Life cycle assessment for carbon emissions from procurement of UCL Bartlett

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1. Introduction

With the development of society and economics, climate change has been more and more serious. Therefore, some problems are appearing and influencing the ecosystem and human society. For example, the continuous rising of the earth's surface temperature can lead to the reduction of snow cover and rising sea level, which can affect people's lives and cause extreme weather (McCarthy, J. J. et al., 2001). Greenhouse gases (GHGs) indicate gases which can cause the greenhouse effect, including many types of gases and the major greenhouse gases are carbon dioxide, methane, nitrous oxide, and fluorinated gases (EPA, 2020). As a result, reducing greenhouse gas (GHGs) emissions is an effective way to mitigate climate change. There are already some policies and conferences regarding climate change, such as the UN climate change conference, United Nations Framework Convention on Climate Change (UNFCCC), etc. To respond and contribute to the mitigation of climate change, many universities have started to focus on their greenhouse gas emissions. The University of Cambridge has published some reports in terms of environmental strategy and carbon emissions (University of Cambridge, 2021). Yale University research assesses its carbon emissions according to the procurement of the university (Thurston, M. et Eckelman, M. J., 2011).

University College London (UCL) has also made its commitment to become a zero-carbon university by 2030 and every part of the university should contribute to the goal (UCL, 2021). According to UCL's sustainability annual report (table 1), procurement of buying products is the main contributor to greenhouse gas emissions and compared to the baseline of 2018-2019, UCL has made big progress to reduce its carbon emissions by 17%.

	Tonnes CO_2e 2020-21	**% of total CO_2e**	**% Change from Baseline 2018-19**
Energy for our campus	28,522	7%	-48%
Travel	2,179	0.5%	-94%
Food	2,815	0.7%	7%
Waste & Water	642	0.2%	12%
Products that we buy	392,839	92%	-7%
Total	424,727		-17%

Table 1 Total greenhouse gas emissions (CO_2 eq) of UCL 2020-21 (Sustainable UCL, 2022)

The Greenhouse Gas Protocol has classified carbon emissions into scope 1, scope 2 and scope 3 emissions. Scope 1 includes the direct emissions of production processes while scope 2 included the indirect emissions of energy and fuel (EPA, n.d.).

Compared with scope 1 and scope 2 emissions, scope 3 emissions, also referred to as value chain emissions contain downstream emissions from distribution to waste treatment and upstream emissions associated with purchasing goods and services (Greenhouse gas protocol, n.d.). Based on the research of EPA (n.d.), scope 3 emissions are the majority of organisations' total greenhouse gas emissions. As a result, it is important to identify the scope 3 emissions based on the procurement.

Various ways can be used to calculate and estimate greenhouse gas emissions such as different types of life cycle assessment methods. Process-based life cycle assessment (LCA) is a bottom-up approach that evaluates the environmental impacts of certain products or production processes. It can calculate carbon emissions based on detailed information and data from manufacturing. Economic input-output life cycle assessment (EIO-LCA) is a more general method compared with LCA and it uses the amount of economic activity and input-output matrix to calculate the environmental impacts (Chang, Y. et al., 2010).

1.1 Aim

To respond to the zero-carbon strategy of UCL, the Bartlett department is moving toward reducing greenhouse gas emissions. This project aims to identify the overall emissions of the Bartlett department from 2018 to 2019 and use LCA to analyse certain data categories that are key environmental contributors. Based on the results, the project can give some recommendations regarding cutting emissions.

1.2 Objectives

- Use Excel to separate material procurement and non-material procurement data and analyse the overall emissions of different data categories based on the procurement through the Higher Education Supply Chain Emissions Tool (HESCET).
- Identify the key contributors according to the results of HESCET and conduct process-based LCA and EIO-LCA to analyse the greenhouse gas emissions of key environmental factors.
- Based on the contribution of different data categories, the report analyses emissions of accommodation from other business services, travel and courier services and GC-MS equipment from lab equipment and chemicals.
- Compare the results of LCA and HESCET.

- Give recommendations based on the results of overall emissions and LCA analysis.

2. Background information

2.1 UCL sustainability strategy and scope 3 emissions

UCL has developed a sustainability strategy to cope with climate change. The strategy involves the whole community and different departments of UCL. It provides a framework and foundation for UCL to contribute to mitigating emissions and environmental impacts. To encourage students and staff to support and involve in sustainability, UCL starts to focus on the study and research related to sustainability and embed sustainability into taught courses. For example, the global citizenship programme has been conducted for students and staff to address societal challenges together and engage with sustainability issues. UCL is also compliant with ISO 14001 standard and integrates sustainability into the plans and development of the campus. It has a great achievement in sustainable buildings and the student centre is one of the most sustainable buildings in the UK. To better understand the emissions of the campus, UCL also publishes annual reports to analyse the emissions and environmental contributors and show the progress that has been made (Sustainable UCL).

As scope 3 emissions discharge most carbon emissions, UCL uses HESCET to address the breakdown of emissions from different categories. The results of the HESCET analysis can provide a better understanding of the scope 3 carbon emissions. Figure 1 (UCL, 2022) shows the emissions of 10 categories and their procurement. According to the figure, the other medical products category is the main contributor to carbon emissions. However, the category that has the most procurement is other regular housing payments, which indicates that the largest procurement doesn't mean the most carbon emissions.

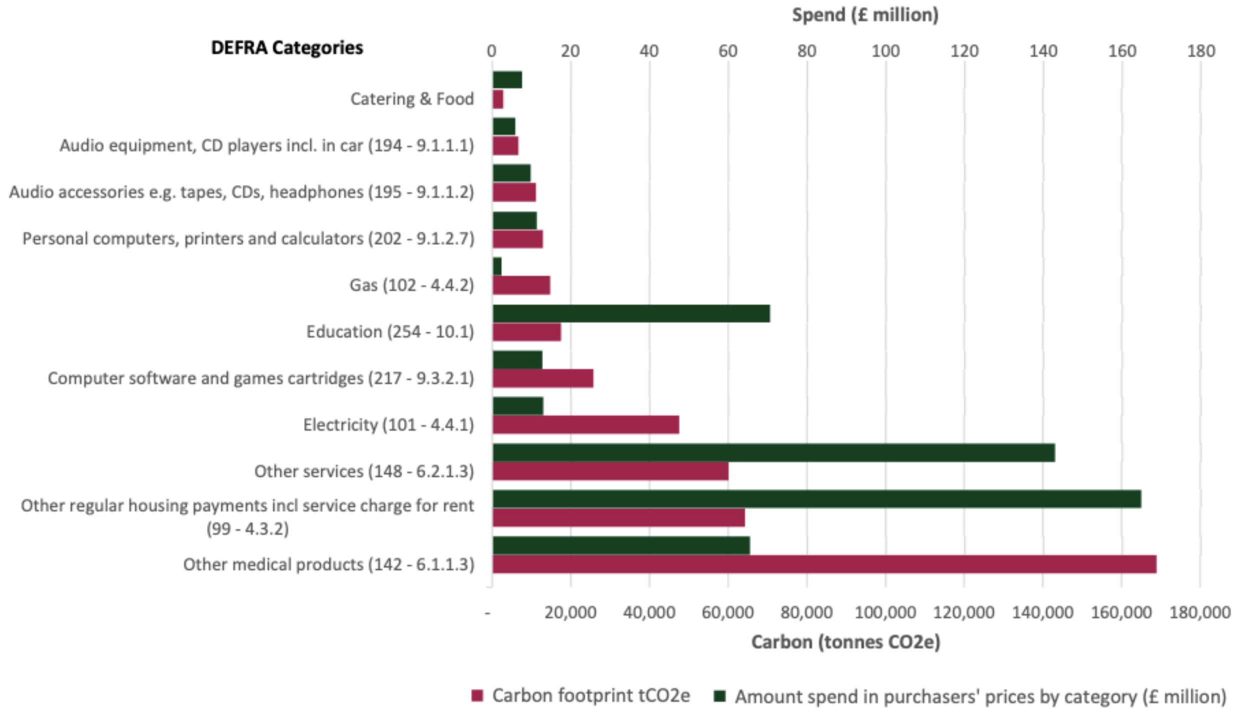

Figure 1 Carbon footprint and procurement of 10 categories (UCL, 2022)

2.2 Process-based life cycle assessment

Life cycle assessment is a tool to evaluate the environmental impacts of inputs during a product's life cycle. It involves every stage of the production process from the treatment of raw materials to waste treatment. LCA should be compliant with international standards such as ISO 14040 and ISO 14044. The standards provide the principles and steps of LCA (Finkbenier, M. et al., 2006). Attributional and consequential LCA are two types of process-based LCA. Attributional LCA (aLCA) indicates the environmental impacts of the physical production process of a product’s life cycle, while consequential LCA (cLCA) is defined as the change of material flows that is in response to different options (Finnveden, G. et al., 2009). There are four main steps of process based LCA (figure 2): defining the goal and scope of the LCA study, collecting inventory data, conducting environmental impact assessment, and interpreting LCA results (Muralikrishna, I. V. et Manickam, V., 2017). There are also some uncertainties during LCA analysis due to the choices of different databases and the accuracy of collecting data. Sensitivity analysis can be used to identify the key environmental factors of the production process and test the robustness of the LCA analysis (Wei, W. et al., 2014).

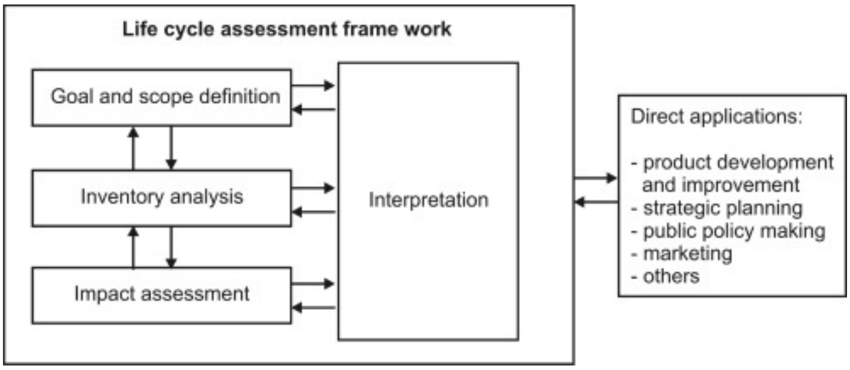

Figure 2 Procedures of LCA analysis (Muralikrishna, I. V. et Manickam, V., 2017)

2.3 Economic input-output life cycle assessment

Economic input-output life cycle assessment (EIO-LCA) is an LCA approach to assessing environmental impacts using monetary value flows. It mainly uses the mathematical matrix related to economic activities included in goods and services to identify the environmental impacts (Kitzes, J. 2013). To use EIO-LCA, researchers need to figure out the procurement and emission factors of different data categories. Compared with process-based LCA, the system boundary of EIO-LCA is wider and includes direct and indirect emissions of different sectors involved in the life cycle of products (Azari, R., 2019). EIO-LCA also focuses on the macro level of goods and services compared to the micro level of process-based LCA. Table 2 (Rebitzer, G. et al., 2004) shows the differences between process-based LCA and EIO-LCA. However, the results of EIO-LCA might not be accurate enough because it doesn't focus on the details of products and services.

Differences	**Process-based LCA**	**EIO-LCA**
Data sources	Unit process data	Economic national accounts
Way of Proceeding	Bottom-Up Approach	Top-Down Approach
Commodity unit flows	Physical flows	Monetary valued flows
Level	Micro level	Macro level
Covered life cycle stages	Complete life cycle	Pre-used and consumption stages

Table 2 Differences between process-based LCA and EIO-LCA (Rebitzer, G. et al., 2004)

3. Methodology

This section describes the emissions factors and data categories used in EIO-LCA and the detailed stages of process-based LCA used for analysing certain data categories. The impact assessment of process-based LCA doesn't include normalisation, because the mid-point method is sufficient in this project. Sensitivity analysis isn't encompassed due to the lack of input data and the estimation and assumption that have been made during the analysis process.

3.1 HESCET and EIO-LCA

This project has used Excel to sort out procurement data of the Bartlett department from 2018 to 2019 into different categories and calculated their procurement. The data categories and procurement are listed in table 3. The higher education supply chain emissions tool (HESCET) is a simple tool used to estimate the greenhouse gas emissions of goods and services based on procurement and the data categories. HESCET uses Defra categories and conversion factors to convert procurement data to greenhouse gas emissions. The results of HESCET can provide an overall review of carbon emissions per category.

Data category	procurement (£ thousand)
IT equipment	478.3
furniture and office equipment	147.3
paper and stationery	187.8
materials	596.3
lab equipment and chemicals	648.1
cleaning products	2.8
other business services	3388.9
travel and courier services	412.2
food and catering	416.0

Table 3 Data category and procurement

This project mainly uses EIO-LCA to estimate the greenhouse gas emissions of accommodation and hotels from the category of other services, because it is hard to use LCA to analyse carbon emissions of other non-material procurement. The estimation of hotel carbon emissions uses Ecometrica (n.d.) as a reference and is compliant with the greenhouse gas protocol of the World Business Council for Sustainable Development (WBCSD). The emission factors used in this project are from UK Government GHG Conversion Factors for Company Reporting (2022) and are listed in table 4. The emission factors are described by multiplying the number of hotel rooms and the number of staying nights. To calculate the carbon emissions of hotel stay, the report uses the number of rooms and the length of staying multiplied by the conversion factors. In the process of analysing hotel emissions, some assumptions

(Table 5) have been made due to the unspecified primary data and lack of conversion factors. The assumptions are made based on the average value of given detailed data.

Activity	Country	Unit	Total kg CO_2e per unit
Hotel Stay	UK	Room per night	10.4
	Brazil	Room per night	8.7
	Denmark*	Room per night	5.4
	Spain	Room per night	7.0
	Netherlands	Room per night	14.8
	Norway	Room per night	5.4
	Belgium	Room per night	12.2
	United States	Room per night	16.1
	France	Room per night	6.7
	Italy	Room per night	14.3
	Germany	Room per night	13.2
	Hong Kong, China	Room per night	51.5
	Ghana*	Room per night	25.2
	Greece*	Room per night	5.4
	China	Room per night	53.5
	Thailand	Room per night	43.4
	Portugal	Room per night	19.0
	Turkey	Room per night	32.1
	Japan	Room per night	39.0
	Korea	Room per night	55.8
	Sweden*	Room per night	5.4
	Europe*	Room per night	11.5

Table 4 Conversion factors of hotel stay (UK Government, 2022; Greenview, 2022)

* The emission factors of these countries aren't provided in the document of the UK Government and are estimated using the average value of the region on the Greenview website.

	Assumption
Hotel stay with unspecified location	Assume the location is Europe and use the average conversion factor from the UK government document
Hotel stay with the unspecified numbers of rooms and nights	Assume the hotel stay consumes 3 rooms and the length of staying is 7 nights

Table 5 Assumptions for the analysis of hotel carbon emissions

3.2 Process-based LCA of travel and courier services

3.2.1 Goal and scope

The LCA study focuses on the travel and courier services of the Bartlett department from 2018 to 2019. Travel data has been classified into four categories: car travel, rail travel, air travel and boat and ferry travel. The destinations of travelling have been divided into five categories: UK, Europe, Africa, United States and Asia for analysing effectively. For courier services, there are three means of transportation: flight, light vehicle, and truck. The destinations of courier services have been classified into Europe, Asia, London, England, and Scotland. This project only includes the travel and courier services with specified destinations.

The functional unit in the LCA study of travel and courier services is per year because the time scale of the LCA study is from 2018 to 2019. The disposal stage and waste treatment stages aren't included in the LCA study. However, the emission factors have encompassed the embedded emissions of manufacturing and use. Figure 3 shows the system boundary of travel and courier services LCA.

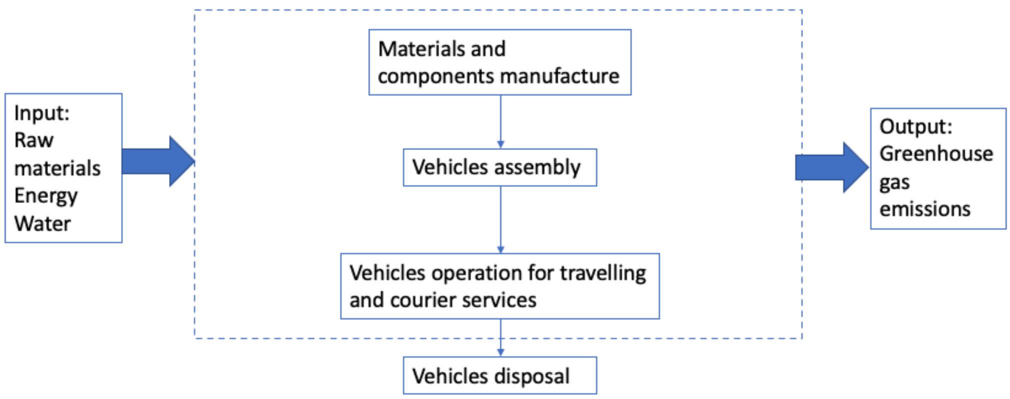

Figure 3 The system boundary of travel and courier services adapted from Lane, B. (2006)

3.2.2 Inventory data

The input data is calculated based on the original data provided by Bartlett. The inventory data for the LCA study comes from the ecoinvent database, and the emission factors from the database include the emissions from the manufacturing process to the customer use stage. However, due to the difference between the unit of the LCA database and the original data, the original data should be converted based on the LCA unit. The converted input data are listed in Table 6.

Data category	**Amount**	**Unit**
Europe (car travel)	1454.46	km
United States (car travel)	614.86	km
UK (Car travel)	407.44	km
Europe (air travel)	1549296.05	personkm*
United States (air travel)	632052.29	personkm
Africa (air travel)	568204.75	personkm
Asia (air travel)	1448836.95	personkm
Europe (rail travel)	14238	personkm
UK (rail travel)	327474.54	personkm
Europe (boat and ferry travel)	181.86	tkm*
Europe (courier services)	6926.76	tkm
Asia (courier services)	31349.92	tkm
Scotland (courier services)	660.91	tkm
England (courier services)	1004.83	tkm
London (courier services)	200.79 (vehicle)	tkm
	10.47 (lorry)	

Table 6 Input data of travel and courier services (from data provided by Bartlett)

*Personkm is a unit used in LCA analysis that represents the numbers of passengers multiplied by travel distance.

*Tkm is a unit that refers to the weight of the shipment multiplied by shipping distance.

3.2.3 Analysis method and assumptions

The Recipe midpoint (H) method is used in the LCA analysis, and this study focuses on the greenhouse gas emissions of travel and courier services and the calculation result is displayed by CO_2 equivalent. Some assumptions (Table 7) have been made due to the lack of data description.

Data category	Assumption
courier services	the unspecified big package is 100 kg the unspecified small package is 100g estimate the weight of packages according to the detailed description Courier services in Europen and Asia use planes Courier services in other places apart from Europe use vehicles and trucks
rail travel	For trip without knowing the amount of people, assume the amount is 10 people
air travel	For trip without knowing the amount of people, assume the amount is 10 people
boat and ferry travel	Assume weight of per person is 50 kg

Table 7 Assumptions for LCA study of travel and courier services

3.3 Process-based LCA of GC-MS lab equipment

3.3.1 Goal and scope

Based on the total procurement of lab equipment and chemicals, the expense of equipment contributes to 94.53 % of total procurement. And GC-MS equipment is 44.8 % of the total procurement of lab equipment. Therefore, this report analyses the carbon emissions of GC-MS equipment according to the contribution of procurement.

GC-MS equipment is important and expensive lab equipment used for separating mixed compounds and analysing the components of chemicals. This LCA study only includes the process of equipment manufacturing and assembly and excluded equipment operation, transport during the production process, equipment maintenance and waste management stage. The functional unit of the LCA study is per GC-MS equipment and the system boundary is shown in figure 4.

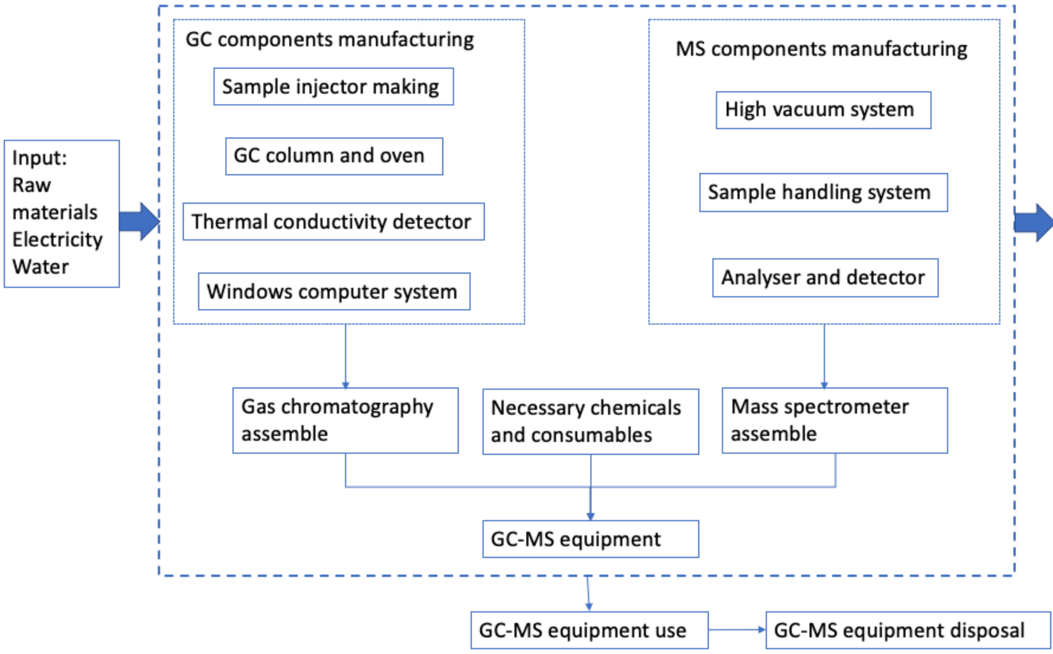

Figure 4 The system boundary of GC-MS equipment LCA study

3.3.2 Data inventory

The inventory data for the GC-MS equipment production process is collected from the literature. For the input data that cannot be found in the literature, the project uses EIO-LCA to estimate the emissions of the manufacturing process based on procurement. The emission factors for input data come from the ecoinvent database. Table 8 summarised the detailed input data of GC-MS equipment LCA. Table 9 presented the emission factors and procurement data used in EIO-LCA.

Acitivity	procedures and materials	Amount/FU	Unit	Reference
syringe making	water	17.5	kg/FU	Assam Industrial Development Corporation (AIDC) (n.d.)
	PTFE	4.00E-05	kg/FU	Syringe selection guide
	Borosilicate glass	4.40E-04	kg/FU	Hamilton Microliter Syringes
	rubber	1.10E-05	kg/FU	Assam Industrial Development Corporation (AIDC) (n.d.)
	polypropylene (PP)	6.08E-04	kg/FU	Syringe selection guide
	electricity	88	kWh/FU	Assam Industrial Development Corporation (AIDC) (n.d.)
column making	Borosilicate glass	5.72E-03	kg/FU	GC Column selection guide
	Polyethylene glycol	1.00E-07	kg/FU	Sigma-Aldrich. GC Column selection guide
	electricity	160	kWh/FU	Lee, C.T. (2013)
carrying gas	helium	1.61E-03	kg/FU	Edward, B. et al., (n.d.)

Table 8 Inventory data of GC-MS equipment LCA

Component	Procurement data	Emission factor	Reference
GC column oven	£ 1,000	0.62 kg CO_2eq/£	Agilent, 2022 Defra, 2011
Leveno computer	-	419* kg CO_2eq/£	Lenovo product carbon footprint information sheet Defra, 2011
Thermal conductivity detector	£ 4,022	0.62 kg CO_2eq/£	thermalfisher, 2022 Defra, 2011
Mass spectromer	£ 12,750	0.62 kg CO_2eq/£	Salford scientific, 2022 Defra, 2011

Table 9 Inventory data of EIO-LCA for GC-MS equipment

*The emissions of computers come from the product report of Lenovo company.

3.3.3 Analysis method and assumptions

The LCA study for GC-MS equipment production combines the process-based LCA with EIO-LCA. The Recipe Midpoint (H) method is used in the process-based LCA. The assumptions for the LCA analysis of GC-MS equipment are shown in Table 10. The numbers of microliter syringes and parameters of GC columns are assumed based on the technical specifications of GC-MS (2015).

Components	Assumption
Microliter syringe	Assume the GC-MS equipment contains syringes of 1, 5, 10, 25 and 50 microliters each
Computer	Assume the computer is purchased with GC-MS equipment
Detector	Assume the GC-MS equipment uses a thermal conductivity detector because it is the most common and useful type of detector in GC system (Rastrello, F. et al., 2013)
GC column	Assume the length and inner diameter of the GC column are 45 m and 0.3 mm respectively

Table 10 Assumptions for GC-MS equipment LCA study

4. Results and discussion

This section explains and discusses the results of LCA analysis and compares the results of LCA with the calculated data of HESCET.

4.1 Overall emissions and procurement

Figure 5 and figure 6 show the overall emissions and procurement results of Bartlett from 2018 to 2019. The total emissions of Bartlett from 2018 to 2019 are 5422.16 t CO_2eq. According to the result, other business services and lab equipment and chemicals are the key contributors to greenhouse gas emissions. The carbon emissions of the two factors are 2744.6 t CO_2eq and 1307.8 t CO_2eq respectively. Carbon emissions from other business services contribute 50.618% of total emissions and the lab equipment and chemicals category causes 24.12% of overall emissions. Apart from other business services and lab equipment and chemicals, IT equipment and travel and courier services are also key environmental factors for total carbon emissions. They can contribute 437.2 t CO_2eq per year and 456.3 t CO_2eq per year respectively. However, the procurement of IT equipment and travel and courier services are lower than materials for workshop and manufacturing, which indicates that carbon emissions don't necessarily increase with procurement.

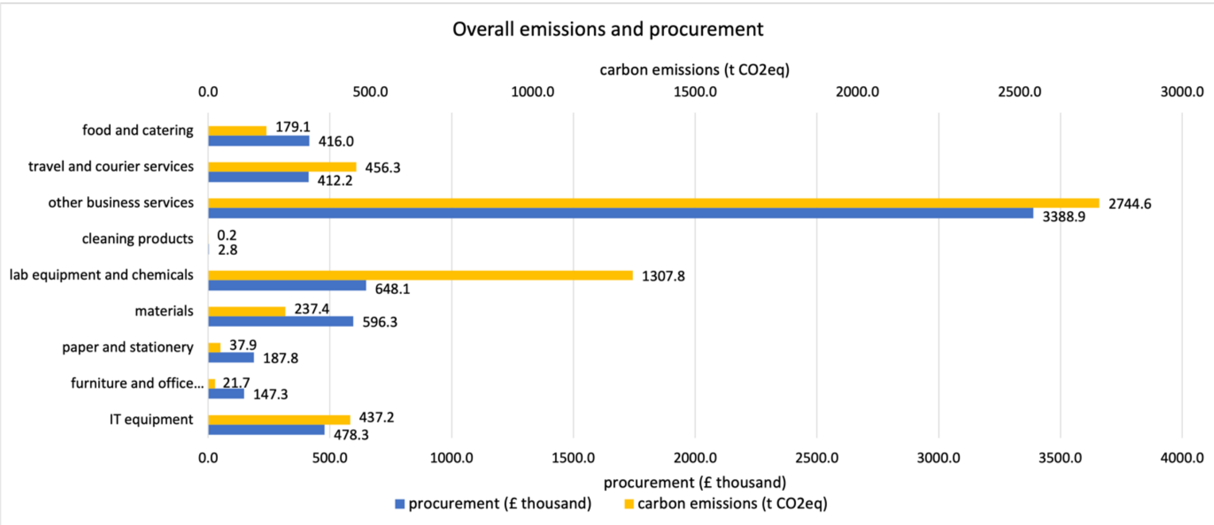

Figure 5 Overall emissions and procurement

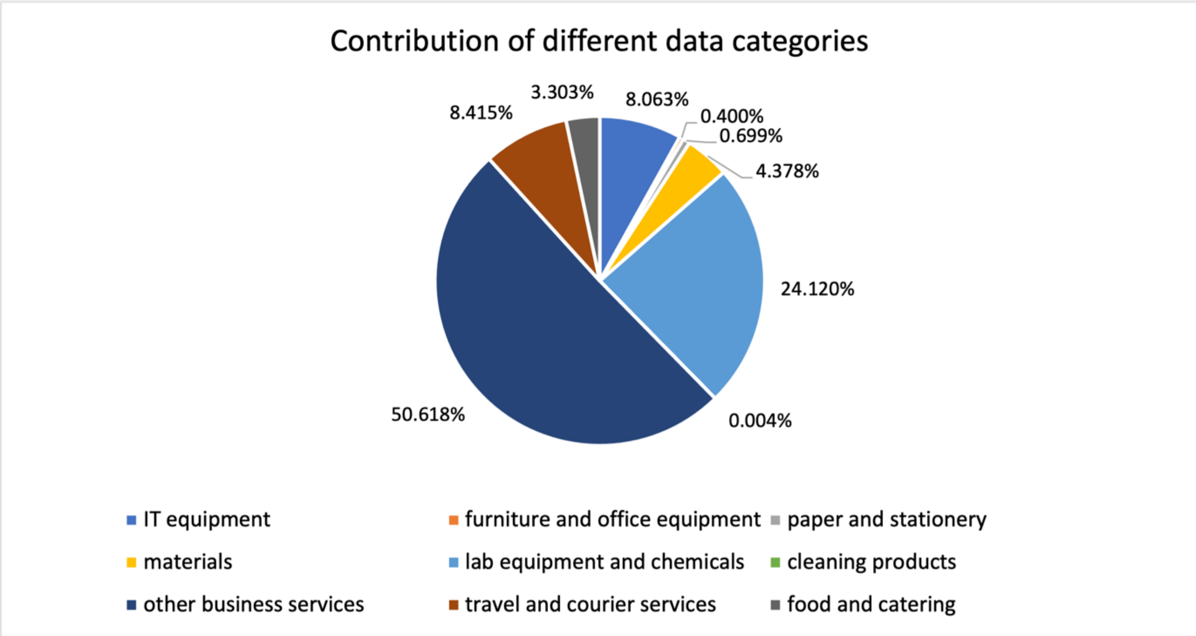

Figure 6 Contribution of different categories

Other business services mainly include non-material services and procurement such as internet subscriptions, education services, research services and accommodation and hotel stay. Figure 7 shows the breakdown details of the emissions of other business services based on Defra categories using HESCET. According to figure 7, internet subscription fees dominate the emissions of other services. Accommodation is described as holidays in the Defra category, and it is also a key contributor to the carbon emissions of non-material services. The carbon emissions of accommodation and internet subscriptions are 291.2 t CO_2eq and 376.2 t CO_2eq respectively. Figure 8 addressed the contribution of internet subscription fees and total hotel stays are 46.87 % and 36.3 % respectively.

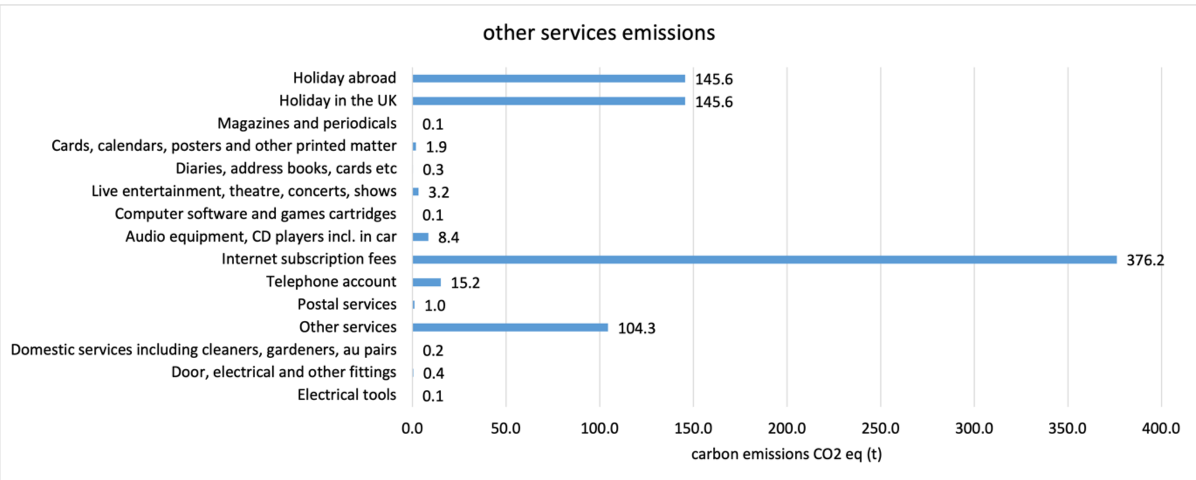

Figure 7 Detailed emissions of other services

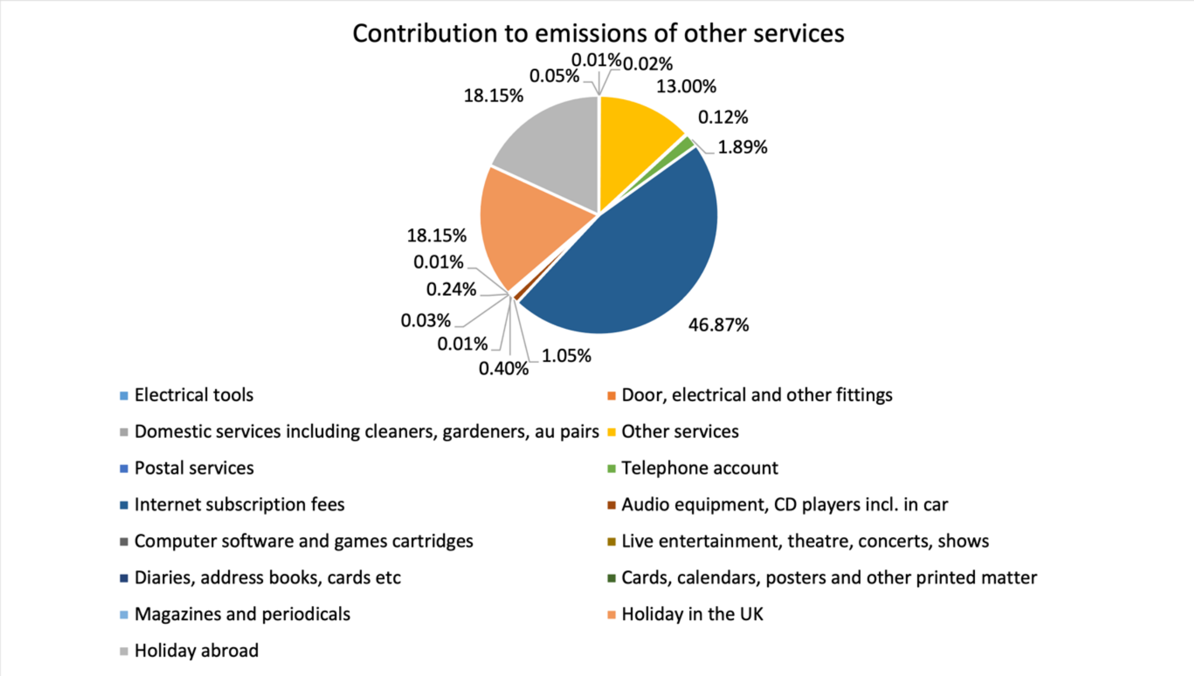

Figure 8 Contribution of different categories to total emissions of other services

Lab equipment and chemicals encompass lab equipment, lab consumables and furniture used in the laboratory. Figure 9 summarises the detail of lab equipment and chemical emissions based on the results of HESCET. The information in figure 8 shows that medical and precision instruments, which means lab equipment is the key contributor to total emissions of lab equipment and chemical emissions. Figure 10 indicates that 99.66 % of lab equipment and chemicals emissions are from medical and precision instruments.

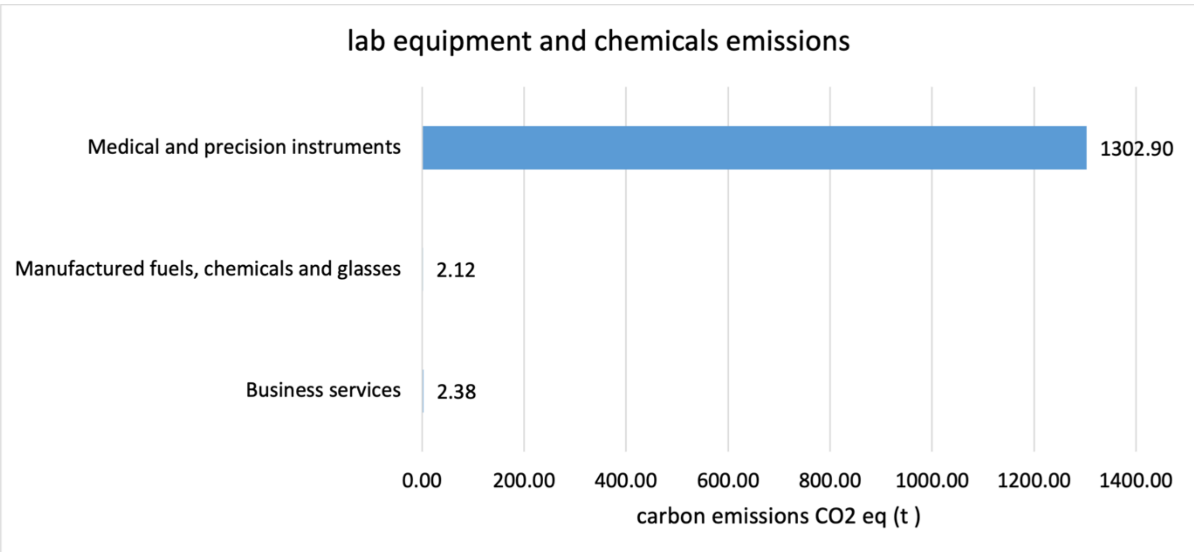

Figure 9 Detailed emissions of lab equipment and chemicals

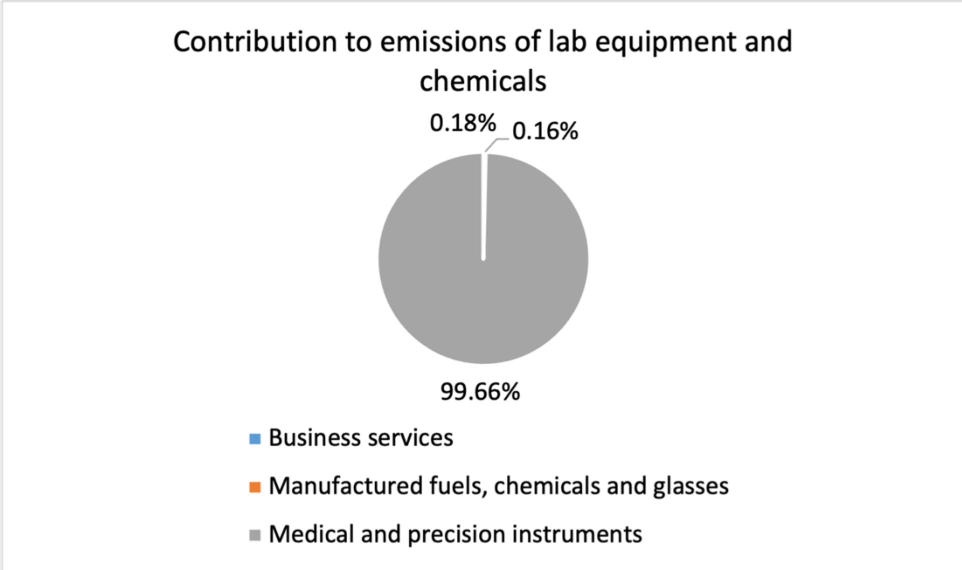

Figure 10 Contribution of different categories to total emissions of lab equipment and chemicals

4.2 Carbon emissions of accommodation

The result of EIO-LCA indicates that the carbon emissions of accommodation are 256.49 t CO_2 eq from 2018 to 2019. Figure 11 shows greenhouse gas emissions of accommodation in different locations. It shows that accommodation in Europe is the most influential factor for carbon emissions of accommodation, which contributes to 144.16 t CO_2 eq. Besides, accommodation in the UK is also a key contributor to accommodation greenhouse gas emissions. It can discharge 72.99 t CO_2 eq. And the percentages of the two environmental factors are 56.20 % and 28.46 % respectively.

Figure 12 compares the results of EIO-LCA and HESCET. The results of EIO-LCA and HESCET analysis are 256.49 t CO_2 eq and 291.2 t CO_2 eq. It indicates that there is only a slight difference between the calculation of EIO-LCA and HESCET because HESCET also uses economic activities to estimate the environmental impacts. Figure 13 shows that the contribution of accommodation to total procurement is 80.99 %. It also addresses that the contributions of carbon emissions from accommodation are 52.03 % and 59.07 % according to the calculation of EIO-LCA and HESCET respectively.

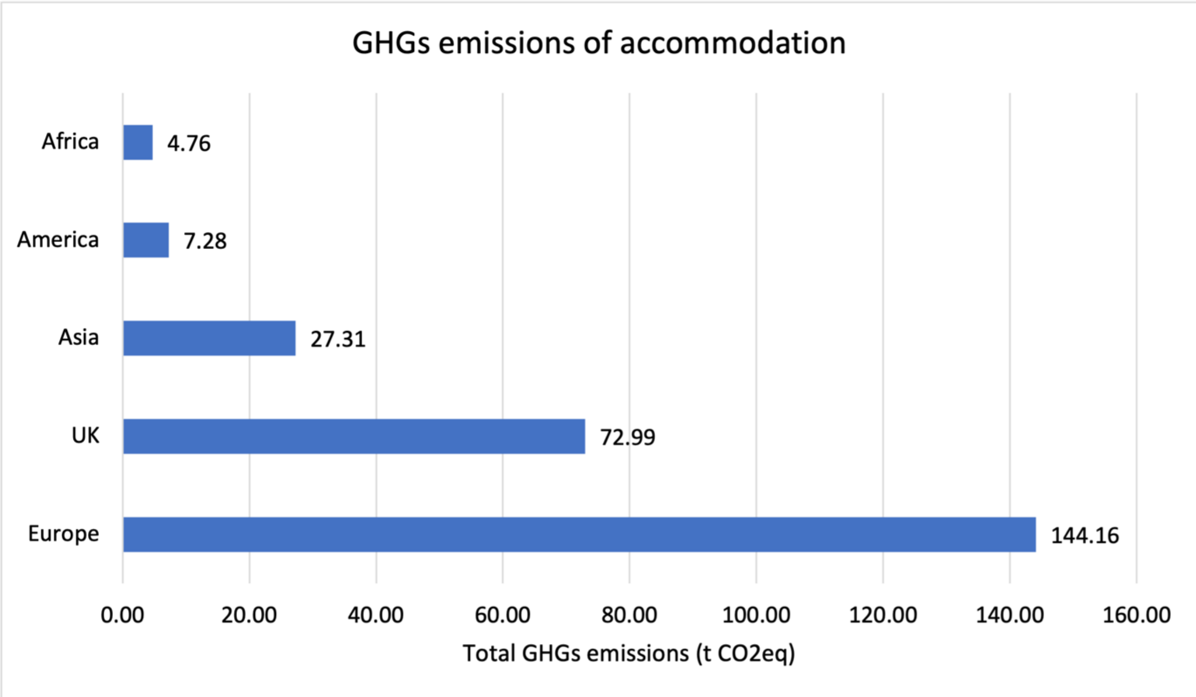

Figure 11 Greenhouse gas emissions of accommodation

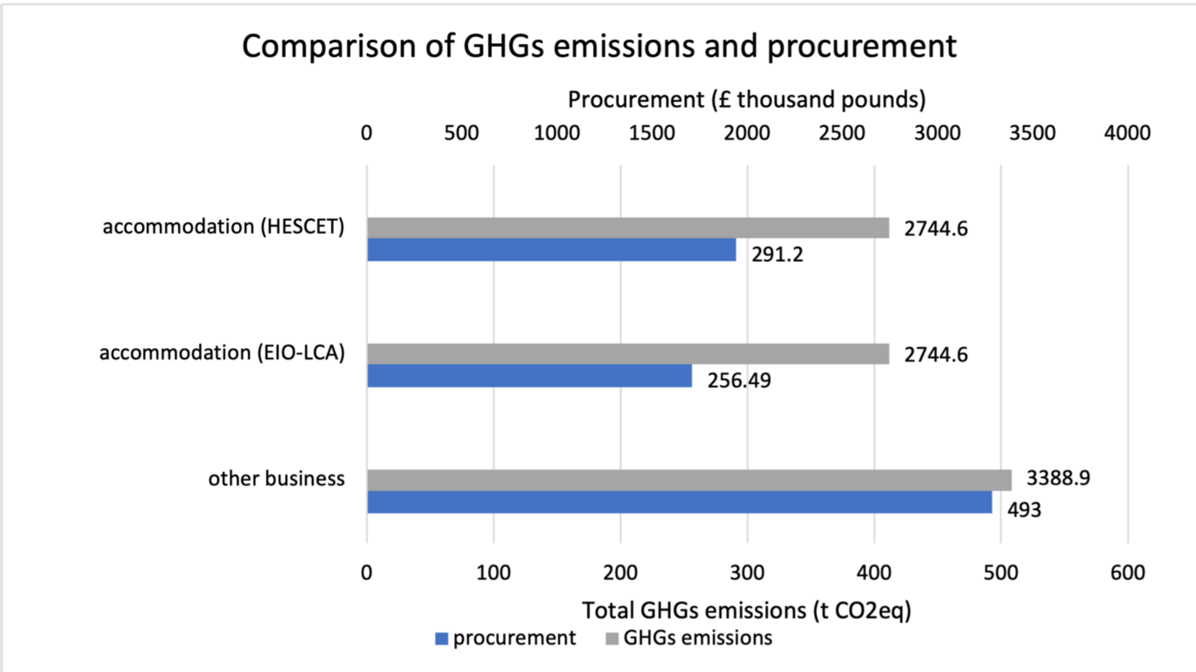

Figure 12 Comparison of accommodation and other business services

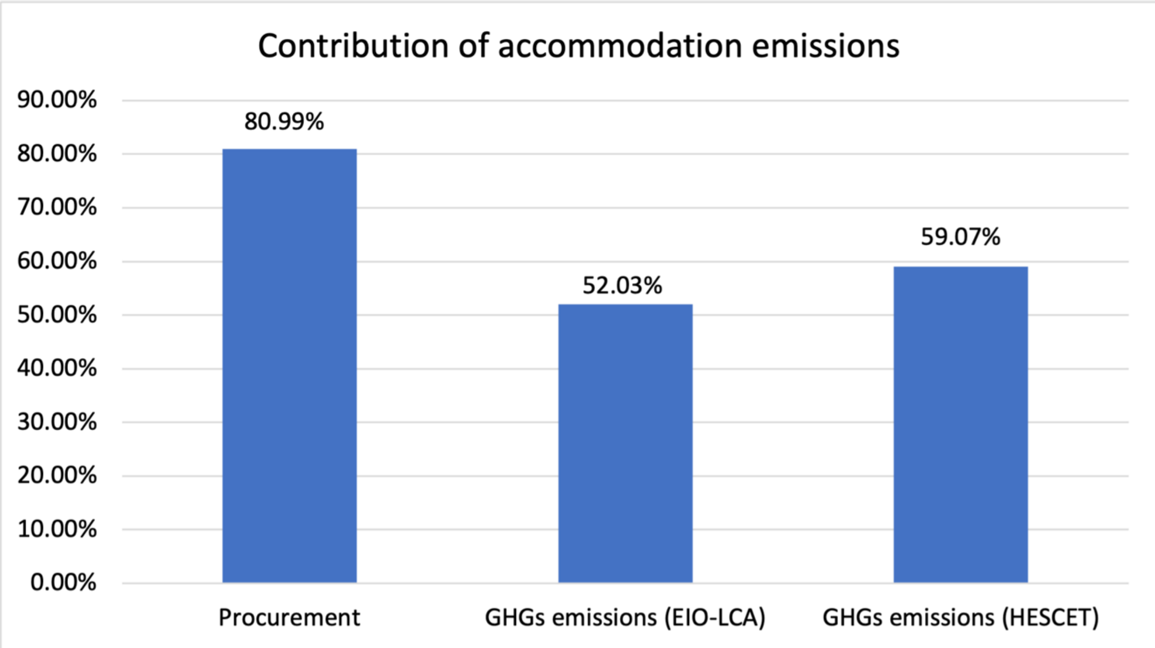

Figure 13 Contribution of accommodation to total GHGs emissions of other business services

4.3 Travel and courier services LCA

The results of travel and courier services LCA indicate the key contributors and their contribution to total greenhouse gas emissions. Total emissions of travelling are 577 t CO_2 eq per year. Figure 14 shows that air travel dominated the global warming potential of travelling and it can cause emissions of 550 t CO_2 eq annually. According to figure 15, 95.243 % of total carbon emissions generated by travelling are from air travel.

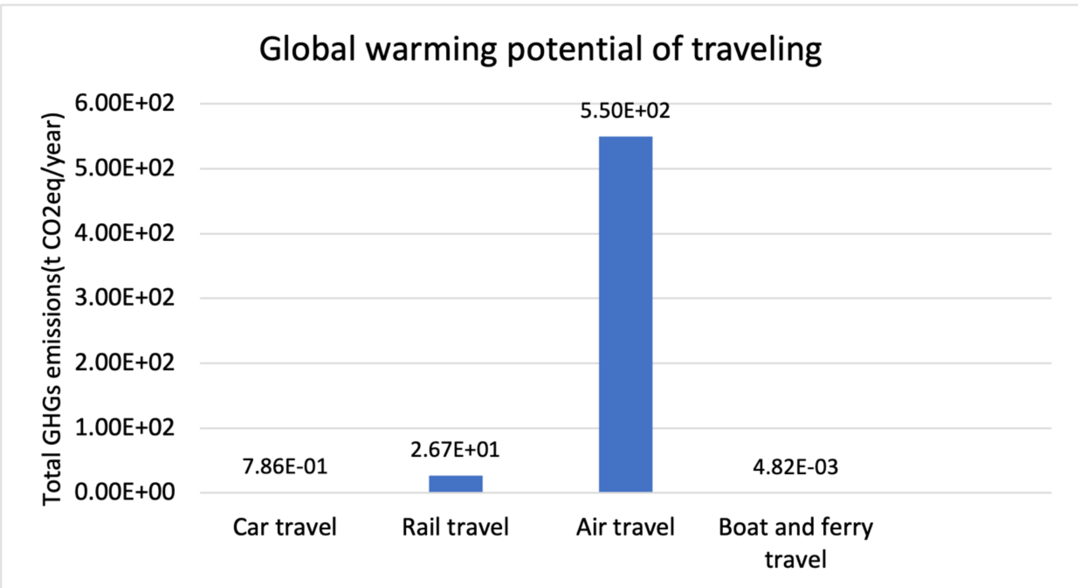

Figure 14 Carbon emissions of travelling

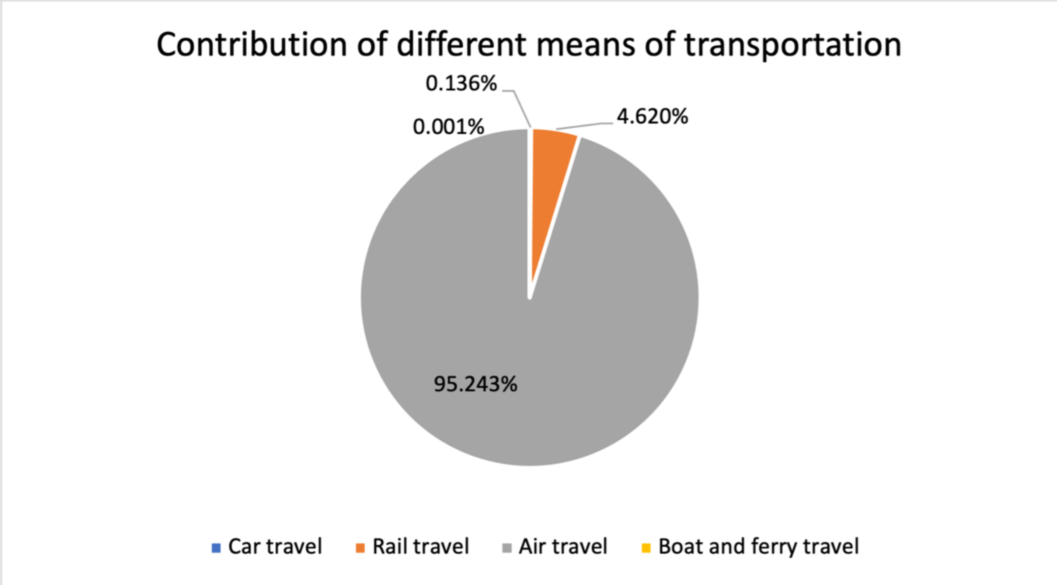

Figure 15 Contribution of different means of transportation to emissions of travelling

Figure 16 indicates that travelling to Europe and Asia are key contributors to total carbon emissions from travelling, which response to the results of carbon emissions of accommodation. The carbon emissions of travelling to Europe and Asia are 204 t CO_2 eq per year and 190 t CO_2 eq per year respectively. Travelling to Europe contributes 35.42 % of total carbon emissions of travelling and travelling to Asia causes 32.87 % of carbon emissions.

Based on figure 17, air travel is the key contributor to emissions from travelling to Europe. It can cause carbon emissions of 203 t CO_2 eq annually and contributes to 99.228 % of total carbon emissions. For travelling to Asia, only air travel contributes to the emissions and is the dominant contributor. Because air travel can generate the most carbon emissions compared with other means of transportation. The emissions of travelling are calculated by distance and the distance of travelling to Asia is the largest. Therefore, travelling to Asia can cause high carbon emissions. Besides, the carbon emissions also depend on the frequency of people going to their destinations. According to the data provided by the Bartlett department, people go to Europe most frequently, which can also cause high greenhouse gas emissions. The total frequency of travelling to Europe is 59.06 % of the total number of times for travelling.

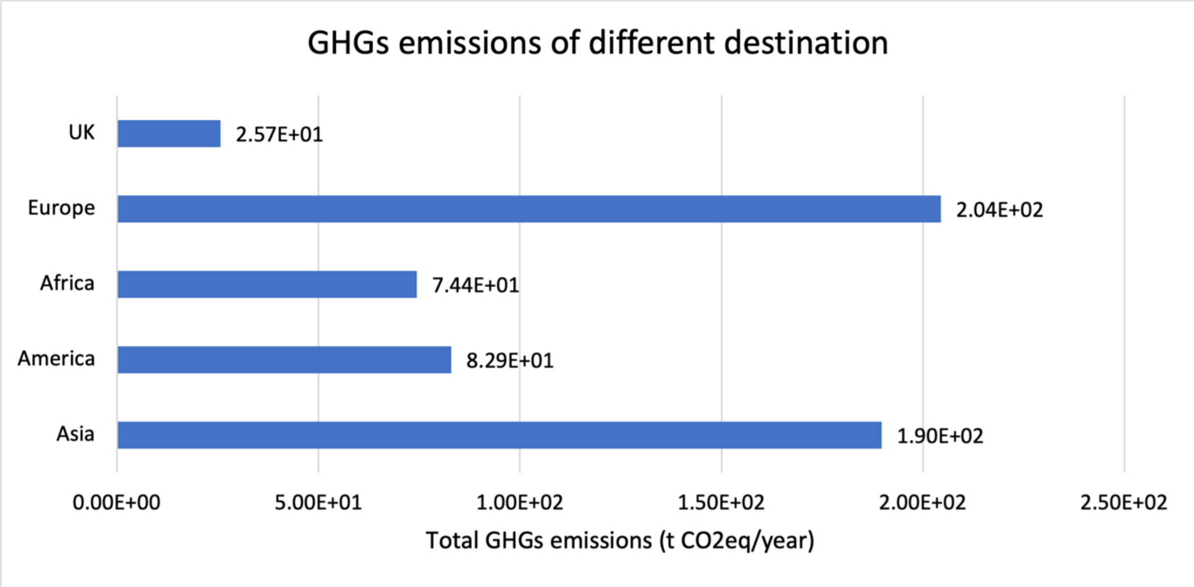

Figure 16 Carbon emissions of different travelling destinations

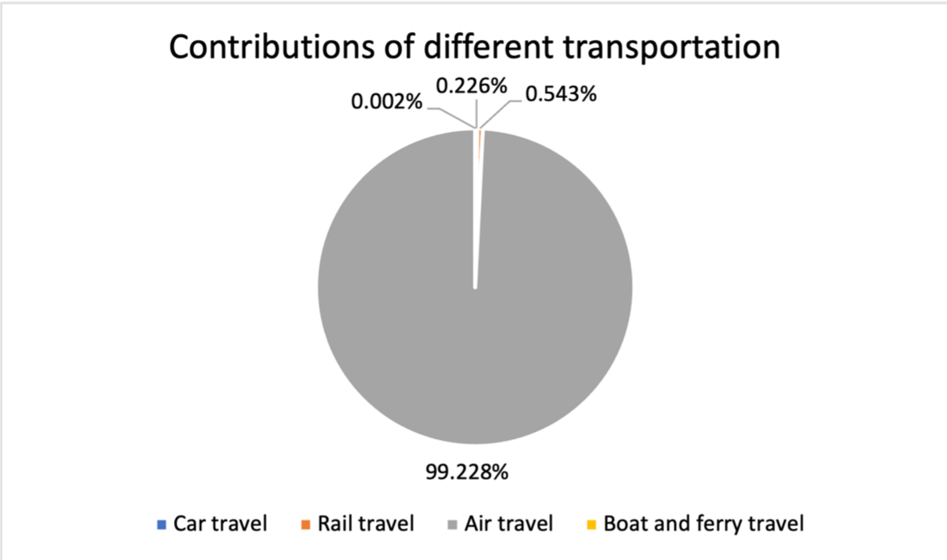

Figure 17 Contributions of different transportation to travelling to Europe

Greenhouse gas emissions from different means of transportation of courier services are summarised in figure 18. Courier services by plane are the most influential factor and it discharges 688 kg CO_2 eq per year. Vehicle for courier services is also a key contributor to total carbon emissions, which can cause greenhouse gas emissions of 477 kg CO_2 eq per year. Figure 19 addresses the carbon emissions of courier services based on different destinations. According to figure 19, courier services in Europe are a major part of total carbon emissions. It contributes 654 kg CO_2 eq annually and causes 54.31 % of total greenhouse gas emissions. Because this project assumes that courier services in Europe use planes, which can lead to a huge amount of carbon emissions because of the high emissions of planes.

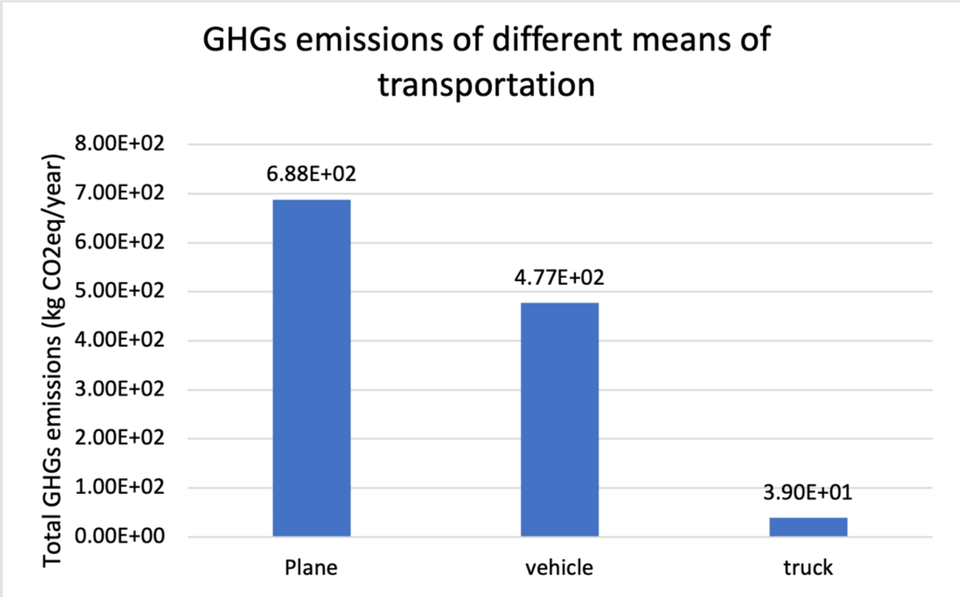

Figure 18 carbon emissions of different means of transportation for courier services

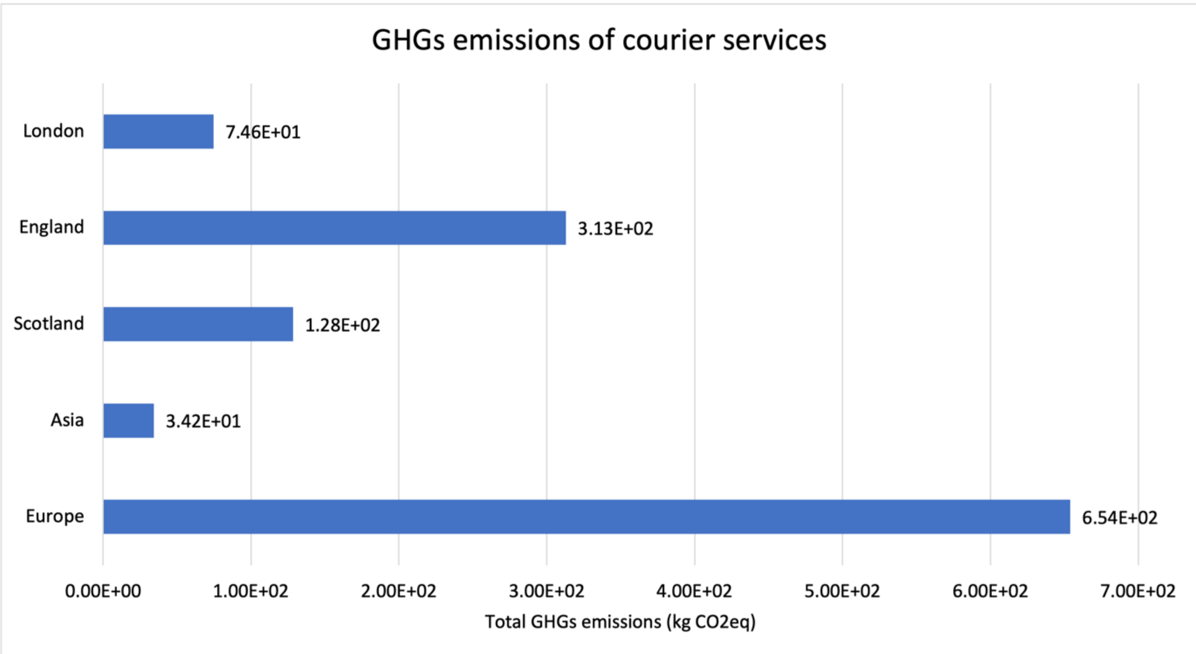

Figure 19 Greenhouse gas emissions of courier services based on destinations

Figure 20 shows the comparison between the carbon emissions result of the LCA study and the estimation of HESCET. It indicates that the carbon emissions calculated by LCA are lower than the estimation of HESCET even though the LCA study doesn't include unspecified travelling and courier services. The possible reason could be that HESCET is a tool estimating carbon emissions through procurement and doesn't consider the details. Therefore, HESCET may underestimate greenhouse gas emissions.

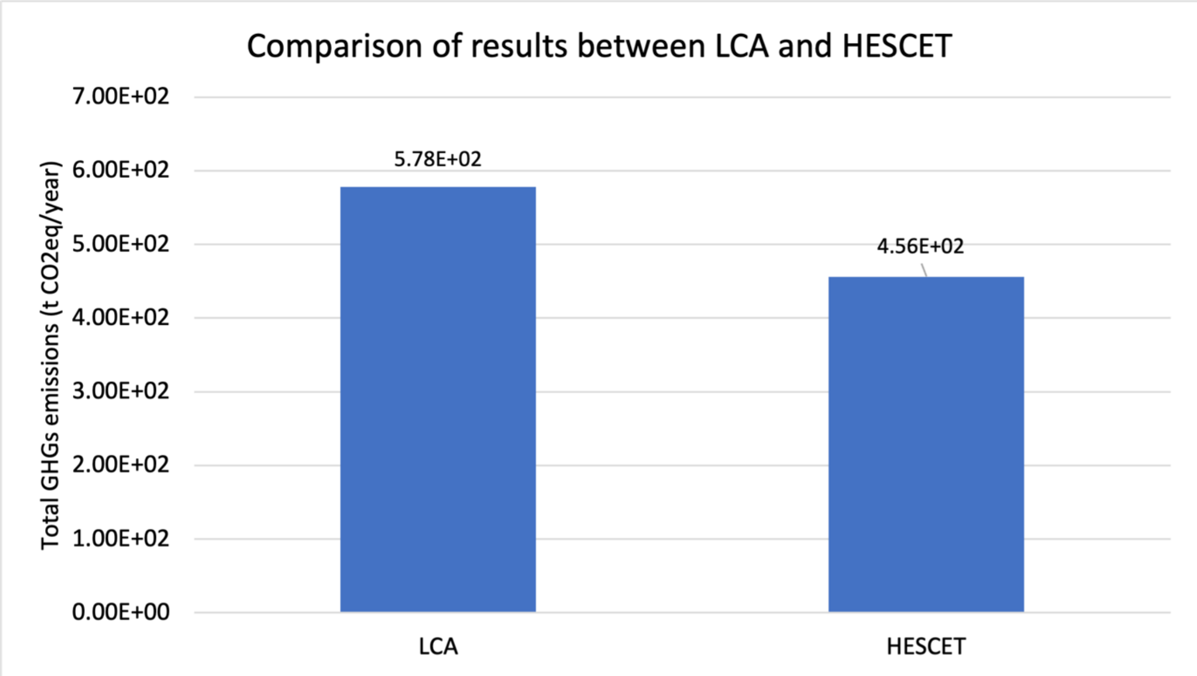

Figure 20 Comparison of results between LCA and HESCET

4.4 GC-MS equipment LCA

The results of GC-MS equipment show the carbon emissions of producing one GC-MS equipment. GC-MS equipment consists of two parts: gas chromatography and mass spectrometer. Figure 21 shows the emissions of the two components. Based on the information in figure 21, the emissions of the two components are 3532.84 kg CO_2 eq and 7905 kg CO_2 eq per GC-MS equipment. The total greenhouse gas emissions of each GC-MS equipment are 11437.84 kg CO_2 eq. Figure 22 indicates that 69.113 % of total carbon emissions of GC-MS equipment come from the production of the mass spectrometer and 30.887 % of greenhouse gas emissions are from producing gas chromatography. Among gas chromatography production, the thermal conductivity detector dominates the carbon emissions. Based on figure 23, the carbon emissions of producing the thermal conductivity detector are 2493.64 kg CO_2 eq per GC-MS equipment and contribute to 21.802 % of total greenhouse gas emissions and 70.58 % of emissions from gas chromatography equipment production. There is no data for the components of the mass spectrometer. Therefore, the results are from the estimation of EIO-LCA using emission factors and there is no detailed LCA for producing a mass spectrometer.

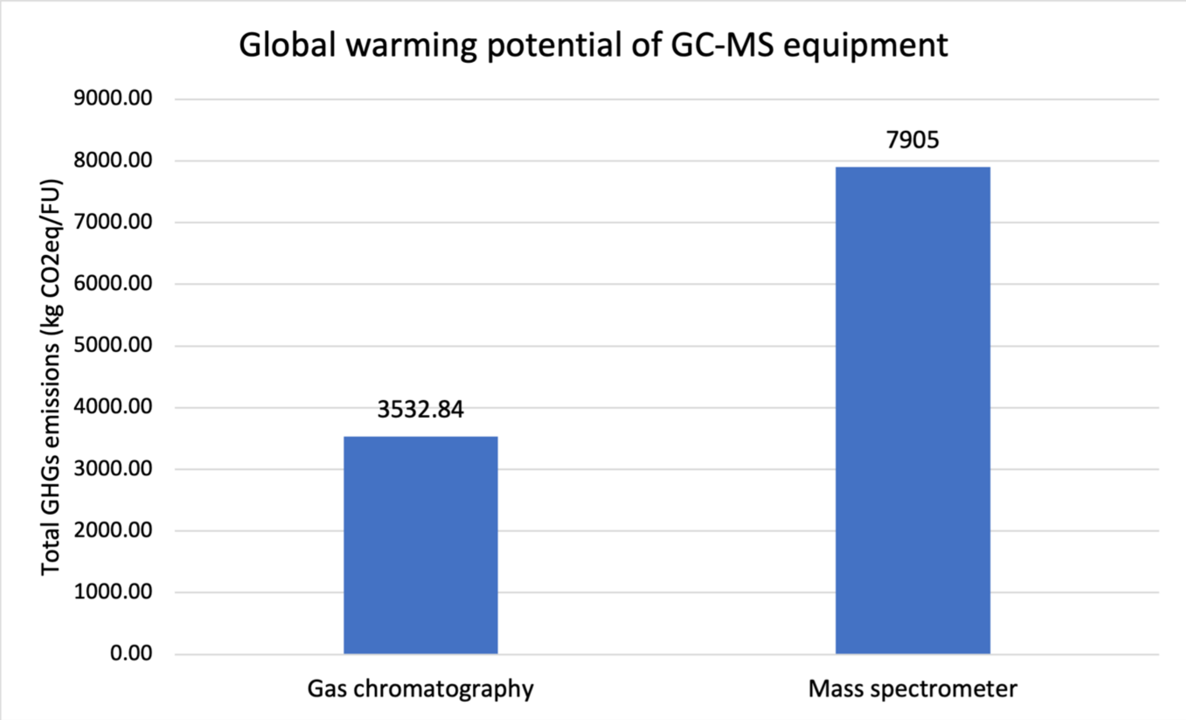

Figure 21 Carbon emissions of GC-MS equipment

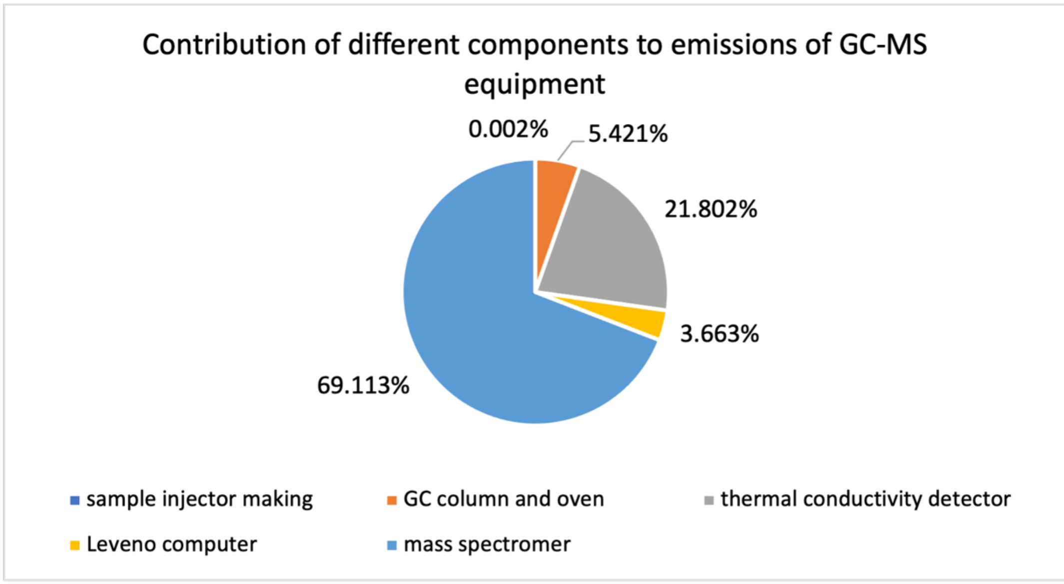

Figure 22 Contribution of components to emissions of GC-MS equipment

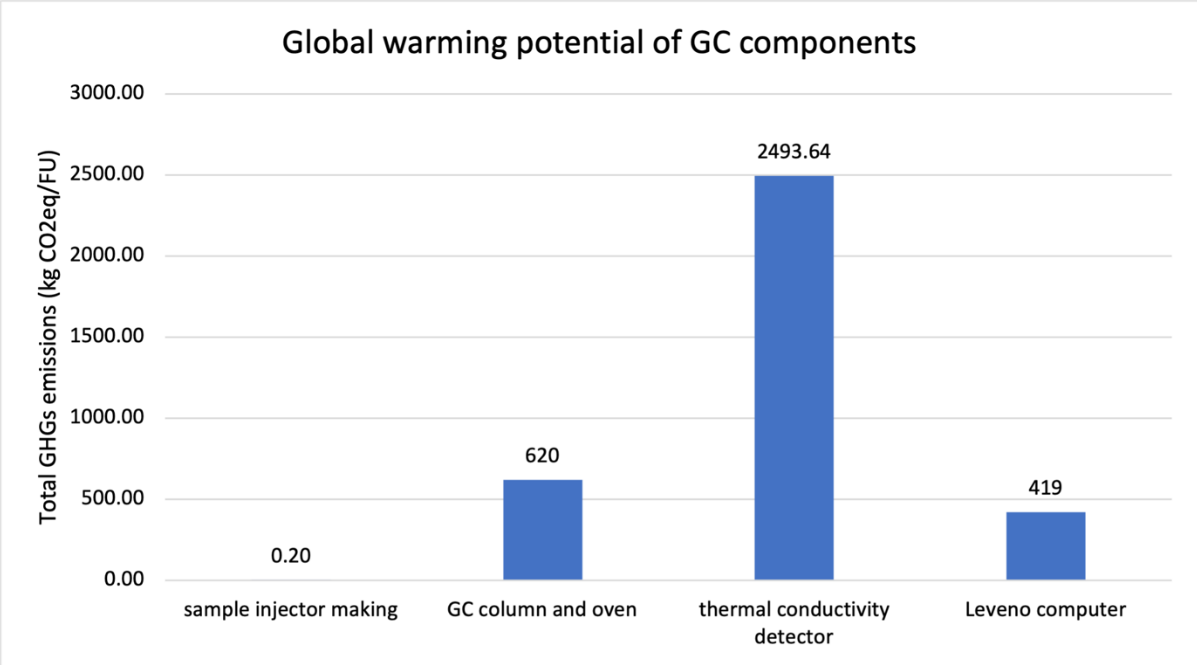

Figure 23 Carbon emissions of GC components

In 2018, the Bartlett department bought 5 GC-MS equipment. Therefore, the carbon emissions from GC-MS equipment of the Bartlett department are 57.2 t CO_2 eq. According to the estimation of HESCET, the carbon emissions of each GC-MS equipment are 571 t CO_2 eq, which is much higher than the LCA results based on the information in figure 24. The reason could be that the LCA study doesn't include the whole GC-MS equipment production process and estimates the emissions of some components using EIO-LCA through emission factors. Therefore, the results of the LCA study may be lower than the HESCET value.

Figure 24 also shows the comparison of carbon emissions and procurement between GC-MS equipment and total lab equipment and chemicals. The results of HESCET show that the carbon emissions of GC-MS equipment contribute to 43.66 % of total greenhouse gas emissions, while the results of LCA indicate that carbon emissions of purchasing GC-MS equipment are 4.37 % of total emissions (Figure 25). The LCA study shows that in the lab equipment and chemicals category, the key contributor is the chemicals used in lab and experiments instead of lab equipment.

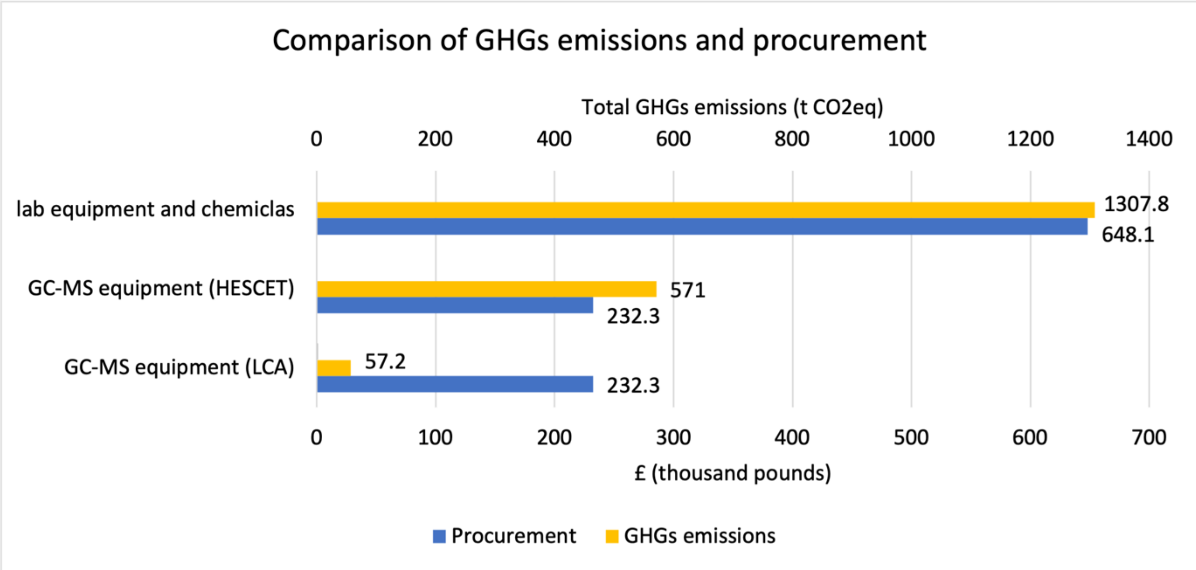

Figure 24 Comparison of GC-MS equipment and lab equipment and chemicals

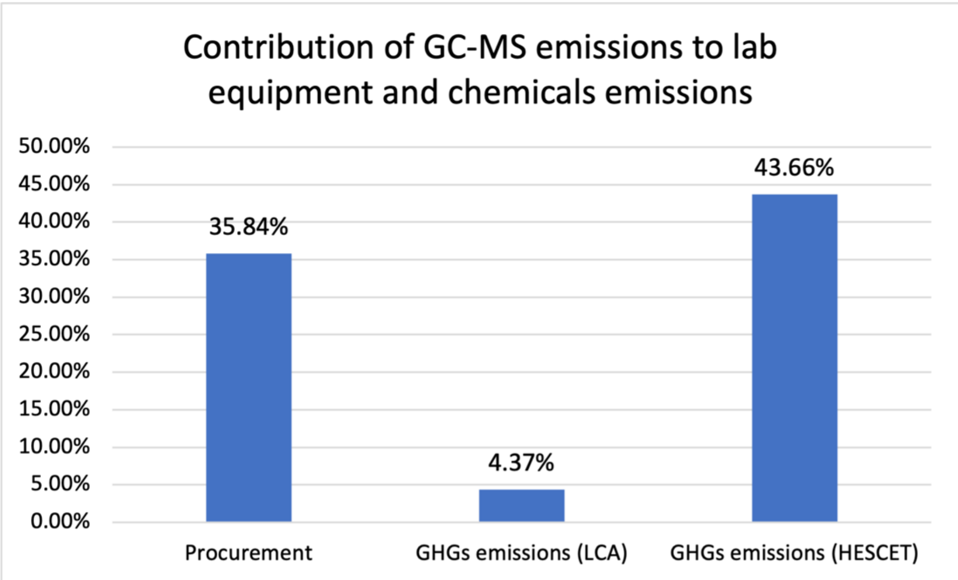

Figure 25 Contribution of GC-MS equipment to total emissions of lab equipment and chemicals

4.4 Limitations

Due to the lack of specified primary data, there are some limitations in this research.

In the analysis of accommodation emissions, some part of the inventory data for analysing the emissions of accommodation is estimated based on the given primary data and there might be differences between the calculated emissions and the actual data.

For analysing emissions of travel and courier services, this research excludes travel and courier services without specified destinations. Therefore, the results are lower than the actual data. This research also lacks the analysis of travel and courier services regarding the aims of transportation and travelling due to the ambiguity of primary data. Besides, the results are not accurate enough because means of transportation for courier services aren't specified in the original data.

For analysis of GC-MS equipment emissions, this project lacks comparison with other research results because there is no previous research on GC-MS equipment carbon emissions. In addition, this report cannot provide sufficient reason for the high emissions of the thermal conductivity detector and the mass spectrometer due to the lack of related research and literature. And there is no sensitivity analysis for the LCA study of GC-MS equipment conducted in this research because the research lacks some part of the input data.

5. Recommendations and future work

Based on the results of this project, a few recommendations related to cutting emissions and recording more comprehensive primary data are given in this report for the Bartlett department.

- The Bartlett department should try to specify the details of travel and courier services such as the destinations and aims, the amounts of people, the weight of packages, etc. for analysing carbon emissions more efficiently and conveniently.
- The results of the travel and courier LCA study indicate that air travel is a key contributor to greenhouse gas emissions. And it is also a dominant environmental factor in emissions of travelling to Europe. Therefore, people should use other means of transportation to replace air travel when going to Europe if it is possible.
- To reduce the carbon emissions from purchasing lab equipment, the Bartlett department can lease large-scale lab instruments instead of buying the equipment.
- For some components of lab equipment, the producer can recycle and reuse them instead of disposing of them directly. Besides, some metal and plastic components can be detrimental to the environment.
- There is not much data on the LCA study for lab equipment. Therefore, further research for the detailed LCA study for lab and precision instruments is needed.

Besides, future research should also focus on the environmental impacts of different raw materials and interior handling systems of lab equipment.

6. Conclusion

This project summarises the overall emissions of the Bartlett department in 2018 based on procurement data using HESCET. The results show that the total emissions of the Bartlett department from 2018 to 2019 are 5422.16 t CO_2eq. Among all the data categories, the key contributors are other business services, lab equipment and chemicals, IT equipment and travel and courier services. The most influential factor is other business services, and it discharges 2744.6 t CO_2 eq in 2018 and contributes to 50.618 % of the total carbon emissions. In other business services, internet subscription fees are the most important environmental factors that can contribute to 46.87 % of greenhouse gas emissions.

However, due to the constraints of applying LCA, this project analyses the carbon emissions of accommodation from other business services. The results indicate that accommodation in Europe takes up a major part of carbon emissions from accommodation, which is 144.16 t CO_2 eq and contributes to 56.20 % of greenhouse gas emissions from accommodation. The percentage of accommodation procurement in other services expense is 80.99 % and the contribution of carbon emissions is 52.03%.

The carbon emissions of travel and courier services are also analysed in this project. Based on the results, air travel is the key contributor that discharges 550 t CO_2 eq in 2018 and contributes to 95.243 % of the carbon emissions from travelling. Travelling to Europe and Asia has the most serious environmental impact. The greenhouse gas emissions are 204 t CO_2 eq and 190 t CO_2 eq and contribute to 35.42 % and 32.87 % of total emissions of travelling. Air travel is still the dominant contributor to carbon emissions from travelling to Europe and Asia. According to the results, the key contributor to travelling and accommodation based on destinations is the expense in Europe and the possible reason could be the high frequency for people going to Europe. Compared with the LCA results, HESCET underestimates the emissions of travelling and services because LCA is a more detailed method. To reduce emissions, people can replace air travel with other ways of transportation when it is possible. Besides, the primary data can be more specific for detailed analysis.

The project analyses the emissions of GC-MS equipment due to its high procurement, which contributes to 35.84 % of the expenses and only 4.37 % of the carbon emissions based on the LCA study. The thermal conductivity detector and mass spectrometer are the key contributors to the carbon emissions, which are 2493.64 kg CO_2 eq and 7905 kg CO_2 eq. For mitigating the environmental impacts, the researchers can lease lab equipment instead of purchase and the producer should try to recycle and reuse the components of instruments for reducing cost and pollution. In addition, more research is needed for the comparison between different studies and more accurate results.

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Appendix

Appendix A: Accommodation emissions

	Unspecified data	Specified data	Total emissions (t CO2eq)	Contribution
Europe	126.2352	17.9199	144.16	56.20%
UK	56.3472	16.64	72.99	28.46%
Asia	1.9005	25.4068	27.31	10.65%
America	3.9375	3.3424	7.28	2.84%
Africa	0	4.7628	4.76	1.86%

Table 11 Detailed data of accommodation emissions

Appendix B: Travel and courier services emissions

destination	Amount	Unit	Emission fator kg CO2	Total emissions kg CO2	Database
Europe	1454.46	km	3.03E-01	4.41E+02	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.1
America	614.86	km	3.03E-01	1.86E+02	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.2
UK	407.44	km	3.03E-01	1.23E+02	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.3

destination	Amount	Unit	Emission fator kg CH4	Total emissions kg CH4	Database
Europe	1454.46	km	4.71E-04	6.85E-01	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.1
America	614.86	km	4.71E-04	2.90E-01	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.2
UK	407.44	km	4.71E-04	1.92E-01	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.3

destination	Amount	Unit	Emission fator kg N2O	Total emissions kg N2O	Database
Europe	1454.46	km	8.95E-06	1.30E-02	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.1
America	614.86	km	8.95E-06	5.50E-03	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.2
UK	407.44	km	8.95E-06	3.65E-03	Transport, passenger car, EURO 3 {RER}| market for | Alloc Def, S. Ecoinvent 3.3

destination	Total emissions kg CO2	CO2 emissions kg CO2 eq	Total emissions CH4	CH4 emissions CO2 eq	Total emissions kg N2O	N2O emissions CO2 eq	Total GHGs emissions kg CO2eq
Europe	4.41E+02	4.41E+02	6.85E-01	1.71E+01	1.30E-02	3.88E+00	4.62E+02
America	1.86E+02	1.86E+02	2.90E-01	7.24E+00	5.50E-03	1.64E+00	1.95E+02
UK	1.23E+02	1.23E+02	1.92E-01	4.80E+00	3.65E-03	1.09E+00	1.29E+02

Figure 26 Detailed LCA data of car travel

destination	Distance (km)	Amount	Unit	Emission fator kg CO2	Total emissions kg CO2	Database
Asia	216895.39	1448836.95	personkm	1.27E-01	1.84E+05	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
America	79923.71	632052.29	personkm	1.27E-01	8.03E+04	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
Africa	30159.56	568204.75	personkm	1.27E-01	7.22E+04	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
Europe	120027.25	1549296.05	personkm	1.27E-01	1.97E+05	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.

destination	Distance (km)	Amount	Unit	Emission fator CH4	Total emissions CH4	Database
Asia	216895.39	1448836.95	personkm	1.40E-04	2.03E+02	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
America	79923.71	632052.29	personkm	1.40E-04	8.85E+01	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
Africa	30159.56	568204.75	personkm	1.40E-04	7.95E+01	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
Europe	120027.25	1549296.05	personkm	1.40E-04	2.17E+02	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.

destination	Distance (km)	Amount	Unit	Emission fator kg N2O	Total emissions kg N2O	Database
Asia	216895.39	1448836.95	personkm	1.39E-06	2.01E+00	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
America	79923.71	632052.29	personkm	1.39E-06	8.79E-01	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
Africa	30159.56	568204.75	personkm	1.39E-06	7.90E-01	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.
Europe	120027.25	1549296.05	personkm	1.39E-06	2.15E+00	Transport, passenger, aircraft {GLO}| market for | Alloc Def, S. Ecoinvent 3.2.

destination	Total emissions kg CO2	CO2 emissions kg CO2 eq	Total emissions CH4	CH4 emissions CO2 eq	Total emissions kg N2O	N2O emissions CO2 eq	Total GHGs emissions kg CO2eq
Asia	1.84E+05	1.84E+05	2.03E+02	5.07E+03	2.01E+00	6.00E+02	1.90E+05
America	8.03E+04	8.03E+04	8.85E+01	2.21E+03	8.79E-01	2.62E+02	8.27E+04
Africa	7.22E+04	7.22E+04	7.95E+01	1.99E+03	7.90E-01	2.35E+02	7.44E+04
Europe	1.97E+05	1.97E+05	2.17E+02	5.42E+03	2.15E+00	6.42E+02	2.03E+05

Figure 27 Detailed LCA data of air travel

destination	Distance (km)	Amount	Unit	Emission fator kg CO2	Total emissions kg CO2	Database
Europe	9014	14238	personkm	7.28E-02	1.04E+03	Transport, passenger train {GLO}| market for | Alloc Def, S
UK	17062.81	327474.54	personkm	7.28E-02	2.38E+04	Transport, passenger train {GLO}| market for | Alloc Def, S

destination	Distance (km)	Amount	Unit	Emission fator kg CH4	Total emissions kg CH4	Database
Europe	9014	14238	personkm	1.74E-04	2.48E+00	Transport, passenger train {GLO}| market for | Alloc Def, S
UK	17062.81	327474.54	personkm	1.74E-04	5.70E+01	Transport, passenger train {GLO}| market for | Alloc Def, S

destination	Distance (km)	Amount	Unit	Emission fator kg N2O	Total emissions kg N2O	Database
Europe	9014	14238	personkm	2.92E-06	4.16E-02	Transport, passenger train {GLO}| market for | Alloc Def, S
UK	17062.81	327474.54	personkm	2.92E-06	9.56E-01	Transport, passenger train {GLO}| market for | Alloc Def, S

destination	Total emissions kg CO2	CO2 emissions CO2 eq	Total emissions CH4	CH4 emissions CO2 eq	Total emissions kg N2O	N2O emissions CO2 eq
Europe	1.04E+03	1.04E+03	2.48E+00	6.19E+01	4.16E-02	1.24E+01
UK	2.38E+04	2.38E+04	5.70E+01	1.42E+03	9.56E-01	2.85E+02

Figure 28 Detailed LCA data of rail travel

destination	Distance (km)	Amount	Unit	Emission fator kg CO2	Total emissions kg CO2	Database
Europe	227.32	181.856	tkm	2.48E-02	4.51E+00	Transport, freight, sea, liquefied natural gas {GLO}| market for | Alloc Def, S. Ecoinvent 3.2

destination	Distance (km)	Amount	Unit	Emission fator kg CH4	Total emissions kg CH4	Database
Europe	227.32	181.856	tkm	6.24E-05	1.13E-02	Transport, freight, sea, liquefied natural gas {GLO}| market for | Alloc Def, S. Ecoinvent 3.2

destination	Distance (km)	Amount	Unit	Emission fator kg N2O	Total emissions kg N2O	Database
Europe	227.32	181.856	tkm	4.87E-07	8.86E-05	Transport, freight, sea, liquefied natural gas {GLO}| market for | Alloc Def, S. Ecoinvent 3.2

destination	Total emissions kg CO2	CO2 emissions CO2 eq	Total emissions CH4	CH4 emissions CO2 eq	Total emissions kg N2O	N2O emissions CO2 eq
Europe	4.51E+00	4.51E+00	1.13E-02	2.84E-01	8.86E-05	2.64E-02

Figure 29 Detailed LCA data of boat and ferry travel

destination	Means of courier	Distance (km)	Amount	Unit	Emission fator kg CO2	Total emissions kg CO2	Database
Europe	flight	6926.76	599.101	tkm	1.06	635.04706	Transport, freight, aircraft {RER}| intercontinental | Alloc Def, S. Ecoinvent 3.1
Asia	flight	31349.92	31.34992	tkm	1.06	33.2309152	Transport, freight, aircraft {RER}| intercontinental | Alloc Def, S. Ecoinvent 3.2
Scotland	vehicle	660.91	66.091	tkm	1.85	122.26835	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
England	vehicle	1004.83	161.197	tkm	1.85	298.21445	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
London	vehicle	200.786	18.2987	tkm	1.85	33.852595	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.3
	lorry	10.47	188.46	tkm	1.81E-01	34.11126	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S Ecoinvent 3.2

destination	Means of courier	Distance (km)	Amount	Unit	Emission fator kg CH4	Total emissions kg CH4	Database
Europe	flight	6926.76	599.101	tkm	1.13E-03	6.77E-01	Transport, freight, aircraft {RER}| intercontinental | Alloc Def, S. Ecoinvent 3.1
Asia	flight	31349.92	31.34992	tkm	1.13E-03	3.54E-02	Transport, freight, aircraft {RER}| intercontinental | Alloc Def, S. Ecoinvent 3.2
Scotland	vehicle	660.91	66.091	tkm	2.85E-03	1.88E-01	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
England	vehicle	1004.83	161.197	tkm	2.85E-03	4.59E-01	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
London	vehicle	200.786	18.2987	tkm	2.85E-03	5.22E-02	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.3
	lorry	10.47	188.46	tkm	2.65E-04	4.99E-02	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S Ecoinvent 3.2

destination	Means of courier	Distance (km)	Amount	Unit	Emission fator kg N2O	Total emissions kg N2O	Database
Europe	flight	6926.76	599.101	tkm	1.13E-05	6.77E-03	Transport, freight, aircraft {RER}| intercontinental | Alloc Def, S. Ecoinvent 3.1
Asia	flight	31349.92	31.34992	tkm	1.13E-05	3.54E-04	Transport, freight, aircraft {RER}| intercontinental | Alloc Def, S. Ecoinvent 3.2
Scotland	vehicle	660.91	66.091	tkm	6.94E-05	4.59E-03	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
England	vehicle	1004.83	161.197	tkm	6.94E-05	1.12E-02	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
London	vehicle	200.786	18.2987	tkm	6.94E-05	1.27E-03	Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, S. Ecoinvent 3.3
	truck	10.47	188.46	tkm	6.55E-05	1.23E-02	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S Ecoinvent 3.2

destination	Means of courier	Total emissions kg CO2	CO2 emissions CO2 eq	Total emissions CH4	CH4 emissions CO2 eq	Total emissions kg N2O	N2O emissions CO2 eq
Europe	flight	635.04706	6.35E+02	6.77E-01	1.69E+01	6.77E-03	2.02E+00
Asia	flight	33.2309152	3.32E+01	3.54E-02	8.86E-01	3.54E-04	1.06E-01
Scotland	vehicle	122.26835	1.22E+02	1.88E-01	4.71E+00	4.59E-03	1.37E+00
England	vehicle	298.21445	2.98E+02	4.59E-01	1.15E+01	1.12E-02	3.33E+00
London	vehicle	33.852595	3.39E+01	5.22E-02	1.30E+00	1.27E-03	3.78E-01
	truck	34.11126	3.41E+01	4.99E-02	1.25E+00	1.23E-02	3.68E+00

Figure 30 Detailed LCA data of courier services

Appendix C: GC-MS equipment emissions

Input	Proccedures and materials	Activity	Amount/FU	Unit	Emission factor (CO2) kg/kg	Total CO2 emissions	Unit	database
mateirial	water	syringe making	17.5	L/FU	6.51E-07	1.14E-05	kg/FU	Tap water, at user {CH}| market for | Alloc Def, S, Ecoinvent 3.1
	PTFE		0.00004	g/FU	9.62	3.85E-04	kg/FU	Tetrafluoroethylene {GLO}| market for | Alloc Def, S
	Borosilicate glass		0.00044	g/FU	2.25	9.90E-04	kg/FU	Glass tube, borosilicate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	rubber		0.000011	g/FU	2.79	3.07E-05	kg/FU	Synthetic rubber {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	polypropylene (PP)		0.000608	g/FU	1.78	1.08E-03	kg/FU	Polypropylene, granulate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
energy	electricity		88	kWh/FU	2.13E-03	1.87E-01	kg/FU	Electricity, low voltage {GB}| market for | Alloc Def, S, Ecoinvent 3.1
material	Borosilicate glass	column making	0.00572	g/FU	2.25	1.29E-02	kg/FU	Glass tube, borosilicate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	Polyethylene glycol		0.0000001	g/FU	1.62	1.62E-07	kg/FU	Ethylene glycol {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
energy	electricity		160	kWh/FU	2.13E-03	3.41E-01	kg/FU	Electricity, low voltage {GB}| market for | Alloc Def, S, Ecoinvent 3.1
mateiral	helium	carrying gas	0.00161	L/FU	3.36	5.41E-03	kg/FU	Helium {GLO}| market for | Alloc Def, S. Ecoinvent 3.2

Input	Proccedures and materials	Activity	Amount/FU	Unit	Emission factor (CH4)	Total CH4 emissions	Unit	database
mateirial	water	syringe making	17.5	L/FU	1.51E-09	2.64E-08	kg/FU	Tap water, at user {CH}| market for | Alloc Def, S, Ecoinvent 3.1
	PTFE		0.00004	g/FU	3.08E-02	1.23E-06	kg/FU	Tetrafluoroethylene {GLO}| market for | Alloc Def, S
	Borosilicate glass		0.00044	g/FU	6.43E-03	2.83E-06	kg/FU	Glass tube, borosilicate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	rubber		0.000011	g/FU	1.14E-02	1.25E-07	kg/FU	Synthetic rubber {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	polypropylene (PP)		0.000608	g/FU	1.20E-02	7.30E-06	kg/FU	Polypropylene, granulate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
energy	electricity		88	kWh/FU	5.29E-06	4.66E-04	kg/FU	Electricity, low voltage {GB}| market for | Alloc Def, S, Ecoinvent 3.1
material	Borosilicate glass	colum making	0.00572	g/FU	6.43E-03	3.68E-05	kg/FU	Glass tube, borosilicate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	Polyethylene glycol		0.0000001	g/FU	8.61E-03	8.61E-10	kg/FU	Ethylene glycol {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
energy	electricity		160	kWh/FU	5.29E-06	8.46E-04	kg/FU	Electricity, low voltage {GB}| market for | Alloc Def, S, Ecoinvent 3.1
mateiral	helium	carrying gas	0.00161	L/FU	1.00E-02	1.61E-05	kg/FU	Helium {GLO}| market for | Alloc Def, S. Ecoinvent 3.2

Input	Proccedures and materials	Activity	Amount/FU	Unit	Emission factor (N2O)	Total N2O emissions	Unit	database
mateirial	water	syringe making	17.5	L/FU	3.01E-11	5.27E-10	kg/FU	Tap water, at user {CH}| market for | Alloc Def, S, Ecoinvent 3.1
	PTFE		0.00004	g/FU	4.27E-04	1.71E-08	kg/FU	Tetrafluoroethylene {GLO}| market for | Alloc Def, S
	Borosilicate glass		0.00044	g/FU	7.97E-05	3.51E-08	kg/FU	Glass tube, borosilicate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	rubber		0.000011	g/FU	1.12E-04	1.23E-09	kg/FU	Synthetic rubber {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	polypropylene (PP)		0.000608	g/FU	3.18E-06	1.93E-09	kg/FU	Polypropylene, granulate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
energy	electricity		88	kWh/FU	6.53E-08	5.75E-06	kg/FU	Electricity, low voltage {GB}| market for | Alloc Def, S, Ecoinvent 3.1
material	Borosilicate glass	colum making	0.00572	g/FU	7.97E-05	4.56E-07	kg/FU	Glass tube, borosilicate {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
	Polyethylene glycol		0.0000001	g/FU	3.92E-05	3.92E-12	kg/FU	Ethylene glycol {GLO}| market for | Alloc Def, S. Ecoinvent 3.2
energy	electricity		160	kWh/FU	6.53E-08	1.04E-05	kg/FU	Electricity, low voltage {GB}| market for | Alloc Def, S, Ecoinvent 3.1
mateiral	helium	carrying gas	0.00161	L/FU	1.51E-04	2.43E-07	kg/FU	Helium {GLO}| market for | Alloc Def, S. Ecoinvent 3.2

Figure 31 Life cycle inventory data of GC-MS equipment

			CO2/FU			N2O/FU			CH4/FU			Total GHG emissions/FU
Input	**Procedures and materials**	**Activity**	CO2 (kg)	CO2eq (kg)	Unit	N2O (kg)	CO2eq (kg)	Unit	CH4 (kg)	CO2eq (kg)	Unit	**CO2eq (kg)**
mateirial	water	syringe making	1.14E-05	1.14E-05	kg/FU	5.27E-10	1.57E-07	kg/FU	2.64E-08	6.61E-07	kg/FU	1.22E-05
	PTFE		3.85E-04	3.85E-04	kg/FU	1.71E-08	5.09E-06	kg/FU	1.23E-06	3.08E-05	kg/FU	4.21E-04
	Borosilicate glass		9.90E-04	9.90E-04	kg/FU	3.51E-08	1.05E-05	kg/FU	2.83E-06	7.07E-05	kg/FU	1.07E-03
	rubber		3.07E-05	3.07E-05	kg/FU	1.23E-09	3.67E-07	kg/FU	1.25E-07	3.14E-06	kg/FU	3.42E-05
	polypropylene (PP)		1.08E-03	1.08E-03	kg/FU	1.93E-09	5.76E-07	kg/FU	7.30E-06	1.82E-04	kg/FU	1.27E-03
energy	electricity		1.87E-01	1.87E-01	kg/FU	5.75E-06	1.71E-03	kg/FU	4.66E-04	1.16E-02	kg/FU	2.01E-01
material	Borosilicate glass	column making	1.29E-02	1.29E-02	kg/FU	4.56E-07	1.36E-04	kg/FU	3.68E-05	9.19E-04	kg/FU	1.39E-02
	Polyethylene glycol		1.62E-07	1.62E-07	kg/FU	3.92E-12	1.17E-09	kg/FU	8.61E-10	2.15E-08	kg/FU	1.85E-07
energy	electricity		3.41E-01	3.41E-01	kg/FU	1.04E-05	3.11E-03	kg/FU	8.46E-04	2.12E-02	kg/FU	3.65E-01
mateiral	helium	carrying gas	5.41E-03	5.41E-03	kg/FU	2.43E-07	7.24E-05	kg/FU	1.61E-05	4.03E-04	kg/FU	5.88E-03

Figure 32 Life cycle impact assessment data of GC-MS equipment

GWP CFs	Midpoint Hierarchist (100 years) in CO2eq/kg	Source
Carbon dioxide (CO2)	1.00E+00	ReCiPe(2016)
Dinitrogen monoxide (N2O)	2.98E+02	ReCiPe(2016)
Methane (CH4)	2.50E+01	ReCiPe(2016)

Table 12 Characterisation factors of LCA study