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The Carbon Footprint of a UK Chemical Engineering Department - The Case of Imperial College London

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Abstract

As the UK strives towards net-zero it is important that all sectors, including Higher Education, take immediate measures to cut their greenhouse gas emissions. The greenhouse gases emitted by different Higher Education institutions are studied and are shown to be large. However, these studies are based on aggregated data, and it is therefore uncertain how effective institute-wide policies to cut emissions are at department level. Herein, we present a generic framework for university departments to calculate their carbon footprint considering Scope 1, 2 and 3 emissions. We estimate the carbon footprint of the Chemical Engineering Department at Imperial College London to be 7,620 and 8,330 tCO_{2eq} in 2018/19 and 2019/20, respectively. Scope 3 emissions account for 54% of the Department's emissions with Scope 1 and 2 accounting for the remaining 46%. Scope 3 emissions are largely driven by purchased goods and travel, while Scope 1 emissions are predominantly from electricity usage.

Keywords: carbon footprint; scope 1 emissions; scope 2 emissions; scope 3 emissions; higher education

1. Introduction

The UK has pledged for its greenhouse gas (GHG) emissions to be net-zero by 2050 [1]. To achieve this goal, emissions must be cut in all sectors, including education. In 2021, 140 UK universities announced their commitments to cut their GHG emissions with the hope of becoming zero carbon by 2050 [2]. Imperial College London is a public research university located in central London and exclusively teaches and conducts research in science, engineering, medicine, and business. In 2021, the College launched their Sustainability Strategy 2021-2026 [3] which outlines how the College will become carbon neutral in Scope 1 and 2 emissions whilst minimizing Scope 3 emissions where possible by 2040. For the College to achieve this commitment, efforts to cut emissions must be made across the different faculties and departments. The Chemical Engineering Department (CED) at Imperial College London is the department which teaches and conducts research in chemical and process engineering, employing 187 staff in 2021.

Studies, both peer reviewed journal papers and institutional sustainability reports, have been carried out to estimate the GHG emissions of universities [4-10]. For UK universities, emissions in 2018/19 ranged from 0.2 to 62 kilotonnes CO_{2eq} ($ktCO_{2eq}$) per institution [11]. The carbon footprint varies greatly depending on geography, type of university (teaching or research heavy, science and engineering orientated, arts orientated etc.) and size (campus area and staff and student populations). These impact the carbon footprint as well as which activities are the main emission 'hot spots'. The College publishes its GHG emissions though their sustainability reports

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[6], but the emissions are aggregated and based on data collected across whole campuses and faculties. Therefore, it is uncertain how much each department contributes and how effective College-wide emission-reduction measures will be: each department is different in their activities and how they operate. By identifying where emissions occur from a department's activities, more targeted actions and measures can be taken to reduce GHG emissions. A large portion of the CED's activities go towards research to develop technologies and processes for achieving sustainable futures, as well as teaching sustainability in modules to students. This is also the case for other engineering departments in the College and other universities. Therefore, it is important to know what the environmental impacts are for a university engineering department's activity and how they can be mitigated.

In this study, we present a framework to estimate the carbon footprint of the CED at Imperial College London and use it to estimate the CED's emissions. The GHG emissions were calculated using data provided by the College and the CED and provides the CED with an overview of their emission sources. The findings of this study provide the CED with the guidance needed to devise an effective strategy for significant emissions reductions.

Nomenclature

$G_{elec,chp}$	Carbon content of electricity produced by the CHP	$kgCO_{2eq}/kWh$
$G_{elec,grid}$	Carbon content of electricity from the grid	$kgCO_{2eq}/kWh$
$G_{heat,tot}$	Blended carbon content of Imperial heat	$kgCO_{2eq}/kWh$
V_{chp}	Volume of natural gas consumed in CHP engines	m^3
V_{boiler}	Volume of natural gas consumed in boilers	m^3
C	Carbon content of natural gas	$kgCO_{2eq}/m^3$
E	Energy content of natural gas	kWh/m^3
η	Boiler efficiency	-
$e_{elec,chp}$	Electricity generated by CHP	kWh
$e_{heat,chp}$	Heat recovered in CHP	kWh
$e_{heat,boiler}$	Heat energy generated by boilers	kWh

2. A framework for university departments to calculate their carbon footprint.

The CED's carbon footprint was calculated following the standards set out in the GHG protocol and considers direct (Scope 1) and indirect (Scopes 2 and 3) emissions over financial years 2018/19 and 2019/20, which for the College run from August 1st – July 31st. Scope 1 and 2 emissions are from energy use and Scope 3 are from other activities in the CED. Classifying which carbon streams fall into Scopes 1 and 2 is straightforward; however, this is not the case for Scope 3 as there are many activities, which can be categorized as Scope 3. To be as comprehensive as possible, we have considered as many streams within Scope 3 as was possible to collect data for (Table 1).

The CED is located on the College's South Kensington Campus, where combined heat and power (CHP) units meets most of the heat and power needs of the campus buildings. F-gases are another stream which would fall into Scope 1, but we were unable to collect data on this.

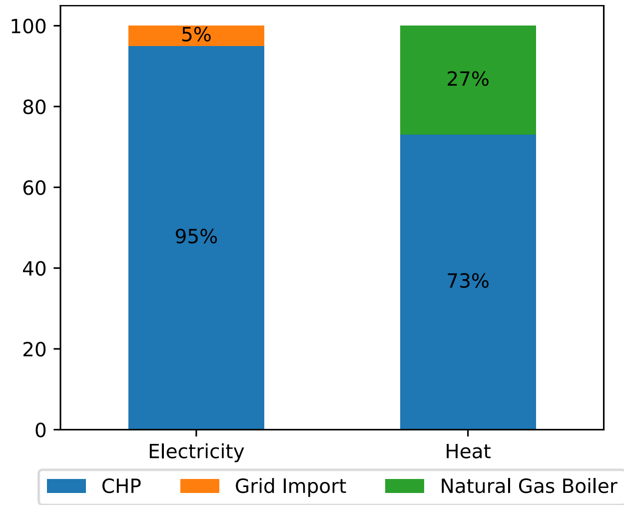

Fig 1: Breakdown of the electricity and heat sources for the South Kensington Campus.

Table 1. Carbon streams considered in Scope 1, 2 and 3 emissions. The GHG Protocol's guidance was used to define the streams and activities which fall under the different scopes [12,13].

	Carbon stream	Activity
Scope 1	CHP unit, boiler system, F-gases	Energy and heat used in buildings, labs (refrigerants)
Scope 2	Grid electricity	Energy used in buildings
Scope 3	Purchased goods and services	Catering, lab supplies, cleaning, safety and security
	Water	Water used in buildings
	Wastewater	Wastewater from buildings
	Waste	Waste collected in buildings
	Business travel	Air travel by staff
	International student travel	Air travel by students
	Staff and student commuting	Car, rail, tube travel by staff and students
	Staff working from home	Energy used by staff working from home
	Students studying from home	Energy used by students studying from home

2.1. Scopes 1 and 2- methodology

The vast majority of electricity consumed on the Imperial South Kensington campus is provided by the onsite CHP system (Fig 1) consisting of two 4.5 MWe GE Power Jenbacher J624 engines. Depending on instantaneous usage and generation, the system can also import or export electricity to and from the electricity grid. Heating and hot water for all buildings in the South Kensington Campus are provided via a district heating network consisting of three 10 MW natural gas fired boilers integrated with the heat recovery component of the CHP system (Fig 1). Emissions related to operation of the on

CHP and boiler systems are attributed to Scope 1 while emissions related to consumption of grid electricity are attributed to Scope 2.

Carbon factors for CHP electricity and overall heat consumption are determined using Equations 1 to 3 and summarized in Table 2 with grid carbon factors. The volume of natural gas consumed in the CHPs and gas boilers is metered individually but only the heat produced from the CHPs is metered. Heat production of the boilers is calculated using an assumed boiler efficiency of 90%. We also assume that all heat produced by the CHP system is used in the College district heating network and has a carbon factor of zero as it is an energy recovery stream. Carbon factors for grid electricity and natural gas are taken from BEIS [14].

$$G_{heat,tot} = \frac{V_{boiler}C}{e_{heat,boiler} + e_{heat,chp}} \quad (1)$$

$$G_{elec,chp} = \frac{V_{chp}C}{e_{elec,chp}} \quad (2)$$

$$e_{heat,boiler} = \eta V_{boiler}E \quad (3)$$

Table 2: Electricity and carbon factors used [$kgCO_{2eq}/kWh$]

Financial Year	$G_{elec,grid}$	$G_{elec,chp}$	$G_{heat,tot}$
2019-20	0.256	0.651	0.080
2018-19	0.283	0.556	0.084

2.2. Scopes 1 and 2 - results

Scope 1 emissions totalled 3,200 and 3,180 tCO_{2eq} in 2018/19 and 2019/20, respectively, while Scope 2 emissions reached 175 and 135 tCO_{2eq}. Annual Scope 1 emissions (Fig 3) are primarily driven by electricity demand which is on average three times greater than the heating demand. Electricity generated from the CHP also has a carbon factor 6.5 to 7.9 times greater when compared to heat generation, primarily as all heat recovered from the CHP is a zero carbon stream. These two factors lead to electricity demand accounting for 97% of Scope 1 emissions.

Table 3 gives a summary of the energy intensity in the CED and compares this to benchmarks based on measured values from a range of office buildings [15]. Across the two years in question the CED has an average electricity intensity of 80 W/m^2 during occupied hours, noticeably higher than the 25 W/m^2 figure quoted for office buildings. This is as expected given that 30% of the CED's area is dedicated to laboratory space, which often requires energy intensive equipment such as chillers, fume hoods etc. The average heating intensity during occupied periods (29 W/m^2) is also higher than the reference figure of 20 W/m^2.

The effect of the 1st national COVID-19 lockdown (23rd March – 1st June 2020) can be seen in Fig 4. The daily energy use prior to COVID-19 was 16.8 MWh on average, which fell 29% to 11.6 MWh during the lockdown. Even with no occupants the hourly electricity demand of the CED is around 500 kW, which is equivalent to 1,200 UK households [16].

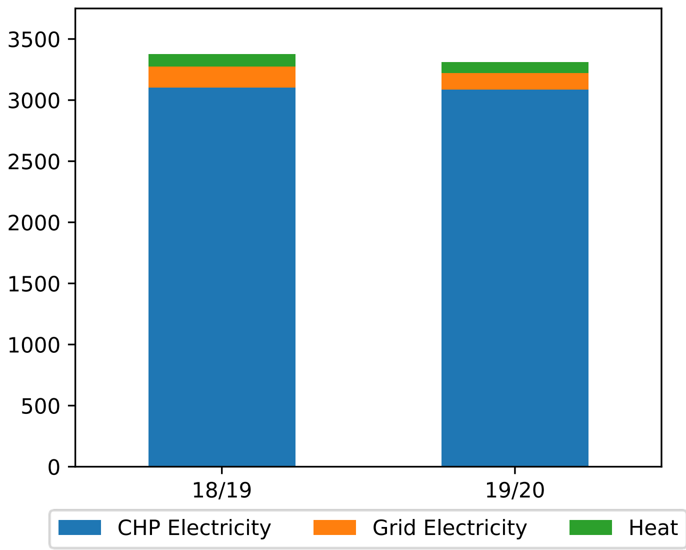

Fig 2: Scope 1 and 2 emissions breakdown by source.

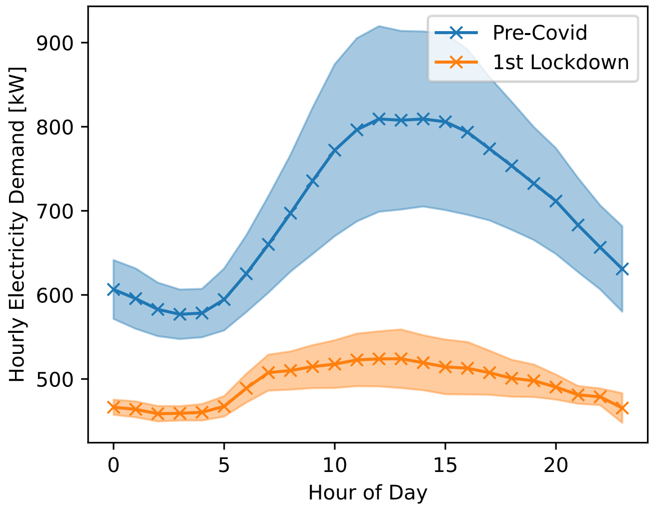

Fig 3: Average hourly electricity demand in 2019-20 before and during the first COVID-19 lockdown. Highlighting shows ± 1 standard deviation from the mean. The profile for heat is similar but the demand is much smaller.

When fully-occupied, the Department's daily electricity use is equivalent to 1,700 UK households. As there is no electricity submetering in the Department buildings it is difficult to identify the cause of the high baseload demand, but there are several pieces of equipment in the Department which are in constant use which could be the cause.

Table 3: Energy intensity for the Chemical Engineering Department (CED) compared to a typical office.

	CED (18/19)	CED (19/20)	Typical Office
Electricity Intensity [W/m^2]	84[a]	75[a]	25
	69[b]	63[b]	
Heating Intensity [W/m^2]	33[a]	25[a]	20
	31[b]	26[b]	

[a]for occupied hours

[b]for unoccupied hours (outside of 09.00 to 17.00)

2.3. Scope 3- methodology

The Scope 3 emissions were calculated by multiplying an activity factor by an emission factor. Activity data was collected from the Estates Team and the Finance Division at the College for all activities except business travel, commuting, international student travel and working/studying from home. Emission factor data from BEIS [14] and HESCAT [17] were then used to calculate emissions. Data from Egencia (the College's recommended travel management company) records the carbon footprint of each business trip taken, so there was no need to estimate the carbon footprint. For commuting, data from HESA on staff commuting were used with emission factor data from BEIS to estimate these emissions (Table 4). For student travel, data on country of origin of non-home students were used to estimate flight distances, and emission factors from BEIS (Table 4) used to estimate emissions.

Table 4: Emission factors used to estimate Scope 3 emissions.

Activity	Emission factor [14,17]	Units[a]
Purchased goods and services- Catering	0.154 to 2.471	$kgCO_{2eq}/£$
Purchased goods and services- Cleaning	0.083 to 0.297	$kgCO_{2eq}/£$
Purchased goods and services- Lab purchases	0.278 to 2.080	$kgCO_{2eq}/£$
Purchased goods and services- Safety and security	0.116 to 2.080	$kgCO_{2eq}/£$
International student travel - plane	0.154 to 0.193	$kgCO_{2eq}$/passenger km
Waste	0.989 to 1042	$kgCO_{2eq}$/tonne waste
Water	0.344	$kgCO_{2eq}/m^3$
Wastewater	0.708	$kgCO_{2eq}/m^3$
Working/studying from home	0.341	$kgCO_{2eq}$/FTE working hour
Commuting- passenger vehicle	0.285	$kgCO_{2eq}$/mile
Commuting- motorbike	0.186	$kgCO_{2eq}$/mile
Commuting- bus	0.082	$kgCO_{2eq}$/passenger km
Commuting- tube	0.041	$kgCO_{2eq}$/passenger km
Commuting- train	0.031	$kgCO_{2eq}$/passenger km

As we are considering the years 2018/19 to 2019/20, it is important to acknowledge the impact of COVID-19, as the national lockdowns imposed by the UK Government had a profound impact on the way the CED operated during this period. In particular, there was a large shift in how staff and students worked, with the vast majority working/studying from home. To estimate emissions from working/studying from home, we assumed that staff and students worked from 09.00 AM to 17.00 PM, taking a one-hour lunch break and two 15-minute breaks (6.5 hours per day working). With the hours per day spent working from home, we then needed to calculate the number of days staff and students spent working/studying from home. We consider the financial year at the College, which is 1st August to 31st July. From this, we took into consideration, the number of weekends, bank holidays, term dates and annual leave/holiday, to estimate the total number of days spent working in 2019/20. The total hours spent working/studying from home were then multiplied by an emission factor from BEIS (Table 4).

2.4. Scope 3- results

Scope 3 emissions contributed 4,150 and 4,910 tCO_{2eq} in 2018/19 and 2019/20, respectively. The emissions are largely driven by purchased goods and services, predominately lab purchases (Fig 5). This is because spending by the Department increased during the pandemic which resulted in emissions increasing. The COVID-19 lockdown had a significant impact on the distribution of emissions. Pre-pandemic, business travel was a significant emissions source but during the pandemic, emissions reduced dramatically because of national lockdowns, travel restrictions and the move towards hosting events virtually. Despite the restrictions to travel, emissions from international students travelling to Imperial College London were not affected as much. The country of origin of these students is the main factor which influenced emissions.

During the pandemic, staff and students were required to work/study from home with very few staff allowed on campus. After lab purchases and student travel, working/studying from home is the biggest emission source, with students accounting for a larger proportion of these emissions as the student population exceeds the staff population by a factor of four.

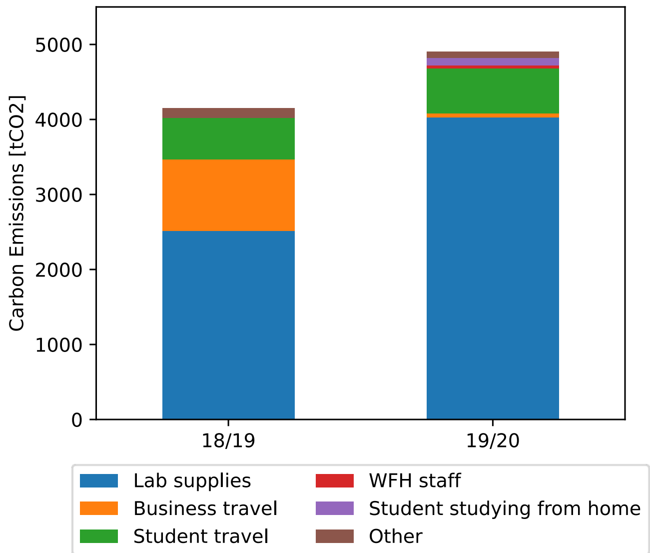

Fig 4: Scope 3 emissions breakdown by source.

3. Discussion

3.1. Overall carbon footprint

When the emissions are combined, emissions are roughly equal between Scopes 1 and 2 and Scope 3, with Scope 3 being marginally bigger (54%, Fig 6). The results indicate that a significant portion of the CED's emissions may be tackled directly through actions such as reducing energy consumption and less travel. Despite Scope 1 and 2 emissions falling due to the pandemic, Scope 3 emissions increased by a larger amount, resulting in total emissions increasing from 7,620 to 8,330 tCO_{2eq} between 2018/19 and 2019/20. However, these emissions are estimated using emission factors which are cost dependent i.e., $kgCO_{2eq}$ per £ spent. Despite this, cutting emissions from purchased goods and services is difficult to address, as it is doubtful that lab managers can limit what they purchase while still meeting their research objectives. Business travel is another area with significant carbon emissions (12% of total) which could be targeted. For student travel, for many international routes there is no travel alternative to flying, but for short-haul flights from the UK to some mainland European countries, such as France, Belgium and the Netherlands, these could be replaced by rail travel, reducing carbon emissions by up to 95% [18].

As over a third of emissions are caused by activities outside of what the CED can directly influence, if the Department were to cut their carbon footprint to the greatest degree possible, they would need to consider schemes beyond reducing energy usage in buildings, such as sharing chemicals and equipment between labs (any excess can be used by other lab groups) and working with goods and service providers to reduce their products' carbon footprint.

In Scopes 1 and 2, electricity use is the clear target for emission reductions, which is further motivated by unprecedented energy prices and market volatility. Laboratories will be the main electricity users, but without any system submetering it is difficult to target other areas where usage can be reduced. Institutions should look to understand which appliances have higher energy demand, and ensure such equipment is being used in an optimal way. For example, fume hoods are estimated to use 4 kW of electricity on average, but this is greatly affected if the fume cupboard sash is left open unnecessarily, as fan power is a function of flowrate cubed [19]. With 167 fume hoods in the Department, using all fume hoods for one hour every day of the year would result in 244 MWh electricity demand (4-5% of the CED's total electricity consumption). Other equipment which are in constant use are dryers, furnaces, fridges and freezers. Reducing the quantity and hours run would be impactful towards lowering energy consumption and Scope 1 and 2 emissions.

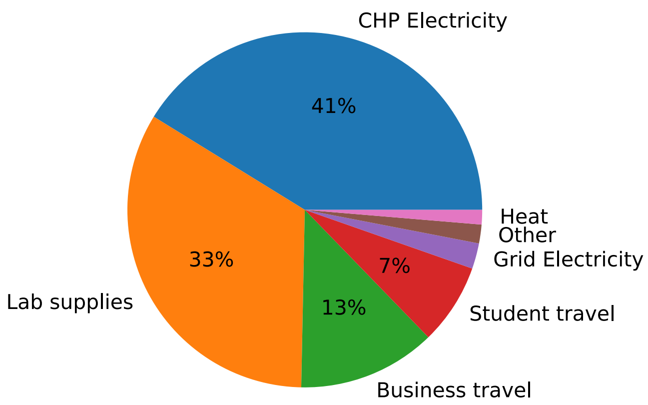

Fig 5: Total emissions breakdown by source.

3.2. Comparison to literature

It is difficult to directly compare our results to other studies. This is because other studies have estimated the carbon footprint of universities as a whole and streams considered in Scope 3 differ by study i.e., some only consider commuting while some consider a broader range. Our estimate of 8,330 tCO_{2eq} in 2019/20 is within range of the estimated emissions of the College in 2019/20 (235 $ktCO_{2eq}$) [6]; the CED is responsible for around 4% of the College's emissions. We found energy use to be responsible for 46% of the CED's carbon footprint, which is similar to other universities [5]. Our finding that Scope 3 emissions, specifically procurement of good and services, are the second largest emission source is also similar to other universities [9,10]. When we compare our results to the College's Carbon Management and Sustainability report we find that our results do not match up, as the sustainability report found Scope 3 emissions to account for 74% of the College's emissions [7]. This could be because the CED is one of numerous departments at the College, as well as construction, refurbishment, capital projects, consultancy and other Scope 3 streams being included in the College wide figure, so the emissions profile of each department will be different and would not match the emissions profile of the College as a whole.

4. Conclusions and recommendations

The proposed carbon accounting framework presented in this work can be easily applied to any university department as most should have a record of their historical electricity usage, business travel and procurement spending. Accurate and thorough accounting of departmental carbon footprints is important especially when many activities occurring in a department are for the advancement of technologies and processes to reach sustainable futures. They are also important for ensuring that universities take the actions needed to transition their activities to ones which are compatible with a carbon-neutral landscape. Due to the varied nature of different university departments, it is expected there will be a wide range of carbon footprints, mainly determined by the number of research labs and the amount of business travel. Using this framework, we have estimated the CED of Imperial College London to have emitted 7,620 to 8,330 tCO_{2eq} in 2018/19 and 2019/20, respectively, with emissions being nearly equal between Scopes 1 and 2 and Scope 3. Based on the findings, the CED will engage with stakeholders to devise and implement carbon reduction measures and use the results to shape the Department's wider sustainability strategy.

The below recommendations are given to university departments and other engineering research institutes looking to reduce their carbon footprint:

- Quantify Scope 1, 2 and 3 carbon emissions to highlight the most intensive areas.
- If labs are present, ensure highly energy intensive appliances such as fume hoods are being used appropriately and good working practices are in place.
- Where possible substitute flights for rail to reduce carbon emissions by up to 95%.

- Where possible, limit procurement of lab supplies or attempt to find a lower carbon alternative, as well as sharing equipment.

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