Evaluating the Life Cycle GHG Emissions of University Purchases

A Preliminary Analysis of the UCL Bartlett Faculty of the Built Environment

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Table of Contents

1. Introduction ... 4
1.1. Background ... 4
1.2. Aim and Research Questions ... 8
1.3. Method and Scope ... 9
1.4. Report Structure ... 9
2. Key Information ... 9
2.4. Goal and Scope Definition ... 9
2.4.1. Goal ... 9
2.4.2. System Boundary ... 10
2.4.3. Functional unit ... 12
2.5. Inventory Analysis ... 12
2.5.1. Laptops ... 12
2.5.2. Paper Products ... 16
3. Key Findings ... 20
3.4. Results ... 20
3.4.1. Laptops ... 20
3.4.2. Paper Products ... 25
3.5. Discussion ... 29
3.5.1. Laptops ... 29
3.5.2. Paper Products ... 31
4. Conclusion ... 33
Bibliography ... 35
Appendix ... 40

List of Figures

Table 1: Quantity of Different Models of Laptops Procured by the Bartlett Faculty in 2018/19. ... 12
Table 2: Quantified Paper Products in the Bartlett's Expenditure (Data provided by the Bartlett) 18
Table 3: Cradle-to-gate laptop emissions from literature data ... 20
Table 4: Cradle-to-grave laptop emissions from literature data ... 21
Table 5: Cradle-to-grave laptop emissions for supplier data ... 21
Table 6: Summary of emissions from differing data sources ... 23
Table 7: Relative contributions of different phases to a laptop's emissions ... 24
Table 8: Cradle-to-gate and cradle-to-grave emissions values for A4 80 gsm virgin copy paper from literature and the corresponding total emissions for the Bartlett ... 25
Table 9: Cradle-to-gate emissions values for A4 80gsm recycled copy paper from literature and the corresponding total emissions for the Bartlett ... 26
Table 10: Cradle-to-gate and cradle-to-grave emissions values for tissue paper from literature and the corresponding total emissions for the Bartlett ... 26
Table 11: The mean, minimum and maximum value of the paper products GHG emissions for the Bartlett ... 28
Table 12: References for laptop supplier data ... 39
Table 13: Other quantified paper products ... 40

Figure 1: UCL Scope 3 Emissions for the 2018/19 Academic Year (HESA, 2019) ... 5
Figure 2: Cradle-to-Grave Life Cycle Assessment of a Laptop Used in Poland (Grzesik-Wojtysiak, K. and Kukliński, 2013) ... 10
Figure 3: Cradle-to-Grave Life Cycle Assessment of Paper Products in America (AF&PA 2010). ... 11
Figure 4: Share of laptop procurement for each department of the Bartlett ... 14
Figure 5: Contribution of each Department to the Quantified Paper Products in the Bartlett's Expenditure (Data provided by the Bartlett) ... 17
Figure 6: Share of Quantified A4 Paper Product Sheets in the Bartlett's Expenditure (Data provided by The Bartlett) ... 18
Figure 7: Box-and-whisker plots for the total GHG emissions per laptop purchased by the Bartlett according to literature and supplier data sources ... 24
Figure 8: Box-and-whisker plots for the total GHG emissions of paper products purchased by the Bartlett based on literature ... 28
Figure 9: Standard Deviation of the Range of Paper Products Emissions Values from Literature ... 29
Figure 10: Distribution of carbon footprint across the life cycle of a ream of office paper (AF&PA, 2010) ... 32

1. Introduction

1.1. Background

As universities aim to be exemplary institutions for climate action, tracking and reducing their greenhouse gas (GHG) emissions is increasingly becoming essential. Findings from a GHG inventory conducted for Yale University show that indirect emissions from procured goods and services were a significant source of total emissions (Thurston and Eckelman, 2011). These emissions fall under scope 3 according to the GHG Protocol Corporate Standard. University College London (UCL) has committed to become a net-zero institution by 2030. Products bought by the university accounted for 83% of total emissions in the 2019/20 academic year (Sustainable UCL, 2021), reiterating how important procurement is to achieve UCL's climate mitigation targets. Figure 1 below indicates the significant categories under scope 3 emissions for UCL in the 2018/19 academic year (HESA, 2019). Scope 3 emissions such as business travel, waste and water management are typically measured on university campuses. The remaining emissions from purchased goods and services require comprehensive accounting across supply chains, which poses many challenges (Thurston and Eckelman, 2011). Laptops and paper products purchased by the Bartlett UCL Faculty of the Built Environment (henceforth referred to as the Bartlett) are considered for this report due to their contributions to the faculty's scope 3 emissions.

Life Cycle Assessment

Globally, Life Cycle Assessment (LCA) has been used to determine the allocation of inputs and outputs of a product system from other systems (Ta Thi and Thi Anh, 2020). LCA is a useful tool to determine the quantity and source of a product's GHG emissions, also known as a 'carbon footprint'. Other methods such as the GHG Protocol Corporate Standard use an attributional cut-off method, which refers to the omission of non-relevant life cycle stages from the system model. However, this method cannot determine the environmental burdens shared between stages in the complete life cycle of a product.

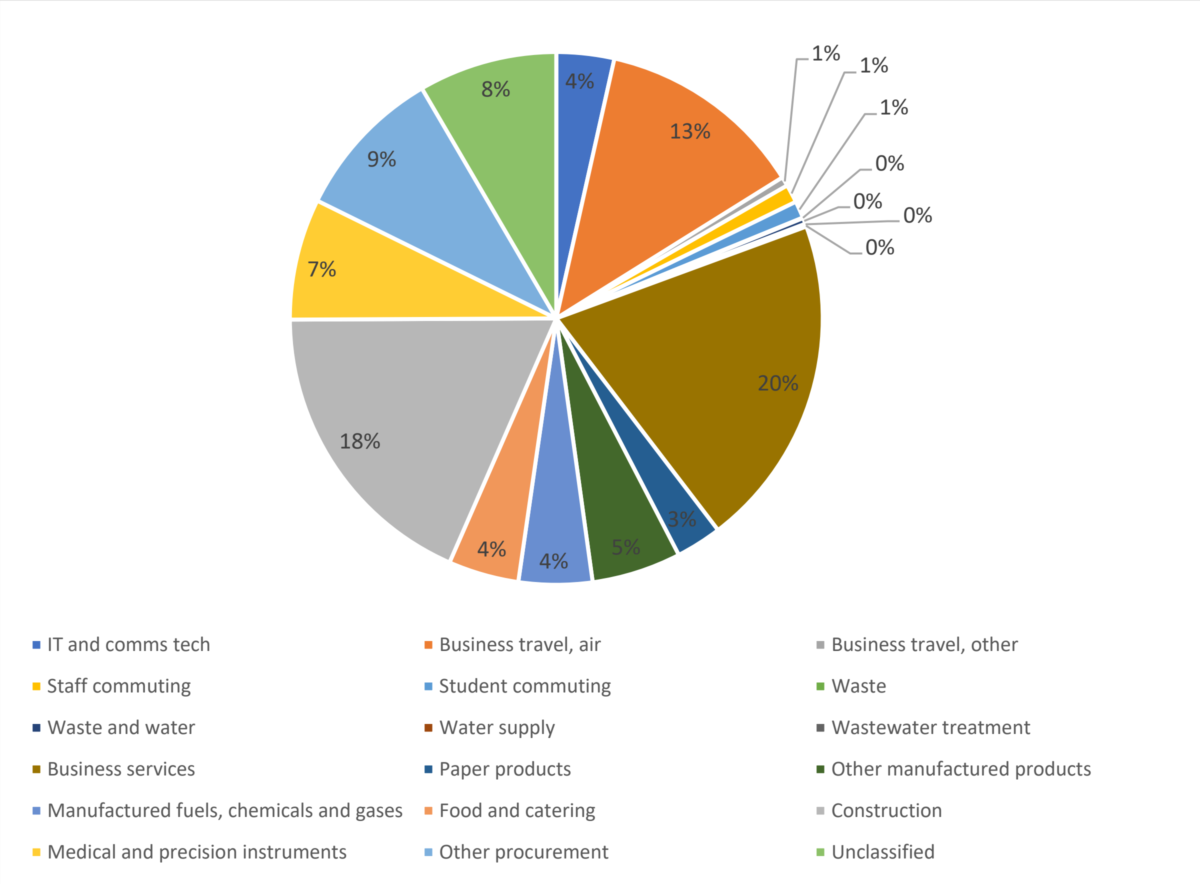

Figure 1: UCL Scope 3 Emissions for the 2018/19 Academic Year (HESA, 2019)

One of the key life cycle methods used is the process-based bottom-up approach. This involves assessing the supply chain through facility-level data on material and energy use flows (Teh et al., 2017). However, key issues with this method include truncation error from processes not accounted for in complex supply chains (Deng, Babbitt and Williams, 2011). For example, if a metal such as aluminum is used in the creation of a product, but the specifics of the supply chain are not well known. This is a particular issue for information technology, for example, it has been seen to be the case with desktop computers (Williams, 2004; Subramanium and Yung, 2017).

The ISO 14067 product carbon footprint accounting standards guides the LCA method for the quantification of a product’s footprint. This method distributes the environmental burden between product life cycle stages through credit and debit. Credit is given for recycling the product after use and a debit is given to pay the burden of using virgin materials (Ta Thi and Thi Anh, 2020). However, this method also has its own limitations. For example, ISO 14067 does not account for the environmental burdens from the operations at a paper mill such as pulp processing and converting materials (Ta Thi and Thi Anh, 2020).

Economic Input-Output Assessments

According to Thurston and Eckelman (2011), the GHG emissions from university purchases can be assessed using publicly available economic input-output LCA (EIO-LCA) software. An EIO-LCA contrasts processed-based LCA by using a top-down approach. As this method is based on national sectoral data, an EIO-LCA model is holistic, although it is prone to aggregation errors due to the lack of process-specific data (Williams et al., 2009). Additionally, the centrality of price parameters and their uncertainty presents further issues (Deng, Babbitt and Williams, 2011). One way to overcome this is by utilising parameter ranges instead of scalar values (Ibid.).

Despite the proliferation of LCA in recent years, its continued use means that it must be robust and reliable as a method. Its reliability however is questioned through the observation of diverse and even contradicting results in academic literature (Farrell et al., 2006). For example, literature ranges of the energy required to manufacture a desktop computer vary from 1000 MJ to 8300 MJ per computer (Williams, 2004). To overcome issues associated with both bottom-up and top-down LCA, Deng, Babbitt and Williams (2011) are advocates of a hybrid LCA. This denotes a combination of both top-down EIO and bottom-up process-based LCA. This is good at addressing variability in process data of bottom-up LCA and price uncertainty in top-down LCA.

Significance of Laptops and Paper Products

Mass production of both laptops and paper products contribute to climate change through the production of GHG emissions. Therefore, a key assumption of this study is that the production and use of these products has implications for climate mitigation solutions. Consequently, purchasing these products could affect UCL achieving its net-zero target by 2030.

Laptops

Significant amounts of energy and resources are required to create a laptop, as shown by a study conducted by the World Economic Forum which projects that electronics will contribute 14% of global GHG emissions by 2040, which is equal to half of the current contribution from the transport sector (WEF, 2019). Information technology (IT) and communications accounted for 4% of UCL emissions in the 2018/19 academic year (HESA, 2019).

The main body of a laptop consists of a printed circuit board assembly, along with other small electrical parts such as resistors, semiconductors and connectors (Hoang et al., 2019). This is often included as part of the manufacturing stage, hence the large amounts of energy used to create components such as these means that this is one of the largest contributors to the life cycle emissions of laptops (Choi et al., 2006). For example, only 7% of the emissions of a laptop from the Ecoinvent database in 2008 were from the use phase, with the rest almost completely coming from manufacturing and transport (Ecoinvent, 2008).

Unfortunately, components such as these cannot be recycled, emphasising the need for refurbishment and upgrading to maximise the product’s lifetime (Williams, 2004). It is also important that elements which can be recycled are. Furthermore, due to the pervasiveness of this product in society, laptops account for a considerable fraction of e-waste (Hoang et al., 2009). When old laptops cease to function effectively, they are frequently disposed of in landfills or transported to other countries, causing environmental pollution (Carro, 2008) and forgoing emissions reductions which could be made by refurbishment or recycling.

Paper

Paper products account for a significant proportion of the carbon footprint of organisations (EPA Victoria, 2013). Globally, the paper and pulp industry is the fourth most energy-intensive industry (Ta Thi and Thi Anh, 2020). Paper products alone accounted for 2% of UCL's total emissions in the 2018/19 academic year (HESA, 2019). However, there is a knowledge gap surrounding how emissions vary amongst different paper grades (Tomberlin et al., 2020). Furthermore, there is insufficient data from paper producers on the GHG emissions of their operations, resulting in high uncertainty of the emission factors (EPA Victoria, 2013). According to the American Forest and Paper Association and the Forest Products Association of Canada, one metric tonne of cradle-to-gate paper products vary between 1300 kg CO_2 eq. and 1600 kg CO_2 eq. This study also found that paper production and the end-of-life phase contribute the most to the carbon footprint (AF&PA, 2010). While the rate of paper recycling has increased and the world has transitioned to digital communication, these solutions have implications for energy consumption. Gaidajis and Angelakoglou (2011) performed an LCA of offices for educational purposes and found that energy consumption for electronic appliances had a significant influence on the environmental impact categories assessed. Furthermore, the choice between recycled or virgin copy paper makes little difference in terms of GHG emissions (EPA Victoria, 2013).

1.2. Aim and Research Questions

This report aims to identify environmental hotspots in the life cycle of laptop and paper products, and where emissions reduction strategies can make the most impact. This background raises the following research questions:

1. What are the Scope 3 emissions for laptop and paper products?
2. Where do these emissions occur?
3. What methods can quantify these emissions?

1.3. Method and Scope

The Bartlett's procurement expenditure for the 2018/19 academic year was used to determine the number of laptops and paper products purchased. This financial data was supplied by the Bartlett. Commercially available data and peer reviewed academic literature were used to find emission factors for different laptop models and paper products. A mean, minimum and maximum value of the Bartlett's total GHG emissions per product are determined by the range of these emission factors. The data was analysed using MS Excel. Global Warming Potential (GWP) is the only impact category considered and it is assumed that there is no double counting of emissions.

1.4. Report Structure

This report follows the standard LCA reporting structure, by firstly providing key information which defines the goal and scope followed by an inventory analysis of the product systems. This section is followed by results and interpretation of the emissions values. Finally, the study concludes with a summary of the findings and recommendations for the future.

2. Key Information

2.4. Goal and Scope Definition

2.4.1. Goal

The goal of this study is to identify laptop and paper products with significant indirect scope 3 emissions from the financial expenditure of the Bartlett.

2.4.2. System Boundary

Laptops

Cradle-to-Gate and Cradle-to-Grave

Cradle-to-gate and cradle-to-grave assessments of laptops are conducted in parallel. Cradle-to-gate accounts for life cycle stages including raw materials acquisition such as mining of metals such as silica and gold, the transport of these materials, manufacturing of components from these materials, and assembly of components to create a finished product (Yung et al., 2018). Product distribution is also included in cradle-to-gate emissions and is self-explanatory, referring to the distribution of laptops (See Figure 2 below). Cradle-to-grave includes all the aforementioned phases, with the addition of the use and end-of-life disposal phases. As only part of the laptop is recycled, this is not deemed gate-to-gate[1].

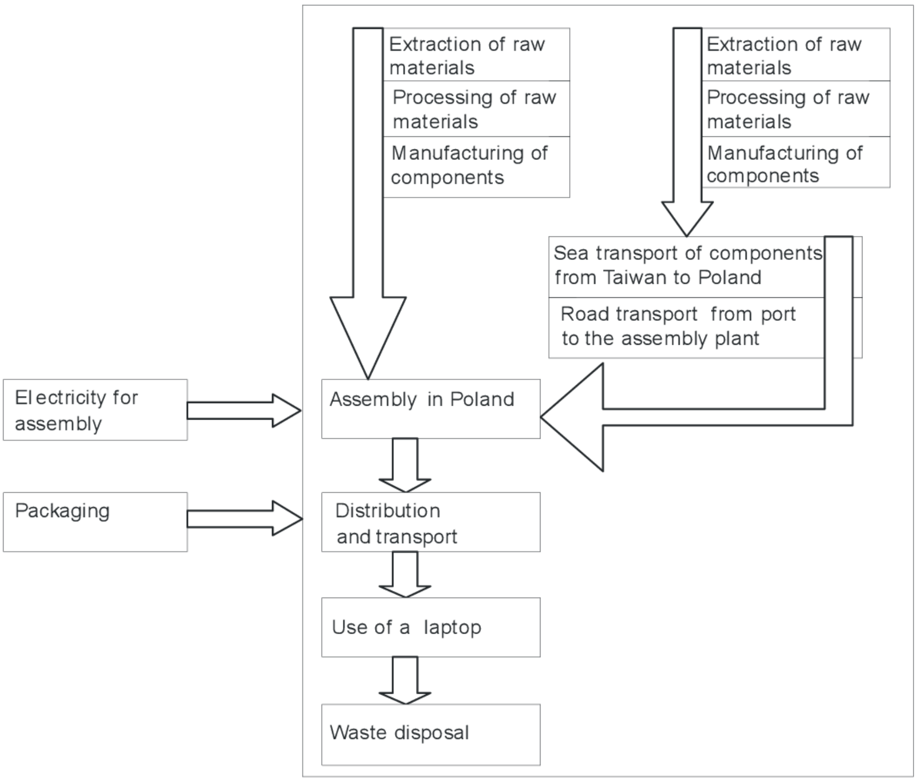

Figure 2: Cradle-to-Grave Life Cycle Assessment of a Laptop Used in Poland (Grzesik-Wojtysiak, K. and Kukliński, 2013)

[1] Gate-to-gate refers to circular economy LCA in which all the initial inputs are either reused or recycled at the disposal phase so that there is no waste

Paper

Cradle-to-Gate

Figure 3 below shows the cradle-to-grave life cycle stages for paper products, which include raw material acquisition of wood fibre, pulping and paper production, production of the final product, use and end-of-life phases. Fibre procurement includes operations in forestry, processing recycled materials and off-site recovery and chip reduction. This is followed by pulping and paper production, such as converting paper into rolls and reams [2]. Final product manufacturing is the third life cycle stage which converts paper into its specified function such as writing and binding. The use and disposal phase are self-explanatory, with landfilling, burning and energy recovery as different options for disposal. Generally, it is assumed that recycling of recovered material occurs outside the system boundary (AF&PA 2010). A cradle-to-gate system includes all stages except for the use and disposal phase of paper products.

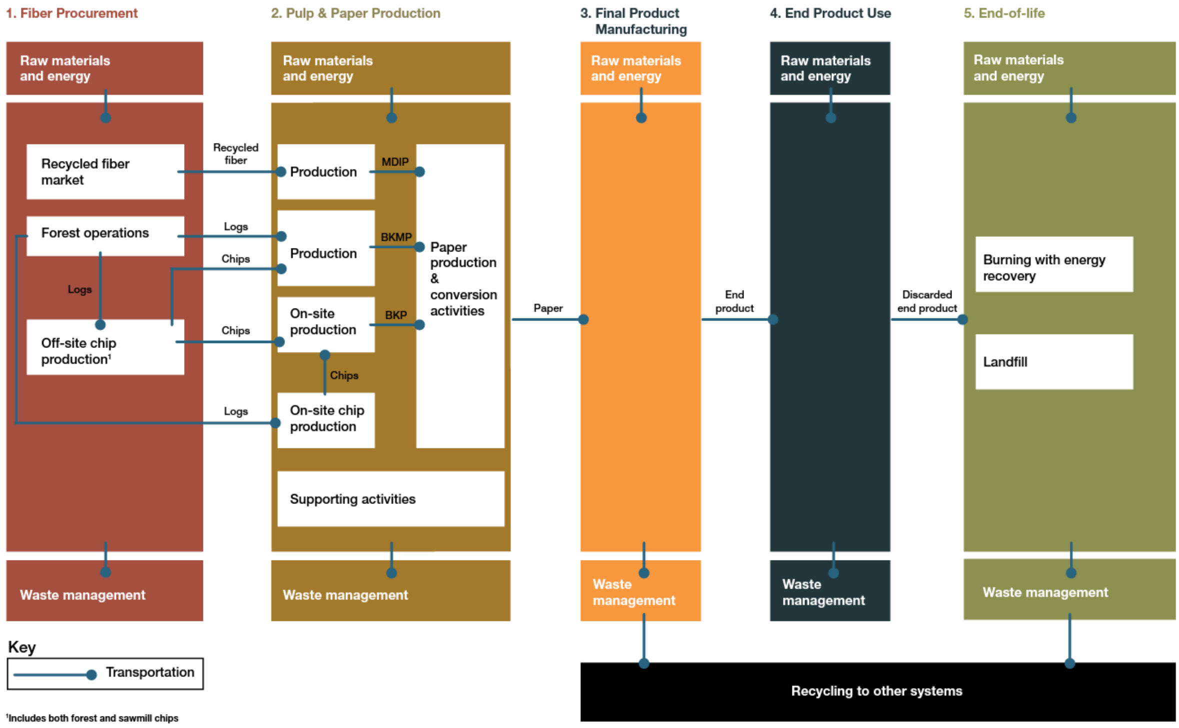

Figure 3: Cradle-to-Grave Life Cycle Assessment of Paper Products in America (AF&PA 2010).

[2] A unit of paper quantity. A ream of paper is 500 sheets of the same size and quality by international standards.

2.4.3. Functional unit

A functional unit has not been defined since this report is a preliminary analysis to quantify GHG emissions and not an explicit LCA. However, the reference flows for laptop and paper products are:

- Number of laptops
- Sheets of 2 ply tissue paper
- Packs of 6 rolls of 2 ply tissue paper
- Reams of virgin and recycled copy paper
- Sheets of virgin and recycled copy paper

2.5. Inventory Analysis

2.5.1. Laptops

In total, 104 laptops were purchased by the Bartlett in the 2018/19 academic year. This information was found through an analysis of the faculty's expenditure data for procurement. Within this, 25 different models were identified, and an additional category named 'laptop generic' accounts for those expenditures which did not specify the certain model (See Table 1 below). The laptop model is highly varied, from heavier gaming computers such as the Dell Alienware M17 (2.5kg), to light transportable laptops such as the Lenovo Yoga C930 (0.88kg) being procured. Multiple IT companies are used to source laptops for the faculty, most commonly Dell and Apple, however laptops are also purchased from Lenovo, HP, Microsoft and MSI. The number of each type of laptop model is recorded in Table 1.

Table 1: Quantity of Different Models of Laptops Procured by the Bartlett Faculty in 2018/19.

Laptop Model	Quantity	Weight (kg)
Lenovo Yoga (5th gen)	1	1.60
Lenovo ThinkPad A485	1	1.65
Thinkpad P52	1	2.84
Dell XPS 13 9370	2	1.27
Dell XPS 13 - not specified*	2	1.27

Dell XPS 13 9380	1	1.27
Dell XPS 15 9570	1	2.05
Dell Alienware M15 *	1	2.42
Dell Alienware M17*	1	2.50
Dell Latitude 5490	1	1.60
Precision 3530 Dell	1	2.03
Dell Latitude 7400	1	1.54
HP Elitebook	1	1.65
Macbook pro 13	10	1.40
Macbook pro 15	7	1.83
Dell Latitude 7390	12	1.19
MacBook Air	17	1.25
Dell Latitude 7490	28	1.40
Dell G5 15*	1	2.34
Lenovo Yoga C930	1	0.88
Inspiron 15 7000*	1	2.00
Microsoft Surface*	1	1.27
Dell Mobile Precision 7530*	1	2.53
ThinkPad X280*	1	1.26
MSI GE63VR 7RF Raider*	1	2.39
Laptop generic - Dell Latitude 5410	9	1.52
Total number laptops	104	

*The emissions for these laptop models could not be found so were then added to the laptop generic category for LCA emissions calculations. Table 1 shows that nine laptops did not have any model specified in the expenditure data. These were added to the present nine laptops in the generic category for emissions calculations, bringing the total number of generic laptops to 18, as seen in

Table 6.

Figure 4 below shows how the Bartlett School of Architecture, Bartlett School of Energy and Environmental Resources and the Bartlett School of Construction and Project Management account for the majority of purchased laptops by the faculty.

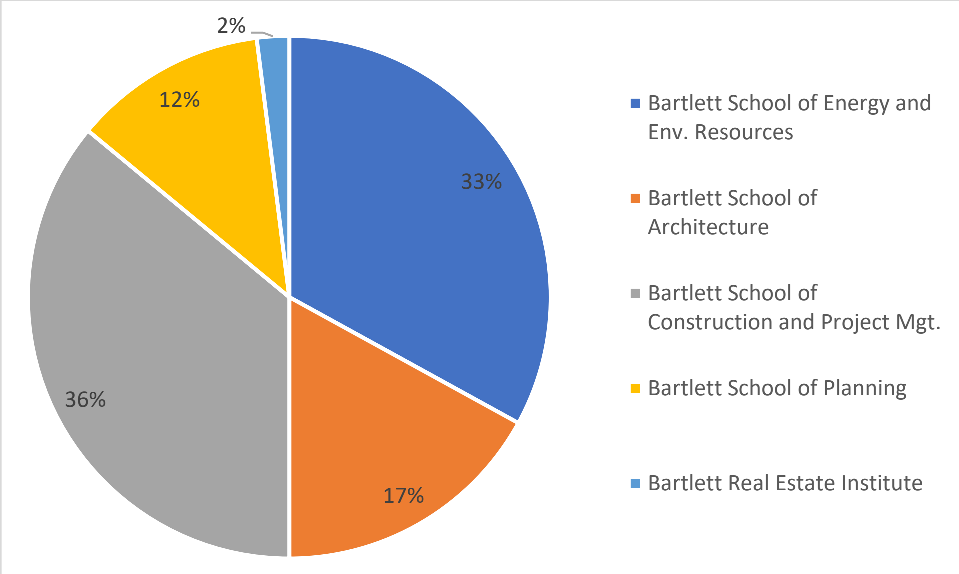

Figure 4: Share of laptop procurement for each department of the Bartlett

To calculate both emissions per laptop and the total emissions from laptops for the Bartlett, two sources of data were used. The first data source was the IT company itself, as they frequently report emissions for laptop models currently being manufactured. The other emissions data source originated from peer-reviewed literature. All emissions values were derived from process-based LCA apart from one value specified by Deng, Babbitt and Williams (2011) which uses EIO-LCA. Both these data sources enabled both a range of emissions per laptop and for the faculty as a whole to be calculated. The literature data did not always specify the laptop model and those studies which did, did not analyse models procured by the Bartlett. The supplier data however did specify emissions for models procured for the 2018/19 academic year, which enabled a model's specific total emissions to be calculated.

The range and mean emissions for both per laptop product and total emissions for the Bartlett were calculated in kg CO_2 eq. for both types of data. Additionally, the emissions for life cycle phases of the literature and supplier cradle-to-grave data (including manufacturing, transport and disposal) were found wherever possible.

Assumptions

- The model of the generic laptop was chosen as a Dell Latitude 5410 because this is the standard laptop for UCL procurement.
- Whether cables such as chargers were accounted for in emissions values varied between study. However, it is considered okay to compare the studies despite this since the emissions contributions of these parts are negligible (O'Connell and Stutz, 2010).
- The studies examined here either assumed a 75% recycle rate for the disposal phase or did not specify what occurred during this phase.
- There is no double counting of emissions.

Limitations

- Lack of clear descriptions of products in the financial expenditure data can lead to ambiguity in counting the number of laptops procured. A laptop computer was only counted when its expenditure was clear. Due to this, the laptop quantity stated here may underestimate the true quantity.
- Supplier data of emissions has a more rigorous LCA method presented than that found in peer-reviewed studies, meaning that there is perhaps less transparency in the breakdown of processes and emissions.
- Literature data however frequently lacks specificity in terms of the model, geographic location of production and use, and the weight of the laptop. In addition, most of the literature on laptop emissions is at least 10 years old, meaning it is questionable as to whether these calculations are representative of the emissions of laptops purchased in 2018/19. None of the models procured by the Bartlett are analysed in any of the literature studies. Due to advances in technology, the sources of emissions in a laptop LCA have changed over time. This will be elaborated upon in the discussion.

2.5.2. Paper Products

The density or thickness of paper produced from wood pulp is expressed in grams per square metre (gsm). There are four main categories of paper: tracing paper (40 – 90 gsm), layout paper (50 gsm), copy paper (80 gsm) and cartridge paper (80 – 140 gsm). The function of a paper product depends on its density. For example, 80 gsm copy paper is solely used for printing and photocopying and cartridge paper is used for all colour mediums such as watercolour and crayons (BBC, 2021).

The types of paper products are varied in the faculty's expenditure data for procurement in the 2018/19 academic year, ranging from paper bags to posters. The product description was used to categorize each transaction in the data by product type, size and density where available. This information was used to determine the quantity of each paper product. For example, there is a transaction of GBP 179 for "Ream 500 Sheets Paper Bright White Office Depot A4 80Gsm 150Cie Recycled". The cost of one unit or ream of this product is GBP 4.64 according to Vikings, a supplier of office materials and resources. This results in a total number of 39 reams. Where specific information about the size of the product was not available, online supplier data was used to make an estimation. For example, it is estimated that the "Box 2500 Everyday Print Paper Data copy A4 80 Fsc1" transaction contains 5 reams of paper according to the Vikings supplier data. A total of 48 transactions were quantified into aggregated and disaggregated amounts of paper products. An aggregated amount of paper is measured in reams and disaggregated amount in sheets. The corresponding units for other paper products such as tissue paper is rolls and sheets. The product description for tissue paper, "BLUE ROLL, 2PLY, CENTREFEED, 150M (PK6); Wipe Length: 395mm; Wipe Material: Tissue Paper; Wipe Width:190mm" meant the number of sheets per roll could be calculated by dividing the area of the entire roll by the area of one sheet, which gives 380 sheets per roll.

The paper categories established and quantified from the Bartlett's expenditure data are: filter coffee paper; paper bags; paper plates, tissue paper, A4 80 gsm virgin copy paper, A4 80 gsm recycled copy paper, A3 80 gsm recycled copy paper, A4 cartridge paper (density not specified), A2 150-220 gsm cartridge paper, A4 90 gsm tracing paper, A3 90 gsm tracing paper, A4 100-250 gsm office paper, A3 160 gsm office paper, A4 225-350 gsm watercolour paper, A3 350 gsm watercolour paper and A3 kraft paper.

Only paper with a density of 80 gsm was classified as copy paper. Paper which exclusively stated “cartridge paper” in the product description is classified as such. Office paper differs from other paper categories in that neither of these requirements were met and the density was greater than 90 gsm.

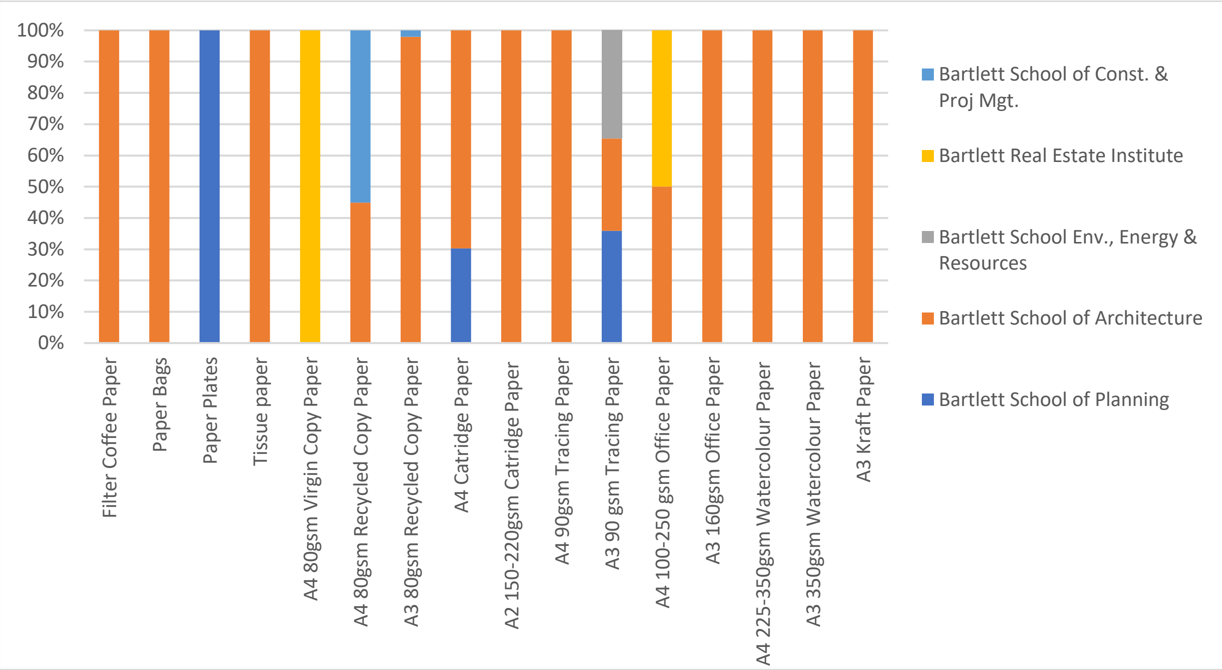

Figure 5: Contribution of each Department to the Quantified Paper Products in the Bartlett’s Expenditure (Data provided by the Bartlett)

As illustrated in Figure 5 above, the inventory data shows that the Bartlett School of Architecture, Bartlett School of Planning and Bartlett Real Estate Institute account for a significant share of purchased paper products. Considering emission values are widely available for A4 copy paper and tissue paper, other products are excluded in this analysis. Figure 6 below shows the share of A4 paper products in the inventory, most of which is virgin and recycled copy paper. Therefore, the paper products under analysis are A4 80 gsm virgin copy paper, A4 80 gsm recycled copy paper and tissue paper

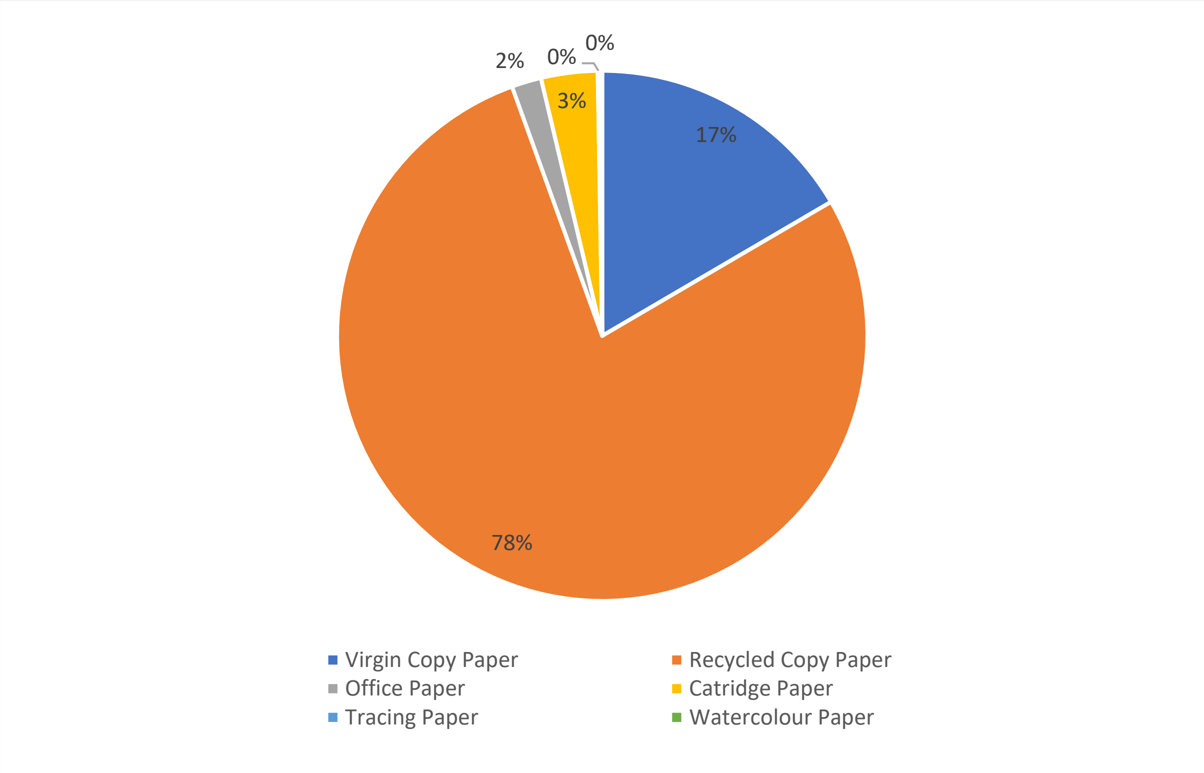

Figure 6: Share of Quantified A4 Paper Product Sheets in the Bartlett's Expenditure (Data provided by The Bartlett)

The quantity of these products is summarized in Table 2 below. The mass was calculated using assumptions detailed below.

Table 2: Quantified Paper Products in the Bartlett's Expenditure (Data provided by the Bartlett)

Paper Product	**Aggregated**	**Unit**	**Disaggregated**	**Unit**	**Mass (kg)**
Tissue Paper	284	Rolls	107857	Sheets of 2 ply tissue paper	134
Virgin Copy Paper	18	Reams	9143	Sheets of A4 80 gsm copy paper	45
Recycled Copy Paper	86	Reams	42996	Sheets of A4 80 gsm recycled copy paper	215

The emissions value for each paper product was calculated using a range of values from cradle-to-gate LCA studies. There was a limited number of cradle-to-grave LCA studies to obtain a range of emissions values for the paper products under assessments.

Assumptions

The key assumptions to quantify the paper products are:

- 1 Pack of 2 ply blue roll weighs 2.84 kg (Amazon, 2021)
- 1 Ream of paper is 2.5 kg (Paper Sizes, 2021)
- 1 Ream of paper is 500 sheets
- Number of reams can be determined by taking the expenditure data and dividing it by the cost of one unit of the product based on supplier data
- There is no double counting of emissions.

For emissions values from literature, it is assumed that the data is representative of paper products currently purchased by the Bartlett, although they are derived from studies conducted in other regions and different temporal scopes. For example, the study by Environment Protection Authority (EPA) Victoria (2013) is based on Australian Plantation Products and Paper Industry Council (APPPIC) data from 2006.

Limitations

Generally, it was not obvious to distinguish between whether a product was purchased for printing or whether the service of printing was acquired. Although other paper categories were established and quantified, the absence of emission factors for paper of different dimensions and thickness meant their emission values could not be determined. These quantities can be found in the Appendix. Other paper products such as cards, labels, tape and sticky notes that are recorded in the expenditure data were neither quantified nor included in the scope of this study. Paper products in the form of rolls which did not specify the width and length per sheet were also excluded, such as tape and one entry for tracing paper. These dimensions are required to determine the number of sheets or other reference flows. In terms of emissions values from literature, the availability of this data was limited to copy paper and most studies were only cradle-to-gate studies. As such, the impact of the use and disposal phase is not quantified for the Bartlett.

3. Key Findings

3.4. Results

3.4.1. Laptops

The range of emissions per laptop for the literature data for cradle-to-gate is 62.2-256 kg CO_2 eq. and the mean emissions per laptop is 163 kg CO_2 eq. The range of emissions per laptop for the literature data for cradle-to-grave is 122.2-614.46 kg CO_2 eq. and the mean is 230.2 kg CO_2 eq. It is evident that there is a much greater spread in the literature data which accounts for the full life cycle.

Table 3: Cradle-to-gate laptop emissions from literature data

Source	Type of laptop	Weight (kg)	Total CO2 emission per laptop (kg CO_2 eq.)	Location
Deng, Babbit and Williams (2011)	Dell Inspiron 2500 15" (2001)	n/a	114.5	USA
Deng, Babbit and Williams (2011)*	Dell Inspiron 2500 15" (2001)	n/a	248.5	USA
Teehan and Kandlikar (2013)	12.1" HP Omnibook with dock (2003)	3.3	256	Canada
Teehan and Kandlikar (2013)	HP 530 Laptop, 16" (2009)	2.8	108	Canada
Teehan and Kandlikar (2013)	HP Mini 110−1030 CA Netbook, 10” (2009)	1.3	62.2	Canada
Lui et al (2016)	14" HP	n/a	189	China

**This study was the only one which used EOILCA, all the others used process based LCA.*

Table 4: Cradle-to-grave laptop emissions from literature data

Source	Type	Weight (kg)	Total emission per laptop (kg CO_2 eq.)	Manu. (kg CO_2 eq.)	Manu. and Transport (kg CO 2 eq.)	Transport (kg CO_2 eq.)	Disposal (kg CO_2 eq.)	Production location
European Commission (2007)	15" laptop	2.8	92.52	80.15	n/a	10	-1	Southeast Asia
Tekawa et al (1997)	n/a	n/a	122.2	n/a	114.4	n/a	7.8	Japan
Ecoinvent (2007)	n/a	3.2	614.46	n/a	613.8	n/a	0.66	Switzerland
PE international (2008)	n/a	1.5	151.7	n/a	168.1	n/a	-16.4	n/a
O'Connell and Stutz (2010)	14" Dell	n/a	170	175	n/a	25	-30	Europe

Table 5: Cradle-to-grave laptop emissions for supplier data

Laptop model	Qty.	Emissions per laptop (kg CO_2 eq.)	Manu. (kg CO_2 eq.)	Transport (kg CO_2 eq.)	Disposal (kg CO_2 eq.)	Weight (kg)	Screen size (in)	Production location	Total emissions from laptops (kg CO_2 eq.)
Lenovo Yoga (5th)	1	196.8	174.7	22.1	0.00	1.60	11.6	China	196.8
Lenovo ThinkPad A485	1	272.4	264.0	8.4	0.00	1.65	14.0	China	272.4
Thinkpad P52	1	540.5	499.0	41.6	0.00	2.84	15.6	China	540.5
Dell XPS 13 9370	2	260.2	246.5	12.8	0.89	1.27	13.3	China	520.3
Dell XPS 13 9380	1	279.9	268.2	11.1	0.63	1.27	13.3	China	279.9

Dell XPS 15 9570	1	266.0	251.4	13.9	0.65	2.05	15.6	China	266.0
Dell Latitude 5490	1	206.8	196.5	9.8	0.50	1.60	14.0	China	206.8
Precision 3530 Dell	1	276.7	261.3	14.4	1.01	2.03	15.6	China	276.7
Dell Latitude 7400	1	281.9	270.1	11.2	0.64	1.54	14.0	China	281.9
Macbook pro 13	10	180.1	164.9	13.0	2.17	1.40	12.0	US	1801.1
Macbook pro 15	7	285.5	263.5	18.3	2.85	1.83	13.8	US	1998.4
Dell Latitude 7390	12	195.1	187.1	7.5	0.44	1.19	12.5	China	2341.7
MacBook Air	17	165.4	135.5	28.1	0.35	1.25	12.0	US	2812.5
Dell Latitude 7490	28	210.6	201.2	8.9	0.48	1.40	14.0	China	5687.1
Lenovo Yoga C930	1	179.8	139.2	40.6	0.00	0.88	10.8	China	179.8
ThinkPad X280	1	257.2	185.2	16.7	0.00	1.26	12.5	China	257.2
Laptop generic	18	275.8	260.8	11.1	0.65	1.52	14.0	China	4964.3

Table 6: Summary of emissions from differing data sources

Data origin	Qty. of emission values assessed	Mean weight of laptop	Mean emission per laptop (kg CO_2 eq.)	Range of emissions per laptop (kg CO_2 eq.)	Total emissions mean (kg CO_2 eq.)	Total emissions range (kg CO_2 eq.)
Literature Cradle-to-gate	6	2.5	163.0	62.2-256	16955.5	6468.8-26624
Literature Cradle-to-grave	5	2.5	230.2	122.2-614.46	23938.3	9622.1-63903.8
Supplier Cradle-to-grave	26	1.73	225.2	165.4-540.5	23423.5	17201.2-56212

The mean emissions per laptop (determined by the model) for the supplier data is 225.2 kg CO_2 eq. and the range is 165.4-540.5 kg CO_2 eq., which is very similar to the cradle-to-grave literature estimates. The spread of the data can be seen in the box plot in Figure 7. This box plot shows however, that whilst the range and mean of the supplier and literature cradle-to-grave emissions estimates are similar, the variability in the literature data is much higher than in the supplier data.

When scaled up to the total emissions for the faculty, ranges were 6468.8-26624 kg CO_2 eq. and 9622.1-63903.8 kg CO_2 eq. for the literature cradle-to-gate and cradle-to-grave emissions respectively. The mean total emissions are 16955.5 kg CO_2 eq., and 23423.5 kg CO_2 eq. Comparatively, supplier emissions ranges for the faculty are between 17201.2-56212 kg CO_2 eq., and the mean total emissions is 23423.5 kg CO_2 eq.,

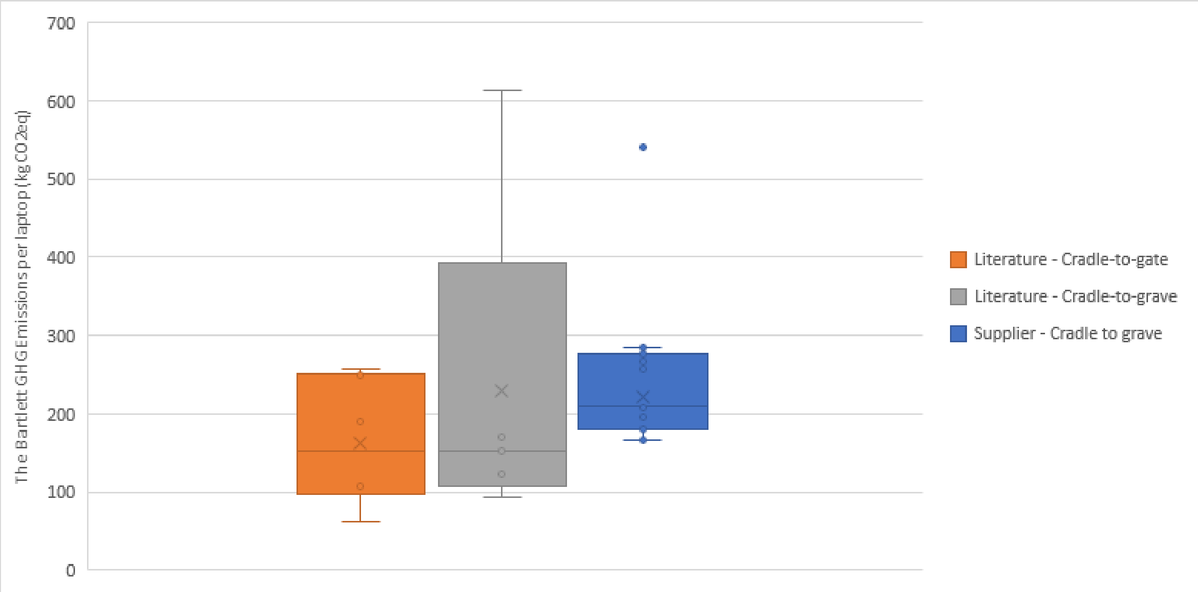

Figure 7: Box-and-whisker plots for the total GHG emissions per laptop purchased by the Bartlett according to literature and supplier data sources

The cradle-to-gate literature did not outline emissions contributions from the differing phases of a laptop's lifecycle, unlike the cradle-to-grave literature and supplier data sources. Table 7 shows that manufacturing is the largest contributor to laptop emissions, as already alluded to in the literature review section. Transport is more varied for the supplier data; however, the disposal emissions are more varied for literature data. Unlike other phases, the disposal phase is often recorded as negative emissions if the laptop is partially recycled during end-of-life.

Table 7: Relative contributions of different phases to a laptop's emissions.

Data source	Manufacturing	Manufacturing and Transport	Transport	Disposal
Supplier Cradle-to-grave	72%-96.9%	n/a	3.1%-22.6%	0.0%-1.2%
Literature Cradle-to-grave	86.6%-102.9%	93.6%-110.8%	10.8%-14.7%	-17.6%-6.4%

3.4.2. Paper Products

Tables 8-10 below shows emissions per functional unit (FU) for the different paper products from literature. The FU is described under specifications. The total emissions for the Bartlett is calculated by multiplying these emission factors by the quantity of paper products summarized in Table 2 above. It is assumed the emission factor of writing paper provided by Ta Thi and Thi Anh (2020) can be used for copy paper and the study by Ozawa-Meida et al. (2013) is a cradle-to-gate assessment.

Table 8: Cradle-to-gate and cradle-to-grave emissions values for A4 80 gsm virgin copy paper from literature and the corresponding total emissions for the Bartlett

System Boundary	GHG (kg CO_2 eq./FU)	Specifications	Location	Bartlett Total Emissions (kg CO2 eq.)	Source
cradle-to-grave	4.25	Per ream of office paper: 500 sheets of 75 gsm	America	77.71	AF&PA, 2010
cradle-to-gate	1.3	Per kilogram of copy paper (Average: Domestic)	Australia	59.43	EPA Victoria, 2013
	0.7	Per kilogram of copy paper (Lower Boundary: Domestic)		32.00	
	1.48	Per kilogram of copy paper (Upper Boundary: Domestic)		67.66	
	1.08	Per kilogram of copy paper (Average: Imported)		49.37	
	0.7	Per kilogram of copy paper (Lower Boundary: Imported)		32.00	
	1.48	Per kilogram of copy paper (Upper Boundary: Imported)		67.66	
	1364	Per ton of paper product (writing paper)	Vietnam	62.35	Ta Thi and Thi Anh, 2020
	608	Per metric ton of product	America	27.79	Tomberlin et al., 2020
	0.74	Per GBP spent on paper products	United Kingdom	39.22	Ozawa-Meida et al., 2013

Table 9: Cradle-to-gate emissions values for A4 80gsm recycled copy paper from literature and the corresponding total emissions for the Bartlett

GHG (kg CO_2 eq./FU)	Specifications	Location	Bartlett Total Emissions (kg CO_2 eq.)	Source
1224.41	Per ton of paper product	Vietnam	263.22	Ta Thi and Thi Anh, 2020
1.52	Per kilogram of copy paper (Avergae: Domestic)	Australia	326.77	EPA Victoria, 2013
1.35	Per kilogram of copy paper (Lower Boundary: Domestic)		290.22	
1.7	Per kilogram of copy paper (Upper Boundary: Domestic)		365.46	
1.28	Per kilogram of copy paper (Average: Imported)		275.17	
1.17	Per kilogram of copy paper (Lower Boundary: Imported)		251.52	
1.5	Per kilogram of copy paper (Upper Boundary: Imported)		322.47	
0.74	Per GBP spent on paper products	United Kingdom	713.36	Ozawa-Meida et al., 2013

Table 10: Cradle-to-gate and cradle-to-grave emissions values for tissue paper from literature and the corresponding total emissions for the Bartlett

System Boundary	GHG (kg CO_2 eq./FU)	Specifications	Location	Bartlett Total Emissions (kg CO_2 eq.)	Source
cradle-to-grave	646.00	Per 68,000 European commercial centre fed roll wiper sheets	Europe	1024.64	ERM, 2007
	55.10	Per 40,000 American bathroom tissue sheets	America	148.57	
cradle-to-gate	751.25	Per ton of recyled tissue paper produced in Vietnam in 2018	Vietnam	101.00	Ta Thi and Thi Anh, 2020

	1061.00	Per ton of virgin paper produced in Vietnam in 2018		142.64	
	1720	Per metric ton of product	America	149.81	Tomberlin et al., 2020
	0.74	Per GBP spent on paper products	UK	296.00	Ozawa-Meida et al., 2013

Only one cradle-to-grave value from literature was obtained for A4 80 gsm virgin copy paper at 4.25 kg CO_2 eq. per ream of office paper (AF&PA, 2010), and two values for tissue paper at 646.00 4.25 kg CO_2 eq. per 68000 sheets and 55.1 4.25 kg CO_2 eq. per 40000 sheets respectively (ERM, 2007). These sets of values were obtained from one source each. Therefore, a range of emissions values could only be obtained for cradle-to-gate assessments. The cradle-to-gate range of GHG emissions values for the different paper products in the scope of this study that are purchased by the Bartlett is shown in Figure 8 **Error! Reference source not found.**. The range reflects the varying assumptions made by different literature sources specific to the product system analyzed. For example, the study by Ta Thi and Thi Anh (2020) in Vietnam assumes electricity from the national grid and heat processes are powered by coal. On the other hand, the study by AF&PA (2010) study in North America, found that 62% of the resources required to produce office paper is renewable. An outlier of 713.36 kg CO_2 eq. for the Bartlett's total emissions from A4 80 gsm recycled paper is omitted from the range. This is based on the emissions factor of 0.74 per GBP spent on paper products provided by Ozawa-Meida et al., (2013). However, the results from using this factor for A4 80 gsm copy paper and tissue paper are also outliers and are included in the respective total emissions range.

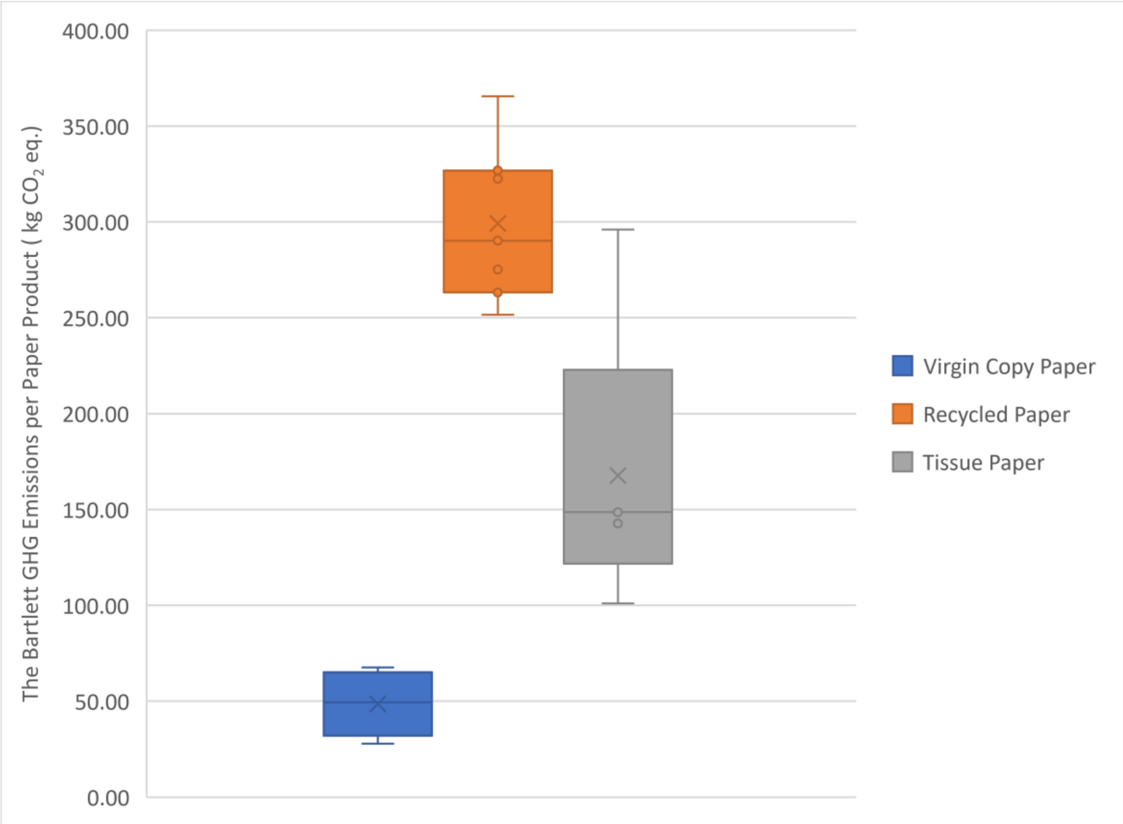

Figure 8: Box-and-whisker plots for the total GHG emissions of paper products purchased by the Bartlett based on literature

As illustrated in Figure 8, the greatest source of emissions for paper products under assessment at the Bartlett comes from A4 80 gsm recycled paper. This is followed by tissue paper and then virgin copy paper. However, these emissions cannot be compared since they are absolute values and are not normalized. Alternatively, an intensity metric such as GHG emissions per student for the specific departments which purchase these paper products could be established, however this is outside the scope of this study. Table 11 summarizes the mean, minimum and maximum value of the paper products GHG emissions for the Bartlett.

Table 11: The mean, minimum and maximum value of the paper products GHG emissions for the Bartlett

	Mean (kg CO_2 eq.)	**Minimum (kg CO_2 eq.)**	**Maximum (kg CO_2 eq.)**
Virgin Copy Paper	48.61	27.79	67.66
Recycled copy Paper	299.3	251.5	365.5
Tissue Paper	168	101.00	296
Total Emissions	515.48	380.32	729.12

The range of total emissions for virgin copy paper is 48.61 – 67.66 kg CO_2 eq. with a mean of 48.61 kg CO_2 eq. The corresponding values for recycled copy paper are 251.5 – 365.5 kg CO_2 eq. and 299.3 kg CO_2 eq. For tissue paper, the range is 101.00 – 296.00 kg CO_2 eq., with a mean of 168 kg CO_2 eq. This results in a total emissions range of 380.32 – 729.12 kg CO_2 eq., with a mean of 515.48 kg CO_2 eq. for the Bartlett. Figure 9 below shows the standard deviation of the range of emission factors from literature.

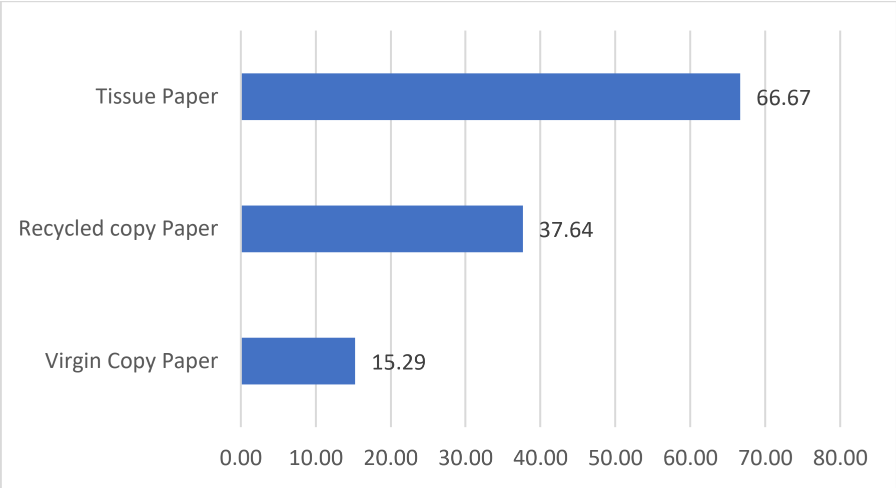

Figure 9: Standard Deviation of the Range of Paper Products Emissions Values from Literature

The low standard deviation of virgin copy paper of 15.29 units as illustrated in Figure 9 is due to the widely available literature values for these products. Tissue paper has a relatively high standard deviation suggesting emissions values for this product it are the least reliable.

3.5. Discussion

3.5.1. Laptops

The low variance of the supplier data is due to the much greater availability of emissions values for specific models. This is unlike the literature data, for which there are only five and six emissions values available for cradle-to-grave and cradle-to-gate respectively. Interestingly, given that the disposal phase often results in emissions reductions when a 75%

recycling rate is assumed, it would be expected that mean emissions for cradle-to-gate would be higher than cradle-to-grave emissions, however this is not the case here. This is an example of how differing assumptions in studies impact emissions calculations.

Given that the supplier emissions results are very similar to the cradle-to-grave literature emissions estimates, the validity of supplier's estimates are made more legitimate, despite a relative lack in transparency. In turn, this shows the potential for using supplier's estimates in the assessment of university emissions, or another organisation's emissions. This is especially pertinent considering literature availability on laptop emissions is severely lacking and outdated. The fact that suppliers themselves are more knowledgeable about the materials and processes in their supply chain, as well as geographic production location, means they can avoid sources of uncertainty associated with process-based LCA.

In terms of technological advancements, an example of a change for laptops which has impacted their emissions over time is the shift from using CCFL to light up LCD screens in laptops manufactured prior to 2009, to using LED to light up LCD laptop screens post-2009 (Altaf, Babbit and Chen, 2020). Bhakar et al. (2015) conducted a lifecycle assessment of computer monitors and found that those with LCD-LED screens had higher emissions in the manufacturing phase than CCFL-LCD screens, however due to the greater energy efficiency of LED, the emissions from the use phase (not accounted for here) of LCD-LED screens was much lower than CCFL-LED screens. The fact that the cradle-to-gate literature estimates are all from laptops manufactured post 2009, suggests that something else is causing lower emissions in comparison to cradle-to-grave supplier laptops which are largely produced pre-2010. Other examples of technological advancements could be used to explain this. For example, by using recycled materials, notably recycled aluminum, to produce the 13-inch 2018 Macbook air, Apple were able to reduce the products emissions by 47% on the model produced in the previous year (Apple, 2018). It should be noted that whilst the 47% emission reductions were for the whole lifecycle, the use phase only contributes 6% of emissions, hence most of the reduction is seen in manufacturing.

Whilst this goes some way to explaining the difference between the literature LCAs, the fact that the supplier data is much higher than the literature cradle-to-gate emissions should be questioned. This may be explained by the specific laptop models procured by the Bartlett. This faculty does not just purchase the generic model of laptop for UCL, it purchases multiple specialist laptops, lots of which have the capacity for designing and modelling; things which would be required by departments such as the Bartlett School of Architecture. Teehan and Kandlikar (2013) found a linear positive correlation between embodied laptop emissions and product mass. Due to the hardware of these laptops tending to have higher mass, this could partially explain the differences in emissions. On the other hand, a superficial examination of the emissions of the supplier data brings this conclusion into question. The relationship between product mass and emissions could not be tested within the remit of this study, however it should be explored in future. Furthermore, the laptop models for which emissions data was not available from suppliers tended to be the heavier, more specialist laptops, hence the current emissions could be an underestimation.

Consequently, in addition to obtaining more literature sources of emissions values, more research into how the impact of technological advancements impact laptop emissions and the ranges from different models should be explored. Whether the Bartlett hence has atypical emissions from laptops can only be hypothesised at this point.

3.5.2. Paper Products

According to EPA Victoria (2013), the energy mix of grid electricity used and the source of energy for heating during pulping have the most significant influence on paper emission factors. For the production of virgin material, waste wood and other biomass energy is used. On the other hand, fossil fuels are used in the production of recycled paper (EPA Victoria, 2013). This explains the high emissions observed for recycled paper in the results section. The Bartlett is an institution in the United Kingdom and likely purchases virgin copy paper from producers that use renewable energy, which is consistent with the AF&PA (2010) study in North America. However, for regions in the Global South, virgin paper products would have greater emissions than recycled paper products which is observed in the study by Ta Thi and Thi Anh (2020) in Vietnam. This should carefully be considered as the Bartlett aims to align its ambitions with UCL's net-zero by 2030 goal. Considering the high variability of emissions for tissue paper, it is up to the suppliers of these paper products to provide the necessary data to account for emissions values.

Where in the supply chain do these emissions occur?

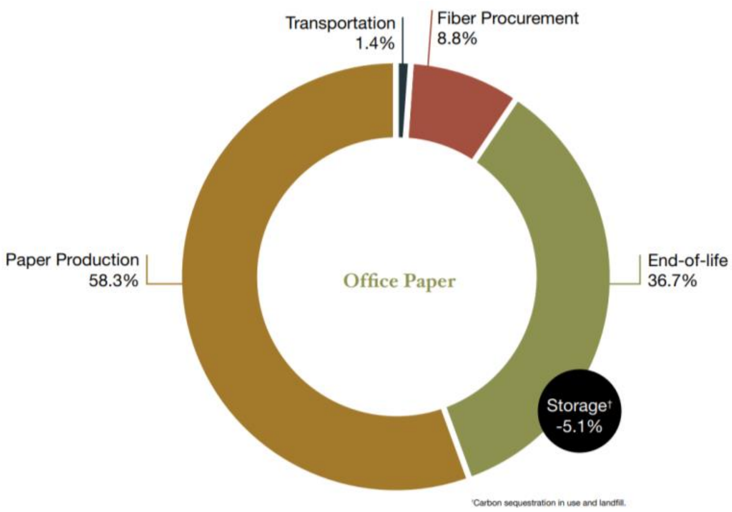

Figure 10: Distribution of carbon footprint across the life cycle of a ream of office paper (AF&PA, 2010)

According to Figure 10 above, paper production and end-of-life are the life cycle stages with the most significant footprint with a contribution of 58.3% and 36.7% respectively (AF&PA, 2010). A life cycle carbon footprint study by Tomberlin et al. (2020) showed fuels have the most significant contribution and should be a key priority for reduction strategies.

The Bartlett

For the scope of this study, the Bartlett Real Estate Institute accounts for 100% of A4 80 gsm copy paper. The Bartlett School of Construction and Project Management accounts for 55% of A4 80 gsm recycled copy paper and the Bartlett School of Architecture accounts for the remaining 45%. Finally, The Bartlett School of Architecture accounts for 100% tissue paper, specifically 2ply blue roll likely used to wipe surfaces. These departments can use the results to inform decision-making for purchasing these paper products in the future, for example, consider using materials such as cloths to wipe counters or implementing strategies to reduce printing.

Methods to quantify paper product emissions

Although LCA studies are useful to determine the environmental impacts of paper products, they require a significant amount of time and resources to generate data that is representative of these products. According to Tomberlin et al. (2020), it is impractical to perform LCAs on a large-scale for each mill with traditional methods. Alternative or hybrid methods such as EIO-LCA may offer the Bartlett data that is more accurate and could potentially model the entirety of their paper products to establish better GHG emissions reduction strategies.

4. Conclusion

This study presents greenhouse gas emissions for laptops and paper products procured by the Bartlett in the 2018/19 academic year. The emissions of laptops are characterised by significant variability between sources. This is largely due to lack of consistency in assumptions, large time spans over which studies have taken place, differing system boundaries considered and differences in emissions from laptop models. Emissions found however do confirm that the largest source of emissions occurs in the manufacturing phase of the life cycle. The emissions of paper products are specific to its size and density. This creates challenges for estimating emissions for products that are largely varied, which is the case at the Bartlett. The availability of data from suppliers is necessary as LCA studies are limited to copy paper for printing and data for tissue paper is highly varied. Additionally, using a hybrid EIO-LCA method could generate results that are more representative of paper products purchased by the Bartlett. Generally, the production phase of paper was shown to have the greatest emissions. Recycled copy paper has higher emissions due to the use of fossil fuels in the production phase for paper in the Global North, compared to the use of renewables for the production of virgin copy paper.

Recommendations

Laptops

- The contribution of manufacturing is significant, hence strategies to reduce emissions should be focused here. In addition, effort should be made to refurbish laptops which are not operating effectively in order to extend their lifespan. If this is not possible, then they should be recycled to encourage emissions reductions.
- Further exploration into the causes of differing emissions from data sources and over time should be conducted.
- Future work could also explore the difference between EIO-LCA and process based. As Deng, Babbitt and Williams (2011) found emissions from process based were 93-136, compared with 227-270 for EIO-LCA. Sources of disparity such as these need to be explored, however, due to reasons already discussed, the LCA method itself is not the only thing responsible for inconsistencies.

Paper

- Adopt responsible consumption and management of paper products.
- Increase the scope of paper products to obtain results of emissions that are more representative of the Bartlett's expenditure by using EIO-LCA
- Source recycled paper produced from renewable energy and environmentally friendly energy resources

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Table 12: References for laptop supplier data

Laptop Model	Source	Year of report
Lenovo Yoga (5th gen)	https://www.lenovo.com/us/en/social_responsibility/PCF-ThinkPad-11e-Yoga-11e-5th.pdf	2018
Lenovo ThinkPad A485	https://www.lenovo.com/medias/PCF-ThinkPad-A485.pdf?context=bWFzdGVyfHNvY2lhbF9yZXNwb25zaWJpbGl0eXw0MzI5MjV8YXBwbGljYXRpb24vcGRmfHNvY2lhbF9yZXNwb25zaWJpbGl0eS9oNGEvaGM3Lzk4MDYxNjYzOTI4NjIucGRmfGQ1ZGRmOTU0YTYwNGJkMThhNTE5ZDc0ODgyZTgxZTIzMmMyNDc2OWZjZTY1YjEyYTBlYzhhOGI4YTBhMzk3ZGI	2018
Thinkpad P52	https://www.lenovo.com/medias/PCF-ThinkPad-P52.pdf?context=bWFzdGVyfHNvY2lhbF9yZXNwb25zaWJpbGl0eXwzMDYwMTh8YXBwbGljYXRpb24vcGRmfHNvY2lhbF9yZXNwb25zaWJpbGl0eS9oYzQvaGZiLzk4MDYzNjQ1NDA5NTgucGRmfDFlYzQxYzA2YzhlOTM0NWM2ZTNiMTFiZGRhZWMzNzdhOWM0NjNjNzE0OGFjZDkyNGYwN2E0ZTFhNTVmN2FjZGI	2018
Dell XPS 13 9370	https://i.dell.com/sites/csdocuments/CorpComm_Docs/en/carbon-footprint-xps-9370.pdf	2018
Dell XPS 13*	https://i.dell.com/sites/csdocuments/CorpComm_Docs/en/carbon-footprint-xps-9370.pdf	2018
Dell XPS 13 9380	https://corporate.delltechnologies.com/asset/en-us/products/desktops-and-all-in-ones/technical-support/xps-13-9380.pdf	2019
Dell XPS 15 9570	https://i.dell.com/sites/csdocuments/CorpComm_Docs/en/carbon-footprint-xps-15-9570.pdf	2018
Dell Alienware M15 *	https://dl.dell.com/topicspdf/alienware-m15-r4-laptop_users-guide_en-us.pdf	2021
Dell Alienware M17*	https://www.dell.com/en-uk/work/shop/laptop-computers-for-businesses/new-alienware-m17/spd/alienware-m17-r3-laptop/n00awm17r307#features_section	2021
Dell Latitude 5490	https://i.dell.com/sites/csdocuments/CorpComm_Docs/en/carbon-footprint-latitude-5490.pdf?newtab=true	2018
Precision 3530 Dell	https://i.dell.com/sites/csdocuments/CorpComm_Docs/en/carbon-footprint-precision-3530.pdf	2018
Dell Latitude 7400	https://corporate.delltechnologies.com/asset/en-us/products/laptops-and-2-in-1s/technical-support/latitude-7400.pdf	2019
HP Elitebook	https://h22235.www2.hp.com/hpinfo/globalcitizenship/environment/productdata/Countries/_MultiCountry/productcarbonfootprint_notebo_20201217224913509.pdf	2020
Macbook pro 13	https://www.apple.com/environment/pdf/products/notebooks/13-inch_MacBookPro_PER_May2020.pdf	2020
Macbook pro 15	https://www.apple.com/environment/pdf/products/notebooks/16-inch_MacBookPro_PER_Nov2019.pdf	2019
Dell Latitude 7390	https://i.dell.com/sites/csdocuments/CorpCommDocs/en/carbon-footprint-latitude-7390.pdf	2018
MacBook Air	https://www.apple.com/environment/pdf/products/notebooks/13-inch_MacBookAir_w_Retina_PER_oct2018.pdf	2018
Dell Latitude 7490	https://i.dell.com/sites/csdocuments/CorpComm_Docs/en/carbon-footprint-latitude-7490.pdf	2018
Dell G5 15*	https://www.dell.com/en-uk/shop/laptops/new-dell-g5-15/spd/g-series-15-5500-laptop/cng5005sc#features_section	2021
Lenovo Yoga C930	https://static.lenovo.com/ww/docs/regulatory/eco-declaration/PCF_Yoga_Book_C930.pdf	2018
Inspiron 15 7000*	https://www.dell.com/uk/dfh/p/inspiron-15-7560-laptop/pd	2021
Microsoft Surface*	https://www.microsoft.com/en-gb/surface/devices/surface-laptop-3/tech-specs	2021
Dell Mobile Precision 7530*	https://www.dell.com/en-uk/work/shop/laptops/precision-7530-mobile-workstation/spd/precision-15-7530-laptop	2021
ThinkPad X280*	https://www.lenovo.com/us/en/social_responsibility/PCF-ThinkPad-X280.pdf	2018
MSI GE63VR 7RF Raider*	https://www.msi.com/Laptop/support/GE63VR-7RF-Raider	2021
Laptop generic - Dell Latitude 5410	https://corporate.delltechnologies.com/asset/en-us/products/laptops-and-2-in-1s/technical-support/latitude-5410-pcf-datasheet.pdf	2020
Access date	All accessed on 25th July 2021	

Appendix

Paper

Table 13: Other quantified paper products

Paper Product	Aggregated	Unit	Disaggregated	Unit
Recycled Copy Paper	59	Reams	29458	Sheets of A3 recycled copier paper 80 gsm
Office Paper	2	Reams	1000	Sheets of A4 office paper 100 - 250 gsm
Office Paper	1	Pack	250	Sheets of A3 office paper 160 gsm
Catridge Paper	76	Pads of Catridge Paper	1901	Sheets of A4 catridge paper
Catridge Paper	2	Pads of Catridge Paper	350	Sheets of A2 catridge paper 150 - 220 gsm
Paper Plates	8	Packs	800	Paper plates
Paper Bag	1	Pack	1000	Paper bags
Filter Coffee Paper	1	Pack	250	Filter coffee paper
Tracing Paper			557	A3 Sheets of tracing paper 90 gsm
Tracing Paper			50	A4 Sheets of trcaing paper 90 gsm
Watercolour Paper			100	A4 Sheets of Watercolour Paper 225 - 350 gsm
Watercolour Paper			50	A3 Sheets of Watercolour Paper 350 gsm
Kraft Paper			10	A3 Sheets of kraft Paper