities.

C. Construction of Variables

We categorize all sources of energy and associated CO2 emissions into four groups (Table 1). The first group E_1, includes all energy that is produced using different types of oils. This includes burning oil, fuel oil, gas oil, and lubricants. The second group, E_2, comprises energy from different types of gas (e.g., compressed natural gas, liquefied natural gas, liquefied petroleum gas, natural gas excluding that used as input for a CHP unit, and Other petroleum gas). The third group includes energy from grid electricity (E_3). Finally, all renewable and green energy sources such as onsite photovoltaic, onsite wind, other onsite renewables, steam and heat, biofuels, CHP heat and electricity, petroleum coke, and biomass are included in the fourth group (E_4). Corresponding CO2 emissions, $C_1 - C_4$, are also reported.

Total energy consumption remained relatively stable on average, after an initial sharp drop from 58.680 kWh in 2012-13 to 53.989 kWh in 2013–14, which was associated to a similar reduction in gas use from 28.157 kWh to 23.929 kWh during the same period. Energy use stabilized from then on and fluctuated around 55.000 kWh for total energy consumption and around 24.500 kWh for energy from gas. Average energy consumption from oils ranges 0.153–0.291 kWh with slightly lower values for later periods. Grid electricity constantly provided energy between 21.178 and 22.193 kWh on average. The consumption of energy from renewable and green sources, on the other hand, fluctuated between 8.038 and 9.532 kWh with high standard deviations relative to mean values for all the years.

Total carbon emissions decreased by 29% over the study period, from 17.119 kg CO2e to 12.162 kg CO2e on average. Since energy consumption remained mostly stable, this improvement has probably caused by technical efficiency of the sources of energy in reducing emissions, instead of universities themselves switching to more carbon-neutral sources.

Table 2 reports the variables constructed for the extended Kaya identity analysis. $C_xE_x\ \forall x$ shows the carbon intensity of the respective sources in kg CO2e per kWh of generated energy. $S_1E_x\ \forall x$ represents the shares of each carbon-emitting energy sources in total carbon-emitting energy. Gas and grid electricity together made up about 90% of the total consumption of carbon-emitting energy. Overall, carbon-emitting energy comprises 99.7% of the energy demand on average.

Average total income (Y) of UK HEIs, measured in million GBP, has increased steadily by 38% over the study period from £213.237 million in 2012–2013 to £295.143 million in 2018–2019. The full-time equivalent (FTE) number of students (P) also went up but at a much slower rate of 8.6%, from 12,445 FTE students per university in 2012-13 to 13,518 FTE students in 2018–19. Therefore, the income per student (G) rose from £16,470 to £20,194, which accounts for an increase of 22.6%. Finally, the aggregate energy intensity of activities (I), which is constructed of income and total carbon emissions, has decreased from 0.272 kg CO2e/£1 to 0.2 kg CO2e/£1, or by 26.5%.

5. Results and discussion

Table 3 contains the complete results of the LMDI decomposition indices, which are then plotted in Fig. 3. The total carbon emissions of the UKHE sector, C_{tot}, have decreased by 29% over the study period. Among the specific components, C_{emc} and C_{int} were reduced considerably by 24% and 25%, respectively. These improvements potentially emerge from investments and technological developments in the use of gas and the withdrawal of coal in the national electricity generation. On the other hand, energy intensity benefited from investments in waste reduction measures and more effective use of heat and electricity. In addition, C_{repe} was also reduced by 2.2% implying that the share of renewables declined over the study period. Moreover, C_{ypc} and C_{pop} were increased considerably by 22% and 8% respectively, in addition to a 2% increase in C_{ffse}.

Table 4 reports the correlation between C_{tot} and the indices on the right-hand side of equation (4). For all universities, correlation coefficients show that the intensity effect (C_{int}) and the emission coefficient effect (C_{emc}) have strong and positive correlation with the annual change in total CO2 emissions. Moreover, the affluence effect (C_{ypc}) is negatively correlated to C_{tot}, i.e., increased C_{ypc} reduced C_{tot} probably through increased investments in emissions reduction technologies.

Table 2
Construction of variables.

Variables	Description	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019
Y	Income – million GBP	213.237 (223.046)	224.550 (236.568)	243.066 (268.822)	253.553 (281.024)	260.873 (289.215)	279.673 (339.697)	295.143 (369.008)
P	No. of FTE students (thousands)	12.445 (6.738)	12.421 (6.718)	12.451 (6.963)	12.687 (7.229)	13.057 (7.508)	13.319 (7.806)	13.518 (8.003)
C_1E_1	kg CO2e per kWh energy – oil and other sources	0.714 (0.360)	0.727 (0.357)	0.727 (0.358)	0.722 (0.357)	0.747 (0.351)	0.747 (0.350)	0.737 (0.357)
C_2E_2	kg CO2e per kWh energy – gas sources	0.548 (3.367)	0.281 (0.426)	0.883 (6.789)	0.327 (0.897)	0.397 (1.504)	0.290 (0.500)	0.310 (0.657)
C_3E_3	kg CO2e per kWh energy – grid electricity	0.445 (0.000)	0.494 (0.000)	0.462 (0.000)	0.412 (0.000)	0.352 (0.000)	0.283 (0.000)	0.256 (0.000)
C_4E_4	kg CO2e per kWh energy – renewables	0.257 (0.416)	0.235 (0.399)	0.214 (0.380)	0.170 (0.350)	0.149 (0.333)	0.125 (0.303)	0.131 (0.314)
S_1E_1	Share of oil energy in total brown energy	0.006 (0.015)	0.005 (0.012)	0.005 (0.011)	0.004 (0.009)	0.004 (0.009)	0.004 (0.010)	0.004 (0.009)
S_1E_2	Share of gas energy in total brown energy	0.554 (0.130)	0.521 (0.136)	0.534 (0.133)	0.527 (0.134)	0.521 (0.133)	0.537 (0.130)	0.532 (0.131)
S_1E_3	Share of grid electricity energy in total brown energy	0.440 (0.131)	0.474 (0.137)	0.461 (0.135)	0.469 (0.136)	0.475 (0.135)	0.459 (0.132)	0.465 (0.132)
S_2E_B	Share of total brown energy in total energy	0.914 (0.142)	0.906 (0.150)	0.892 (0.161)	0.898 (0.156)	0.887 (0.161)	0.890 (0.150)	0.891 (0.153)
I	Aggregate energy intensity of activities (kg CO2e per GBP income)	0.272 (0.086)	0.236 (0.073)	0.232 (0.076)	0.221 (0.075)	0.213 (0.072)	0.211 (0.072)	0.200 (0.068)
G	Income per student (thousand GBP per student)	16.470 (12.451)	17.227 (12.789)	18.383 (13.985)	18.893 (14.842)	18.881 (14.617)	19.531 (16.406)	20.194 (17.489)

Notes. Standard deviations are shown in parentheses. All data comes from the Higher Education and Statistics Agency (HESA) dataset for the fiscal years 2012-13 to 2018–19. All monetary values are expressed in GBP. Energy units are expressed in kWh, whereas emission units are in kg CO2e. All the variables follow the definitions in equation (1) – (3).
Source: Author's own calculation using HESA data, based on stata software

Therefore, reductions in C_{int} and C_{emc} and increase in C_{ypc} are the principal drivers behind overall reductions in emissions (Fig. 3).

Such strong declines in emissions were partially counteracted by the population effect (C_{pop}): a positive correlation between C_{tot} and C_{pop} implies that the increase in the number of students resulted in a partial rebound effect on emissions.

On the other hand, fossil fuel substitution effect (C_{ffse}) and the renewable energy penetration effect (C_{repe}) have positive correlations with C_{tot}. However, they were not influential in determining C_{tot} due to their relatively unchanged levels over the study period.

To investigate whether there exists any regional variation due to varying structures within England and between the different legislative bodies in the UK and to check the overall validity of our results, we separately calculate the correlation coefficients for three regions as reported in columns 2–4 of Table 4. Universities located in London and the southeast of England are distinguished from those in the rest of England and further from those under the administrative rule of the local governments of Northern Ireland, Scotland, and Wales.

For most of the indices, the magnitudes of correlation coefficients vary by regions but the directions of relationships remain the same. C_{int} and C_{emc} show the strongest and homogenous correlation with the changes in total carbon emissions in all the regions. Other indices have more regional variations. For example, while the fossil fuel substitution effect (C_{ffse}) is negatively correlated with the total effect (C_{tot}) for the rest of the UK, it shows significantly positive correlation for two English regions. At the same time, the per-capita income effect was strongly negatively correlated in London and the Southeast and the rest of England but the correlation was negative for the Rest of the UK. These estimated correlation coefficients are further confirmed by Fig. 4.

Despite reducing emissions by 29%, the UKHE sector is well behind its 43% emissions reduction goal for 2020 due to increasing number of students and underutilization of renewable and carbon-neutral energy sources. Moreover, since total energy consumption roughly remains at the same level, such emissions reductions definitely stemmed from important yet relatively short-term mitigating factors such as reduced emission intensity and emissions coefficient and increased affluence instead of renewable energy sources which can provide the long-term sustainable mitigation. Especially for London and the Southeast, increasing their share of renewables can at least partly offset the rebound effects those universities experience from increased number of students.

Overall, the short-term nature of the mitigating factors can make the current levels of emissions reductions unsustainable unless the UK universities increase their use of renewables in addition to improvements in

Table 3
Components of LMDI I.

Variables	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019
C_{tot}	1	1.012 (0.123)	0.999 (0.181)	0.918 (0.169)	0.842 (0.167)	0.762 (0.161)	0.710 (0.152)
C_{emc}	1	1.085 (0.093)	1.055 (0.125)	0.972 (0.118)	0.904 (0.121)	0.801 (0.127)	0.762 (0.144)
C_{ffse}	1	1.032 (0.059)	1.016 (0.045)	1.030 (0.080)	1.028 (0.063)	1.022 (0.098)	1.019 (0.081)
C_{repe}	1	0.992 (0.059)	0.978 (0.109)	0.986 (0.118)	0.972 (0.112)	0.976 (0.105)	0.978 (0.121)
C_{int}	1	0.874 (0.090)	0.862 (0.133)	0.820 (0.157)	0.797 (0.163)	0.793 (0.179)	0.749 (0.167)
C_{ypc}	1	1.052 (0.059)	1.123 (0.081)	1.152 (0.107)	1.157 (0.120)	1.186 (0.162)	1.218 (0.174)
C_{pop}	1	1.001 (0.044)	0.998 (0.084)	1.014 (0.115)	1.044 (0.148)	1.062 (0.182)	1.077 (0.196)

Notes. Standard deviations are shown in parentheses. All data comes from the Higher Education and Statistics Agency (HESA) dataset for the fiscal years 2012-13 to 2018–19. All the variables follow the definitions in equations (4) and (5).
Source: Author's own calculation using HESA data, based on stata software

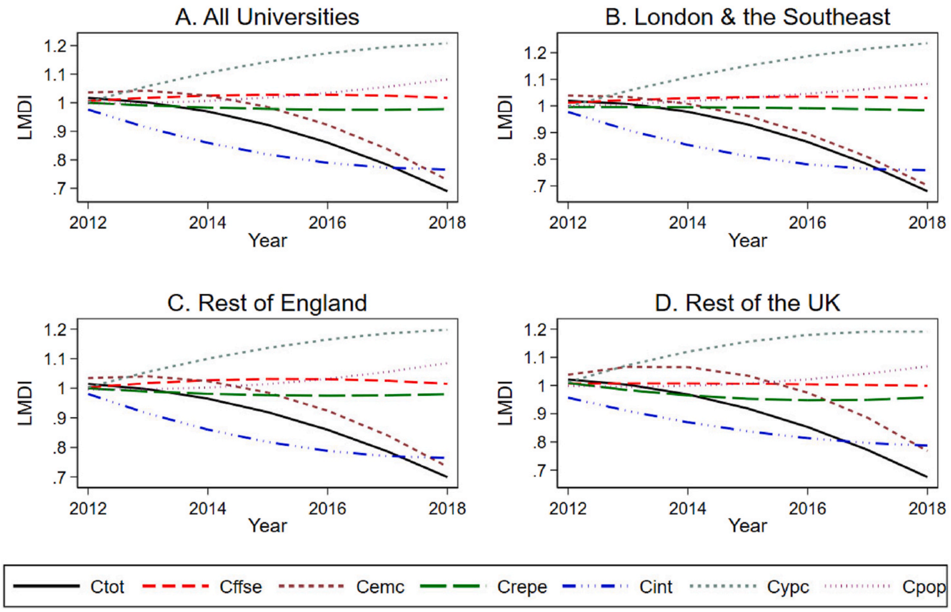

Fig. 3. LMDI for CO2 emissions of UK universities, 2012-13 to 2018-19.
Source: Author's own calculation using HESA data, based on stata software.

Table 4
Correlation matrix.

	C_{tot}			
	All University	London & the Southeast	Rest of England	Rest of the UK
C_{emc}	0.42***	0.38***	0.49***	0.35***
C_{ffse}	0.18***	0.37***	0.10*	−0.32***
C_{repe}	0.09*	0.12	0.06	0.13
C_{int}	0.66***	0.68***	0.67***	0.64***
C_{ypc}	−0.24***	−0.39***	−0.26***	−0.02
C_{pop}	0.04	0.20**	−0.02	−0.14

Notes. ***, ** and * represent statistical significance at 1%, 5%, and 10% levels, respectively. All data comes from the Higher Education and Statistics Agency (HESA) dataset for the fiscal years 2012-13 to 2018–19. All the variables follow the definitions in equations (4) and (5).
Source: Author's own calculation using HESA data, based on stata software

other indices to tackle increased population pressure. Universities can invest in on-campus energy generation such as rooftop solar energy and photovoltaic plants (Bódis et al., 2019), whereas the rural universities can additionally invest in hydropower and wind energy. The government can provide necessary supports through programs like the British Feed-in Tariffs, which funded installation and maintenance of photovoltaic plants over 2010–2019. During this period, the installed capacity of this technology rose from 95 MW to 13,398 MW (IRENA, 2020). Similar projects will be important in increasing the adoption of renewables in the universities in particular, and other economic and service sectors in general.

A higher share of renewables can indicate an university's commitment towards social justice, which might be an indicator of their intent for excellence in global ranking (e.g., Salvioni, Franzoni, and Cassano, 2017). Since students are increasingly concerned about climate change and 90% of UK students agree that their place of study should incorporate and promote sustainability (Students Organising for Sustainability, 2018), increased share of renewables may attract higher number of students as well. Hence, responsible energy management, which requires the inclusion of renewables, is an important factor for long-term growth of individual university.

The strong variations in efficiency change also carry opportunities for the universities, especially for newer institutions who can develop greener infrastructures. On the other hand, older universities might also invest in renovate their infrastructures to increase energy efficiency. In fact, energy efficiency refurbishments and compliance with high-efficiency criteria in new building projects are economically advantageous for all kinds of buildings and regions (Pikas et al., 2015; Zundel and Stieß 2011). With higher expected energy prices for the future and the longevity of buildings, investments become more of a necessity than an option.

In sum, the UKHE sector as well as other public service providers and businesses need to increase their use of renewable sources of energy to comply with national net-zero commitment by 2050. Focus can be given on increasing energy efficiency of existing infrastructure and generating renewable energy on-campus, with a special focus on solar energy generation that can be most easily employed locally. The UK government needs to take a clear and strong role in the transition process to a carbon-neutral society by creating adequate schemes and guiding the sector's development.

6. Conclusion

Nearly two-third of UK universities are unlikely to fulfill their ambition of reducing carbon emissions by 43% over 2005–2020 (Lightfoot, 2019), which is in stark contrast with the UK government's planned net-carbon-neutrality by 2050. This paper investigates the combination of energy sources that universities use and their respective carbon emissions. Based on an extended Kaya identity, we apply a Log Mean Divisa Index (LMDI I) decomposition method to decouple the effects of different factors on the changes in total carbon emissions of UK universities.

The main finding suggests a striking underutilization of GHG reduction potential from the use of carbon-neutral renewable energy sources. Universities can increase their energy efficiency and long-term profitability by increasing their investment in renewables such as photovoltaic, which is easy to install and maintain within existing facilities. Furthermore, carbon reduction was mainly caused by gains in carbon efficiency of energy generation and lower energy intensity of income creation. Due to widescale variations in their use of energy sources and progresses made in emissions reduction, it can be concluded

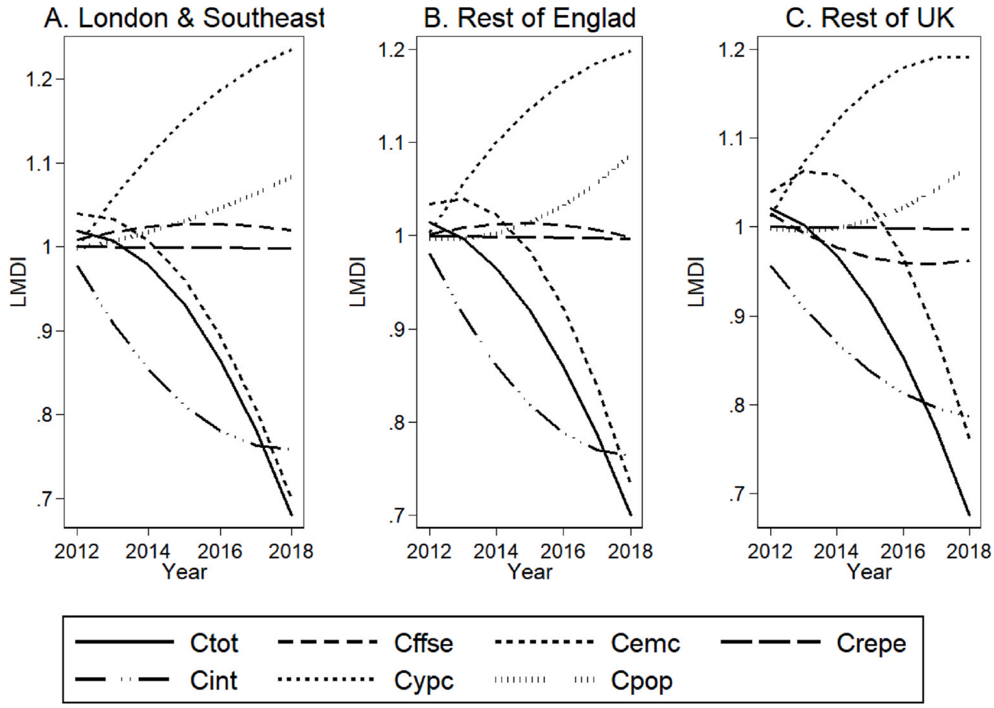

Fig. 4. LMDI for CO2 emissions of HEIs by regions, 2012-13 to 2018-19.

that UK universities require greater coordination and supervision in their transformation process.

Our findings for the UKHE sector offer insights and implications for other economic sectors in the UK and abroad with similar energy mix. Depending on data availability, future research might replicate our study for other economic sectors to provide additional understanding of the transformation process towards a green energy infrastructure and best practice strategies to master it.

The scope, method, and results of this study open interesting opportunities for future research. First, in addition to replicating the study for other economic sectors, additional insights can be obtained from varying the classification of energy sources. For example, future studies can consider zero-emission (e.g., solar and wind energy) and non-zero but low-emission (e.g., biomass) energy, both were included in our classification of renewable energy sources, as separate categories. Next, progresses towards achieving their 43% emissions reduction target might also be assessed through implementing a stochastic frontier model.

In addition, there are some limitations of this study that can be addressed in future research. First, we only focused on the sources of energy, whereas the emissions associated to different uses such as residential and non-residential use of energy can be a separate but related research issue. Finally, while increased per-capita income slows down emissions reduction, we do not draw any causal relationship between income and emissions for the UK universities. Several factors including the increased number of students might have confounding effects, which might be an interesting topic for future research.

CRediT authorship contribution statement

Shaikh M.S.U. Eskander: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Jakob Nitschke:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices.

Table A.1
Sources of energy

VARIABLES	Mean	SD	Minimum	Maximum
Burning oil	0.061	0.289	0.000	3.227
Fuel oil	0.038	0.290	0.000	5.480
Gas oil	0.112	0.337	0.000	3.223
Compressed natural gas	2.130	14.065	0.000	160.148
Liquefied natural gas	0.000	0.000	0.000	0.000
Liquefied petroleum gas	0.014	0.068	0.000	0.906
Natural gas excluding that used as input for a chp unit	22.804	22.364	0.000	136.323
Other petroleum gas	0.000	0.000	0.000	0.000

(*continued on next page*)

Table A.1 (*continued*)

VARIABLES	Mean	SD	Minimum	Maximum
Grid electricity	21.689	24.656	0.736	145.922
Coal	0.000	0.000	0.000	0.000
Steam and hot water	1.799	7.032	0.000	90.246
Other onsite renewables	0.023	0.126	0.000	1.098
Lubricants	0.000	0.006	0.000	0.106
Biofuels	0.004	0.057	0.000	1.224
Heat consumed from onsite chp	3.639	11.101	0.000	97.876
Electricity consumed from onsite chp	3.093	8.290	0.000	69.575
Petroleum coke	0.000	0.000	0.000	0.000
Biomass	0.213	1.091	0.000	19.731
Onsite photovoltaic	0.061	0.143	0.000	2.640
Onsite wind	0.057	0.436	0.000	5.213

Source: Author's own calculation using HESA data, based on stata software

Table A.2
Sources of emissions

VARIABLES	Mean	SD	Minimum	Maximum
Burning oil	0.015	0.071	0.000	0.792
Fuel oil	0.010	0.078	0.000	1.468
Gas oil	0.030	0.091	0.000	0.890
Compressed natural gas	0.392	2.591	0.000	29.474
Liquefied natural gas	0.000	0.000	0.000	0.000
Liquefied petroleum gas	0.003	0.015	0.000	0.194
Lubricants	0.000	0.002	0.000	0.028
Natural gas	5.931	7.311	0.000	41.888
Other petroleum gas	0.000	0.000	0.000	0.000
Grid electricity	8.379	9.814	0.213	65.793
Coal	0.000	0.000	0.000	0.000
Steam and hot water	0.370	1.485	0.000	19.533
Biofuels	0.000	0.002	0.000	0.048
Petroleum coke	0.000	0.000	0.000	0.000
Biomass	0.005	0.045	0.000	0.824
Onsite photovoltaic	0.000	0.000	0.000	0.000
Onsite wind	0.000	0.000	0.000	0.000
Other onsite renewables	0.000	0.000	0.000	0.000

Source: Author's own calculation using HESA data, based on stata software

Table A.3
Correlation Matrix

C_{tot}	C_{emc}	C_{ffse}	C_{repe}	C_{int}	C_{ypc}	C_{pop}	C_{tot}	C_{emc}	C_{ffse}	C_{repe}	C_{int}	C_{ypc}	C_{pop}
Panel A. All Universities							**Panel B. London & the Southeast**						
1.00							1.00						
0.42***	1.00						0.38***	1.00					
0.18***	−0.18***	1.00					0.37***	−0.31***	1.00				
0.09*	−0.47***	0.02	1.00				0.12	−0.35***	−0.03	1.00			
0.66***	0.25***	−0.08*	−0.10**	1.00			0.68***	0.15*	0.19**	0.07	1.00		
−0.24***	−0.43***	0.10**	0.09*	−0.37***	1.00		−0.39***	−0.48***	0.12*	−0.02	−0.41***	1.00	
0.04	−0.12***	0.04	−0.02	−0.29***	−0.25***	1.00	0.20**	−0.12	0.05	0.03	−0.28***	−0.25***	1.00
Panel C. Rest of England							**Panel D. Rest of the UK**						
1.00							1.00						
0.49***	1.00						0.35***	1.00					
0.10*	−0.05	1.00					−0.32***	−0.16	1.00				
0.06	−0.45***	0.00	1.00				0.13	−0.65***	0.20*	1.00			
0.67***	0.39***	−0.30***	−0.16***	1.00			0.64***	0.07	−0.45***	−0.09	1.00		
−0.26***	−0.47***	0.18***	0.05	−0.42***	1.00		−0.02	−0.32***	−0.16	0.27**	−0.27**	1.00	
−0.02	−0.19***	0.02	−0.01	−0.31***	−0.24***	1.00	−0.14	0.09	0.02	−0.20*	−0.29**	−0.30***	1.00

Notes. ***, ** and * represent statistical significance at 1%, 5%, and 10% levels, respectively. All data comes from the Higher Education and Statistics Agency (HESA) dataset for the fiscal years 2012-13 to 2018–19. All the variables follow the definitions in equations (4) and (5).
Source: Author's own calculation using HESA data, based on stata software

Table A.4
List of UK universities covered in this study

Aberystwyth University	Leeds M University	University of Brighton	University of Plymouth
Anglia Ruskin University	Leeds T University	University of Bristol	University of Reading
Aston University	Liverpool H University	University of Cambridge	University of SMSJ
Bangor University	Liverpool JM University	University of Chester	University of Salford
Bath Spa University	London M University	University of Chichester	University of Sheffield
Birkbeck College	London SB University	University of Cumbria	University of Southampton
Bishop G University	Loughborough University	University of Derby	University of St Andrews
Bournemouth University	Manchester M University	University of Durham	University of Stirling
Brunel University	Middlesex University	University of East Anglia	University of Sunderland
Bucks New University	Newman University	University of Edinburgh	University of Surrey
Canterbury CC University	Nottingham T University	University of Essex	University of Sussex
Cardiff M University	Oxford Brookes University	University of Exeter	University of Teesside
Cardiff University	QMU Edinburgh	University of Gloucestershire	University of Ulster
City University	QMU London	University of Greenwich	University of Wales TSD
Coventry University	QU Belfast	University of Hertfordshire	University of Warwick
Cranfield University	Ravensbourne	University of Huddersfield	University of Westminster
De Montfort University	Robert Gordon University	University of Hull	University of Winchester
Edge Hill University	Rose Bruford College	University of Keele	University of Wolverhampton
Edinburgh N University	Royal Holloway	University of Kent	University of Worcester
Falmouth University	SMU Twickenham	University of Lancaster	University of Writtle
Goldsmiths	Sheffield Hallam University	University of Leeds	University of York
Guildhall	Solent University	University of Leicester	University College Birmingham
Harper Adams University	Staffordshire University	University of Lincoln	University College Lancashire
Heriot-Watt University	Swansea University	University of Liverpool	UCL
Imperial College	University of Abertay	University of Manchester	University of East London
King's College	University of Bath	University of Newcastle	University of West London
Kingston University	University of Bedfordshire	University of Northumbria	University of West Scotland
LBS	University of Bolton	University of Nottingham	University of WE Bristol
LSE	University of Bradford	University of Oxford	York SJ University

Source: Author's own conception using HESA data.

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