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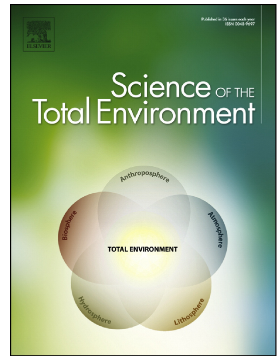

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PII: S0048-9697(20)37495-7

DOI: https://doi.org/10.1016/j.scitotenv.2020.143964

Reference: STOTEN 143964

To appear in: *Science of the Total Environment*

Received date: 25 September 2020

Revised date: 30 October 2020

Accepted date: 14 November 2020

Please cite this article as: V. Filimonau, D. Archer, L. Bellamy, et al., The carbon footprint of a UK University during the COVID-19 lockdown, *Science of the Total Environment* (2020), https://doi.org/10.1016/j.scitotenv.2020.143964

The carbon footprint of a UK University during the COVID-19 lockdown

Viachaslau Filimonau[1]*, Dave Archer[1], Laura Bellamy[1], Neil Smith[1], Richard Wintrip[1]

[1]Faculty of Management, Bournemouth University, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB, UK

Viachaslau Filimonau, email: vfilimonau@bournemouth.ac.uk

Dave Archer, email: darcher@bournemouth.ac.uk

Laura Bellamy, email: lbellamy@bournemouth.ac.uk

Neil Smith, email: nsmith@bournemouth.ac.uk

Richard Wintrip, email: rwintrip@bournemouth.ac.uk

*Corresponding author

Abstract

The COVID-19 pandemic has provided a unique opportunity to compare the carbon intensity of higher education delivered on- and off-campus. This is attributed to governmental lockdown orders that have forced Universities to close their campuses, ban business travel and move all teaching and learning activities online. This study represents a first known attempt to compare the carbon footprint of a mid-sized UK University produced during the COVID-19 lockdown (April-June 2020) against that generated within the respective time period in previous years. Although the overall carbon footprint of the University decreased by almost 30% during the lockdown, the carbon intensity of online teaching and learning was found to be substantial and almost equal to that of staff and student commute in the pre-lockdown period. The study contributed to an emerging academic discourse on the carbon (dis)benefits of different models of higher education provision in the UK and beyond. The study suggested that policy and management decisions on transferring education online

should carefully consider the carbon implications of this transfer.

Highlights

- An initial proposal on how to scope GHG emissions from work/study from home
- Carbon benefits of online education can be less significant than anticipated
- Work/study at home generates as much carbon footprint as the University commute
- Complete closure of University campuses does not result in low GHG emissions
- The model of blended teaching and learning may have low carbon efficiency

Keywords

Higher education, Online teaching, Sustainable development, GHG emissions, Pandemic

1. Introduction

In their capacity of the key providers of higher education Universities and colleges are increasingly recognised as important promoters and advocates of the global agenda for sustainable development (Figueiro and Raufflet 2015). This is because they can shape the mindsets of future decision-makers in business, academia and politics, thus being important sustainability knowledge multipliers (Findler *et al.* 2019). This is also due to their ability to 'lead by example' which implies close integration of the principles of sustainability in day-to-day operations of many institutions of higher education worldwide (Caeiro *et al.* 2020). Such integration signals commitment of Universities and colleges to the sustainability goals (Disterheft *et al.* 2015) and can, therefore, empower the key stakeholders concerned, i.e. students, staff and suppliers (Dentoni and Bitzer 2015), to pursue these goals outside the sector of higher education, thus creating a positive spillover effect (Cebrian *et al.* 2015).

The role of Universities and colleges as agents of positive societal transformations and enablers of worldwide progress towards the goals of sustainable development will become even more important in the future (Ceulemans *et al.* 2015). This is attributed to the envisaged continuous growth of the global sector of higher education (HM Government 2013) and rising student expectations for sustainability actions embraced by Universities and colleges worldwide (Students Organising for Sustainability 2018). This is further assigned to the growing anticipation by various (inter)national stakeholders of the wider scope and larger extent of the sustainability work which should be undertaken by institutions of higher education. For example, in the UK, a student-led initiative, the People & Planet's University League (2020) has been established. The league ranks all UK Universities by their environmental and ethical commitment and performance, thus informing current and prospective students about sustainability credentials of their host institutions. At a global scale, the Higher Education Sustainability Initiative (2020) has been created by the United Nations Organisation. This initiative aims to engage Universities and colleges worldwide in the fulfilment of the United Nations Sustainable Development Goals (UNSDG), in particular UNSDG17: Partnerships for the Goals. Such high stakeholder expectations/anticipations imply significant responsibility held by institutions of higher education in terms of the adoption and promotion of sustainability initiatives, now and in the future (Genus and Theobald 2015).

Although Universities and colleges represent important facilitators of sustainable development, they can also noticeably contribute to global unsustainability (Lozano *et al.* 2013). This contribution is primarily exemplified by the exploitation of natural resources with its related detrimental environmental externalities, particularly climate change (Scheuer *et al.* 2003). It is well recognised that institutions of higher education produce large amounts of greenhouse gas (GHG) emissions due to student (Shields 2019) and staff (Wynes *et al.* 2019) mobility, but also because of excessive on-campus consumption of energy (Hawkins *et al.* 2012) and water (Parece *et al.* 2013). Most Universities and colleges possess significant capital assets whose embodied carbon footprint can be large albeit difficult to estimate (Robinson *et al.* 2018). To support on-campus operations, institutions of higher education procure extensive inventories of goods and services, and these procurement practices can be carbon-intense (Filho *et al.* 2019). Lastly, Universities and colleges generate substantial volumes of waste, especially organic, whose collection and treatment requires energy with associated GHG emissions (Ridhosari and Rahman 2020).

Research on the assessment of the carbon impacts of Universities and colleges is rapidly emerging (Robinson *et al.* 2015). To date, it has been represented by case studies focused on the institutions of higher education operating in Chile (Yanez *et al.* 2020), China (Li *et al.* 2015), India (Sangwan *et al.* 2018), Indonesia (Ridhosari and Rahman 2020), Mexico (Mendoza-Flores *et al.* 2019), the Netherlands (Versteijlen *et al.* 2017), Norway (Larsen *et al.* 2013), Saudi Arabia (Adenle and Alshuwaikhat 2017), South Africa (Letete *et al.* 2011), Spain (Gomez *et al.* 2016), Thailand (Aroonsrimorakot *et al.* 2013), the UK (Ozawa-Meida *et al.* 2013) and USA (Bailey and LaPoint 2016). Research has demonstrated the disproportionate contribution made by student (Barros *et al.* 2019) and staff (Arsenault *et al.* 2019) travel, as well as on-site energy consumption (Clabeaux *et al.* 2020), to the GHG emissions of Universities and colleges, thus outlining these operational processes as prime opportunities for carbon footprint prevention and mitigation in the global sector of higher education (Yanez *et al.* 2020). Research has further outlined a wide array of analytical techniques employed for carbon footprint assessment of Universities and colleges (Findler *et al.* 2019), ranging from full-scale life cycle assessment (see, for example, Clabeaux *et al.* 2020) and environmentally-extended input-output analysis (see, for instance, Townsend and Barrett 2015) to streamlined/simplified life cycle energy analysis (see, for example, Sangwan *et al.* 2018). In line with this methodological diversity, a call to unify carbon footprint standards in the global sector of higher education has been made to ensure comparability of all future studies and facilitate wider adoptability of the most effective methods of carbon impact appraisal (Robinson *et al.* 2018).

Online education has recently been discussed in light of measures required to reduce the carbon impacts of institutions of higher education (Caird and Roy 2019; Carr *et al.* 2019; Versteijlen *et al.* 2017). To date, rapid technological progress has provided multiple digital platforms and created numerous smart tools for online teaching/learning, thus facilitating its broad(er) uptake by Universities and colleges worldwide (Song *et al.* 2016). For example, the Open University represents a popular public institution of higher education in the UK which specialises in the delivery of online courses and distance-based learning (Sharples *et al.* 2012). Although online education has a number of shortcomings related to, for instance, limited student engagement and retention (Gazza and Hunker 2014), it has been increasingly argued that it should be considered a viable, yet more climate-friendly, alternative to traditional, rather carbon-intense, on-campus operations of Universities and colleges worldwide (Jarillo *et al.* 2019). Limited empirical evidence exists, however, to (dis)prove the carbon (dis)benefits of the different models of higher education provision (Versteijlen *et al.* 2017).

The COVID-19 pandemic has imposed a number of dramatic impacts on all sectors of the global economy (Filimonau *et al.* 2020). The sector of higher education is no exception as governmental lockdown orders have forced Universities and colleges worldwide to temporarily cease their operations and move teaching/learning provision online (Murphy 2020). It is argued that the recent lockdown regimes represent a 'once-in-a-lifetime' opportunity to conduct a 'reality check' for carbon impacts of online education in Universities and colleges. Abandoned campuses and prohibited student and staff mobility, coupled with teaching/learning delivered fully online, provide scope for a comparative analysis of the GHG emissions generated by on-campus and off-campus operations of institutions of higher education. Besides highlighting the carbon (dis)benefits of online and face-to-face education, such comparative studies can demonstrate the relative contribution of different operational processes (for instance, student and staff mobility, on-campus and off-campus energy consumption) to the GHG emissions associated with the provision of traditional (campus-based) and online models of higher education. This can pinpoint the extent of policy-making and management interventions required to reduce the carbon impacts of Universities and colleges.

Based on these premises, this paper reports on the carbon footprint generated by a UK-based University, during the COVID-19 lockdown and compares it against the GHG emissions produced by this institution of higher education during identical operational periods in previous academic years. The research questions that the paper has set to answer are, thus, as follows: (1) *what is the direct carbon footprint of online/off-campus education in comparison to face-to-face/on-campus teaching/learning provision?*; (2) *what are the main contributors to direct GHG emissions in the online and on-campus teaching/learning modes?*; and (3) *what measures can be applied to prevent and mitigate the direct carbon footprint of online and on-campus University education?* Next section presents the case studied University, explains how its carbon inventories have been created and highlights the process behind GHG emissions calculations, before and during the COVID-19 lockdown.

2. Materials and methods

2.1. Bournemouth University

Bournemouth University (BU) is a mid-sized public institution of higher education in Bournemouth and Poole, Dorset, UK. Founded in 1992, today BU offers a broad range of undergraduate and postgraduate courses delivered on two campuses, Lansdowne (Bournemouth-based) and Talbot (Poole-based). As of March 2020, BU had 16283 enrolled students (including placement students), 728.5 full-time equivalent academic staff and 881.5 full-time equivalent professional/support staff. Most students and staff are domestic and come from all over the UK. International students and staff mainly come from EU-28 countries, but also, in the case of students, from the main source markets of China, Taiwan, Thailand, Vietnam and India.

BU was chosen for analysis due to data availability. BU has committed to sustainable development and this commitment has been embedded in the University's strategic vision (Bournemouth University 2020a). In terms of climate change, BU has had a Carbon Management Plan since 2009. Refreshed in 2016, it set the target to reduce BU's GHG emissions by 40% by 2020/2021 against the 2005/2006 baseline (Bournemouth University 2020b). To achieve this target, considerable decarbonisation investments have been made to date by installing energy-efficient LED lighting, a biomass boiler, two ground source heat pumps and over 1500 solar panels on the institution's both campuses. Bus travel, cycling and lift share are encouraged and regularly promoted among students and staff. To this end, BU collaborates with a local bus operator to provide frequent bus service between its two campuses and other locations in Bournemouth and Poole and participates in the Cycle to Work scheme (Bournemouth University 2020b). To understand the dynamics of the carbon footprint from staff and student commute as well as business travel, BU conducts biennial staff and student surveys and maintains an accurate business travel register. The data obtained from these are routinely converted into GHG emissions for reporting and monitoring purposes. In 2018/2019, the University sent nothing to landfill and recycled 75% of its waste on-site with all organic fraction being anaerobically digested (Bournemouth University 2020b). BU works with ethical suppliers to mitigate the climate implications of its procurement practices, including the reduction of 'food miles'. In recognition of the University's efforts applied towards the integration of sustainability principles in BU's operations, the institution was twice included in top 15% of Universities across the world in the Times Higher Education University Impact Rankings. Further, it was ranked third place in the UK for its contribution towards UNSDG13: Climate Action and tenth position globally for UNSDG12: Responsible Consumption and Production (Bournemouth University 2020b). Lastly, in 2019, BU occupied the 26th position in the UK's People & Planet's University League (2020) out of 154 institutions of higher education assessed.

2.2. UK lockdown

The national lockdown was ordered in the UK on 23 March 2020. As part of the order all institutions of higher education had to instantly close their campuses and moved all operations online. Wherever possible, this involved all UK students going back home. Although many international students remained in the UK, they were not allowed to access University facilities. Whilst a small number of support staff remained on campuses for security and maintenance purposes, the absolute majority of University staff and all students were required to work/study from home. Business travel was prohibited and most procurement activities ceased. All UK Universities remained closed until July 2020 when some institutions of higher education began to gradually re-open.

2.3.System boundary set-up for carbon footprint assessment

The carbon footprint of BU was assessed within the period of 1 April to 30 June 2020 in academic year 2019/20, i.e. the lockdown period. It was further compared against the carbon footprint generated by BU within April-June in academic years 2017/18 and 2018/19, i.e. the pre-lockdown periods. The comparative analysis was performed in order to set benchmarks for assessment and gain a better understanding of the temporal dynamics of the institution's carbon footprint. Figure 1 provides an overview of the carbon footprint assessment procedure.

[Insert Figure 1 here]

Importantly, BU experienced no significant changes during all three periods of assessment. This is crucial to note as, for example, adding another building to its campus or increasing dramatically the student population can distort significantly the GHG emissions of a University, thus affecting the comparison results. In the current study, no significant deviations in the BU's operational (i.e. student and staff numbers) and non-operational (i.e. infrastructure) features was observed in all assessment periods.

The choice of the start and end dates for carbon footprint assessment was dictated by the data availability needs, as on-campus energy and water consumption were recorded on a monthly basis. The selection of the end date was further driven by the academic timetable of BU. In line with this timetable, all BU teaching finished at the end of June 2020 and, under normal circumstances, many students would start going home straight afterwards.

The carbon footprint assessment period included 91 calendar days with 48 days of teaching/studying. The shorter teaching/studying period was attributed to the Easter break which ran from 6 April to 24 April 2020 inclusive, and two UK Bank Holidays (8 May and 25 May 2020), which is in addition to weekends when no work/study was assumed to take place. Same teaching pattern was followed by BU in academic year 2017/18 and 2018/19 but, in previous years, most teaching was delivered to students face-to-face and a very small fraction of courses was provided online. It is important to note that, under normal circumstances, BU would be closed during the UK Bank Holidays but many members of staff, and some students, would continue working/studying on-campus during the Easter break. In terms of working arrangements at BU, prior to the national lockdown, a mixture of on-campus and from-home work was allowed for academic and professional services staff, i.e. the procedure known as flexible working.

Figure 2 presents the system boundary for carbon footprint assessment which was set in accordance with the UK Governance's guidance on corporate GHG reporting (GOV.UK 2020). Following recommendations of GHG Protocol (2020), GOV.UK (2020) divides corporate carbon footprint into the three scopes of its origin. It further prescribes that the GHG emissions from Scope 1 and 2 should be mandatory for UK companies to report while integrating the Scope 3 GHG emissions into carbon footprint assessments is voluntary but should be considered best practice.

[Insert Figure 2 here]

In line with GOV.UK (2020)'s guidance, this study incorporated the carbon footprint associated with electricity (Scope 2 GHG emissions), natural gas (Scope 1) and water (Scope 3) consumption as the system's inputs. Food waste, other solid waste and sewerage (Scope 3) were integrated into the system as its outputs.

As for operations, in academic years 2017/18 and 2018/19 all University processes that were required to deliver on-campus teaching, research and support services to staff and students (Scope 1) were accounted for in the assessment. Further, all instances of (1) use of BU's fleet of vehicles for staff travel (Scope 1), (2) staff and student daily commute to University campuses (Scope 3) and (3) staff business travel (Scope 3) were also included. The related data were extracted from BU's records of fuel consumption, biennial staff and survey travel surveys and the University's business travel register for the appropriate periods of assessment, i.e. April-June 2017/18 and 2018/19, respectively. For example, according to the staff travel survey results, car was the most popular means of travel to campus among BU's staff members. Likewise, in line with the student travel survey results, most students travelled to University's campuses by bus (63%) and on foot (24%). Interestingly, a unified standard for carbon footprint assessment and management in Universities and colleges proposed by Robinson *et al.* (2018) recommends excluding staff business travel from analysis due to insufficient quality of business travel records. It was, however, retained in the current study given that primary data of good quality were available in the BU's business travel register.

In April-June of academic year 2019/20, due to the University's complete closure and ban on business travel, the above three processes consumed no energy, thus generating no carbon footprint. Instead, a number of extra operational processes were added into the system that related to working and studying from home (Figure 2). These operational processes represented a pattern of off-campus work/study. To obtain this pattern, the method of online mini-interviews (Pau *et al.* 2013) was employed. As the method of primary data collection, mini-interviews are suitable for the situations whereby recruitment of study participants can be difficult (Filimonau and Högström 2017). Mini-interviews are also useful in the contexts whereby the scope of the project does not require extensive data mining (Pau *et al.* 2013). Lastly, the application of mini-interviews is feasible for the projects that need to obtain a 'rapid assessment' of a problem under review due to time and labour constraints (Filimonau and Högström 2017). Given the uncertainty of COVID-19 and its dynamics in the UK in the time of the national lockdown, mini-interviews were, therefore, deemed suitable as a method for primary data collection and analysis in this project.

Fifteen mini-interviews were held with BU's staff members and twenty five mini-interviews were conducted with its undergraduate and postgraduate students in the last two weeks of May 2020. May 2020 was deemed most appropriate for interviewing given that it was the 2nd consecutive month of the national lockdown in the UK and the middle of the online teaching/learning provision in UK Universities. Interview participants claimed that their pattern of working/studying from home had become routinized by the end May.

The exact number of interviews was determined by the 'saturation effect'. Data saturation describes the situation whereby no new information is found to be emerging from interviews due to interview participants' contributions becoming repetitive (Saldana 2016). Saturation is normally reached within 10-30 interviews (Thomson 2010 cited Marshall *et al.* 2013) and this project meets this criterion. On the basis of interviews conducted with staff and students, an 'averaged' work/study from home pattern was derived (Figure 3). Importantly, in October 2020, the UK's Carbon Footprint Ltd consultancy assessed the carbon footprint of online work in the UK (Carbon Footprint Ltd 2020). The result was a very similar pattern of working from home as the one established in this current project. This adds further credibility to this study's findings.

[Insert Figure 3 here]

Work/study from home was considered in line with the following pattern: all staff (except for 5% support staff who were maintaining University campuses during the lockdown) and students (except for 1448 placement students who did not participate in University teaching due to work in the industry) worked/studied from 9.00 to 17.00, 5 days a week, from Monday to Friday, excluding holidays. During a typical work/study day, a laptop or a desk PC was in constant use. It was assumed that half of staff and students used laptops while the remaining half used a desktop PC. Breakfast and lunch were included as well as one rest break. For breakfast and lunch, one instance of use of microwave, toaster and kettle/coffee-maker for preparing food was assumed. For a rest break, one instance of use of kettle/coffee-maker was integrated into the assessment. As the period of April-June in the UK is characterised by mild temperatures, no heating was assumed. However, half a day (4 hours) of lighting was included into the assessment as the mini-interview participants from among both staff and students claimed they would sometimes keep light on when working/studying from home. All other instances of energy use while working/studying from home during the lockdown, such as shopping, laundry and dinner preparation, were excluded from analysis as these were deemed to not directly relate to University business. The GHG emissions due to food consumption at home were also excluded due to data availability. Because of the same reason, water use for breakfast, lunch and rest break was excluded and so was the related generation, collection and treatment of wastewater, organic and solid waste. It is acknowledged that these processes, especially waste collection and treatment, could have added significantly to the overall carbon footprint of work/study from home.

Across all periods of assessment, capital goods and infrastructure at the stage of material inputs into the system (for example, any energy required to deliver University supplies by external providers), operations (for instance, any energy embodied in the University's buildings and equipment) and outputs from the system (for example, any energy required to transport waste from BU's campuses to the point of disposal by contracted waste collectors) were excluded from analysis due to data availability, Figure 3. This is in agreement with Robinson *et al.* (2018) who recommend discounting capital infrastructure from carbon footprint assessments of Universities and colleges. Data availability also determined why University procurement (such as food and other supplies) as well as travel home by students and staff not permanently residing in Bournemouth were left aside. This is also in line with the guidelines provided by Robinson *et al.* (2018). Lastly, the carbon footprint of BU's student halls of residents was excluded as these properties are primarily managed and maintained by external companies.

Table 1 highlights the main datasets used in the carbon footprint assessment, explains how these have been obtained, provides the units of measurement and lists the respective GHG conversion factors. It is important to note that two datasets were not available and approximations had to be made. To assess the carbon footprint of staff and student commute, the data from BU's staff and student travel surveys were employed. The survey data were available for 2018 in the case of the staff travel survey and for 2019 in the case of the student travel survey. Given the lack of staff travel data for 2019, the 2018 dataset was used as a proxy. Same approach was adopted when modelling student travel in 2018.

[Insert Table 1 here]

3. Results

Table 2 lists inventory data alongside the carbon footprint estimates. Figure 4 presents the results of carbon footprint assessment. It shows that prior to COVID-19, i.e. in academic years 2017/18 and 2018/19, student and staff commute held the largest share in the total carbon footprint of BU, i.e. 54%. This was followed by utilities, i.e. electricity and gas consumption (35-41%, depending on a year of assessment), and staff business travel (3-10%). The contribution of such input and output processes as water use, waste and wastewater treatment to the institution's GHG emissions was marginal. In terms of the distribution of carbon footprint per scope of its assessment, Scope 3 accounted for the largest share of BU's GHG emissions (Figure 5).

[Insert Table 2 here]

[Insert Figure 4 here]

[Insert Figure 5 here]

During the lockdown, the total carbon footprint of BU within the studied period decreased from 2140 (year 2019) to 1521 (year 2020) tonnes of CO_2-e, i.e. by circa 29%. This equals to 33.7 tonnes of GHG emissions generated per each day of University operations off-campus. The largest contribution was made by the processes attributed to working/studying from home (73%) whereby the most significant share was held by students (66%). The cumulative contribution of (academic and professional/support) staff working from home was only 7% which was due to their small numbers compared to the BU's student population. The relative share of electricity (19%) and gas (6%) consumption by the University's shut campuses in the total carbon footprint of BU during the lockdown was also substantial. Interesting is that, despite its completely shut campuses, the overall reduction of the BU's carbon footprint due to decreased use of utilities was lower than anticipated, i.e. 45% in the case of electricity and 51% in the case of gas, compared to the reference year 2018/19. This suggests that substantial amounts of energy are necessary to maintain University campuses even in the absence of staff and students.

In terms of the scope of GHG emissions assessment, the 'traditional' Scope 3 carbon footprint during the lockdown was almost zero (Figure 5). If work/study from home was considered the 'new' Scope 3 GHG emissions under the lockdown conditions, then this scope would dominate in the total carbon footprint of BU. Its relative contribution would be higher than the Scope 3 GHG emission in the pre-lockdown years.

Lastly, when the carbon footprint is calculated on a 'per capita' basis, 68 kg of CO_2-e were produced during the lockdown period of 48 working/studying days. This equates to 1.41 kg of CO_2-e generated per capita per working/studying day. Interestingly, the same amount of GHG emissions is produced when travelling 34 km by domestic rail in the UK (GOV.UK 2020) which is equivalent to a one-way travel distance from Bournemouth to Southampton where a number of BU's students and staff reside. As for the pre-lockdown period, the 'per capita' GHG emissions within April-June were equal to 130 kg of CO_2-e. However, given that many members of University staff and some students went to campus in academic years 2017/18 and 2018/19 during the Easter break, the per capita per working/studying day carbon footprint should be calculated accounting for this extra period of time. Excluding the Easter break gives 65 days of working/studying which results in 1.43 kg of CO_2-e generated per capita/day. This figure is almost identical to the carbon footprint produced on this basis during the lockdown, as per above.

4. Discussion

4.1. Carbon footprint under 'normal' circumstances (academic years 2017/18 and 2018/19)

The findings of the part of the study which reports on the carbon footprint of BU in the pre-lockdown period have a number of commonalities but, concurrently, differences with past academic research on the GHG emissions of institutions of higher education in the UK and beyond. The differences can be observed when the carbon footprint estimate of BU is benchmarked and/or compared against the GHG emissions of other UK Universities. For example, Ozawa-Meida *et al.* (2013) have estimated the annual carbon footprint of the De

Monfort University as 51000 tonnes of CO_2-e, while Townsend and Barrett (2015) have assessed the GHG emissions of the University of Leeds as 162000 tonnes of CO_2-e. This equates to about 4300 and 13500 tonnes of CO_2-e produced per month on average which is almost six- and twenty times larger than the monthly GHG emissions of BU, respectively. De Monfort University and Leeds University are, however, significantly bigger than BU in terms of their student and staff numbers, but also capital assets they have to manage. Further, the above two studies have adopted different methodological approaches to carbon footprint assessment. Through the lens of life cycle analysis, Ozawa-Meida *et al.* (2013) have meticulously examined the GHG emissions of most operational and non-operational processes, such as visitor travel, energy use in student halls of residence and procurement. These have been excluded in the current project due to data availability. Likewise, Townsend and Barrett (2015) have applied an extended input-output analysis which considers a broad range of direct as well as indirect GHG emissions. This method is, therefore, considerably more detailed compared to the streamlined carbon footprint assessment technique employed in the current study. Further, the GHG emissions figures obtained by Ozawa-Meida *et al.* (2013) and Townsend and Barrett (2015) are representative of the 2008/09 and 2010/11 academic years, respectively. As UK institutions of higher education have achieved substantial progress in their sustainability performance recently (Robinson *et al.* 2018), any benchmarking and/or comparisons with the carbon footprint data that are almost a decade old should be made with caution. This highlights the need for more recent academic research looking at the carbon footprint of UK universities in order to quantify the progress made in the reduction of the sector's GHG emissions within the last decade. Such longitudinal, comparative studies can demonstrate the carbon savings made, if any, by the national sector of higher education in pursuit of the UK's sustainability targets and relevant UNSDGs, such as UNSDG13: Climate Action.

The commonalities of this study's findings and past research rest in the estimate of the relative distribution of carbon footprint across BU in terms of the scopes of its assessment. While some studies have reported the dominance of electricity (Scope 2) in the GHG emissions of Universities and colleges around the world (see, for instance, Ridhosari and Rahman (2020) for Indonesia and Clabeaux *et al.* (2020) for USA), the bulk of research has highlighted the disproportionate contribution of the Scope 3 GHG emissions to the total carbon footprint of institutions of higher education. For example, beyond the UK, Alvarez *et al.* (2014) have established the extent of the Scope 3 GHG emissions as equal to 59% of the total carbon footprint of a Spanish University. Versteijlen *et al.* (2017) have shown that the Scope 3 GHG emissions account for 40-90% of the total carbon footprint in Dutch Universities. Lastly, the relative contribution of the Scope 3 GHG emissions is the largest in the case of institutions of higher education in India where, according to Sangwan *et al.* (2018), these may account for up to 99% of the total carbon footprint. In the UK, the Scope 3 GHG emissions are responsible for 51% and 79% of the total carbon footprint of Universities and colleges, see Townsend and Barrett (2015) and Ozawa-Meida *et al.* (2013), respectively, which is in line with the results of the current study.

Another commonality can be observed in the disproportionate contribution of staff and student mobility to the overall carbon footprint of BU prior to the COVID-19 lockdown as similar patterns of GHG emissions have been established for Universities and colleges worldwide. For example, Yanez *et al.* (2020) have recognised this contribution as being equal to circa 50% in the case of a University in Chile with similar findings reported in the Dutch context (Versteijlen *et al.* 2017). This current study provides further evidence for the need to reduce the carbon implications of staff and student mobility, especially in terms of the University commute for face-to-face teaching and learning.

4.2.Carbon footprint under the COVID-19 lockdown (academic year 2019/20)

Although the carbon footprint of BU decreased during the lockdown period, which is rather intuitive and in line with initial expectations, a closer analysis highlighted some interesting features in its distribution across major University processes. This interest primarily concerns the magnitude of the GHG emissions associated with working/studying from home which this study has revealed as significant. Indeed, within April-June 2020, BU's staff and students cumulatively generated 1100 tonnes of CO_2-e, which is almost equal to the GHG emissions attributed to their University commute (1160 tonnes of CO_2-e) in the respective period of on-campus teaching/learning in academic years 2017/18 and 2018/19. This suggests that, unlike previous studies have argued (Caird and Roy 2019; Carr *et al.* 2019; Versteijlen *et al.* 2017), online teaching/learning can be less climate-friendly than it is anticipated to be. Indeed, given that work/study from home can generate as much carbon footprint as the University commute, a large share of the carbon savings achieved by moving education online in pursuit of avoided student and staff mobility can be effectively negated.

Concurrently, one explicit advantage of non-commuting is reduced air pollution (Ma *et al.* 2020). This suggests that environmental (dis)benefits of work/study from home should be evaluated on a multi-impact basis accounting for local conditions. For example, given poor air quality in many metropolitan areas around the world, especially in developing economies (Sun *et al.* 2018), online teaching/learning can be a feasible option for local institutions of higher education. Not only non-commuting can contribute to the reduction of air pollution in these areas, but it will also save time for staff/students due to avoided traffic congestion.

In line with the above point, what is also important to note is that the carbon footprint of working/studying from home assumed in this study can be considered as the 'best case'/lowest carbon intensity scenario. This is because it incorporates a bare minimum of in-home activities required to provide teaching and/or enable learning off-campus, i.e. certain hardware/energy use and limited occasions of food consumption. If other, supplementary or support, activities are accounted for, such as any extra occasions of food consumption and, most importantly, shopping for food as well as the carbon footprint embodied in this food, the GHG emissions of online education can grow significantly. Past studies have long highlighted the high, yet increasing, carbon intensity of household activities in the UK (Druckman and Jackson 2009) and beyond (Sommer and Kratena 2017). This scientific evidence should not be ignored in the emerging scholarly debate on the relative climate-friendliness of the 'traditional' on-campus and 'novel' online education models. This is particularly important in the context of the temporal boundary of this current study which was conducted in spring. Should have the lockdown in the UK taken place during the winter months, the carbon footprint of work/study from home would have been much more significant due to the increased lighting but especially added heating needs of students and staff.

Another interesting point is in that the carbon footprint of (almost completely) shut University campuses did not reduce to (near) zero. This indicates that substantial quantities of energy are required to maintain University capital assets/infrastructure regardless of whether or not these are in actual use. This suggests that the calls for blended learning, whereby Universities and colleges can provide some courses online and some courses can be offered on-campus, as a (more) climate-friendly way of teaching/learning delivery (Caird and Roy 2019) should be taken with caution. This is because this will result in the under-utilised capacity of University campuses during online teaching provision. Despite being not in use, campuses will still consume substantial amounts of utilities due to their maintenance while significant additional GHG emissions will be generated by staff and students working from home.

This study shows that provision of either fully on-campus or fully online teaching/learning can be more beneficial in carbon footprint terms due to the full utilisation or, in contrast, due to the complete removal of University's capital assets, respectively. Should institutions of higher education move all their teaching provision online, there is no need to have a 'proper' campus due to its high energy and, consequently, carbon intensity. Renting some offices in energy-efficient buildings in town centers and using these offices as space for ad-hoc student and staff interaction should be sufficient from the viewpoint of carbon efficiency. In addition, central location will reduce the GHG emissions of student and staff mobility or may, at least, encourage use of (more climate-friendly) public transport which is due to parking restrictions.

This finding also supports the need for better use of University buildings during campus closures and/or their conversion into 'intelligent' buildings (Stavropoulos *et al.* 2010). Such buildings can utilise smart technology for switching parts of the buildings on/off to better suit student/staff needs, thus accounting for temporary, often last-minute, variations in demand. Intelligent buildings may, therefore, reduce significantly the carbon footprint of completely shut University campuses and minimize the GHG emissions of the institutions of higher education specializing in the provision of online and/or blended teaching/learning.

In terms of carbon footprint reduction, this study demonstrated the need to discourage student and staff mobility in order to minimise GHG emissions of BU during on-campus teaching/learning. This finding is in agreement with past research (see, for instance, Li *et al.* 2015; Perez-Neira *et al.* 2020; Shields 2019) and, therefore, rather conventional. In the case of BU, bus travel and walking as the means of the University commute are already popular with students, but not staff. Measures are necessary to popularise these transportation modes among staff members, such as provision of free bus passes. Interestingly, the case of BU indicated the relatively small, but growing, carbon footprint of business travel. Whilst BU is not a 'classical' research-led UK University, such as Leeds, it actively strives to develop its research profile. This study shows that this ambition may come at a cost of increased GHG emissions attributed to growing research-related staff travel, as showcased by Achten *et al.* (2013). Institutional policies are, therefore, required to review staff business travel at BU. This review should attempt to categorise staff business travel as ‘research critical’ and ‘research desirable’. The former should be allowed, subject to using carbon-efficient transportation modes, while the feasibility of undertaking the latter should be scrutinised from the viewpoint of its GHG emissions. The ‘Travel Better Package’ developed by the Environmental Association for Universities and Colleges provides some useful guidelines for institutions of higher education on how to reduce air travel by academics and professional services staff (EAUC 2020).

An interesting and important finding of this study is in the established need to reduce the carbon footprint of work/study from home. This is because online education holds potential to shift significant quantities of GHG emissions from the sector of higher education to households. In the case of this study this is evidenced by almost complete replacement of the carbon footprint of the University commute with the GHG emissions of in-home teaching/learning. In addition, some households are not always carbon-efficient due to the use of obsolete and/or energy-intense electronic devices and electric appliances (Escriva-Bou *et al.* 2015). In contrast, many Universities and colleges utilise state-of-the-art energy technology, infrastructure and equipment, thus indicating better carbon efficiency achieved when working on-campus (Geng *et al.* 2013). Concurrently, students and staff are less likely to save energy when on campus compared to working/studying from home (Cotton *et al.* 2016). This is because energy use at home is closely linked to the cost factor while this factor is not pronounced in the context of working/studying on campus whereby students and staff do not pay for the energy consumed. It is argued that students and staff may, therefore, be more concerned with energy savings at home, and the potential for the reduction of the related carbon footprint is, thus, higher in the case of online education. This argument needs, however, to be empirically validated. What is more important is that, with a growing popularity of online teaching in the aftermath of the COVID-19 pandemic (Bao 2020), institutions of higher education worldwide should now consider not only encouraging energy-saving behaviour of students and staff on their campuses, but also in their homes.

Lastly, aside from the carbon (dis)benefits of working/studying from home, assessments are necessary to establish its effect on mental well-being of students and staff. Online teaching/learning fails to provide a crucial element of education which is socialisation, face-to-face interaction and interpersonal communication (Gazza and Hunker 2014). Despite the proliferation of digital productivity and communication tools, such as Zoom and Microsoft Teams, these cannot replace the 'human' touch of education provision. As a result, while some anecdotal evidence pinpoints the improved work life balance of teaching/learning from home, some highlights the challenges of working/studying in isolation (Bao 2020). These two dramatically opposite, positive and negative, effects of online education on students and staff should be comprehensively assessed in order to understand its impact not only on the environmental but also socio-economic dimension of sustainability. The method of social life cycle assessment (see, for example, Dreyer *et al.* 2006) can be adopted to address the above research need.

4.3. Limitations

As in the case of any research, this study had a number of limitations. The main shortcoming was in the exclusion of some non-operational processes that could have increased the carbon footprint figures derived in this assessment. However, as this exclusion was consistent across all periods of analysis and in line with the recommended carbon footprint assessment standards, it could have affected the overall magnitude of the GHG emissions established, but not the comparative outcome of analysis.

Another potential drawback was attributed to the limited temporal scope of carbon footprint assessment which was restricted to a 3-month period. This was dictated by the length of the lockdown order in the UK but it would have been interesting to estimate GHG emissions across a full year of University operations under the COVID-19 restrictions. It would particularly be useful to assess the carbon footprint of blended, i.e. on-campus and online, teaching/learning during the winter months. The GHG emissions of the model of blended education are likely to be high(er) due to increased energy use at home but also on University's campuses. For example, in the UK, in order to meet the government COVID-19 based advice, institutions of higher education are required to heat and ventilate their buildings more frequently. Significant growth in the on-campus consumption of electricity (for ventilation) and gas (for heating) is, therefore, expected.

The assumptions of work/study at home adopted in this study may not have represented the entire student/staff population of BU. The flexibility of working/learning from home suggests no control over human behaviour. This implies that some students and staff may have spent time during a working/studying day on activities that were non-work/study related. Future research is necessary to establish a more robust, 'typical', pattern of working/learning from home to aid in the design of future projects on carbon footprint assessment in the sector of higher education, especially for the courses delivered fully online or in a blended mode.

Lastly, the scope of this study excludes the assessment of any energy demand which is required for the development of specific educational programmes, delivered on-site as well as online. It further excludes the analysis of the carbon implications of any networking activities required to facilitate (offline and online) curricula development. The GHG emissions of online events held by students and academics beyond the scope of their work/study were also excluded.

4.4. Future research

The study outlined a number of interesting directions for future research. First, studies are required to measure the long(er)-term impacts of the COVID-19 pandemic on the carbon performance of institutions of higher education. Most UK Universities will adopt a blended model of teaching provision in academic year 2020/21 and, possibly, longer. As this model incorporates some on-campus and off-campus activities, future research should aim at understanding the implications of such rather unconventional operational models for corporate GHG emissions. In particular, studying the effect of preventative and protective measures implemented on University campuses in light of the pandemic is necessary. For example, social distancing rules may require Universities to increase the frequency of teaching which implies extended working timetables or more frequent use of University facilities and amenities, such as libraries, research laboratories and sport halls. This will affect energy consumption in University buildings. Likewise, social distancing rules will have to be adhered to on public transport with the related growth in the carbon footprint of the University commute due to increased bus frequency. In fact, bus may become less popular as a University commute mode due to the public fear of public transport as a means of spreading the virus. This may prompt students and staff to make more frequent use of cars with an associated growth in carbon footprint. Further, increased water use for disinfection and enlarged quantities of packaging and other solid waste (for instance, single-use cutlery, face masks and gloves) on University campuses will impact the GHG emissions of institutions of higher education in the UK and beyond. These impacts should be closely monitored and accurately quantified.

Second, a dedicated stream of research is necessary to investigate and compare the carbon implications of different teaching/learning modes such as fully offline, blended, fully online. Although this current study has provided some initial evidence towards the GHG emissions of online education, this evidence should be reinforced with a larger number of dedicated case studies. These case studies should target Universities and colleges of different size and specialisation, in the UK and beyond.

Although not directly related to the sector of higher education, tailor-made research is required on the carbon footprint of working from home for office-based companies to understand the carbon implications of shifting all service jobs online, including education. Such research can enable comparisons of the carbon savings achieved, if any, across the different sectors of services. This is to justify, or deny, the need to move traditional office-based/on-campus occupations to the in-home work environment. Such research is necessitated due to mounting evidence which shows that many employees in services industries are willing to remain working from home.

Lastly, it is important to note that future research on work/study from home should aim at evaluating its phenomenon in a wider societal context and from the perspective of urban ecology and (smart) cities. Work/study from home can aid cities in re-thinking mobility patterns of their residents and in re-designing urban environment. By moving work/study online can reduce not only the carbon footprint, but also air pollution. Further, work/study from home can benefit public health and contribute to subjective well-being of urban residents. Reduction in commute can free public space in cities which can be re-purposed. For example, urban parks can be set instead of highways as these have proven their importance as places of relaxation and self-reflection during national lockdowns. Future studies should consider these indirect, spill-over effects.

5. Conclusions

This study shed light on the carbon footprint of a University during the COVID-19 lockdown. From the practical perspective, it contributed to the growing bulk of research on the GHG emissions of institutions of higher education with further empirical evidence collected in the UK context and with a case study of the forced shutdown of University operations. From the theoretical viewpoint, the study made a contribution to the emerging academic debate on the carbon (dis)benefits of online education compared to a ‘traditional’ model of on-campus teaching provision. The findings indicated that the carbon savings achieved from moving teaching/learning fully online are lower than initially anticipated, at least in the case of a mid-sized UK University committed to sustainability, BU. Further, this holds implications for the design of future educational courses in the sector of higher education and beyond. As this study demonstrated, blended teaching may be less carbon beneficial than fully online or fully on-campus teaching. The educators responsible for the design of University curricula should, therefore, be considerate of the climate implications of their decisions and undertake a thorough review of potential carbon implications of different models of teaching delivery. The methodological contribution of this study is in drafting an initial proposal on how to scope the GHG emissions attributed to working/studying at home. In light of potential future growth in online education, carbon footprint assessment methodologies and standards should consider the most effective way to conceptualise and quantify the related carbon footprint. This study proposes that the GHG emissions from in-home work/study should be considered within the Scope 3 carbon footprint but this proposal is in no way conclusive but aims to spark an academic debate on this topic instead.

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Table 1. Data requirements for carbon footprint assessment, GHG conversion coefficients and their sources.

Scope of GHG emissions	Process	Unit	Primary data source	GHG conversion coefficient (CO_2e) 2018	2019	2020	Source of GHG conversion coefficient, if	Remarks
2+3	Electricity	kWh	University energy and water meter readings	0.3072	0.2773	0.25319	GOV.UK (2018, 2019, 2020)	Includes transmission and delivery losses
1	Gas	kWh		0.18396	0.18385	0.18387		-
3	Water supply	m^3		0.34400				-
3	Water treatment	m^3		0.70800				-
1	Fleet	kg CO2e	University fleet	-	-	-		-
3	Food waste	kg	University waste audit	10.2039				Sent for anaerobic
3	Other solid	kg		21.3167	21.3538	21.3167		Sent for combustion
3	Employee commute	kg CO_2e	University staff travel survey 2018	-	-	-		2018 data were used to model staff travel in 2019
3	Student commute	kg CO_2e	University student travel survey	-	-	-		2019 data were used to model student travel in 2018
3	Business travel	Rail (Eurostar) km	University business travel register	0.01226	0.00597	-		-
3	Business travel	Rail (Domestic) km		0.04424	0.04115	-		-
3	Business travel	Flight (Domestic) km		0.03267	0.13483	-		Excludes radiative forcing; economy class
3	Business travel	Flight (International) km		0.01533	0.073195	-		
3	Business travel	Flight (Short Haul) km		0.0175	0.08233	-		
3	Business travel	Flight (Long Haul) km		0.01783	0.0792	-		
		Work/Study from home (see Figure 2 for details)						
-	Microwave	kW per use	Assumptions based on mini-interviews with staff and students	1			Smarter Business	-
-	Toaster	kW per use		1.2			Center for Sustainable Energy (2020)	-
-	Kettle	kW per use		0.11			Smarter Business	-
-	Laptop	kWh		0.05			Smarter Business	-
-	Desk PC	kWh		0.1			Smarter Business	-
-	Light bulb	kWh		0.06			Smarter Business	-

Table 2. Inventory data and carbon footprint estimates.

Item	**Unit of primary data**	**Primary data (see appropriate units)**			**Carbon footprint data (kg CO2e)**		
		April-June	**April-June**	**April-June**	**Apr-June**	**Apr-June**	**Apr-Jun**
Electricity	kWh	2153514	2036539	1233087	661560	564732	312205
Gas	kWh	1161083	1058149	512735	213593	194541	94277
Water supply	m3	11076	9734	4549	3810	3348	1565
Water treatment	m3	10522.2	9247.3	4321.55	7450	6547	3060
Fleet	kg CO2e	5666	3262	0	5666	3262	0
Food waste	kg	12690	15080	0	129	154	0
Other solid waste	kg	102100	98900	2500	2176	2112	53
Employee commute	kg CO2e	285932	-	0	285932	285932	0
Student commute	kg CO2e	-	873568	0	873568	873568	0
Business travel	Rail (Eurostar) km	6010.55	11341.44	0	74	71	0
Business travel	Rail (Domestic) km	20[illegible]721	194011.28	0	8880	7984	0
Business travel	Flight (Domestic) km	3961.85	8259.59	0	129	1114	0
Business travel	Flight (International)	342699.69	662441.51	0	12919	48488	0
Business travel	Flight (Short Haul) km	2147456.28	388547.21	0	37580	31989	0
Business travel	Flight (Long Haul) km	342866.1	1462006.4	0	6113	115791	0
Work from home, academic staff	kg CO2e	-	-	-	-	-	49316
Work from home, professional and support	kg CO2e	-	-	-	-	-	56690
Study from home, students	kg CO2e	-	-	-	-	-	1004224
TOTAL					**2119580**	**2139633**	**1521390**

Figure 1. Carbon footprint assessment procedure.

Figure 2. System boundary for carbon footprint assessment. Orange colour indicates Scope 1 GHG emissions; green colour – Scope 2 and blue colour – Scope 3. Red colour indicates operational processes related to work and study from home during the COVID-19 lockdown (see Figure 2 for details). Grey colour indicates processes that have been excluded from analysis.

Figure 3. An ‘averaged’ pattern of working/studying from home during the COVID-19 lockdown and the related instances of energy use.

Figure 4. Comparative analysis of carbon footprint in April-June 2018, 2019 and 2020 (in kg of CO_2-e).

Figure 5. Breakdown of GHG emissions per scope of assessment.

Conflict of interest

The authors declare no conflict of interest

Credit Author Statement

Viachaslau Filimonau Conceptualization, Data curation, Writing – initial draft

Dave Archer Conceptualization, Data collection, Writing – final draft

Laura Bellamy Conceptualization, Data collection, Writing – final draft

Neil Smith Conceptualization, Data collection, Writing – final draft

Richard Wintrip Conceptualization, Data collection, Writing – final draft

Graphical abstract

Stage	Purpose	Method/Approach	Output
1	To obtain inventory data for carbon footprint assessment of on-site operations	Direct measurements (utilities and outputs) Surveys (staff and student travel) Register analysis (business travel)	Inventory data of on-site carbon impacts
2	To establish the pattern of working/studying from home	Mini-interviews with staff and students	Inventory data of at-home carbon impacts
3	To assess the carbon footprint of working/studying from home and compare it against that generated on-site	Desk-based research using GHG conversion coefficients from GOV.UK (2020).	Combined carbon footprint estimates

Figure 1

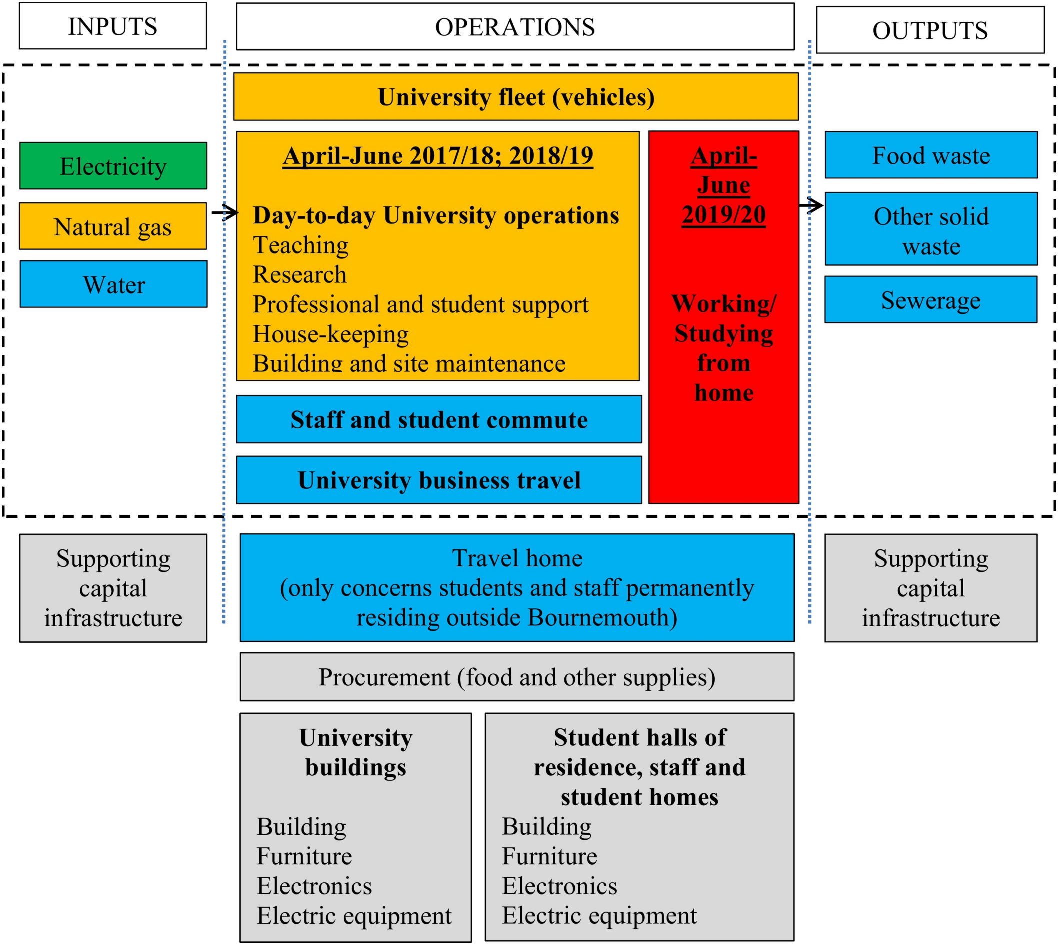
INPUTS
OPERATIONS
OUTPUTS
University fleet (vehicles)
Electricity
Natural gas
Water
April-June 2017/18; 2018/19
Day-to-day University operations
Teaching
Research
Professional and student support
House-keeping
Building and site maintenance
April-June 2019/20
Working/ Studying from home
Food waste
Other solid waste
Sewerage
Staff and student commute
University business travel
Supporting capital infrastructure
Travel home (only concerns students and staff permanently residing outside Bournemouth)
Supporting capital infrastructure
Procurement (food and other supplies)
University buildings
Building
Furniture
Electronics
Electric equipment
Student halls of residence, staff and student homes
Building
Furniture
Electronics
Electric equipment

Figure 2

<table>
<tr><th>Time</th><th colspan="4">Activity consuming energy</th><th colspan="3">Equipment/Device/Appliance consuming energy</th></tr>
<tr><td colspan="8">START</td></tr>
<tr><td rowspan="3">9.00</td><td rowspan="13">ACADEMIC STAFF: Preparation and delivery of lectures/seminars/tutorials, research</td><td rowspan="13">SUPPORT AND PROFESSIONAL STAFF: Administrative and support tasks</td><td rowspan="13">STUDENTS: Attendance of lectures/seminars/tutorials, self-study and revision</td><td rowspan="3">Breakfast</td><td rowspan="13">In-room lighting (bulb, 4 hours)</td><td rowspan="13">Laptop/Desk PC (8 hours)</td><td>Microwave</td></tr>
<tr><td>Toaster</td></tr>
<tr><td>Kettle</td></tr>
<tr><td>10.00</td><td></td><td></td></tr>
<tr><td>11.00</td><td></td><td></td></tr>
<tr><td rowspan="3">12.00</td><td rowspan="3">Lunch</td><td>Microwave</td></tr>
<tr><td>Toaster</td></tr>
<tr><td>Kettle</td></tr>
<tr><td>13.00</td><td></td><td></td></tr>
<tr><td>14.00</td><td></td><td></td></tr>
<tr><td>15.00</td><td>Coffee break</td><td>Kettle</td></tr>
<tr><td>16.00</td><td></td><td></td></tr>
<tr><td>17.00</td><td></td><td></td></tr>
<tr><td colspan="8">FINISH</td></tr>
</table>

Figure 3

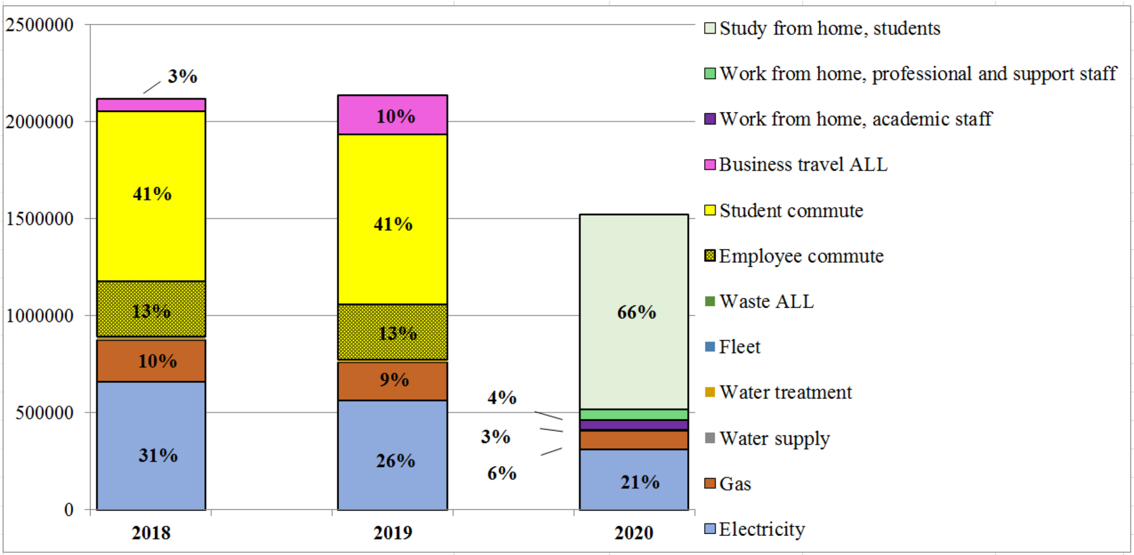
2500000
2000000
1500000
1000000
500000
0
3%
41%
13%
10%
31%
10%
41%
13%
9%
26%
4%
3%
6%
66%
21%
2018
2019
2020
Study from home, students
Work from home, professional and support staff
Work from home, academic staff
Business travel ALL
Student commute
Employee commute
Waste ALL
Fleet
Water treatment
Water supply
Gas
Electricity

Figure 4

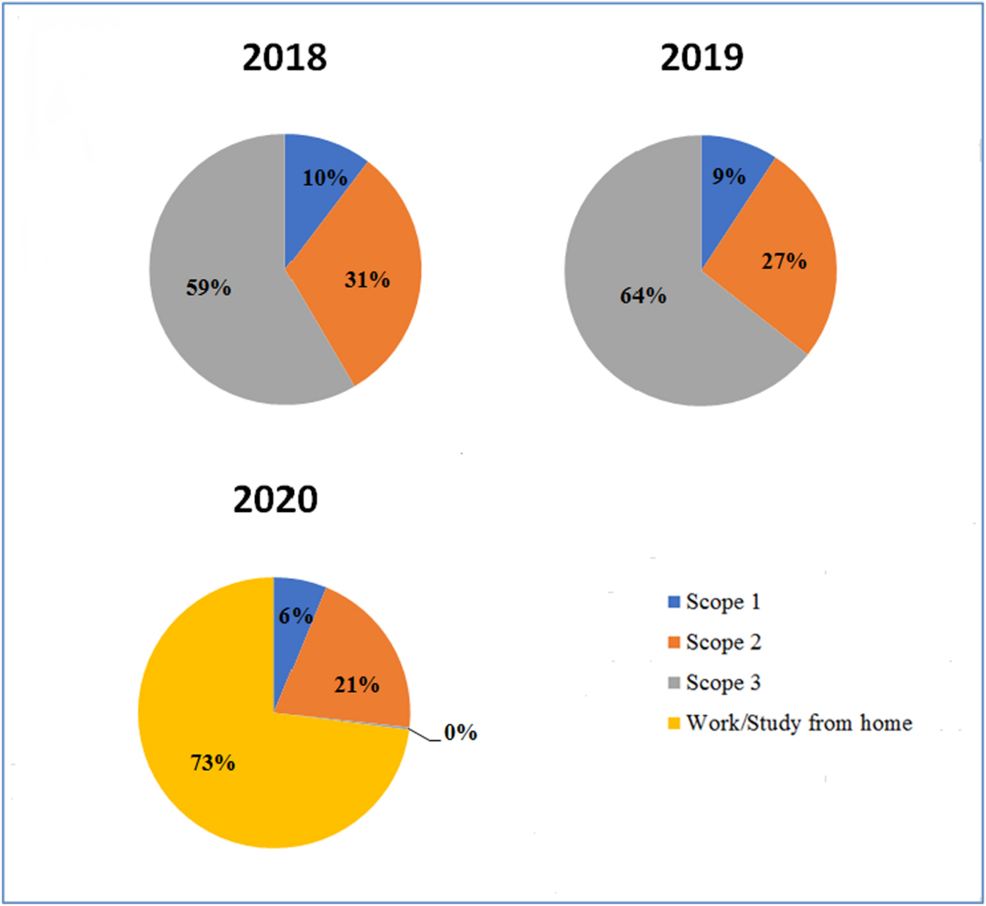
2018
10%
31%
59%
2019
9%
27%
64%
2020
6%
21%
0%
73%
Scope 1
Scope 2
Scope 3
Work/Study from home

Figure 5