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Design of higher education teaching models and carbon impacts

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Structured Abstract:

Purpose

This research examines the main findings of the SusTEACH study of the carbon-based environmental impacts of 30 higher education (HE) courses in 15 UK institutions, based on an analysis of the likely energy consumption and carbon emissions of a range of Face-to-face, Distance, Online and ICT-enhanced blended teaching models.

Design/methodology/approach

An environmental assessment of 19 campus-based and 11 distance-based HE courses was conducted using questionnaire surveys to gather data from students and lecturers on course-related travel; the purchase and use of Information and Communication Technologies (ICTs) and paper materials; residential energy consumption, and campus site operations. Results were converted into average energy and CO₂ emissions, normalised per student per 100 study hours, and then classified by the primary teaching model used by lecturers.

Findings

The main sources of HE course carbon emissions were travel; residential energy consumption; and campus site operations. Distance-based HE models (Distance, Online and ICT-enhanced teaching models) reduced energy consumption by 88% and achieved significant carbon reductions of 83% when compared with campus-based HE models (Face-to-face and ICT-enhanced teaching models). The Online teaching model achieved the lowest energy consumption and carbon emissions, although there were potential rebound effects associated with increased ICT-related energy consumption and paper used for printing.

Practical implications

New pedagogical designs using online and distance-based teaching methods can achieve carbon reductions by reducing student travel, residential and campus accommodation.

Originality/value

Few studies have examined the environmental performance of HE teaching models. A new classification of HE traditional, online and blended teaching models is used to examine the role of ICTs and the likely carbon impacts.

Introduction

Greening higher education (HE) teaching systems is part of government strategies to address climate change challenges. The UK Higher Education (HE) sector is a fast growing sector serving 2.5 million students in 2011/12 (HESA, 2013). Total sector energy and resource consumption accounts for carbon emissions calculated at 3.34 million tonnes of carbon dioxide (MtCO₂) (HEFCE, 2010), which is approximately 0.7% of total annual UK carbon dioxide emissions, estimated at 497 MtCO₂ (Energy Information Administration, 2011). The Higher Education Funding Council (HEFCE) has consequently set challenging targets to reduce carbon emissions by 43 per cent by 2020 and by 83 per cent by 2050 compared with 1990 baseline levels, in line with the 2008 UK Climate Change Act (HEFCE, 2010).

The challenges of transition to environmentally sustainable higher education have not yet been fully addressed (Tilbury, 2011). The main sources of UK HE sector carbon emissions, include electricity (41%), transport (37%), natural gas (19%), waste (2%), other sources (1%) (HEFCE, 2010). The focus of HE carbon reduction programmes has been on: greening campus buildings and technologies, and on establishing policies and initiatives covering, waste and water management, energy-efficient Information and Communication (ICT) systems, and sustainable procurement. An additional priority has been teaching about sustainability with, for example, the Education for Sustainable Development initiative (see <http://educationforsustainabledevelopment.com>).

UK HE institutions are obliged to report direct (Scope 1) emissions from sources that they own or control, and indirect (Scope 2) emissions from the consumption/use of electricity (HEFCE 2010). From 2012/2013 HE data collection and reporting includes indirect (Scope 3) emissions that arise from the full-scale of organisational activities outside institutional control, including water supply, wastewater treatment, and waste disposal, and may extend to include travel and supply chain procurement (<http://www.hefce.ac.uk/whatwedo/lgm/sd/carbon/carbonfaq/>). Consequently, the future design of low carbon HE will need to address various challenges of carbon reduction targets, data collection and reporting.

Teaching is the core business of higher education, yet few studies have considered the whole of system environmental impacts of different methods of delivering HE. One notable exception has been the Factor 10 Visions study 'Towards Sustainable Higher Education', which assessed the key sources of energy consumption and carbon emissions of campus-based and distance learning-based HE delivery systems (Roy *et al.*, 2008). This study found that distance-based education systems consumed 90% less energy and produced 85% fewer CO₂ emissions per student per 10 study credits than campus-based systems (Roy *et al.*, 2008). Exploring the potential for redesigning HE systems to address carbon reduction challenges, the study argued that the lower impacts of distance compared with campus courses was mainly due to a major reduction in travel, elimination of much of the energy use in students' housing and more efficient utilisation of campus site buildings. Other factors

such as the purchase and use of ICT devices and print and paper materials were not a significant source of the carbon emissions of HE teaching systems surveyed (Roy *et al.*, 2008).

Since the Factor 10 Visions study was conducted, UK higher education has been transformed by the use of ICTs, the digital resources and technologies utilised for the preparation, administration, and provision of teaching, learning and assessment, and the widespread deployment of ICT-based infrastructure, such as Virtual Learning Environments (VLEs), Local Area Networks, wireless networks and cloud computing services. Experimentation in using ICTs within that infrastructure has supported pedagogical innovation, leading to technology-enhanced teaching and learning (see www.jisc.ac.uk), and the development of digital education resources.

These changes have begun to blur distinctions between campus-based and distance institutions' methods of providing HE. More campus-based institutions have moved towards providing technology-enhanced teaching and learning and a greater range of digital educational resources. In addition, advances in ICT have enabled distance-based teaching institutions to offer learning experiences, only previously available in the classroom or the field at residential schools. Blended or hybrid learning becoming the dominant HE scenario (see Johnson *et al.*, 2012), and this may take place at the course, qualification and/or institutional level. Radical new online learning designs have led institutions to:

- Offer wholly or primarily online e-learning courses and qualification programmes. Consequently environmental audits of HE courses now needs to account for the range of increasingly complex pedagogical designs using ICTs and rich media. This is often referred to as 'e-learning' or 'online learning'. In practice, there is a continuum, from complete use of ICTs replacing traditional classroom-based face-to-face teaching and print-based distance methods, to blended online and traditional teaching approaches, to almost no use of ICTs in traditional place-based teaching methods.
- Publish and/or develop courses based on openly licensed online education resources (OER) (such as OpenLearn (www.open.edu/openlearn/);
- Offer Massive Open Online Courses (MOOCs) that support global online learning communities, and help learners to contribute to developing educational resources and services (e.g. the Futurelearn platform led by the Open University – (www.futurelearn.com/).
- Set up global collaborative university partnerships to widen access to millions of students (e.g. Coursera established by Stanford University (<https://www.coursera.org/>) and Edx set up by Harvard University and Massachusetts Institute of Technology (MIT), (<https://www.edx.org/about>).

Growth in new, more online pedagogical designs together with increased use of ICT devices, infrastructure and the Internet raise questions about how such changes impact on the energy consumption and emissions of HE courses. The ICT sector accounted for around 2% of global carbon dioxide emissions in 2007 (Horrocks *et al.*, 2010), with Internet energy consumption estimated at between 1.1%- 1.9% of annual global energy consumption (Raghavan and Ma, 2011). Such impacts need to be considered in relation to potential trade-offs against other environmental impacts.

The SusTEACH project examined the transformative role of ICTs in delivering sustainable teaching and learning, and conducted a detailed environmental assessment of UK HE courses with different pedagogical designs and teaching models, using ICTs, and face-to-face and print-based teaching methods to deliver teaching, learning and assessment. Building on the Factor 10 Visions project, SusTEACH updated, reanalysed and extended the previous course data collection and analysis. The authors' work to conceptualise the role of ICTs in HE teaching models led to a new classification of

traditional, online and blended teaching models that was applied to support the analysis of HE courses' environmental impacts.

Sample

A total of 30 courses and modules from 15 UK HE institutions were included in the present study. They included 20 courses from the existing Factor 10 Visions project (reanalysed within the present methodology framework), together with an additional 10 courses selected to represent teaching models using ICTs to a varying extent across UK institutions (Table 1). The criteria for inclusion included campus-based and distance-based undergraduate and postgraduate courses (from The Open University or OU) in a variety of city centre, suburban and 'out of town' university locations. The terms course and module are alternately used in HE to refer to the set of modular, standardised, independent, or interrelated teaching units that construct an undergraduate or post-graduate degree qualification programme. Degree programmes may also be called courses but to avoid confusion the term course is used in the first sense (i.e. to include courses and modules).

A representative group of students and lecturers were selected from each of the 10 additional courses and invited to respond to online surveys and provide information on their course-related activities. The sample included the different lecturers responsible for producing, presenting and/or delivering distance education courses. Distance-taught courses typically have large numbers of student participants supported by small teams of lecturers who work on course production and presentation. Associated with them are large teams of Lecturers/Tutors who deliver tuition online, by post, or face-to-face in regional centres, and were included.

Methodology

There were a number of steps involved in undertaking the carbon-based environmental assessment of courses to determine whole HE system impacts.

The first step involved classifying the sample of HE courses within a typology of teaching models or designs. This was based on lecturers' ratings of the way teaching, learning and assessment were delivered to students, and their use of teaching delivery methods, including: face-to-face teaching; and the relative use of print-based educational materials; and ICTs plus rich media to supplement or substitute traditional methods. This approach helped to classify each course by reference to its primary teaching model. For this study those models included: Face-to-face and ICT-enhanced Face-to-face teaching models within campus-based systems; Distance, ICT-enhanced Distance, and Online teaching models in a supported distance teaching system (Table 1).

Table 1: Classification of higher education (HE) Teaching Models

Classification of Higher Education (HE) Teaching Models	Number of courses	Under-graduate	Post-graduate	Number of Students Responses	Number of Lecturers & Associate Lecturers
The Face-to-face Teaching Model -uses mainly face-to-face teaching methods with no ICT-enhancement.	14	8	6	274	8
The Distance Teaching Model - uses mainly classic distance teaching methods such as using printed educational materials with supported learning and has limited or no ICT-enhancement.	3	1	2	284	66
The Online Teaching Model - provides mainly online teaching, learning and assessment, available on the course/module Virtual Learning Environment. The model may include some minimal face-to-face teaching e.g. to attend day schools.	4	3	1	51	24
The ICT-enhanced Distance Teaching Model -uses classic distance teaching methods, enhanced by some use of ICTs e.g. to provide online links to downloadable resources or audio-visual digital resources.	4	2	2	921	156
The ICT-enhanced Face-to-face Teaching Model -uses face-to-face teaching methods enhanced by some use of ICTs, e.g. to provide online links to downloadable resources.	5	1	4	46	18
Total	30	15	15	1576	272

The second step established a methodology for conducting the environmental assessment of HE courses based on the Factor 10 Visions study (Roy *et al.*, 2008). Questionnaires were designed to gather data from courses on a consistent basis. They were either directly emailed to staff and students or emailed to students via lecturers.

Several questionnaire forms were designed in order to reflect variations in course designs and education systems. These variations related to differences between distance and campus-based education systems; semester and term structures; and programmes presenting courses in parallel or

sequentially in intensive time blocks. Questionnaire data on course activities were further refined in order to compartmentalise data based on time periods, such as 'the typical week', 'the whole module/course', and 'a previous academic year' with the data apportioned to the number of course weeks.

Data were collected on the main sources of energy consumption and carbon emissions associated with HE systems including:

- Travel to and from places where the teaching or learning takes place. Data gathered included information on types of trip, number of trips, round trip distance, mode of travel, regular and occasional travel, and travel at the beginning and end of term or semester;
- Purchase and use of ICT devices. Data gathered included purchase of ICT devices, and the time spent per week using ICT devices on and off-campus for connecting to the Internet, university websites, and for offline study;
- Purchase of books and publications, the provision and transportation of educational materials, and the use of paper for printing and photocopying;
- Choice of residential accommodation and home energy use for student study and lecturers homework. Primary data gathered included information on types of dwellings, heating systems, lighting, and electrical appliances. This was supported by secondary data sources on buildings' energy-consumption and modelling software;
- Campus site operations, including data available on energy consumption from the Higher Education Statistics Agency (HESA) database and university estates departments (see www.hesa.ac.uk). Data collected also included information on specific characteristics of the distance-based teaching system, such as the module production and presentation process, and transportation of teaching materials.

The carbon assessment focused on key sources of energy consumption in HE systems and did not include wider waste, water and procurement (supply chain) impacts that give rise to Scope 3 emissions.

In cases where the lecturers surveyed worked as part of a team to provide only a fraction of a course, the 'main academic equivalent' method was used to calculate the proportionate contribution of the main lecturer's course activities to estimate lecturer-related impacts. Impacts were then calculated on a per student basis, using information collected on lecturer: student ratios. The estimation of course energy and carbon impacts from all data sources was calculated using the average per student measure.

The third step involved normalising the data collected to enable comparison of the courses under investigation. The standard UK Credit Accumulation and Transfer Scheme (CATS) system of HE institutional arrangements for measuring student progression towards defined learning outcomes and qualifications was used in this study. It offers a time-based measure for comparing the environmental impacts of courses with defined study hours (see www.qaa.ac.uk). This partly matches the European Credit Transfer Scheme within the European HE Area where 1 ECTS=2 CATS. The CATS system identifies 1 CATS credit as equivalent to 10 hours total study including writing assignments, field work, etc. A further 120 CAT credits is equivalent to full-time study per academic year, while 360 CATS credits are required for a UK undergraduate Bachelor's degree, and 180 credits for a post-graduate Master's degree. Normalising the data in this way allowed for inter-institutional and intra-institutional comparisons of courses.

The fourth step involved converting measures of energy consumption into megajoules (MJ) and carbon conversions in kilograms of carbon (Kg CO₂) in order to standardise the environmental assessment.

Data collected on course-related activities were first converted into energy consumption in megajoules (MJ), and then converted to CO₂ data using the latest carbon conversion factors available from the UK Departments for Environment, Food and Rural Affairs (Defra) and Energy and Climate Change (DECC). These provide conversion factors for all fuel sources based on units of consumption and for transport modes for the UK context (Defra/DECC, 2011).

The environmental assessment focused mainly on measures of delivered energy and direct greenhouse gas emissions of fossil fuels at the point of use, as this was a consistent measure provided by most data sources on CO₂ emissions. This measure refers to the amount of energy delivered without any adjustment for the indirect emissions associated with fuels consumed during the production prior to the point of use or fuel combustion. These measures were used for calculating the carbon impacts associated with using transport vehicles, heating systems or printers for study.

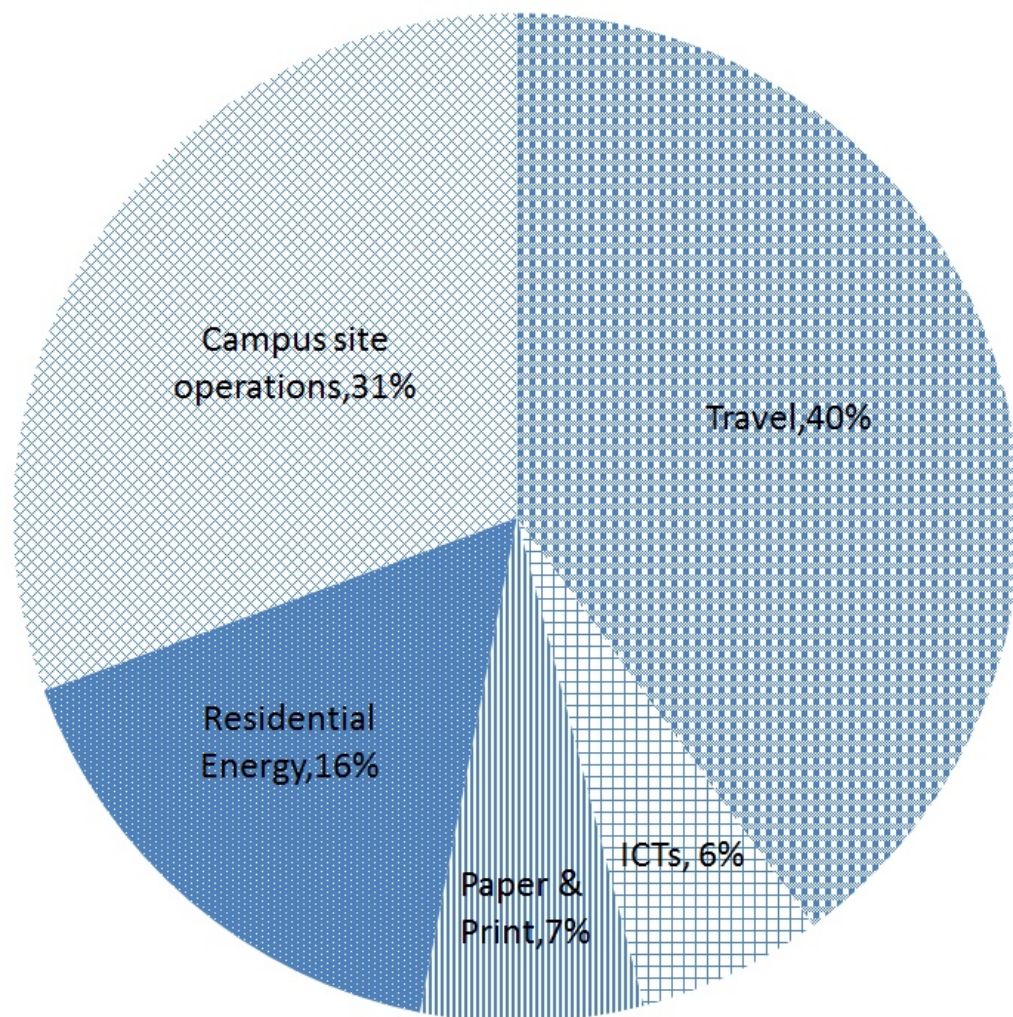
For paper and printed materials, it was determined to be appropriate to use measures of embodied energy. These measures refer to calculations of primary energy consumed over the life-cycle of a product or system associated with extraction, production, distribution, use and eventual disposal that gives rise to indirect emissions. With ICT equipment, it was appropriate to use measures of both embodied energy and delivered energy during use. Measures of energy consumption and carbon conversions were established with reference to environmental impact life-cycle studies (Caird *et al.*, 2012).

Finally, course data gathered on each type of course activity were normalised using CATS credits (or hours of study). This was then averaged for each course environmental impact. Then the application of carbon conversion measures provided the average energy consumption and CO₂ emissions of a course, using the *per student/per 10 CATS credits measure* (i.e. equivalent to 100 hours of study). This approach allowed for the classification of courses within the HE Teaching Models framework and further comparisons.

Results

Overall the main sources of carbon emissions for all HE teaching models were travel (40%), campus site operations (31%) and residential energy (16%) (Figure 1).

Figure 1: Teaching and learning in HE courses: Percentage of average CO₂ emissions from each source



The results of the carbon assessment and data analysis of courses were classified by their primary teaching model and are presented in Table 2 and Figures 2-3. Analysis of the results for part-time and full-time students showed that relative to CATS credits, there were no significant differences, and consequently the results were aggregated for analysis.

Table 2: Average energy consumption (MJ) and CO₂ emissions (kg) of teaching models (per student per 100 study hours)

energy consumption (MJ)						
Teaching models	Travel	ICTs	Paper, print, and other materials	Residential energy	Campus site operations	TOTAL
Face-to-face	2224.54	35.70	193.12	1014.22	825.74	4293.31
Distance	235.40	14.76	197.78	23.37	152.11	623.42
Online	31.61	106.64	60.49	12.17	152.11	363.02
ICT-enhanced distance	85.89	109.19	106.62	47.17	152.11	500.99
ICT-enhanced face-to-face	2385.25	56.27	180.91	811.48	825.74	4259.64
CO₂ emissions (kg)						
Teaching models	Travel	ICTs	Paper, print, and other materials	Residential energy	Campus site operations	TOTAL
Face-to-face	128.50	4.33	11.39	57.00	76.69	277.91
Distance	16.98	2.00	13.04	1.59	15.51	49.12
Online	2.28	12.83	4.20	0.82	15.51	35.65
ICT-enhanced distance	6.18	13.38	6.93	3.11	15.51	45.11
ICT-enhanced face-to-face	107.48	6.40	11.18	44.26	76.69	246.01
All Teaching Models	52.28	7.79	9.35	21.36	39.98	130.76

[Note: The larger number of involved stakeholders associated with courses with Distance, ICT-enhanced Distance and Online models compared with the campus-based Face-to-Face and ICT-enhanced models led to higher levels of student and staff responses.]

Figure 2: Average energy consumption (MJ) of HE Teaching Models (per student per 100 study hours)

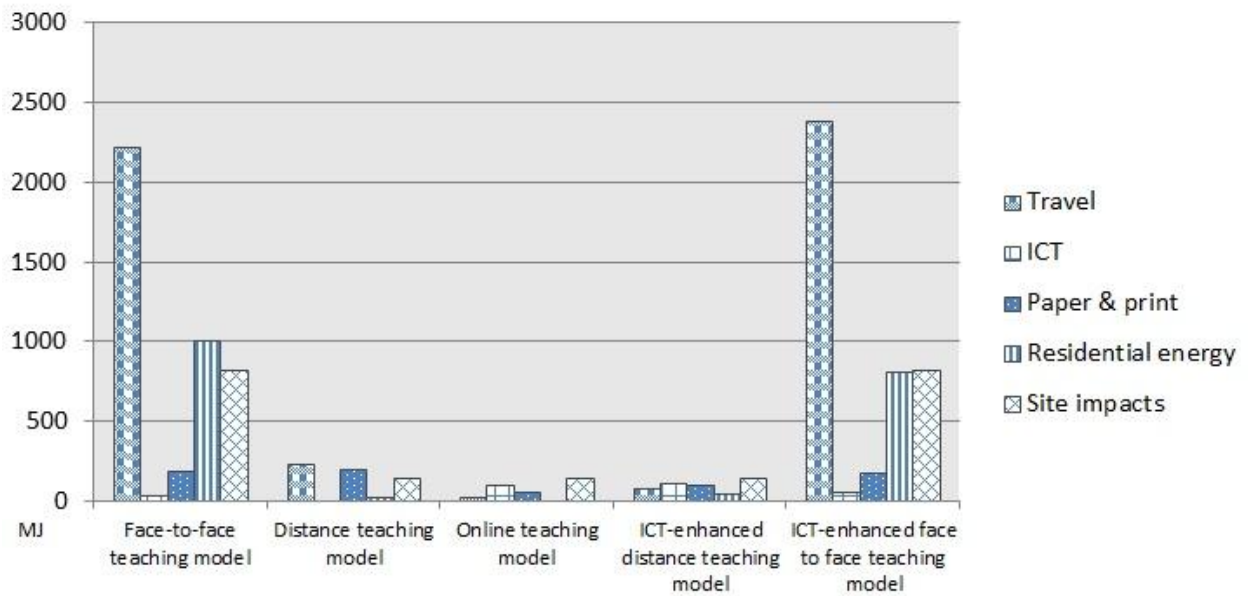


Figure 3: Average CO₂ emissions (kg) of HE Teaching Models per student (per student per 100 study hours)

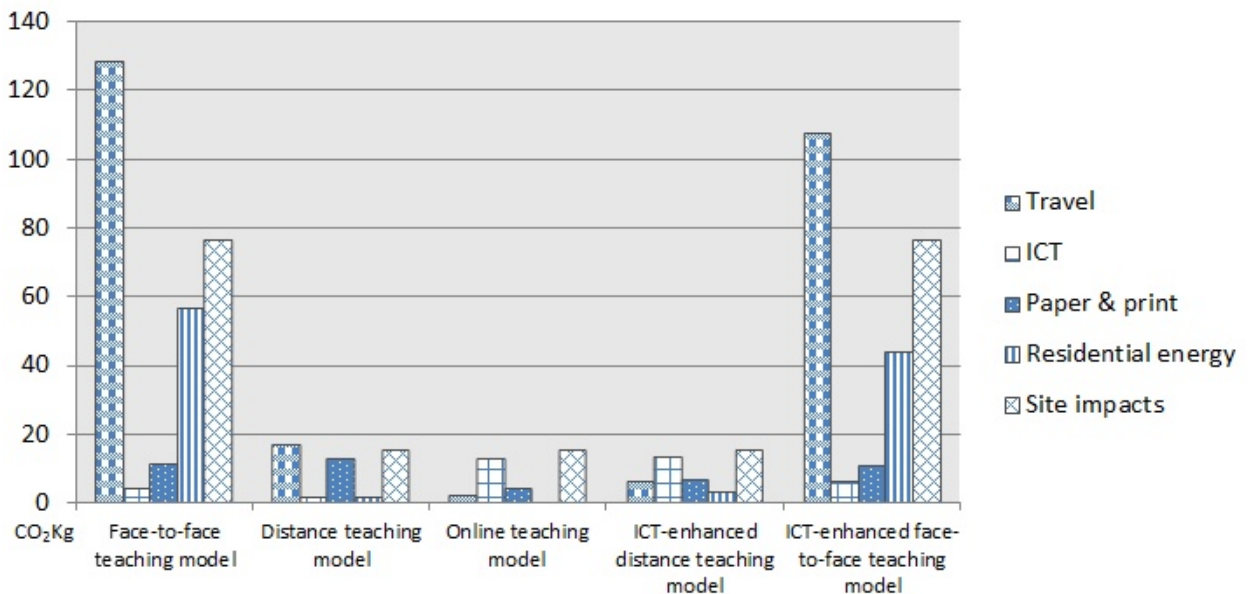


Figure 3 is reprinted from Caird et al. (2013) in: Caeiro et al. (Eds.), *Sustainability Assessment Tools in Higher Education – Mapping Trends and Good Practices at Universities round the World*, Figure 1, Springer International Publishing Switzerland. With kind permission from Springer Science+Business Media B.V.

Course-related travel

Although course-related travel made the greatest contribution (40%) to the carbon emissions of all HE courses, there were striking differences between the travel impacts of the campus-based and distance-based teaching models. Within campus-based systems, there was considerable variation in travel between courses in terms of regular commuting between the term-time residence and campus; travel between the main/usual home and term-time residence; and occasional journeys

including travel to other campus sites, on field trips etc.. In distance-based education systems, students usually studied at home, at work or local places of their choice, although students sometimes travelled as part of course preparations or to attend occasional tutorials, field trips, day schools, residential schools, and/or final examinations.

Student travel data were weighted to represent the proportions of UK-domiciled and overseas students on each campus-based course, relying on lecturers' information to obtain this data. The main type of carbon-intensive travel associated with the two campus-based models was travel between the home and term-time residence, accounting for approximately 88Kg CO₂ per student on average, per 10 CATS credits. Removal of this would halve overall energy consumption (by 54%) and carbon emissions (by 45%), provided that alternative carbon-intensive travel modes were not used.

The *ICT-enhanced Face-to-Face model* had the highest travel-related energy consumption of 2385(MJ) per student per 10 CATs credits (Table 2). Most of this consumption was attributable to student air travel which produced 81% of travel-related emissions. Students on ICT-enhanced campus-based courses with a high intake of foreign students (>30%) travelled an average 876 miles per 10 CATS credits (i.e. 100 study hours). This travel for foreign students was nearly three times higher than courses with mainly UK-domiciled students who travelled on average 309 miles for equivalent study hours.

The high rate of air travel emissions noted above needs to be placed in context. In particular, the *ICT-enhanced Face-to-Face model's* higher energy consumption did not produce the highest travel-related carbon emissions (Table 2). That is because air travel displays a relatively low carbon factor; for example long haul air travel has a conversion factor of 0.96Kg CO₂ per passenger mile, equivalent to one third of car emissions and half of bus emissions (Defra/DECC, 2011). As a result, there was little difference between the two campus-based models' travel impacts despite the ICT-enhancement (Table 2). In some cases, ICT-enhancement of campus-based courses enabled students to travel longer distances to attend short periods of face-to-face teaching, whilst studying online for part of the course.

Comparisons show that transportation was responsible for a relatively modest proportion of the carbon emissions associated with the *Distance teaching model* (35%), the *ICT-enhanced Distance teaching model* (14%), and the *Online teaching model's* emissions (6%) (Table 2). In the latter model with the least intensive travel demand, students made on average less than 1 journey per 10 CATS credits covering an average distance of 10 miles per journey. This explains the *Online teaching model's* lowest travel-related impacts of 2.28Kg CO₂ per student per 10 CATs credits (Table 2), and supports the importance of online teaching for reducing transport energy consumption.

ICT purchase and use

Only 6% of the carbon emissions of all HE courses were directly ICT-related (Figure 1). Within these figures, unsurprisingly ICT purchases and use were responsible for a relatively high proportion of carbon emissions associated with the *ICT-enhanced Distance teaching* (30%) and *Online teaching models* (36%). They were a main source of these models' impacts, producing on average 13Kg CO₂ per student per 10 CATs credits (Table 2). Students taught with these models typically used ICT devices for all the planned study hours. They were online doing course activities for 72% of the time on the *ICT-enhanced Distance teaching model*, and 82% of the time on the *Online teaching model*.

The *ICT-enhanced Face-to-face teaching model's* ICT-related impacts were about half of the *ICT-enhanced Distance teaching* and *Online teaching models*, and contributed a small proportion of carbon emissions (<3%), similar to the traditional *Distance teaching and Face-to-face teaching models* (Table 2). This may be explained by the relatively low levels of ICT-enhancement of the campus-based courses under investigation.

Within the *Online teaching model* and both ICT-enhanced teaching models, the results confirmed that the primary ICT devices used at the time of the study were laptops, and were used for over half of course activities. The results revealed that with the *Online teaching model*, students used laptops, tablets and other portable devices for 65% of activities, considerably more than they used desktop personal computers (35%). The results also showed that for online courses the increased use of portable ICT devices enabled learning to take place in multiple locations, including the home (82%), in work-places (11%), while travelling (4%), and in libraries (3%).

With *ICT-enhanced Face-to-face taught courses*, the findings showed that students had an even higher use of lightweight, portable devices (used for 80% of activities) compared with personal desktop computers (20%). This choice of ICT devices enabled mobile learning in classrooms and term-time and home locations.

Paper and print

Overall only 7% of total HE course emissions was related to paper and printed materials consumption (Figure 1). Unsurprisingly the use of paper materials was responsible for a higher proportion of emissions in the distance-based system, including the *Distance teaching* (27%), *ICT-enhanced Distance teaching* (15%) and *Online teaching* (12%) models. With campus-based *Face-to-face teaching* and *ICT-enhanced Face-to-face teaching models*, paper and print consumption were responsible for only 5% and 4% of carbon emissions respectively (see Table 2), most of which was due to book purchases (83% and 76% respectively).

There were different patterns in paper and print use across the teaching models, including book purchases, use of paper and educational materials. In the distance-based education system, some educational materials are specially produced and mailed to students. This accounted for half of the materials-related carbon emissions of the print-based *Distance teaching model* and a third of the *ICT-enhanced Distance teaching model's* emissions. By contrast the *Online teaching model* replaced most of the requirement to produce and deliver materials with online resources, explaining the lowest materials-related impacts of 4Kg CO₂ per student per 10CATs, which was only one third of the carbon emissions of the *Distance teaching, Face-to-face teaching and ICT-enhanced Face-to-face teaching models* (Table 2).

A contradictory finding was that despite the lower overall materials-related impacts of the *Online teaching model*, students consumed a third more paper mainly for printing (195 sheets per 10 CATS credits), compared with students in the *Distance teaching model* where there was a high provision of printed materials (132 sheets per 10 CATS). Analysis within the distance-based system showed there was a strong correlation (0.95) between the ICT-intensiveness of a course and levels of student paper consumption. While the overall materials consumption associated with the *Online teaching model* was reduced, students printed more paper – a compensating activity with environmental impact.

Similarly within the campus-based system, the *ICT-enhanced Face-to-face teaching model* was associated with increased student paper consumption, up by a quarter (202 sheets per 10 CATS), compared with the *Face-to-face teaching model* (153 sheets per 10 CATS). Overall the *ICT-enhanced Face-to face teaching model* achieved minimal materials-related carbon reductions (<2%) compared with the *Face-to face teaching model* (see Table 2). This may be explained by students' preference to print online resources rather than read on-screen, as it is unlikely that increased printing on ICT-enhanced courses was because students had limited regular access to computers.

Residential energy consumption

Data obtained from questionnaires on types of student residences was combined with other data sources to estimate the impacts associated with residential energy consumption.

For students living in *university residences*, data sources on university accommodation from Estates Departments (see HESA, 2011a) were accessed to estimate university residential energy consumption per student from the energy data on residential buildings and the number of student residential places. Excluding the impacts of room use outside the academic year, this led to the calculation of 1281 (MJ) and 78Kg CO₂ per student per 10 CATS credits. As some part-time students used *temporary accommodation* on occasions for overnight or short stays we used university residential data to calculate the energy impacts per room and per day as the facilities are similar to a hotel.

For students living in *non-university accommodation*, such as shared houses, flats, and lodgings the English Housing Surveys: Stock Report provided data on the annual energy consumption and emissions for average dwellings, based on their heating system and fuel type (Communities and Local Government, 2011). Assuming an occupancy of 3 students per dwelling with an average size of 91m², and excluding impacts outside the academic year, this produced figures of 1969(MJ) and 96Kg CO₂ per student per 10 CATS credits.

For students *living at their main/usual home* during the course and lecturers working from home, the questionnaires were designed to identify any additional hours of heating, printing and lighting for coursework required above normal usage. The National Home Energy Rating (NHER) Surveyor software for modelling the energy consumption and emissions of typical UK dwellings, based on using specific heating systems and fuels was used (NES, 2005) together with the latest carbon conversion factors.

Following the methodology of the Factor 10 study, it was considered that energy used by students in term-time residences is an intrinsic part of studying full-time in campus-based HE institutions, and therefore a proportion is attributable to each course being studied (Roy *et al.*, 2008). Whilst it is possible that university residential energy consumption offsets energy consumption in the student's main home, recent research by the Energy Saving Trust with over 250 UK households suggests that household energy consumption is dwelling-related rather than occupant-related, with the finding that that energy consumption from single occupancy households equalled or exceeded that of family occupied homes (EST, 2012). When students live away from home, their term-time residential consumption is arguably an additional energy impact attributable to the HE course.

The findings showed that residential energy consumption was a relatively minor source of carbon emissions associated with the three distance teaching models. For example, residential energy-related emissions were only <2% of the *Online teaching model's* emissions (see Table 2). When students learn within a distance-based system and/or travel from home to attend classes, this eliminates the energy impacts associated with living away from home. By comparison the impacts of using additional energy to provide heat and power for learning at home were minimal.

Despite the low residential energy consumption associated with teaching models in the distance-based system, residential energy accounted for 7% of the *ICT-enhanced distance teaching model's* emissions (see Table 2). Further examination showed this was due to the mainly winter presentation of courses sampled, creating higher heating and lighting requirements. An interesting implication is that the usual summer university closures may ignore an opportunity for carbon saving.

In campus-based teaching models, residential energy consumption accounted for about a fifth of carbon emissions as a result of high numbers of students living away from home, and was higher than the total *Online teaching model's* emissions (see Table 2).

Campus site operations and impacts

To calculate campus site energy consumption and carbon emissions that are attributable to a specific course, it is important to account for variations between universities' non-residential energy impacts. This includes identifying the proportion that is attributable to teaching, rather than to research and other activities, and relating this to the number of full-time-equivalent (FTE) students. Annual non-residential energy consumption and emissions data for UK universities are available from official Estates Management Statistics (HESA, 2011a). The proportion attributable to teaching for all universities was calculated to be 72 % using funding information for 2009/2010 available from the UK Higher Education Funding Councils for England (www.hefce.ac.uk), Wales (www.hefcw.ac.uk), and Scotland (www.sfc.ac.uk). Dividing the non-residential energy consumption and CO₂ emissions data attributable to teaching by the total number of FTE students at UK universities (HESA, 2011b), and assuming 120 CATs study credits per year, campus-based site operations impacts were calculated as 825.74(MJ) and 76.69kg CO₂ per student per 10 CATs credits.

A similar procedure was followed using data from the OU on funding combined with HESA data to calculate impacts for distance-based HE systems' site operations. To this was added the results of a separate scoping study of the impacts of course production and presentation based on surveys to determine staff activities per study credits, with estimations of environmental impacts calculated relative to student numbers during a typical course lifetime of 8 years. Distance-based institutional site operations were calculated as 152.11(MJ) and 15.51 Kg CO₂ per student per 10 CAT credits.

Although campus site operations were a key source of energy consumption and emissions for all HE courses (Figure 1), comparisons showed that the distance-based HE system's site operations consumed markedly lower energy consumption and produced a fifth of the CO₂ emissions of the campus-based system per student per 10 CATs credits (Table 2). This is mainly due to efficiencies and economies of scale associated with teaching thousands of students from one central campus supported by several regional centres.

Comparison of Teaching Models

The analysis revealed striking differences between the teaching models adopted in the distance-based and campus-based education systems. Teaching models in the distance-based education system, including the *Distance teaching*, *ICT-enhanced Distance teaching* and *Online teaching models*, consumed on average 88% less energy and produced 83% fewer carbon emissions than the *Face-to-face teaching* and *ICT-enhanced Face-to-face teaching models* in the campus-based system. Within the distance-based system, students are supported to learn via distance and online teaching methods, with minimal face-to-face teaching whilst living at home, thereby reducing the need for students to take additional residential accommodation, travel to university sites, and use campus facilities.

The *Online teaching Model* achieved the lowest energy consumption (363MJ) and emissions 36kg CO₂ per 10 CATs credits (Table 2). Compared with the *Distance teaching model*, both the *Online teaching* and *ICT-enhanced Distance teaching models* achieved carbon reductions of 27% and 21% respectively, (see Table 2), mainly by reducing materials and transport impacts.

Within campus systems, the ICT-enhanced model was associated with carbon reductions of only 11% compared with traditional Face-to-face teaching and there was little difference in the energy consumption figures (See Table 2). The campus-based courses had relatively low ICT-enhancement

and typically used ICTs to supplement and enhance rather than replace classroom-based face-to-face teaching. Further examination revealed that 35% of the carbon emissions associated with the ICT-enhanced Face-to-face teaching model was attributable to student air travel between their home and term-time residence. In some cases, blended models in campus systems enabled students to travel longer distances to attend short periods of face-to-face teaching, whilst studying online for part of the course.

Conclusions

Few studies have examined the environmental performance of HE Teaching Models and the impacts of new pedagogical designs using ICTs. Conducting an environmental assessment of teaching models is complex and gives rise to methodological issues that have been detailed here to aid research on the environmental impacts of teaching and learning. Further research is needed to extend data collection to a larger sample of courses using various online and ICT-enhanced pedagogical designs in HE systems, while longitudinal studies should monitor the impacts of different pedagogical designs and changes in student lifestyle behaviours, and take account of the carbon reductions expected with further greening of buildings, UK grid decarbonisation.

The present SusTEACH project findings are consistent with previous research that has shown that the main sources of energy consumption and CO₂ emissions for UK HE systems are travel, campus site operations and residential energy use (Roy *et al.*, 2008). The present research developed a classification of HE teaching models to examine the transformative role of ICTs on HE teaching models, and has found differences in the environmental performance of different teaching models. Whilst there is variation in the environmental impacts within and across teaching models, this study has shown that pedagogical design is important for reducing carbon emissions.

The Online teaching model achieved the lowest energy consumption and emissions, although the most striking differences were between the impacts of the distance-based teaching models by comparison with campus-based HE models. The use of *online*, *ICT-enhanced distance* and *distance teaching models* reduced the main sources of energy consumption and emissions by reducing the requirements for students to travel to classrooms, establish residential accommodation away from their main home and use campus facilities. These are the key areas to tackle to reduce CO₂ emissions in higher education, as is already reflected in many universities' energy and sustainability policies and carbon reduction programmes.

In distance-based HE systems, pedagogical designs using ICTs have the potential to achieve significant carbon reductions by comparison with classic distance teaching. In addition, the potential movement towards purchase of lightweight portable ICT devices by student should achieve lower carbon emissions as lifecycle studies showed that a laptop produces a third (and a tablet a quarter) of the emissions produced using a desktop PC (SusteIT Footprinting Tool, 2009).

With international movements towards radical online learning designs, such as Massive Open Online Courses, pedagogical use of ICTs is auspicious for low carbon HE futures. This conclusion is subject to the caveat that in campus-based HE systems there is little evidence that the *ICT-enhanced face-to-face teaching model* results in lower energy consumption and emissions than *face-to-face teaching*. One reason for this is that students appear to prefer printed learning materials even if they have access to online sources. Another explanation is the contribution of student air travel, which can account for significant carbon emissions, particularly for cohorts of foreign students. Such travel impacts are a concern as statistics show strong growth in the numbers of non-UK domiciled students which constituted 17% of students in UK universities in 2011/2012 (HESA, 2013). ICT-enhanced teaching designs that require students to travel for even short periods of classroom-based teaching are unlikely to achieve carbon reductions, even if most of the learning is online.

The different patterns of using paper and print materials in courses presents a mixed message on whether ICTs help to dematerialise education. In the campus-based system, there is little evidence that ICT-enhancement was associated with lower overall materials' consumption in courses. By contrast in the distance-based education system, the *Online teaching* and *ICT-enhanced distance teaching models* replaced most printed materials with online resources and have the lowest materials-related energy impacts. However, in both campus-based and distance-based education systems, ICT-enhancement of courses is associated with increased use of paper for printing, and this suggests that carbon reductions may be achieved by encouraging more on-screen reading without printing out materials.

Overall, the findings have practical implications for the design of low carbon HE teaching models. They suggest that existing carbon reduction programmes can and should be broadened beyond 'greening' campus buildings, technologies and the curriculum so as to focus on new pedagogical designs using ICTs and distance-based teaching methods. If carefully designed they may reduce the requirements for student travel, residential and campus accommodation, and provide carbon benefits. Thus, a primary challenge for HE in the near future is likely to be the creation of new pedagogical designs to deliver the benefits of carbon reduction, while supporting the strategic and sustainability objectives of HE institutions.

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