Original Research Article

Modelling Carbon Emissions Efficiency from UK Higher Education Institutions Using Data Envelopment Analysis

ABSTRACT

Aims: To correlate the energy and carbon emission efficiency relative to research income, gross internal area, and population for all the Higher Education Institutions (HEIs) in the UK and to assess the comparative carbon emission efficiency of HEIs relative to economic metrics.
Study design: Analytical panel data study.
Place and Duration of Study: This paper evaluates the energy efficiency of 131 HEIs in the UK subdivided into Russell and non-Russell groups from 2008 to 2015.
Methodology: Data Envelopment Analysis (DEA) and Malmquist productivity indexes (MPI) are used for the efficiency calculations.
Results: The empirical results indicate that UK HEIs have relatively high energy efficiency scores of 96.9% and 77.6% (CRS) and 98.5%, 86.3% (VRS) for Russell and non-Russell groups respectively.
Conclusion: The evidence from this study reveals that HEIs are not significantly suffering from scale effects, hence, an increase in energy efficiency of these institutions is feasible with the present operating scale but would need to work on their technical improvements in energy use. Malmquist index analysis confirms the lack of substantial technological innovation, which impedes their energy efficiency and productivity gain. Findings show that pure technical efficiency accounts for the annual efficiency obtained in the DEA model, the technological progress in contrast is the source of their energy inefficiency.

Keywords: [Data Envelopment Analysis, energy efficiency, Malmquist, Carbon emissions, Greenhouse gases]

1.0 INTRODUCTION

It is predicted that the nearest decades would experience enormous socioeconomic challenges, chiefly because of the current trends in energy consumption and its impact on the built environment. Today's centralized and fossil dominant energy in the face of escalating global population is confronted with resource depletion and high carbon emission rates. This necessitates the ongoing call and debate on energy transition especially in Europe. The extensive objectives of this transition are centred on energy efficiency and decarbonization at the level of economic activities.

The United Kingdom in its capacity is building a sustainable framework to achieve net zero carbon future and have singled out Higher Education sector as a pivotal sector to drive energy efficiency and carbon reduction across Britain [1-3].

1.1 Energy consumption and Carbon emission trends in the UK Higher Education Institutions (HEIs)

The traditional myths that universities are solely academic habitat is fast eroding, chains of diverse activities are going on at these institutions on the daily basis. This is giving the institutions a good replica and nomenclature of a city model. The education sector is consistently witnessing substantial growth in terms of population, income and the area of their buildings in terms of gross internal area (GIA). Notably, the population of full-time equivalent students in the UK is estimated as 2,280,830 in 2016/17 from 166 providers which is 3.4% of the total UK population. This makes the sector bigger than many UK cities [4], this growth is also accompanying with high energy demand and high carbon emissions. In England, the yearly costs for energy is £200 million with a consequential release of over 3million tonnes of CO2e into the atmosphere [2]. However, the commitment of higher education (HE) sector to reduce the sector emission by 43% by 2020 from a 2005 baseline, has witnessed relative reductions in emission levels over the year. It is without doubt that the reduction in carbon emission, also known greenhouse gases (which are made up of carbon dioxide, methane, nitrogen oxide, aerosols among others) will reduce environmental pollution [5].

Recent findings show that, consequent to high energy consumption and with only 3 years to 2020 target, only 32% of England HEIs are on track to meet the emission target, while about 60% are most likely to default [6]. In addition to this, only 17% emissions reduction is recorded so far against 2005 baseline and should the trend prolongs, the HE sector would only achieve the maximum of 23% reduction of carbon emissions by 2020. This is a reflection of a slow decrease in emission, until now, the best carbon offset was in 2015/16 where about 2million tCO2e was offset representing 7% drop in emission levels [6].

According to Roy et al. (2005) [7], most education institutions increase in their emission levels as a result of a rise in population and energy demand. This study therefore seeks to evaluate the energy efficiency of UK HEIs from the angle of emission levels, population, building area and financial metrics.

1.2 Measurement of Energy Efficiency Review

There is no unequivocal definition and quantification of energy efficiency, however, in a simple term, it involves cutting down the amount of energy needed to execute an action. In other words, it is the ratio useful output of a process to the Energy input into a process.

Energy efficiency plays a major role not only in reducing the level of energy consumption but enhances the possibility of reducing greenhouse gas (GHG) emissions especially in the short- to mid-term. The strength and the future of energy efficiency is entrenched in right policymaking, in the UK, certain policies have been promulgated to support the national high energy efficiency goal; Carbon Emission Reduction Target (CERT), Community Energy Saving Programme (CESP), under the National Energy Efficiency Data-Framework (NEED) [8].

Several approaches are considered for assessing the energy efficiency of any sector or organization. However, one similarity among them is the estimation of the principal factors that influence energy consumption relative to the accompanying economic activities and structural switches in the economy. Technical and non-technical improvements are the metrics.

Some studies measure consumption-based energy balances which involve the quantification of direct and indirect energy use, identification of potential thresholds in energy utilization per economic activity and conducting material and energy flow analysis. Another approach is the analytical predictive method which involves numerical modelling and simulation. This includes the design of fuel economy low-emission, and waste energy recovery systems and scenarios with the aim of translating it into industrial applications [9].

In recent times, several econometric methods have gained acceptance in measuring energy efficiency performance, this includes; regression analysis [10], simple ratio analysis and Data envelopment analysis [11-13]. The flexibility and ability to handle multiple input and output without being bias towards unit make data envelopment analysis (DEA) better suitable for performance measurement.

1.2 Data Envelopment and Malmquist index in Energy efficiency modelling

Although energy efficiency levels across economic sectors in the world has attracted exceptional academic interest over the decades, very few studies had focused on the higher education sector. The reason for this is not farfetched, levels of emissions from HE sector relative to energy consumption was previously regarded as insignificant [7].

Few scholars in the past have attempted to investigate or review the energy efficiency of English HEIs using econometric tools [14-17]. Common in their finding is that English HEIs relatively have higher mean technical efficiency scores than their counterparts in other countries, however, a low average level of efficiency is found when only financial metrics are computed. The drawbacks to these studies are the short or old timeframe covered and the failure to consider the undesirable environmental variables especially the carbon emission. Only Johnes and Tone (2017) [15], attempted to investigate energy efficiency by incorporating environmental metrics but again the study is deficit as it fails to comprehensively account for sources of inefficiency nor the change in efficiency across the time period, instead it focuses on the consistency of evaluation methods. These are properly covered in this study by using DEA models.

DEA also known as Frontier Analysis is a more flexible technique for performance measurement [18]. DEA is a non-parametric linear programming technique used for estimating the relative efficiencies of a similar set of organizations (widely called decision-making units (DMUs)). Efficiency refers to potential to reduce input units or to maximize the output units without wastage of the inputs. The key strengths of DEA over methods include the ability to handle multiple outputs and multiple input and removal of restrictions functional specifications [19]. It has been extensively used in eco-efficiency, banking, and manufacturing literature.

Most recently Zhang et al., (2018) assessed the regional CO2 efficiency of China from the perspective of resource available using DEA technique. Their results show that the eastern China has a high level of carbon emission efficiency performance and while in contrast, the North-western part of China are inefficient. Several attempts have been made to identify the sources of inefficiency, this led to the development of several methods. However, the basic DEA models are constant returns to scale (CRS) and variable returns to scale (VRS). The former was developed by Charnes, Cooper and Rhode (1958) on the assumption that all organizations can increase their output in the same proportion to which their input is increased while the latter was constructed on the assumption that organizations might not reproduce their output in the same proportion with the increase in their input unit [19]. Any inefficiency from the latter depicts scale effect.

To further understand how efficiency changes across the year, Malmquist productivity index (MPI) has been used by several authors on the principle of DEA [21].

This study will therefore fill the gap by utilizing DEA and Malmquist productivity index to calculate the energy and carbon emission efficiency relative to research income, gross internal area, and population for all the HEIs in the UK. In addition to this, it will also estimate the change in their efficiencies and from this generate an efficiency ranking. This is a novel approach to investigating universities energy and emission efficiencies.

2.0 DATA AND METHODS

2.1 Data

A dataset for 131 institutions in the UK from England, Northern Ireland, Scotland and Wales for the period between 2008-2014 are used in this study. The HEIs are divided into Russell and Non Russell groups out which 20 and 111 HEIs respectively are selected, some institutions are excluded due to missing information. The data are collected from Higher Education Statistics Agency (HESA), an accredited organization with 24 years of operation designated by Higher Education & Research Act 2017 to provide up-to-date UK higher education data [22]. These institutions were chosen in no particular order

2.2 Variable Selection

With the objective to evaluate the energy and carbon emissions efficiency of UK HEIs, the method of Chang et al. (2013) [23] which allow for the integration of undesirable output (carbon emission) in the production function while assuming free disposability. In total, five metrics are extracted from the dataset. These include data on; research income (£), gross internal area (m2), population (fulltime equivalent of teaching students, research students and staff), energy (kwh) and carbon emission equivalent (tCO2e).

Energy consumption, staff full-time equivalent (FTE), GIA are selected as input while research income, teaching student FTE and research student FTE are selected as the output. Carbon emission is chosen as the undesirable output. The choice of these input and output variables is supported by the literature. Table 1 indicates the summary of the relationship between input and output variables while table 2 and 3 shows the summary of descriptive statistics of the variables for Russell and non-Russell. Significantly, total staff FTE have strong correlation with research income, research student FTE, GIA and carbon emission representing (0.91, 0.92, 0.87 and 0.85 respectively), energy consumption and GIA are strongly correlated (0.85) whereas Teaching student FTE and CO2 emissions have a relatively weak correlation (0.45) which depicts CO2 emissions can be reduced without reducing the population of the students which has its best relationship with the staff population.

This is in agreement with Fetcher (2009) [24] and Klein-Banai and Theis (2013) [25] argument that floor area has a positive correlation with carbon emissions and that of Disli et al., (2016) [26] that there is an inverted U-shaped relationship between carbon emissions income. However, the findings of Martinez and Maruotti, (2012) [27] reveal that the efficiency of carbon emission is strongly dependent on the energy consumption. Therefore, carbon emission must be integrated into estimating energy efficiency.

Table 1: Correlation analysis of the variables

	Research Income	Teaching student	Research student FTE	Carbon enission (CO2e)	Total staff FTE	Total GIA (m2)	Total energy consumption
Research Income	1						
Teaching student	0.379	1					
Research student FTE	0.875	0.447	1				
Carbon enission(CO2e)	0.815	0.447	0.836	1			
Total staff FTE	0.907	0.545	0.922	0.847	1		
Total GIA (m2)	0.748	0.546	0.786	0.841	0.866	1	
Total energy consumption	0.657	0.445	0.638	0.732	0.688	0.851	1

Table 2: Descriptive statistics of input/output indicators in from 2008-2015 for Russell HEIs.

Indicators	**Mean**	**SD**	**Median**	**Max**	**Min**
Research income (£)	206670775	1.44E+08	159240000	737287000	38578000
Teaching student FTE	18847.26492	5330.589	18450.669	32556.279	8163
Research student FTE	2163.365494	1038.79	1949.8125	4775	475
Total scope 1 and 2 carbon emissions (Kg CO2e)	49050634.28	18919750	46529027	95045107	10948600.2
Total staff FTE	5873.054031	2267.873	5465.6	12305	1885
Total GIA (m2)	466548.8136	159342.7	451219	887531.8	117852.61
Total energy consumption (kWh)	140130988.3	72394250	144836071	294033938	31757

Table 3: Descriptive statistics of input/output indicators in from 2008-2015 for Non-Russell HEIs.

Indicators	Mean	SD	Median	Max	Min
Research income (£)	17129703.6	24349587.39	7101000	157390000	1000
Teaching student FTE	9680.22101	6293.911743	9882.4	29850.846	35
Research student FTE	323.394978	314.8313504	242.9	1803.013	0.9
Total scope 1 and 2 carbon emissions (Kg CO2e)	10592439.4	8015409.387	9200693.397	47944220	521085.568
Total staff FTE	1540.551	988.6596166	1502.355	5995	66
Total GIA (m2)	126928.675	84201.34376	118913	460671	5517
Total energy consumption (kWh)	32369372.1	26997745.65	26658669	162173875.8	18550

2.2 Methodology

DEA method is chosen for this study because it can accommodate multiple variables regardless of the measurement units and can provide the efficiency of the individual participating institution (usually called DMUs). It requires no complex transformation of data and does not require specification of function. The efficiency score of DEA is often expressed between 0 -1 or 0-100%.

This study utilizes CRS and VRS DEA models under the input orientation approach. The CRS model (also known as CCR model) is built on the assumption that a small firm should be able to operate efficiently as a large one while (VRS also known as BCC model) recognizes positive or negative economies of scale. Based on these differences, many authors prefer to evaluate efficiency using both models. The linear programming formulation of these models are given below:

CRS Model [28]

$$min(\theta,\lambda) = \theta$$

Subject to:

$$\theta x_0 - X\lambda = s^-$$
$$Y\lambda \geq y_0$$
$$\lambda \geq 0 \qquad \ldots(1)$$

VRS Model [19]

$$min(\theta,\lambda) = \theta$$

Subject to:

$$\theta x_0 - X\lambda \geq 0$$
$$Y\lambda = y_0 + s^-$$
$$e\lambda = 1 \qquad \ldots(2)$$

Where y_0 and x_o vector are output and input quantities respectively, λ indicates the weights, X and Y represents the input and output matrix. The key discrepancy between these two models is the introduction of convexity constraint ($e\lambda = 1$), this produces the pievewise linear and concave identities.

This study also uses DEA Malmquist productivity Index (MPI) to measure change in efficiency under input orientation. MPI decomposes change in efficiency into five components: efficiency change, pure technical change, technological change, scale efficiency change and total factor productivity change. MPI estimates utilized in this is calculated using Fare et al., (1994) [29] mathematical formulation as given in equation 3.

$$MPI_I^{t,t+1} = \underbrace{\frac{D_I^{t+1}(y^{t+1},x^{t+1})}{D_I^t(y^t,x^t)}}_{\textbf{Efficiency change}} \underbrace{\left[\frac{D_I^t(y^{t+1},x^{t+1})}{D_I^{t+1}(y^{t+1},x^{t+1})}\frac{D_I^t(y^t,x^t)}{D_I^{t+1}(y^t,x^t)}\right]^{1/2}}_{\textbf{Technological change}} \qquad \ldots(3)$$

Where t represents the base year (2008), t+1 represents the reference technology, x and y represent the input and output quantities, I indicates input orientation, D indicates the distance function. The scores are categorized into three: when it is equal to 1, it means there is no change (no improvement), greater than 1 (>1) means a positive change and values lesser than one (<1) depicts a negative change, regression especially for technological change.

3. RESULTS AND DISCUSSION

3.1 Efficiency estimates under CRS, VRS and Scale assumptions

The results of the top energy efficiency performers for Russell and non-Russell HEIs are presented in Table 4 and 5 respectively. As shown in the table 4, the mean technical efficiency score under CRS assumption for the 20 Russell universities are 97.8%, 97%, 96.7%, 93.7%, 97.6%, 95.3%, 98.8%, 98.5%, and while that of the 111 non-Russell HEIs are 74.7%, 77.1%, 80.2%, 67.8%, 83%, 79.2%, 77.9%, 80.8%, and for 2008 to 2015 respectively. Their mean annual technical efficiency score across the sample years are 96.9% and 77.6%, this indicates that the overall efficiency level of UK universities is relatively high. However, the Russell group is more energy efficient than their counterpart non-Russell group. The efficiency profile also shows the HEIs have the potential for reducing their energy by 3.1%(Russell HEIs) and 22.4%(non-Russell HEIs) under the same technology. Conversely, should non Russell HEIs were efficient for each year, their carbon emissions could have declined by 25.3%, 22.9%, 19.8%, 32.2%, 17%, 20.8%, 22.1% and 19.2%, respectively for their corresponding level of outputs from 2008 to 2015 respectively. Notably, more russell HEIs (an average of 56%) are found to be efficient than inefficient, specifically, in 2008 and 2014, fourteen (14) out of twenty (20) are identified to be efficient using CRS. The following Russell HEIs top the efficiency performance as they maintain the efficiency cross the 8 years period; King's College London, The University of Cambridge, The University of Exeter, The University of Glasgow, The University of Oxford, and University College London, only two HEIs (London School of Hygiene and Tropical Medicine, and The Institute of Cancer Research) achieve this feat among the Non-Russell group.

Table 4: Top Performers under CRS Model for Russell Group HEIs

HEIs	2008	2009	2010	2011	2012	2013	2014	2015	Mean	Rank
King's College London	1	1	1	1	1	1	1	1	1	1
The University of Cambridge	1	1	1	1	1	1	1	1	1	1
The University of Exeter	1	1	1	1	1	1	1	1	1	1
The University of Glasgow	1	1	1	1	1	1	1	1	1	1
The University of Oxford	1	1	1	1	1	1	1	1	1	1
University College London	1	1	1	1	1	1	1	1	1	1
London School of Economics and Political Science	1	0.983	1	1	1	1	1	0.986	0.996125	7
The University of Southampton	1	0.967	0.996	0.968	1	1	1	1	0.991375	8
The University of Nottingham	1	1	0.997	0.951	1	0.948	1	1	0.987	9
The University of Leeds	0.96	0.971	1	0.953	0.978	0.964	1	0.983	0.976125	10
Mean efficiency	**0.978**	**0.97**	**0.967**	**0.937**	**0.976**	**0.953**	**0.988**	**0.985**	**0.969**	

Table 5: Top Performers under CRS Model for Non Russell Group HEIs

HEIs	2008	2009	2010	2011	2012	2013	2014	2015	Mean	Rank
London School of Hygiene and Tropical Medicine	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1
The Institute of Cancer Research	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1
Birkbeck College	0.948	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.994	3
Middlesex University	0.747	1.000	1.000	0.977	1.000	1.000	0.993	1.000	0.965	4
Courtauld Institute of Art	1.000	1.000	0.971	0.970	0.960	0.909	0.901	0.925	0.955	5
Heythrop College	1.000	0.945	0.957	0.972	1.000	0.750	0.945	0.881	0.931	6
University of Hertfordshire	0.877	0.874	0.865	0.702	1.000	1.000	1.000	1.000	0.915	7
University of Bedfordshire	0.907	0.936	0.971	0.913	0.964	0.917	0.812	0.822	0.905	8
St George's Hospital Medical School	0.620	0.972	1.000	0.917	1.000	0.740	1.000	0.977	0.903	9
The Arts University Bournemouth	0.618	0.955	1.000	0.735	0.974	0.980	0.975	0.984	0.903	10
Mean Efficiency	**0.747**	**0.771**	**0.802**	**0.678**	**0.83**	**0.792**	**0.779**	**0.808**	**0.776**	

Similarly, as revealed in table 6 and fig 1, the mean efficiency under VRS scale assumption ranges from 96.2% to 99.5%(Russell group) and 79.8 to 85.3%(non-Russell group) for 2008 to 2015 and their average annual means are 98.5% and 86.5%. This implies that the two UK HEI groups have the potential of reducing their carbon emission levels by 1.5% and 13.5% for Russell and non-Russell HEIs respectively and still maintain their present level of outputs.
It is worth noting that common to the two HEI groups, is a gross drop in technical efficiency in 2011 this is as a result of decline in research income by 2.08% and research student by 1.74% for non-Russell group while 4.81% and 3.71% decline in staff population and research student are chiefly responsible for Russell group worst efficiency record. Non-Russell HEIs also suffer a dip in their efficiency in 2008 (25.3% inefficiency) consequent to extremely cold weather conditions in that year which required high energy consumption and conversely high emissions level since two-thirds of energy are sourced from fossil [30]. Hence, only 9 HEIs are on the efficiency frontiers while 45 HEIs are below 70% efficiency.

Table 6: Top Performers under VRS assumption for Russell HEIs

HEIs	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Mean**	**Rank**
Cardiff University	1	1	1	1	0.957	1	1	1	0.995	12
King's College London	1	1	1	1	1	1	1	1	1.000	1
London School of Economics and Political Science	1	1	1	1	1	1	1	1	1.000	1
The University of Birmingham	0.995	0.962	0.983	0.943	0.979	0.996	0.988	1	0.981	15
The University of Bristol	0.934	0.997	0.966	0.936	0.954	0.984	1	1	0.971	17
The University of Cambridge	1	1	1	1	1	1	1	1	1.000	1
The University of Edinburgh	1	0.911	0.967	1	1	1	1	1	0.985	14
The University of Exeter	1	1	1	1	1	1	1	1	1.000	1
The University of Glasgow	1	1	1	1	1	1	1	1	1.000	1
The University of Leeds	1	1	1	1	1	1	1	1	1.000	1
Mean Efficiency	**0.989**	**0.983**	**0.986**	**0.962**	**0.992**	**0.979**	**0.998**	**0.995**	**0.985**	

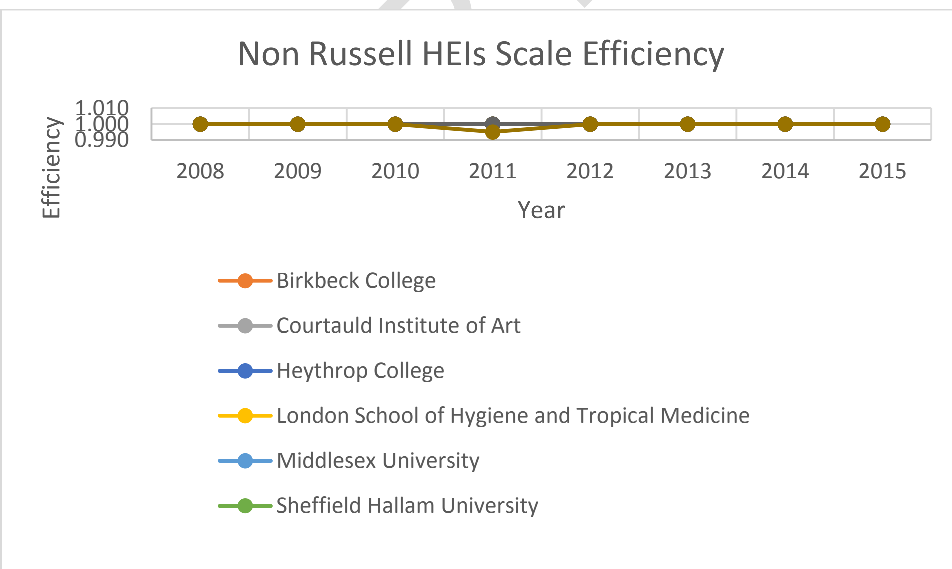

Figure 1: Top Performers under VRS assumption for non-Russell HEIs

As expected the CRSTE scores are lower than VRSTE scores because, efficiency estimations under VRS for each institution is calculated relative to institutions with similar size while CRS efficiency is calculated without regard to scale (size of operation). A similar result is found in Zefeng et al., (2015) [30] study, where mean CO_2 technical efficiency scores for Michigan Greenhouse Growers are 0.387 and 0.505 under CRS and VRS model respectively. Results for 2014 reveal remarkable performance of HEIs above all other years. Although the mean efficiency for all the HEIs is 88.7% depicting potential for input reduction by 11.3%, the number of efficient institutions have grossly increased to 28 from 12 in 2010 under VRS assumption. About 80% of the HEIs are closer to the frontier under the two models, only 4 institutions are far from the frontier.
The results suggest that the sources of HEIs inefficiency can be as a result of scale or non-scale factors. The estimate of scale efficiency (SE) indicates whether HEIs are operating on the right. It is calculated from the ratio of constant returns to scale technical efficiency score (CRSTE) to the variable return to scale technical efficiency scores (VRSTE). The results for the top performers in Scale efficiency are presented in table 3 and fig 2.

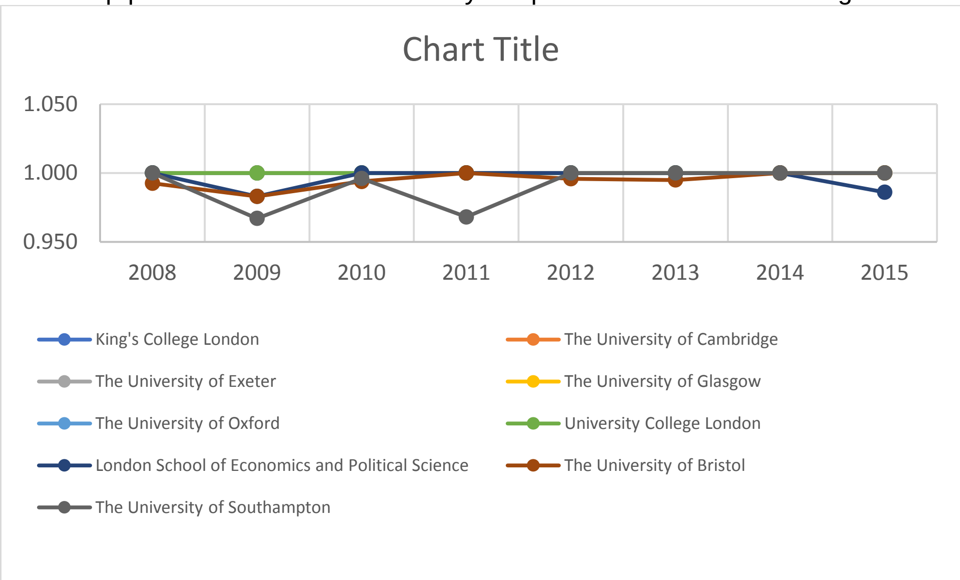

Figure 2:Top Performance of scale efficiency for Russell HEIs

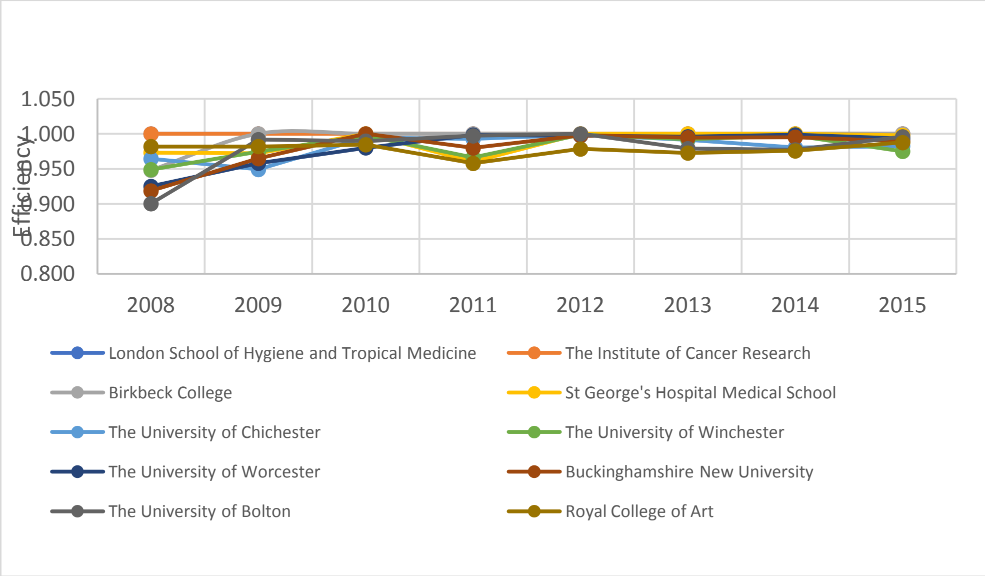

Figure 3: Top Performance of scale efficiency for Non Russell HEIs

More so a relatively high scale efficiency performance is found for all the HEIs (fig 2 and 3), this suggests that all HEIs are operating in the right scale, most especially the Russell group, their efficiency range between 97.4%to 99%. Notwithstanding, a lower mean annual scale efficiency score is found across all the 111 Non Russell institutions of 90.3%, implying that the mean size of these institutions is less than 10% from the optimal size. Some of the HEIs in this group are most likely affected by their scale of operation.
Consistent with CRS and VRS results, in the year 2011 the SE plummets to the least for all the HEIs.

In general, considering the results obtained from three DEA models, HEIs do not show a distinct efficiency pattern. The average annual efficiency undulates across the 8 year period, this suggests that energy consumption has not been overtaken by the right technology that will perpetually upwardly push the efficiency. This therefore implies that the success of HEIs in increasing their energy efficiency will therefore not bother on operating at the right scale or cutting down activities. Interestingly, the results obtained from the scale efficiency dissociates HEIs from being affected by operational size.

Although, the CRS and VRS models show that Russell group HEIs are more energy efficient than the non-Russell group HEIs. In practice, this may not be holistically due to the difference in their sample size. According to Nguyen et al. (2016) [31], DEA could result in biased efficiency scores when comparing samples of varying sizes. Malmquist index analysis is therefore another important tool used in this study to further probe the efficiency change across the HEIs and years. Additionally, it will offer in-depth evidence about the productivity of these HEIs and alleviate the DEA sensitivity to sample size.

3.2 Malmquist Productivity Index Estimates

The mean annual Malmquist indexes for both HEIs groups are reported in table 7 and 8. The results shows that the values for the mean efficiency changes (effch), technological progress changes (techch), pure technical efficiency change index (pech), scale efficiency change index (sech), total factor productivity indexes (tfpch) are (1.0141, 0.849, 1.002, 1.012, 0.861- non Russell group) and (1.001, 0.7233, 1.00095, 1.0001, 0.7286- Russell group) respectively. Notably, among the 131 institutions, none experiences productivity improvement and technological progress. Across the five Malmquist index spectrums, Russell group do not hold substantial performance, as none records improvement in TECHCH and TFPCH. However, 80% of these HEIs maintain a constant pure technical efficiency change while only 15% records growth. With respect to non-Russell HEIs, a significant number of HEIs (82 out of 111), record improvement in their scale efficiency change and about 60% HEIs improve in their pure technical efficiency.

The technological efficiency change (techch) and total factor productivity (tfpch), indicate a negative trend of efficiency drop by 27.7% and 27.1% respectively Russell HEIs and 15.1% and 14%. However, the pure efficiency change, scale efficiency change(pech) [0.1%-Russell, 1.36% -non-russell], and efficiency change (effch), [0.01%, and and 1.16%] depict improvement. With a mean annual total factor productivity change score of 0.860 and 0.729 for Russell and non-Russell HEIs respectively, it shows that the level of efficiency has declined over the whole period. The source of this regression is primarily due to technological change (0.723 and 0.860 for Russell and non-Russell HEIs respectively) and the source of inefficiency is principally a scale issue. By implications, most of the HEIs who are not efficient in their energy utilization are probably not exploring latest technology for their energy consumption. Conversely, this finding indicates that UK HEIs are yet to make significant achievements in technological innovation that could influence their energy efficiency positively and that HEIs operational efficiency level does not notably depend on its size or its function.

Table 7: The mean Malmquist index in the Non-Russell group HEIs, 2008-2015

HEIs	Effch	Techch	pech	sech	tfpch	Rank
The University of Dundee	1.087	0.950	1.000	1.087	0.990	1
Birmingham City University	1.042	0.948	1.014	1.027	0.987	2
Guildhall School of Music and Drama	1.149	0.843	1.148	1.001	0.970	3
Glyndwr University	1.029	0.911	1.002	1.027	0.958	4
Royal College of Music	1.108	0.864	1.099	1.008	0.957	5
Bishop Grosseteste University	1.058	0.901	1.050	1.008	0.954	6
Buckinghamshire New University	1.045	0.910	1.034	1.011	0.951	7
Heythrop College	0.982	0.962	1.000	0.982	0.948	8
Norwich University College of the Arts	1.052	0.900	1.069	0.984	0.946	9
The Arts University Bournemouth	1.069	0.881	1.058	1.010	0.941	10
York St John University	1.059	0.884	1.032	1.026	0.936	11
University of the Arts London	1.019	0.917	0.973	1.047	0.935	12
London School of Hygiene and Tropical Medicine	1.000	0.933	1.000	1.000	0.933	13
The University of Lincoln	1.013	0.916	0.993	1.021	0.928	14
The University of Huddersfield	1.061	0.866	1.033	1.027	0.918	15
The University of Winchester	0.991	0.924	0.988	1.004	0.916	16
The University of the West of Scotland	1.027	0.890	1.012	1.015	0.915	17

Writtle University College	1.046	0.874	1.045	1.001	0.914	18
The University of Central Lancashire	1.023	0.888	1.002	1.021	0.909	19
Leeds Trinity University College	1.004	0.904	1.003	1.001	0.908	20
Liverpool John Moores University	1.047	0.863	1.018	1.029	0.904	21
Anglia Ruskin University	1.030	0.874	1.010	1.020	0.901	22
Mean (111 HEIs)	**1.014**	**0.849**	**1.002**	**1.012**	**0.861**	

Table 8: The mean Malmquist index in the Russell group HEIs, 2008-2015

HEIs	**effch**	**techch**	**pech**	**sech**	**tfpch**	**Rank**
The University of Liverpool	1	0.887	1	1	0.902	1
The University of Edinburgh	1	0.847	1	1	0.894	2
The University of Southampton	1	0.886	1	1	0.886	3
University College London	1	0.835	1	1	0.871	4
Cardiff University	0.993	0.864	1	0.993	0.85	5
The University of Exeter	1	0.845	1	1	0.845	6
King's College London	1	0.81	1	1	0.81	7
The University of Glasgow	1	0.754	1	1	0.754	8
The University of Birmingham	1.006	0.71	1.001	1.005	0.714	9
London School of Economics and Political Science	0.998	0.707	1	0.998	0.706	10
The University of York	1.019	0.686	1.01	1.009	0.7	11
The University of Bristol	1.011	0.684	1.01	1.001	0.692	12
The University of Cambridge	1	0.685	1	1	0.685	13
The University of Oxford	1	0.676	1	1	0.676	14
The University of Manchester	0.996	0.64	1	0.996	0.638	15
The University of Nottingham	1	0.628	1	1	0.628	16
The University of Sheffield	0.998	0.612	1	0.999	0.611	17
The University of Leeds	1.003	0.593	1	1.003	0.595	18
The University of Warwick	0.998	0.571	0.998	1	0.57	19
University of Durham	0.998	0.546	1	0.998	0.545	20
Mean	**1.001**	**0.7233**	**1.00095**	**1.0001**	**0.7286**	

According to Li and Lin (2015) [32], the total-factor energy productivity analysis framework, delivers a viable orientation database for assessing the potential for energy efficiency improvement. As shown in figure 4, there is no significant difference in the productivities of Russell and Non Russell HEIs. However, comparatively, the growth rate of Russell group in year 2 is relatively slower than their counterpart non-russell group. The principal reason for this is that the pure technical progress and scale efficiency change of non Russell HEIs improve (1.061 and 1.002 respectively) while that of Russell group regresses (0996 and 0.999 respectively). By year 4 (2011), the gap is bridged and overtaken in the subsequent year 5, this trend afterwards relatively remains the same. In clear terms, these results show that all HEIs have a huge need and potential to improve on their technological progress. Based on the overall integrated total factor productivity index, the best performing in descending order among non –Russell group HEIs are ; Birmingham City University, Guildhall School of Music and Drama, Royal College of Music, Bishop Grosseteste University, Buckinghamshire New University, Norwich University College of the Arts, and The Arts University Bournemouth while that of Russell group HEIs are The University of Liverpool, The University of Edinburgh, The University of Southampton, University College London, Cardiff University, The University of Exeter and King's College London.

Therefore, since the overall energy efficiency due to technological changes and productivity of UK HEIs are low, more attention and effort should be focused on improving their technological innovation.

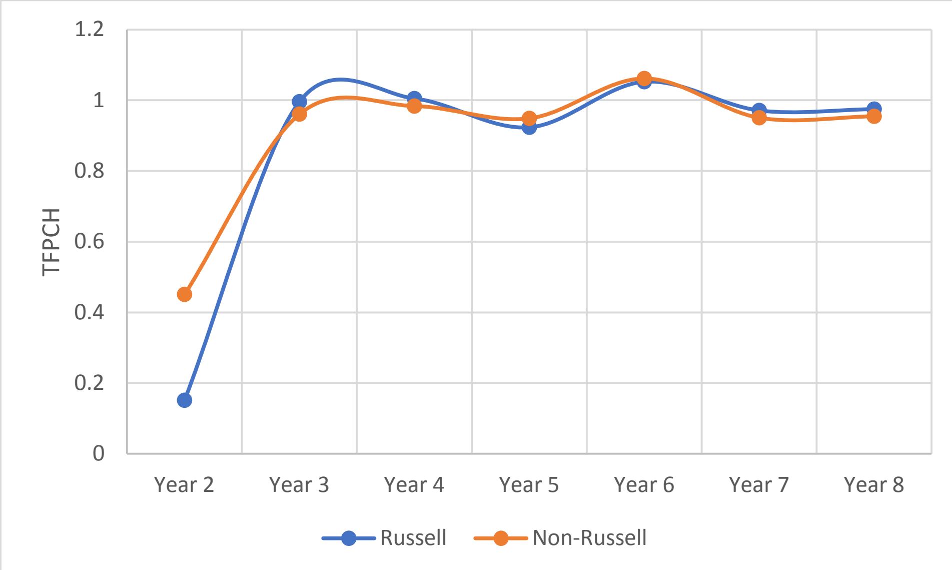

Figure 4: Comparison of Total factor productivity change of Russell and Non-Russell Groups, 2008-2015

3.3 Efficiency Performance without Emission Metrics

Another approach to evaluating HEIs energy efficiency performance is to shift attention from the reduction of CO2 emission. In this regard, emission metric is excluded from the performance indicators, this essentially would help provide further evidence on the HEIs energy efficiency status and sources since it is shown that technological innovation is the backstop of HEIs efficiency relative to carbon emission.

As revealed in figure 5, neglecting CO2 emission gives rise to higher mean annual energy efficiency levels for both HEIs groups (representing 98.5% and 86.3%) with Russell group maintaining the efficiency lead. More so, consistent efficiency pattern is also observed across the years. The implication of this is that emission reduction has a significant influence on the overall energy efficiency. Hence, policy makers will default in attaining an adequate reduction of energy efficiency if they fail to take carbon emission levels into account.

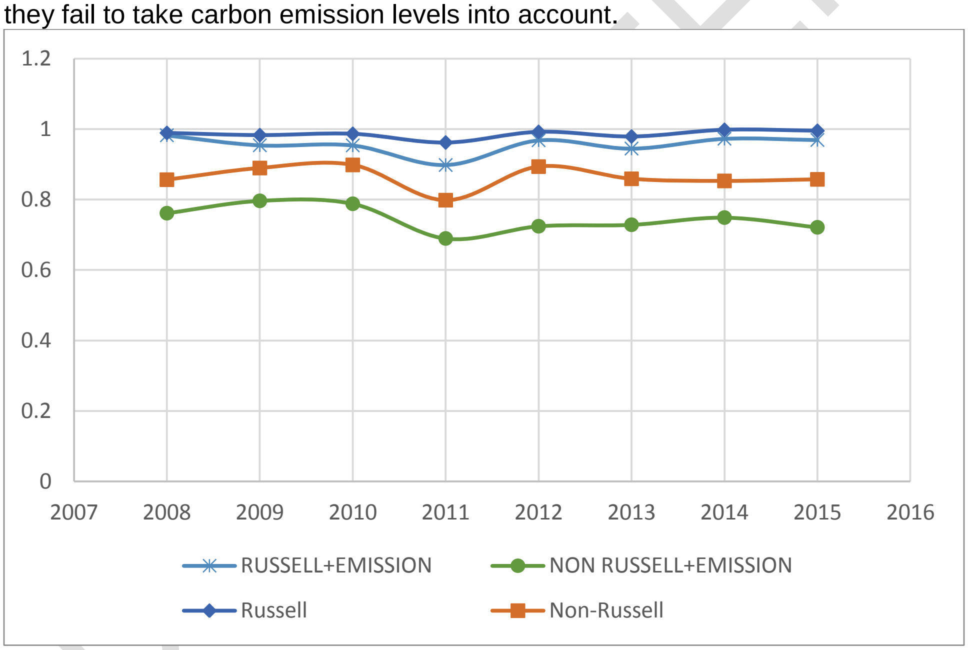

Figure 5: Comparing VRS efficiency of Russell and Non-Russell with and without CO2 emission factor

Notably, the total factor productivity reflects the overall efficiency of all inputs to a production process and its connection to technological improvements and other non-technical factors. As shown in figure 6 and 7, a further regression is recorded in the mean annual total factor productivity (-13.2%russell and -9.81%non-Russell) across the two HEIs groups which is a direct product of decline in the technological innovation (-13.8%russell and -10.2%non-Russell). However, it is evident that with further regression in technological change, both Russell and non Russell HEIs needs to invest more in available best effective technologies.

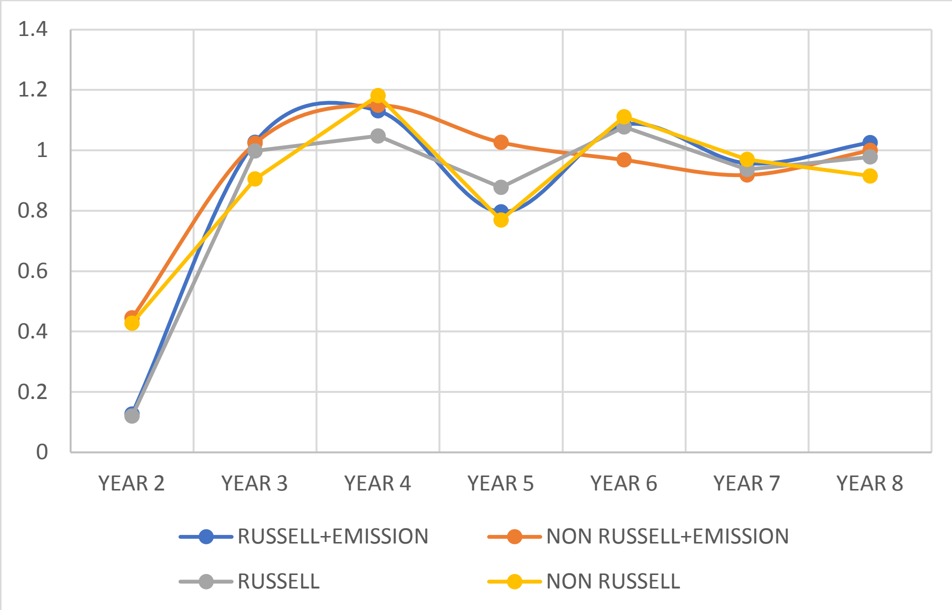

Figure 6: Comparing TECHCH efficiency of Russell and Non-Russell with and without CO2 emission factor

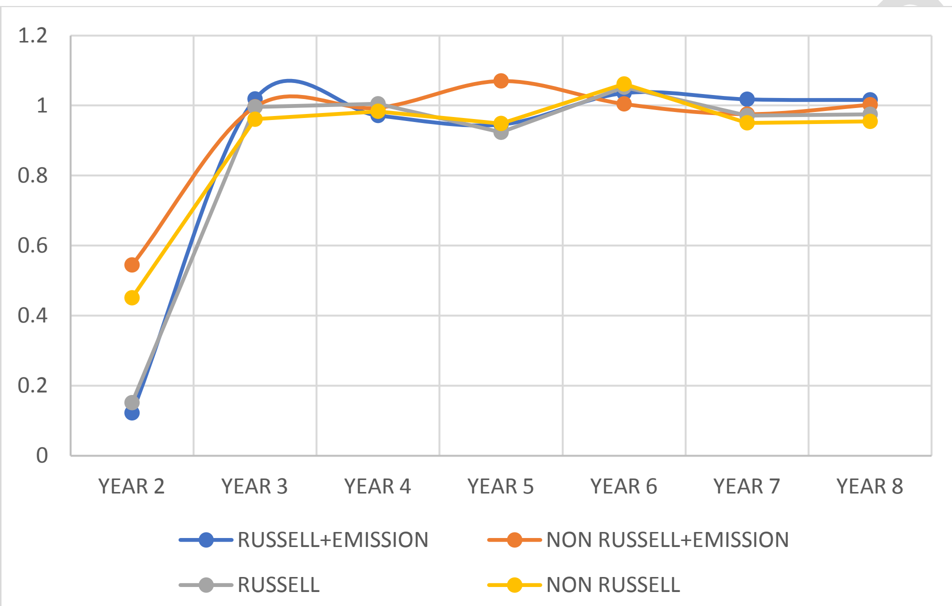

Figure 7: Comparing Total factor productivity of Russell and Non-Russell with and without CO2 emission factor

According to Yang, (2010) [33], there is a significantly relationship between energy or carbon performance and better resource grants. Hence, TPFCH and TECHCH results raise questions for policymakers on the effect of the deployment of the latest efficient technologies on energy and carbon efficiency; and to what extent can increase in research grant promote overall energy efficiency and carbon reduction.

4. CONCLUSION

This study utilizes DEA model to evaluate the energy efficiency of 131 higher education institutions in the UK. The HEIs are divided into Russell and non-Russell groups from which 20 and 111 HEIs respectively are analysed. Malmquist index analysis is also conducted to assess changes in the overall integrated efficiency change, productivity improvement and to rank the energy efficiency performance of the HEIs from 2008 to 2015.
The findings from the constant return to scale (CRS) and the variable to scale (VRS) assumptions show that there is not discrete efficiency pattern, instead, it undulates across the 8 years period of investigation. Based on the mean annual, HEIs have relatively high energy efficiency scores of 96.9% and 77.6% (CRS) and 98.5%, 86.3% (VRS) for Russell and non-Russell groups respectively. The results of these estimates suggest that Russell HEIs are operating on variable return to scale rather than constant return to scale, since more of HEIs efficient on the latter and are less affected by

scale. Additionally, the results suggest that Russell HEIs are more efficient than the non-Russell HEIs. However, since DEA results are sensitive to sample size, caution is essential in applying the results implicitly in any policy framework.

Notably, the results obtained show that 2011 is the worst performing year due to a dip in research income by 2.08% and research student by 1.74% for the non-research based group while efficiency decline is principally a product of reduction in the staff population by 4.8%. 2010 is also a bad performing year for the non-Russell group as a result of the extreme cold weather conditions that account for high energy demand. No Russell group HEI is below 70% efficiency regardless of the assumption model while no greater than 30% of the HEIs have their energy efficient gradient below 70% except for 2008 (45 out 111 HEIs) and 2011(65 out of 111 HEIs) are grossly inefficient. The evidence from this study reveals that an increase in the energy efficiency of these institutions is feasible with the present operating scale. This requires that institutions work on their technical progress in order to become energy efficient.

The results indicate a general improvement over the years as the relative carbon emission performance of HEIs across the period of observation increased slightly due to technological progress.

Based on the Malmquist index analysis for the research and non-research groups, the improvement of efficiency change for both HEI groups fluctuate with values of 1.001 and 1.014 respectively, technological innovation (0.7233 and 0.849, which both depicts regression), pure technical efficiency (1 and 1.002, Russell group remain unchanged , non-Russell improves), scale efficiency change(1.0001 and 1.012, depicts both improves), and total factor productivity change (0.7286 and 0.861, means both deteriorates).

Malmquist index analysis confirms the lack of technological innovation, which impedes their energy efficiency and productivity gain. While pure technical efficiency accounts for the annual efficiency obtained in the DEA model, the technological progress in contrast is the source of their energy inefficiency.

Furthermore, energy efficiency evaluation without considering undesirable emission data results into higher performance and also reveals further dip in technological change and total factor productivity. Therefore a reasonable strategy to address this issue would require that HEIs investigate their activities and facilities, and figure out where and how to switch to the latest technologies that would boost their energy efficiency. Better still, HEIs should invest more in technical innovations. Another effective method to address this subject is to review and improve the efficiency of resource allocation, and specific actions include increasing the enrolment of research students and research grants. UK HEIs have high energy consumption and emission rates, the long-term approach for reducing energy consumption is to encourage diversification from fossil-based energy sources.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 declaration of Helsinki.

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