Department of

BIOLOGY

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Contents

Abstract

Biodiversity loss is increasingly recognised as a major global threat, with environmental and economic consequences. This has led to calls for systemic change, with many organisations committing to “Nature Positive” goals in line with the Global Biodiversity Framework. However, research is limited on how organisations should address supply chain impacts, which are often major drivers of biodiversity loss. In this study, I explored how a large organisation, the University of Oxford, could design a strategy for its supply chains. I examined knowledge about the raw materials and origins of Oxford’s top spend products from across 131 suppliers, before focusing on the University’s coffee supply chain as an example of how region-specific biodiversity impacts could be estimated. I then considered different mitigation strategies, including the potential to harness Oxford conservation researchers’ existing collaborations, and proposed interventions for the coffee supply chain. Only 18 suppliers could provide the raw materials and origins for their products, with only two also providing the Life Cycle Assessment data needed to estimate product impacts. The total biodiversity footprint of Oxford’s purchased coffee was estimated using Life Cycle Impact Assessment models to be 2.68E-09 PDF.year, with a particularly large footprint in East Africa. Oxford researchers were found to have strong collaborations across the globe, suggesting potential to aid location-specific supply chain mitigation strategies. Based on this analysis I developed a conceptual framework that could be utilised by other businesses and organisations to address their supply chain impacts, and support movement towards a Nature Positive future.

1 Introduction

Businesses and Biodiversity

Whilst economic growth has contributed to moving more than a billion people out of poverty since the 1970s, the associated energy, food production and infrastructure has resulted in loss of global biodiversity at alarming rates, with monitored wildlife populations having decreased by 73% in just 50 years (WWF 2024; WEF 2020b). Simultaneously, nature-related economic risks are increasingly being recognised, with studies finding that about $44 trillion of the world's $106.17 trillion GDP relies on nature, but that there is a $598-824 billion funding gap to maintain ecosystem integrity by 2030 (Deutz et al., 2020; WEF 2020a; World Bank, 2025). Acknowledgement of this risk has led to advocacy for systemic change towards a global goal of "Nature Positive" (Milner-Gulland et al., 2022; zu Ermgassen et al., 2022; Booth et al., 2024).

Nature Positive is a concept closely aligned with the Kunming-Montreal Global Biodiversity Framework (GBF), which was adopted at the 15th Conference of the Parties (COP15) in 2022 (CBD, 2022). They share the vision to have more nature[1] in the future than exists today, by halting and reversing biodiversity loss by 2030, and living "in harmony with nature" by 2050 (Booth et al., 2024; zu Ermgassen et al., 2022; Dasgupta, 2021; see Appendix A for footnotes). Nature Positive addresses both direct and indirect impacts across the whole value chain, setting strict "No Net Loss" (NNL)/ "Net Gain" goals underpinned by the four steps of the Mitigation Hierarchy (MH; Figure 1; Milner-Gulland, 2022; Arlidge et al., 2018). These include two preventative measures – (1) Avoidance of impacts and (2) Reduction of unavoidable impacts, and two compensatory – (3) Restoration and (4) Offsets for residual impacts. It is imperative that these compensatory measures are "like-for-like", where the ecosystems restored match those that were originally affected, and that each step in the MH is only considered when the previous has been implemented as fully as possible (Maron et al., 2024). Several initiatives have been developed to help businesses and large organisations move towards Nature Positive, including Science Based Targets Network (SBTN)[2], Taskforce for Nature-related Financial Disclosures (TNFD)[3], and the Mitigation and Conservation Hierarchy (MCH), all built on the foundations of the MH (Arlidge et al., 2018; zu Ermgassen et al. 2022). In particular, the MCH, an extension of the MH, incorporates further contributions towards nature recovery, recognising actions that support biodiversity but do not meet criteria to qualify as formal compensation (Milner-Gulland et al., 2021). Acknowledgement of these contributions is thought to encourage businesses to take responsibility for biodiversity impacts beyond their direct

[1] The "abundance, diversity, integrity and resilience of species, ecosystems and natural processes" (Nature Positive Initiative, n.d.).
[2] A 2019 NGO-founded initiative, that develops targets for cities and companies to address environmental impacts (SBTN, 2022).
[3] 2020 Initiative consisting of corporates, financial institutions, and market service providers. Provides recommendations on nature-related decisions (TNFD, 2023).

value chain, playing an essential role in driving broader transformative change[4], necessary in delivering the GBF and a Nature Positive future (Figure 1; Booth et al., 2024).

Whilst it is widely recognised that businesses and large organisations have a key responsibility in achieving Nature Positive, and setting Net Zero targets has become standard, clear strategies for movement towards Nature Positive are rare (Bull et al., 2022; Berger et al., 2018). Those that do exist seldom focus on impacts outside the direct control of a business or organisation, and footprinting assessments of the whole value chain have revealed that direct impacts only account for a small proportion of total biodiversity impacts (Bull et al., 2022; Kering, 2021; Puma, 2011; Thurston & Eckleman, 2011). As many organisational footprints are dominated by supply chain impacts, this demonstrates that to move towards the Nature Positive goal, it is becoming increasingly vital to focus on supply chains. Figure 1 illustrates how the mitigation hierarchy (MH), with further contributions to nature recovery, can be applied to an organisation's supply chains, to tip the scales from biodiversity loss to Nature Positive outcomes.

[4] A systemic and fundamental reconfiguration "across technological, economic and social factors", normalising sustainability (Díaz et al., 2019)

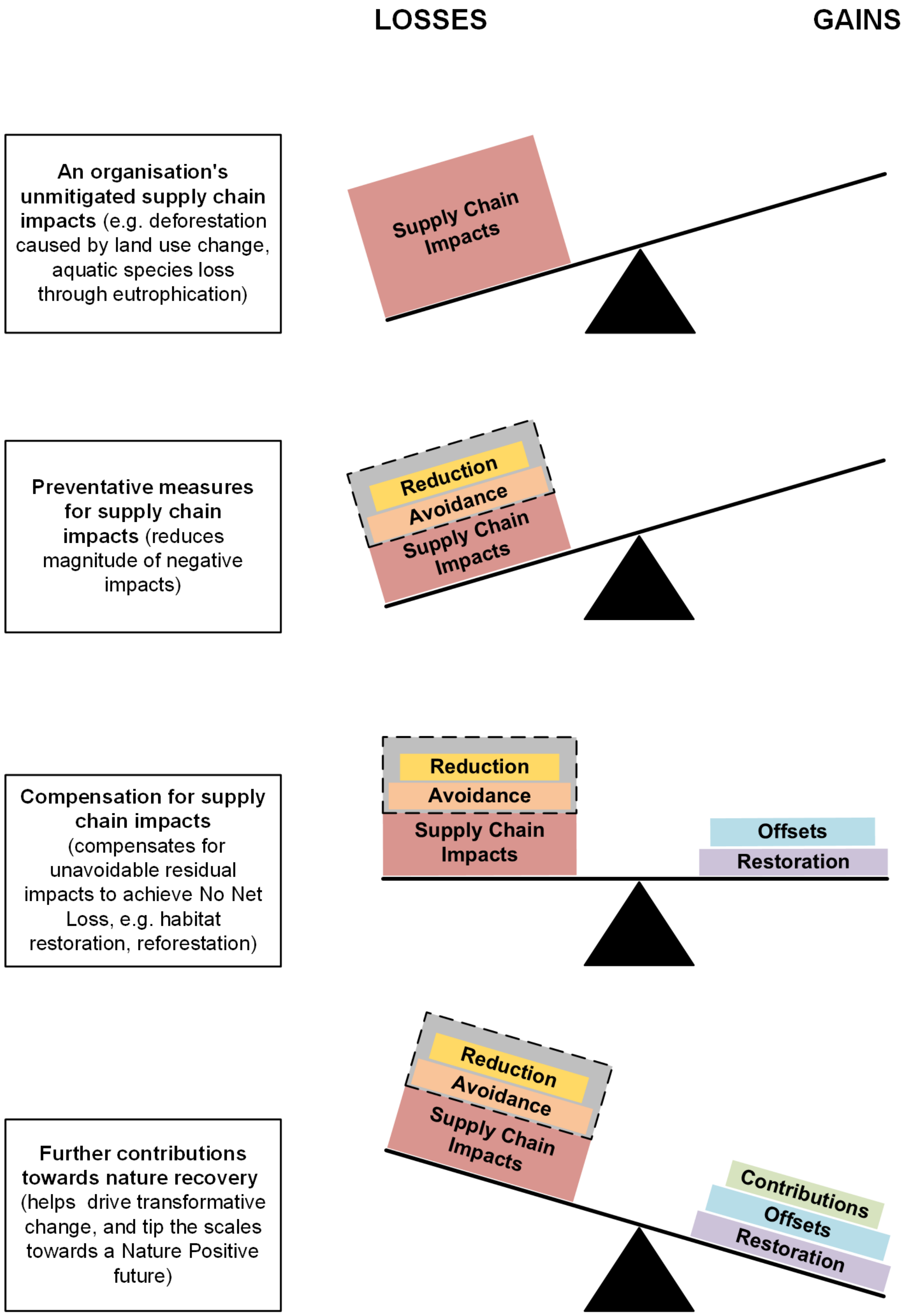

FIGURE 1: **Tipping the scales for supply chain impacts through the mitigation hierarchy and further contributions to nature recovery, towards a Nature Positive future.** Applying the four sequential steps of the mitigation hierarchy (MH) – Avoid, Reduce, Restore, Offset - to an organisation's supply chains can decrease negative impacts (represented by the smaller supply chain impacts box), and compensate for residual impacts, leading to "No Net Loss" (represented by the balanced scales). The Avoid and Reduce steps are shown in a dashed grey box, indicating their preventative role in biodiversity loss. When the MH is fully implemented, and supported by further contributions to nature recovery, these actions can tip the balance beyond No Net Loss, towards Nature Positive outcomes (see the final scales). This figure was inspired by graphics from The Biodiversity Consultancy and the Business and Biodiversity Offsets Programme (TBC, n.d.; BBOP, n.d.)

Understanding Nature Positive within Organisational Contexts

The concept of Nature Positive, operationalised through the MH, requires organisations to balance the biodiversity losses they cause with measurable gains for nature (see Figure 1; Milner-Gulland, 2022; Arlidge et al., 2018). These losses include land degradation, deforestation, and species extinction, and are often driven by environmental pressures such as land-use change and eutrophication. Whilst these pressures can result from both direct and indirect activities, the complex nature of indirect supply chain impacts, coupled with the growing evidence that they comprise most of an organisation's biodiversity footprint, emphasises their need for greater focus (Bull et al., 2022; zu Ermgassen et al., 2022). To effectively compensate for negative supply chain impacts through nature gains, including regeneration and restoration, whilst simultaneously minimising them as much as possible, it is important for organisations to understand the type, scale, and location of impact. This enables identification of where and what kind of compensation and contributions are necessary to achieve true net gain (Arlidge et al., 2018; BBOP, 2012; Cole et al., 2021).

A particular challenge in addressing supply chain impacts is that many contributing products are deemed essential, both for organisational operations, and due to socioeconomic reliance in supplier countries, meaning much of the mitigation must be compensatory rather than preventative. This was evident in Oxford's biodiversity footprint analysis, where supply chain impacts for research commodities including plastics and chemicals contributed substantially, but halting their purchase was unfeasible due to their role in research activities (Bull et al., 2022). Socioeconomic factors further complicate mitigation, as global value chains (GVCs) support exporting countries' economic development, with low-income countries often depending on GVC-linked exports for a large share of their GDP (Glushkova et al., 2019; Chawla & Kumar, 2023). Therefore, whilst compensation steps of the MH are controversial due to concerns such as "Greenwashing" and ensuring "like-for-like", they are essential to reaching Nature Positive, and urgently need exploration if supply chain impacts are to be addressed (Maron et al., 2024; Damiens et al., 2020).

Traceability and Transparency

A foundational step towards appropriately addressing supply chain impacts is establishing raw material source locations, so the affected ecosystems can be identified. However, supply chains have multidimensional complexity, arising from multiple intermediary suppliers or distributors[5] (vertical complexity), and many compound materials (horizontal complexity; Bode & Wagner, 2018; Choi and Hong, 2002). This leads to low traceability (a company's ability to determine product origins) and transparency (disclosure of this information), making it difficult to establish commodity origins (Grimard et al., 2017; Sodhi & Tang 2019).

[5] Purchase products from other suppliers and sell to buyers (Smith et al., 1997)

Whilst there have been studies focused on tracing supply chains and improving transparency, these often use large datasets, and focus on specific commodities at a national or regional scale, such as the soy supply chain in the Brazilian Amazon, or palm oil in Indonesia (Ermgassen et al., 2020, Ermgassen et al., 2022). Studies taking a bottom-up approach are less common, and those that do exist have tended to focus on how suppliers impact transparency, rather than investigating the extent of traceability and transparency in a single organisation's supply chains (Yang & Lu, 2024). Furthermore, whilst there are several tools being developed to improve traceability and transparency including the Trase mapping tool and OpenSC to verify sustainable supply chains, there is no current guidance for companies and organisations on how to approach this complexity, or what interim actions should be taken (Trase, n.d.; West et al., 2022; Kurth et al., 2021).

Scope of Study

In this study I examined how a large organisation might address their supply chain impacts to move towards a Nature Positive future, using the University of Oxford as a case study. My research questions were:

1. **How much traceability and transparency is there in the University of Oxford's supply chains?**

2. **How can the University of Oxford trace and estimate the biodiversity impacts of products, to plan mitigation actions?**

3. **What opportunities does the University of Oxford have to mitigate supply chain impacts, including compensation for residual impacts and further contributions to nature recovery?**

This is the first piece of work to examine supply chain flows of a single organisation, through a bottom-up approach, to allow for informed decision-making regarding supply chain impacts. It provides a fundamental step towards the University of Oxford achieving its Nature Positive goal and presents a conceptual framework that could be applied to other businesses and organisations, to tackle their own supply chain impacts, on the pathway to Nature Positive.

2 Methodology

Methods Overview

To examine Oxford University's supply chains and explore opportunities for mitigation, I structured my research into three parts (Figure 2). I collected information from Oxford's top spend suppliers to address Question 1, to investigate the extent of Oxford's suppliers' knowledge of the raw materials and origins of their purchased products. To address Question 2, I used Oxford's food purchasing data and Life Cycle Impact Assessment (LCIA) methodology to assess the biodiversity impact of one case study product, coffee, at its source, and identify the key pressures driving biodiversity loss. Finally, to approach Question 3, I conducted a survey to identify global collaborations of Oxford biodiversity and conservation researchers. Using insights from the survey and LCIA modelling, I developed a matrix of potential interventions along the coffee supply chain, in alignment with the MH and further contributions to nature recovery. Together, this informed the development of a conceptual framework which could allow other businesses and organisations to address their own supply chain impacts.

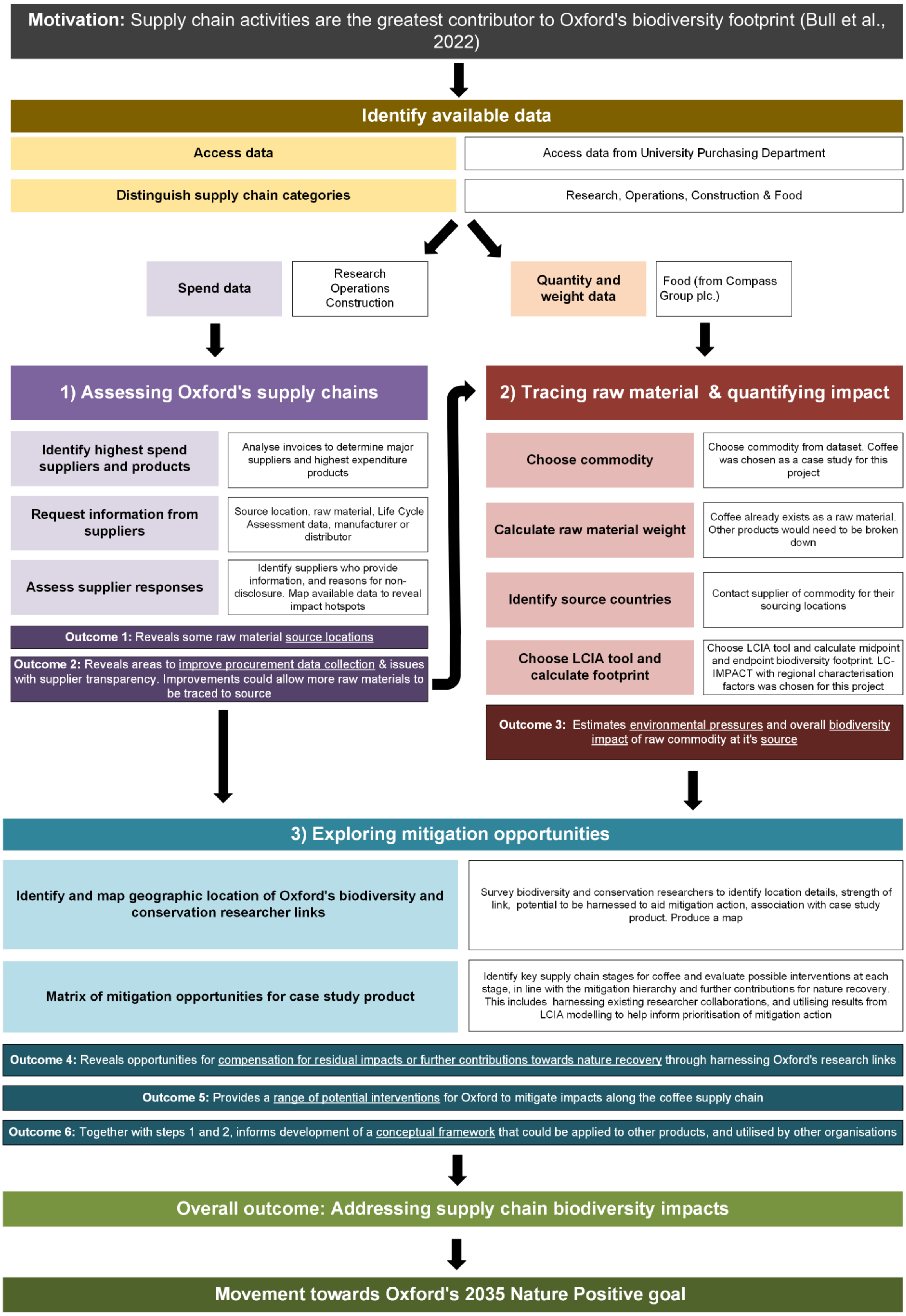

FIGURE 2: **Multi-stage flow diagram to illustrate my methodological approach.** The numbered steps correspond to my research questions and method section headings. Lighter boxes detail how each step was carried out, whilst darker boxes indicate expected outcomes. Steps 1 & 2 are in shown in parallel to reflect actions taken concurrently to address both spend and quantity/weight data. The arrow from Step 1 to Step 2 indicates that Step 1 outcomes (improved procurement data) could support application of Step 2 (more location-specific biodiversity footprints).

2.1 Assessing Oxford's Supply Chains

2.1.1 Oxford's biodiversity footprint

In March 2021, the University of Oxford initiated an Environmental Sustainability Strategy, aiming for Net Zero and Nature Positive by 2035, with the latter being sector leading. They began by identifying activities with the greatest impact on biodiversity by analysing the University's biodiversity footprint, revealing that the biggest contributor was through supply chain-associated activities (Bull et al., 2022). These results, along with the annual repetition of the report, and Oxford's global influence and financial capacity, made the University an ideal case study to examine how a large organisation might tackle supply chain biodiversity impacts (Figure 2).

2.1.2 Identifying categories and analysing data

To identify supply chain categories with the greatest biodiversity impacts, I used categorisation from Oxford's annual biodiversity footprint analysis. Impacts on biodiversity caused by the University can be divided into "Aspects" and broken down into "Descriptions" which define the supply chain category (Bull et al., 2022; Figure 3).

Within the two Aspects that contain supply chain-related activity data ("Resource Use & Waste", and "Built Environment"), I identified three supply chain-associated Descriptions:

- Research supply chain
- Operations supply chain
- Construction supply chain

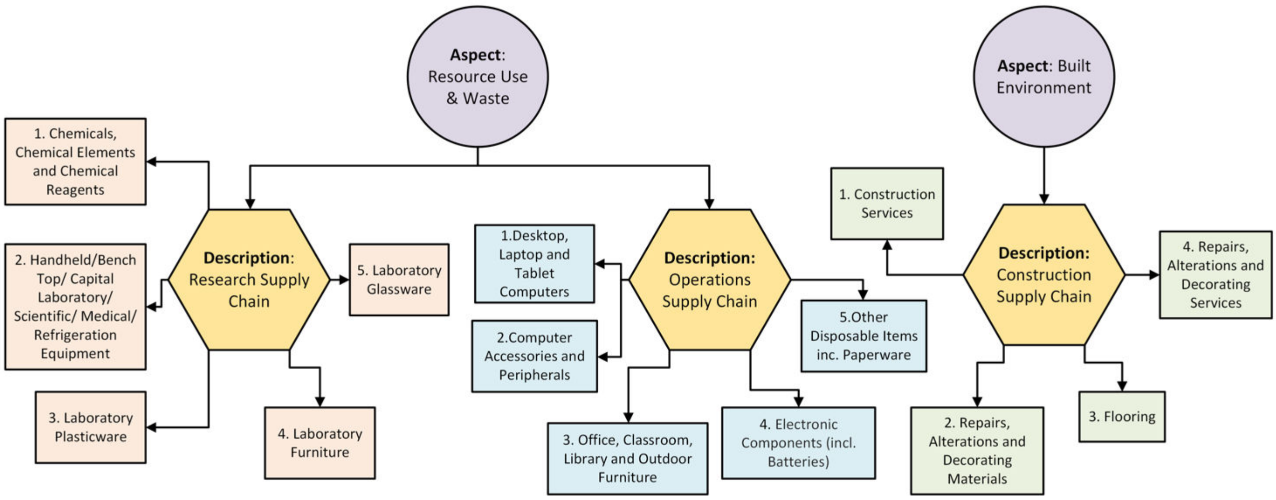

FIGURE 3: **Diagram illustrating the breakdown of Oxford's purchasing data into supply chain categories and subcategories associated with different University activities.** The purple circles represent the "Aspects" where supply chain-related activities are quantified: "Resource Use & Waste", and "Built Environment". The three yellow hexagons depict the supply chain categories associated with these Aspects, known as "Descriptions". Finally, the rectangles show the top spend subcategories within each Description, also known as "Purchasing Category Item Descriptions" (PCIDs).

To establish suppliers and products for enquiry, I analysed Environmental Profit and Loss (EP&L) data, which quantifies environmental impacts of University activities, alongside raw data provided by Oxford Purchasing Department (OUP). The data used was from the financial year 2022/23, as this was the most recent, complete set. Whilst the data contained item-level spend details, it lacked weight or quantity of items purchased.

Using both datasets, I broke down each Description into subcategories known as "Purchasing Category Item Descriptions" (PCIDs; rectangles in Figure 3). I included all PCIDs for Research and Construction, but selected the top five by spend from Operations, as investigating all 29 was not feasible (see Appendix B for all PCIDs).

I identified the top ten highest spend suppliers for each PCID, and top three spend products, removing misclassified invoices (Figure 2, Step 1). These outputs were then cross verified by manual review of invoices for all physical consumables across the top ten suppliers in each Description. In total, I identified 131 suppliers: 50 each for Research and Operations (10 per PCID), and 31 for Construction (only one supplier in the "Flooring" PCID listed physical commodities). Whilst curating the data for analysis, I also documented limitations, such as spend items being categorised in the wrong PCID, to identify points of action for procurement (Appendix C).

2.1.3 Exploring traceability and transparency

To assess the extent of Oxford's knowledge about their product raw materials and origins, I contacted suppliers via targeted emails, inquiring about (a) raw materials used in their products, (b) the source locations, and (c) whether Life Cycle Assessments (LCAs) had been conducted, with related data (e.g. carbon footprints) available (see Appendix D for email template).

I documented receipt of replies, the ability to provide requested information, and, where applicable, reasons for non-disclosure. Finally, I questioned if the supplier was a distributor or a manufacturer, to better understand the vertical complexity of Oxford's supply chains (Smith et al., 1997). I recorded if these distributors were willing to ask for more information from their suppliers, providing transparency insight.

To visualise the flow of information from suppliers, I constructed a Sankey diagram using the "PantaRhei" R package (Bogaart, 2020; R Core Team, 2023). I also used R to map data from suppliers able to provide both raw material and source location, to illustrate the global spread of Oxford's supply chains.

2.2 Tracing & Estimating Impacts

2.2.1 Case study: Coffee

To present a case study for how an organisation might trace a raw commodity's origins and estimate biodiversity impacts, I used data from the Food supply chain, categorised in a separate food-related Aspect (Figure 2, Step 2). Unlike Research, Operations and Construction, which contain spend data for several suppliers, Food supply chain data comes from a single supplier, containing quantity and weight purchased.

Coffee (*Coffea arabica* and *C. canephora,* the two main cultivated species; Perrois et al., 2014) provided an ideal case study, as weight data is more consistent than cost, which often fluctuates due to macroeconomic factors. Additionally, coffee is a raw material, reducing supply chain complexity compared to compound products. It also represents a high impact product where a complete halt to purchasing is unfeasible, as whilst coffee has been found to have a large biodiversity footprint, it also has high socioeconomic importance, contributing substantially to GDP and employment in sourcing countries, which must be factored into mitigation actions (Treanor & Saunders 2021; Fairtrade Foundation 2021; Karuri, 2021).

To calculate the estimated weight of coffee purchased by the University of Oxford in 2022/23, I sourced food purchasing data from Compass Group plc, a multinational foodservice company supplying 19 cafeterias across Oxford. This data was extracted from the larger company procurement platform and included all purchasing for the 1st of August 2022 to 31st July 2023. There are nine other Oxford cafes not supplied by Compass, so I extrapolated the data to account for these (see Appendix E for assumptions). I filtered the data for roast, ground, and whole bean coffee, and multiplied "Pack Size" (weight per pack) by invoice quantity to calculate the total coffee mass purchased. Through communication with Compass, I established that "Change Please Coffee" supply coffee sold in Oxford cafeterias, and through contacting this supplier, identified its five sourcing countries: Columbia, Peru, Brazil, Honduras, and Burundi.

2.2.2 Life Cycle Impact Assessments

One tool increasingly being used to measure biodiversity impacts is Life Cycle Impact Assessment (LCIA) models, which estimate the impact of a product or service on biodiversity, extending the Life Cycle Assessment (LCA) methodology (Carneiro et al., 2017; Hellweg et al., 2023; Figure 4). As biodiversity impacts are complex to measure, this has resulted in several different LCIA frameworks, each measuring biodiversity loss in different units, with different calculation decisions, leading to multiple uncertainties (Ermgassen et al., 2022; Lammerant et al., 2021; Bromwich et al., 2025). For example, models have different characterisation factors (CFs), which are multipliers used to convert activity data into pressures on biodiversity. Furthermore, within a model, CFs can be based on global averages or be country-specific, allowing for additional discrepancies in the final footprint (Bromwich et al., 2025, Martínez-Ramon et al., 2024).

Despite these assumptions and choices, LCIA models offer the only standardised and transparent method for estimating biodiversity impacts across a range of activities and environmental pathways, providing a key practical and analytical starting point for organisations to understand and address their biodiversity impacts (Bromwich et al., 2025; Verones et al., 2020; Huijbregts et al., 2016).

2.2.3 Midpoint calculations

To convert the weight of coffee purchased by Compass into pressures on biodiversity, I sourced country-level midpoint CFs from Poore & Nemecek (2018; Figure 4; Appendix F, Table A1). These CFs represent the mean environmental pressure of a particular food item per functional unit (e.g. per kg coffee) and can be multiplied by the functional unit to estimate the impact of a particular pressure (e.g. per m^2 of land).

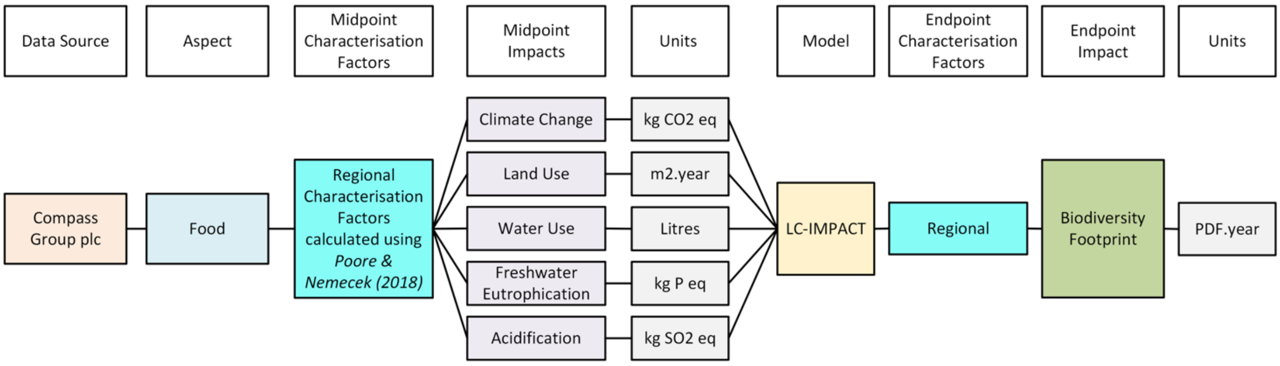

FIGURE 4: **Schematic demonstrating the assessment framework used to calculate the biodiversity footprint of Oxford's coffee.** The characterisation factors (CFs) used are shown in blue, "Midpoint Impacts" represent the environmental pressures, and the chosen model is shown in yellow. This was adapted from Bull et al., (2022).

I assessed the biodiversity impact of coffee at a regional level: South America, Central America, and East Africa. This choice was motivated by a lack of country-specific midpoint CFs for three of the five countries (Burundi, Honduras, and Peru; Poore & Nemecek, 2018). In addition, acidification and freshwater eutrophication midpoint CFs were not available at country-level for Colombia. To calculate the impact of coffee at a regional level, I averaged country-level midpoint CFs for each environmental pressure and region, and multiplied these by coffee weight, assuming the total weight was split equally between regions (see Appendix G for a sensitivity test of this assumption). As Kenya was the only country with midpoint CFs available in the East Africa dataset, its CFs represented this entire region. Furthermore, Kenya lacked CFs for freshwater eutrophication and acidification, meaning there were no regional-level midpoint CFs for these pressures. To complete calculations for East Africa, global averages were used.

2.2.4 Endpoint calculations

I used the LC-IMPACT LCIA framework to convert these midpoint pressures into the endpoint impact on biodiversity (Figure 4). This model calculates overall loss of biodiversity using the metric "Potentially Disappeared Fraction of species per year" (PDF.year), which can be understood as the fraction of species with increased risk of irreversible global extinction over a certain time (Verones et al., 2020). This model was chosen because it has more endpoint CFs with regional specificity compared to other models (e.g. ReCiPe), allowing impact differences between geographies to be captured to a greater extent (Verones et al., 2020; Bromwich et al., 2025). The country-level endpoint CFs used to calculate regional endpoint CFs for each pressure can be found in Appendix F, Table A4. As LC-IMPACT lacks multipliers to convert environmental pressures into units compatible with endpoint CFs, multipliers from the alternative model, ReCiPe, were utilised where necessary (e.g. to convert PO4 to P equivalent; Appendix F, Table A2).

To incorporate a quantitative estimate of uncertainties within these models, I calculated the biodiversity footprint of coffee using three other methods: LC-IMPACT, and ReCiPe, with global and regional endpoint CFs (Appendix H). I also used Spearman's rank to investigate if the relative ranking of midpoint pressures for South America remained consistent when using different LCIA models or endpoint CFs, as ranking differences could affect mitigation strategies (Appendix I). This test was suitable as it evaluates the monotonic relationship between variables, allowing for exploration of parametric uncertainties (spatial specificity of CFs) and interrogation of decision-based uncertainties associated with model choice (Bromwich et al., 2025).

2.3 Exploring Mitigation Opportunities

2.3.1 Researcher survey

To investigate a strategy for how Oxford could approach supply chain impact mitigation, and contribute to nature recovery, I designed and distributed a survey to Oxford's biodiversity and conservation researchers. The survey aimed to map global collaborations and establish whether they align with locations that Oxford's suppliers source raw materials, assessing if links could be harnessed to address Oxford's supply chain impacts (Figure 2, Step 3).

I developed the survey using Microsoft Forms and conducted it with ethics approval (MS IDREC reference number: 933634). Participants were recruited via snowball sampling, beginning with advertisement in relevant newsletters such as the "Ecology and Conservation" section in the Department of Biology. This method was well-suited as there is no centralised database of researchers working on subjects relevant to supply chain impact mitigation and it allowed for collection of a diversity of links within the project timescale. The survey consisted of 15 questions for each collaboration, with the option for respondents to submit five collaborations in total (Appendix J).

The survey gathered data on collaboration locations, institutions involved, and strength of the links. It also asked researchers if they believed their collaboration could support actions to mitigate Oxford's supply chain impacts, and whether they were associated with coffee, or in a coffee growing area. This was done to determine whether Oxford had research links in sourcing regions of the case study commodity. I visualised survey data through a series of three maps, created using R packages “maps” and “countrycode” (Becker et al., 2022; Arel-Bundock, 2025; R Core Team, 2023).

2.3.2 Construction of coffee supply chain matrix

To consider appropriate mitigation actions for coffee, I developed a matrix of potential interventions for each supply chain stage, aligned with the MH and further contributions for nature recovery. I conducted a non-systematic literature review to identify key stages in the coffee supply chain and provide examples for how the MH could be applied at each stage, aided by insight from the researcher survey. In addition, results from LCIA modelling (part 2.2), supported by the literature, were used to identify the dominant environmental pressures at the two source-level supply chain stages.

3 Results

3.1 Step One: Unveiling Oxford’s Supply Chains

3.1.1 Oxford’s supply chains lack visibility

Investigation into Oxford’s Operations, Research and Construction supply chains revealed that only two of 131 suppliers could provide information on raw materials, source locations, and product Life Cycle Assessments (LCAs), with both suppliers coming from the “Office, Classroom, Library and Outdoor Furniture” PCID in the Operations supply chain. Despite endeavours to contact all suppliers, Figure 5 shows there was a sharp decline in engagement and data availability as more detail was requested.

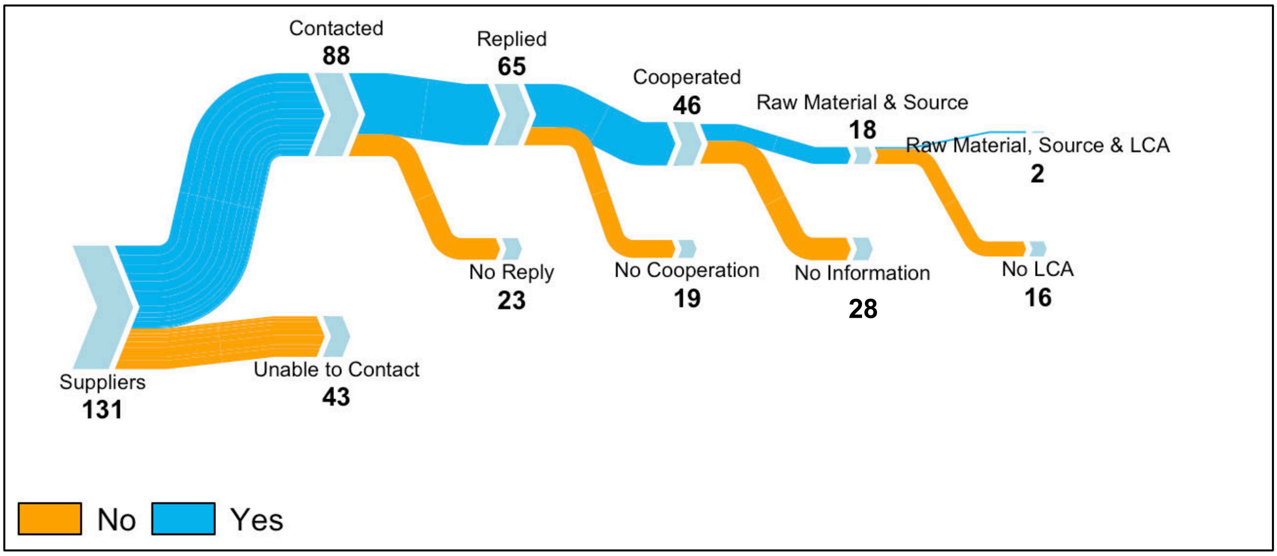

FIGURE 5: **Sankey diagram illustrating the sharp decline in visibility across Oxford’s Research, Operations and Construction supply chains**, from initial identification of suppliers, to detailed commodity-level information. The “Cooperated” stage at node 4 includes suppliers who made an active effort to find out more about their products, even if they were unable to identify raw material or source location. The figure was made using R programming language.

I successfully contacted 88 suppliers, most being from Research (48/50), followed by 32/50 from Operations, and 8/31 from Construction (Figure 5; see Appendix K for more details). Most contacted Construction suppliers (6/8) came from the PCID “Repairs, Alterations and Decorating Materials”, and the primary reason for limited contact was that 68% of Construction invoices were identified as services, rather than traceable physical commodities.

Suppliers were classified as cooperating if they either made efforts or were able to provide information on raw materials, source locations, or product LCAs. Whilst 46/65 (71%) suppliers who replied were willing or able to share some commodity-level information, only 18 could provide raw material and origins for at least one top spend product. This included 13 Research suppliers, four from Operations, and one from Construction. The main reason identified for not providing raw material or origin information was for confidentiality reasons (48% and 43% respectively; Figure 6). Alternatively, 98% of suppliers who replied could not provide product LCAs because this information is not collected. Finally, I found that 48% (42/88) suppliers were distributors, and when asked, only 15 distributors were willing to contact their suppliers for commodity-level information.

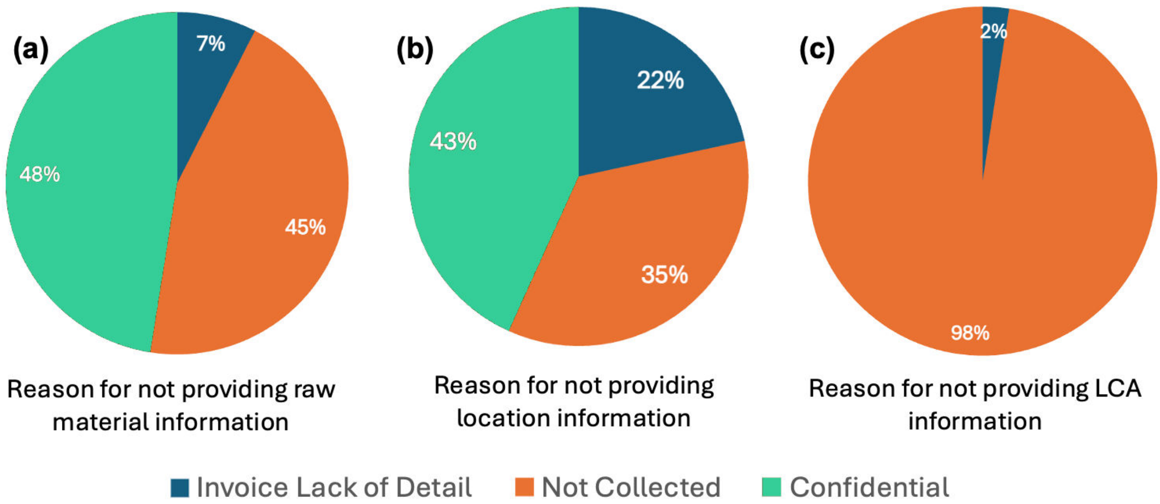

FIGURE 6: **Pie charts showing the reasons why suppliers were not able to provide (a) raw material, (b) source location and (c) LCA information. Dark blue** represents a problem with the invoices, where insufficient detail prevented identification of the product. **Orange** indicates that suppliers do not collect this information. **Teal** represents that the information was confidential and I could not access it.

<u>3.1.2 Data availability was highest for European furniture</u>

Notably, all four Operations suppliers able to provide raw material and origins belonged to the "Office, Classroom and Outdoor Furniture" PCID, with 70% of these materials being sourced from Europe. Whilst the full dataset of materials from 18 suppliers also showed a European concentration (59%), mapping these materials revealed a global spread of Oxford supply chain origins (Figure 7; Appendix K, Table A22).

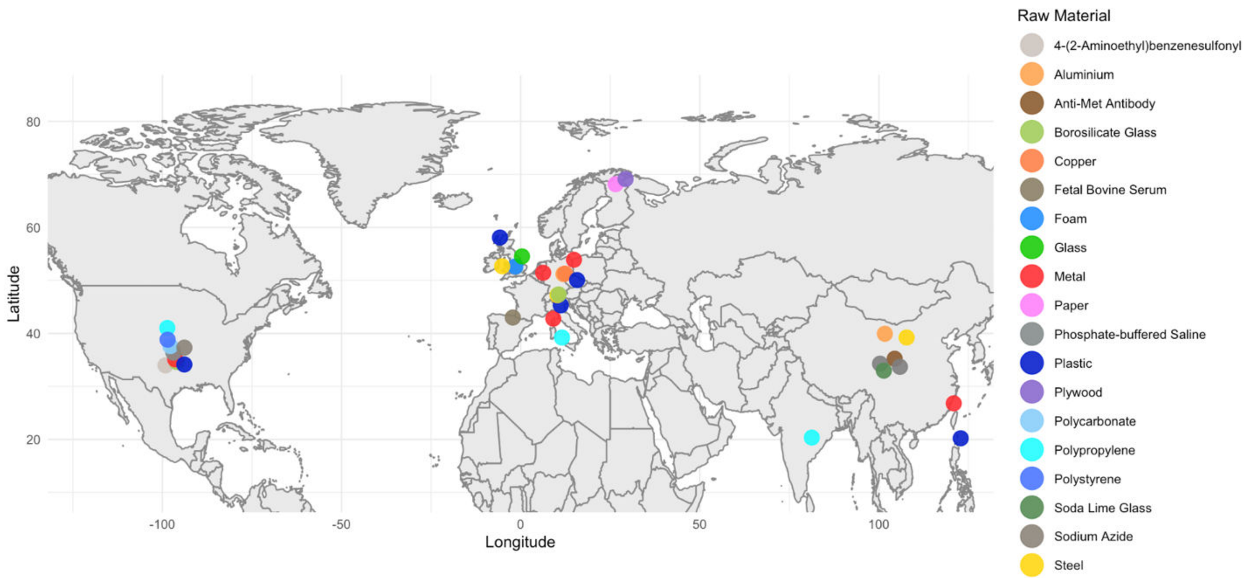

FIGURE 7: **Point map illustrating the global spread of Oxford's supply chain impacts.** Each coloured dot represents the source location of a raw material purchased by the University of Oxford, in the Research, Operations or Construction supply chain. Only spend data is available for these categories, so points are not scaled by quantity or volume. Displaced centroids are used so that all data points can be visualised.

3.2 Step Two: Biodiversity Footprint in Oxford's Coffee-Sourcing Regions

3.2.1 Total biodiversity footprint varied between regions

For the financial year 2022-23, the total biodiversity footprint of Oxford's coffee was estimated at 2.68E-09 PDF.year using the LC-IMPACT methodology and regional endpoint CFs (Figure 4). East Africa's footprint greatly exceeded the other two regions, equalling 1.81E-09 PDF.year, followed by Central America at 5.83E-10 PDF.year, and South America at 2.90E-10 PDF.year (Figure 8; Appendix H, Part I). Assuming equal mass of coffee was sourced from each region, this made the biodiversity footprint of Oxford's coffee in East Africa approximately three times greater than that of Central America, and six times greater than South America. This difference was associated with considerably higher land use per kilogram in East Africa, resulting in the land use pressure accounting for a larger share of the overall impact in this region. Whilst sensitivity testing indicated the endpoint footprint was moderately sensitive to the equal weight distribution assumption, lack of more specific data meant this equal split was considered reasonable (Appendix G).

3.2.2 Distribution of pressure impacts varied between regions

For East Africa and Central America, land use was estimated as the largest contributor to coffee's biodiversity footprint (81% and 44% respectively), followed by freshwater eutrophication and climate change (Figure 8). However, whilst the impact of eutrophication in East Africa was 67% lower than land use, the distribution of these two pressures in Central America was more balanced, differing by only 2%. Whilst land use represented a major pressure across regions, it was not the primary contributor in South America, with acidification accounting for the greatest proportion (28%). This was notable, as acidification was estimated to have a minimal relative impact in the other two regions. In all three regions, water use accounted for a negligible portion of the total footprint.

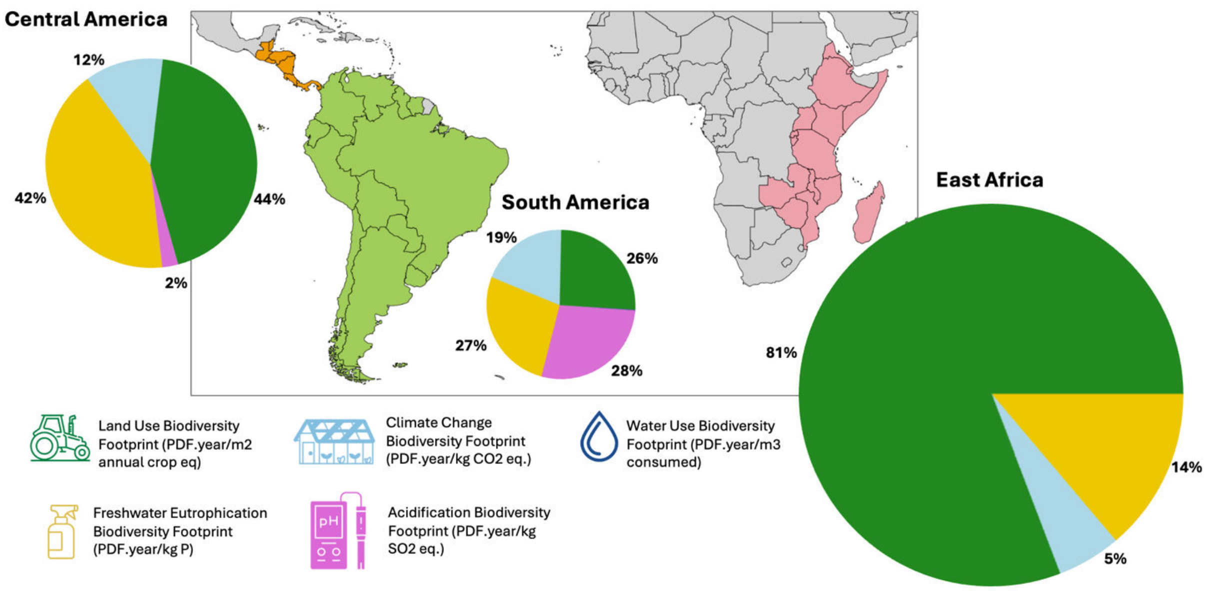

FIGURE 8: **Pie charts showing the proportion of environmental pressures that constitute the total estimated biodiversity footprint of coffee in Oxford's three sourcing regions; Central America, South America, and East Africa.** The size of each pie chart reflects the overall biodiversity footprint. The map and pie charts were produced using R programming language, with icons sourced from Canva.com.

3.2.3 LCIA model and CFs were found to influence pressure distribution

For South America, when using the ReCiPe LCIA model, both methods (global and regional CFs) produced similar results, with land use as the dominant pressure, followed by climate change and acidification (Figure 9; see Appendix H, Part II for comparison in the other two regions; Appendix I for Spearman's Rank). Furthermore, for all four methods, water use comprised a minimal proportion of the footprint.

In contrast, the pressure composition of LC-IMPACT and ReCiPe models, and global and regional CFs for LC-IMPACT, were considerably different. Using LC-IMPACT with regional CFs, acidification and freshwater eutrophication were the main contributors (28% and 27%), whereas for LC-IMPACT with global CFs, most of the footprint was attributed to climate change (39%). This was followed by eutrophication and land use at 28%, with acidification only contributing 4%.

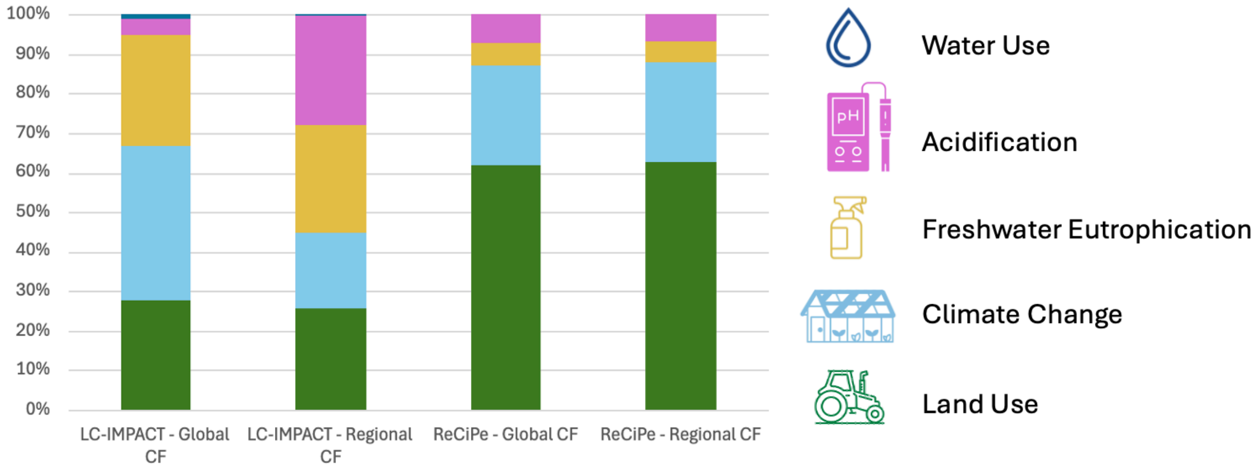

FIGURE 9: **Stacked bar graph comparing the composition of the estimated biodiversity footprint of coffee sourced from South America,** using the two different models (LC-IMPACT and ReCiPe), and either global or regional endpoint characterisation factors (CFs).

3.3 Step Three: Findings from Mitigation Exploration

3.3.1 Collaborations presented opportunities to support mitigation

The 31 Oxford researchers who responded to the survey reported 50 collaborations, distributed across all six inhabited continents. The continent with the highest number of collaborations was Africa (28), and the country with the most was Kenya (six; Figure 10A). Oxford also had a strong research network in Asia (19).

The main institutions involved were Universities and NGOs, with 29 and 28 collaborations respectively. When asked about the nature of these collaborations (participants could select more than one category), most were research-focused (39), followed by on-the-ground conservation (25). Regarding collaboration strength, researchers were asked to rate links on a scale from 1 ("distant and occasional") to 5 ("active and close"), and the majority (48%) selected 5.

Researchers were also asked whether they believed their collaboration could be harnessed to aid mitigation action for Oxford’s supply chain impacts (Figure 10B). Of the respondents, 16% (8) recorded “yes”, whilst 42% (21) entered “maybe”. Africa had the most “yes” or “maybe” responses (20 in total), whilst Asia had the most “yes” answers (5). Collaborations noted as "yes" typically involved direct work with local communities, focusing on conservation interventions, whilst “maybe” responses often reflected opportunities that were indirect or in development (Table 1).

TABLE 1: Table showing whether researchers believe their collaborations could support actions to mitigate Oxford's supply chain impacts, and their reasoning. The first column shows the number and percentage of respondents who selected each of the four options. The middle column lists the main reasons given to justify the researcher's response, whilst the right column provides example quotes to support these points. This data was also used to inform Figure 10B.

Collaboration Could Support Supply Chain Mitigation Action?	Reason Given	Example Quotes
Yes (8 entries, 16%)	The project is directly involved in community-based conservation interventions	*"The project directly feeds into designing and implementing community-based conservation interventions, and experimentally measuring biodiversity and wellbeing outcomes."* *"They are working to conserve a key biodiversity area together with Indigenous communities"*
Maybe (21 entries, 42%)	Project aims include supporting Nature Positive economic activities The project has direct links to farms which could be involved in carbon offsetting	*"We are investigating other activities....one of them is beekeeping...and maybe carbon and biodiversity credits. In this regard, the support and role of Oxford can be pivotal"* *"If Oxford wished to pay farmers to re-forest it could be considered a biodiversity (and carbon) offset"*
Don't Know (7 entries, 14%)	Researcher was not sure if Oxford sourced materials from the country where the research was happening Found it difficult to say what might be possible	*"I am not sure how connected Oxford's supply chains are to Australia"* *"Working in Ethiopia is complex so without know more detail on what this would entail it's difficult to make a judgement"*
No (14 entries, 28%)	The research is not directly involved in conservation	*"It is looking at methods for measuring impacts"*

3.3.2 Coffee-associated collaborations could be harnessed for mitigation

To assess the mitigation potential of research links for coffee supply chains specifically, respondents were asked whether their collaboration was associated with coffee or in a coffee-growing area. 12/50 collaborations indicated associations in 13 countries, with the majority found in South America and Southeast Asia (5 each). No coffee-associated collaborations were reported in Central America, one of the sourcing regions of Oxford's supplier Change Please Coffee (Figure 10C).

All coffee-related collaborations were recorded as having potential to aid mitigation action. Two respondents indicated "yes", both with collaborations in Southeast Asia, which is not a sourcing region of Change Please Coffee. However, most respondents (8) selected "maybe", including the three sourcing countries in South America (Brazil, Colombia, and Peru; Figure 10C).

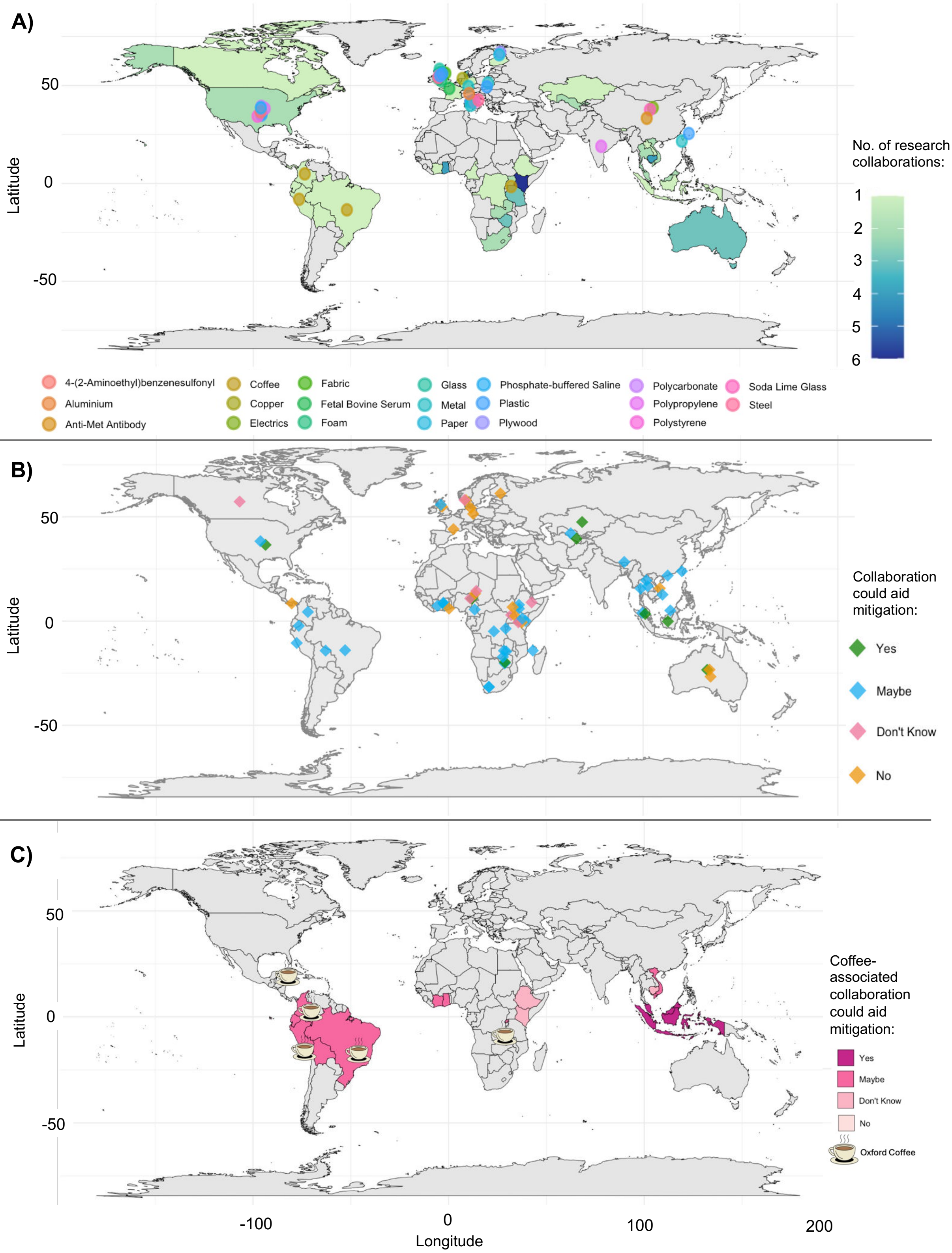

FIGURE 10: **Three maps visualising Oxford's opportunities to harness global biodiversity/ conservation research links for Nature Positive supply chain action.**
(A) Heatmap of research collaborations by country, from most (dark blue) to least (light green), with overlaid points representing raw material sourcing locations across Research, Operations and Construction supply chains. Coffee sourcing locations are also included. **(B)** Map of researcher-identified potential of collaborations to aid supply chain mitigation action, shown as diamond points. **(C)** Heatmap of coffee-associated research links, coloured from dark pink (reported "Yes" for potential to aid mitigation action) to light pink (researcher reported "No" for mitigation potential). Coffee icons indicate current sourcing locations from Oxford's Change Please Coffee supplier. Centroids in 10A & 10B are jittered so that all points are visible.

3.3.3 Intervention matrix developed across coffee supply chain stages

Results from the non-systematic literature review, survey, and LC-IMPACT analysis informed construction of a matrix outlining potential actions the University could take at each stage of the coffee supply chain. Four key stages were identified and included: cultivation, processing, retail, and consumption (Figure 11). Cultivation and processing stages were associated with local impacts in coffee sourcing locations, closely linking them to the midpoint pressures of LC-IMPACT. The leading pressures were found to differ between these stages, with land use and freshwater eutrophication dominating at cultivation, whilst water use and eutrophication were the main pressures during processing. These findings were reflected in the matrix through the mitigation examples given and ordered placement of pressure icons.

	Cultivation (Farm-level)	Processing (Facility-level)	Retail (Cafeteria-level)	Consumption (Consumer-level)
Avoid	**1. Avoid new land and forest clearance** **2. Avoid illegal deforestation** **3. Avoid shifting from shade-grown to sun-grown coffee** e.g. Western Ghats, India, shift to sun-grown negatively impacts biodiversity (Robbins et al., 2020) **4. Avoid toxic pesticides** e.g. Endosulfan, Acetochlor (Tebaldi de Queiroz et al., 2018)	**1. Avoid wet-processed coffee where possible** e.g. Brazil, lower altitude Arabica (*C. arabica*) and Robusta (*C. canephora*; Silva et al., 2000) **2. Avoid use of processing facilities near sensitive ecosystems**	**1. Avoid sourcing from non-certified coffee** e.g. Costa Rica, certified systems provide more ecosystem services (Pico-Mendoza et al., 2020) **2. Sell less coffee, but higher quality** e.g. shade-grown, certified **3. Purchase deforestation-free coffee** e.g. Lavazza with UNDP, world's first deforestation-free coffee (Ecuador), e.g. Rainforest Alliance certified	**1. Reduce number of coffees purchased** **2. Avoid brands where coffee source is unknown (including when purchasing outside of University cafeterias)**
Reduce	**1. Grow coffee varieties requiring fewer inputs and less susceptible to disease** e.g. Batian & Ruiri 11 varieties in Kenya are disease-resistant and need less fertiliser (Kurari 2021) **2. Agroforestry through intercropping with other species** e.g. Intercropping with native Macauba trees in Atlantic Rainforest, Brazil. Positive climate effect & improved coffee productivity (Moreira et al., 2018)	**1. Reduce waste through use of coffee husks as biofuel or compost** (Tamilselvan et al., 2024) **2. Water recycling** e.g. Maximum 40% new water used in each coffee wash cycle in Costa Rica (Adams & Ghaly, 2007) **3. Water efficient processing methods (wet-processed varieties)** e.g."Eco Pulping" in Colombia, Brazil & Kenya - coffee cherries pulped without water (Koskei et al., 2020)	**1. Shift source to certified brand (include this in supplier contracts)** e.g. Organic, Fairtrade, Rainforest Alliance, Bird Friendly **2. Partner with agroforestry or rustic coffee cooperative in region Oxford have research links**	**1. Drink whole cup of coffee to reduce waste** **2. Advocate for a minimum coffee sourcing percentage from agroforestry or rustic coffee farms**
Restore	**1. Landscape restoration for targeted species (i.e. pollinators)** e.g. Restoration for native bees in Costa Rica increases forest cover by 20% & can double landholder profits over 40 years (López-Cubillos et al., 2023) e.g. Restoration in Brazilian Atlantic Forest boosts coffee yield by 10-30% via increased pollination (d'Albertas et al., 2023)	**1. Restoration of wetlands** e.g. In Ethiopia, found to be effective in treating coffee effluents (Berego et al., 2022) **2. Reforestation around processing mills**	**1. Make commitment to restoring degraded areas** e.g. A portion of coffee sales funds land restoration in areas where Oxford source coffee **2. Introduce scheme where for every coffee purchased, a restoration project in source location is funded**	**1. Actively support companies that have made biodiversity restoration commitments, wider than University cafeterias**
Offset	1. **Direct offsetting through riparian buffer restoration** e.g. Central Andes, Colombia, riparian buffers are species rich (Giraldo et al., 2022) **2. Purchase biodiversity credits restoring forest ecosystems in Oxford's source locations** **3. Invest in NGOs funding agroforestry/land restoration in coffee lanscapes** e.g. Conservation International in Peru, Colombia and Brazil, Pan Nature in Vietnam	**1. Wetland construction downstream of coffee processing plant** e.g. In Ethiopia, constructed wetland found to be equally as effective at treating coffee effluent as restored (Mihret et al., 2024) **2. Invest in NGO with clean water initiatives in Oxford coffee sourcing regions** e.g. Nature Conservancy's Water Funds in Colombia & Peru **3. Purchase carbon credits for processing emissions**	**1. Require coffee suppliers to fund offsetting projects as a sustainability commitment**	**1. Donate money to carbon or biodiversity offsetting scheme**
Contribute	**1. Educate farmers on effective use of fertilisers, leveraging research links** e.g. In Vietnam, farmers apply more fertiliser than recommended, resulting in reduced soil fertility through increased acidity (Byrareddy et al., 2019) **2. Create funding mechanism for Oxford researchers to engage in action research in coffee-growing regions** e.g. HARP project in Vietnam & Ghana (NBSi, n.d.)	**1. Fund habitat enhancement or creation around coffee processing facilities** e.g. Pollinator-friendly planting, restoration of native landscapes **2. Invest in clean water infrastructure for communities in coffee sourcing regions** **3. Fund installation of solar panels at coffee processing facilities**	**1. Collaborate with research links to monitor and report on biodiversity benefits** e.g. e.g. HARP project in Vietnam & Ghana (NBSi, n.d.) **2. Require suppliers to aid farmers to shift to accreditation system** e.g. in Kenya, improves farmer livelihood as well as biodiversity (Karuri-Okech et al., 2018) **3. Introduce a coffee levy to fund biodiversity initiatives**	**1. Promote rustic/agroforestry coffee** e.g. through events or student engagement campaigns **2. Provide education on sustainable consumer coffee choices** **3. Set up initiative where each cup of coffee has optional donation towards carbon/biodiversity credits**

Environmental Pressures: Land Use · Freshwater Eutrophication · Climate Change · Acidification · Water Use

FIGURE 11: **Matrix presenting a suite of actions that could be taken by the University of Oxford at each stage in the coffee supply chain (presented horizontally), to support progress towards its Nature Positive goal.** Examples are given for every level of the mitigation hierarchy (where avoidance is preferred), including further contributions that benefit biodiversity ("Contribute"). The icons below "Cultivation" and "Processing" indicate the ranked dominance of midpoint environmental pressures (from LCIA modelling) at these source-level stages of the supply chain.

4 Discussion

Summary of Key Findings

Addressing supply chain impacts on biodiversity is essential for progress towards Nature Positive goals (Bull et al., 2022). This study used the University of Oxford and its purchased coffee as a case study to investigate supply chain biodiversity impacts and identify potential mitigation strategies. In part 1, I found that Oxford's supply chains have low traceability and transparency, highlighting that improved data collection and supplier engagement is needed to meet biodiversity targets (Grimard et al., 2017; Figure 5). In part 2, tracing Oxford's coffee to sourcing regions revealed that biodiversity footprints varied geographically, in both the composition of environmental pressures, and estimated total impact (Figure 8). This underlined the importance of traceability for better accuracy in estimating biodiversity impacts, with the particularly high footprint observed in East Africa illustrating the influence of location-specific data (Bromwich et al., 2025).

Encouragingly, results from part 3 revealed that Oxford's global network has the potential to be harnessed to aid supply chain mitigation (Figure 10), and integrating LCIA modelling, survey responses, and the literature, enabled development of a matrix of potential interventions for the coffee supply chain (Figure 11). Collectively, these components allowed for the creation of a conceptual framework, offering a transferrable tool to aid other businesses and organisations in assessing and mitigating their own supply chain impacts (Figure 12).

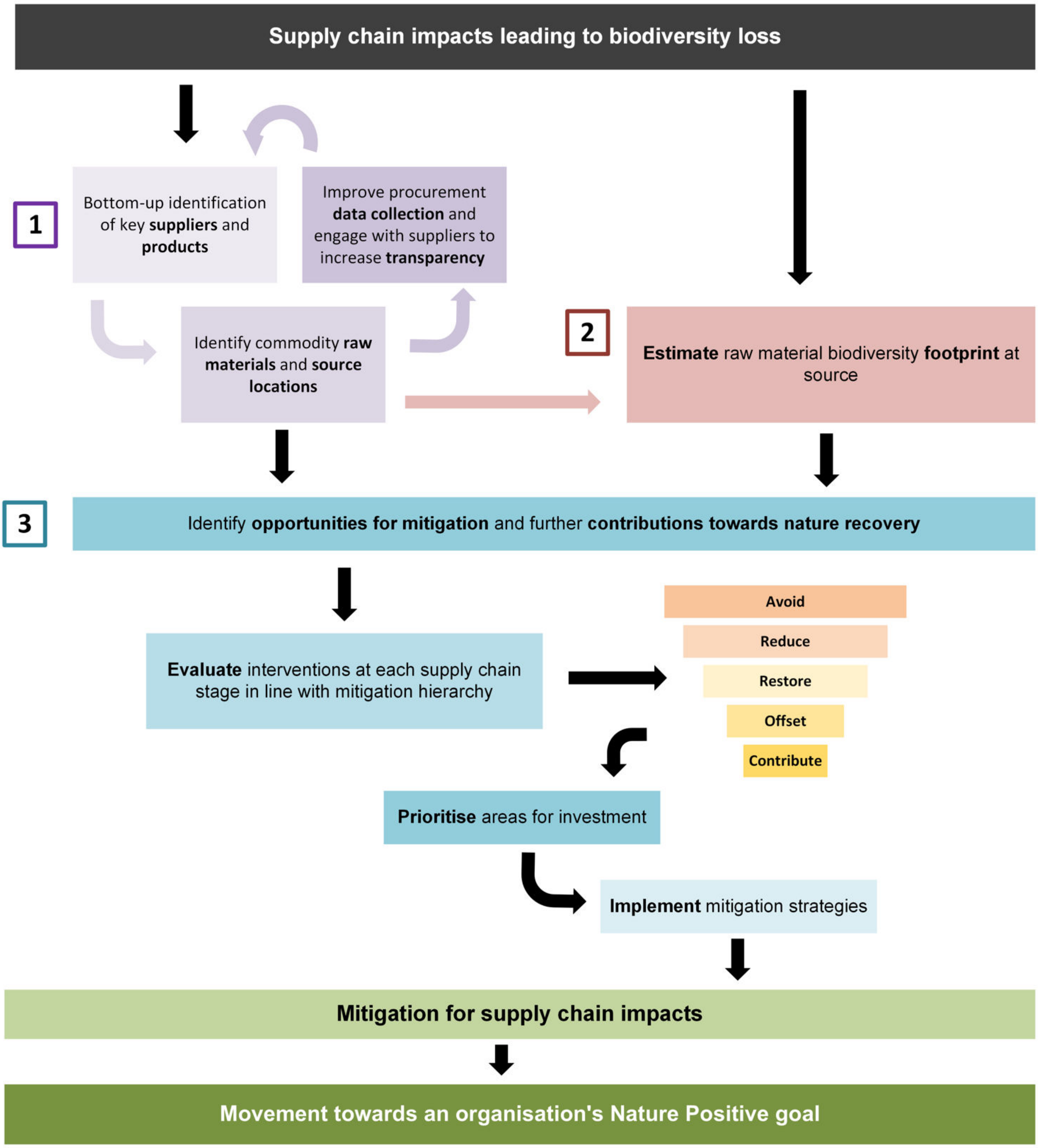

FIGURE 12: **Generalised conceptual framework for how a business or organisation could address biodiversity impacts in their supply chains, to move towards Nature Positive goals.** Numbers and colours correspond to the three research questions, methodological steps, and results sections. Circular arrows in Step 1 illustrate how improvements in supplier relationships and data collection could increase raw material and source identification. Steps 1 & 2 are shown in parallel to reflect their ability to be carried out simultaneously, and the inverted pyramid represents the mitigation hierarchy, and further contributions to nature recovery ("Contribute"). This framework is based on the methodology developed using the University of Oxford as a case study organisation, and coffee as the case study commodity. In Step 3 of the Oxford example, opportunities for compensation and further contributions to nature recovery were explored through identification of Oxford's global researcher collaborations, which could be harnessed to support mitigation action.

4.1 Delving into Oxford's Supply Chains

4.1.1 Complexity clouds clarity

The lack of traceability in Oxford's supply chains was demonstrated by only 18 of 131 identified suppliers providing information on the product origins and raw materials, and only two also providing LCA data. Within Operations, all traceable materials were from furniture suppliers, sourced from Europe. As furniture generally involves fewer components than products such as laptops (lower vertical complexity), and sourcing within Europe could mean fewer intermediary suppliers (lower horizontal complexity), this suggests an association between increased traceability and decreased complexity (and vice versa; Bode & Wagner, 2018; Choi & Hong, 2002).

This was further supported by the finding that 42 of Oxford's suppliers were distributors, adding additional tiers to the supply chain. This increased vertical complexity could help explain the overall low traceability (Sarpong 2014; Choi & Hong 2002). Additionally, only 15 distributors were willing to contact their suppliers for more information, suggesting increased complexity might also reduce transparency.

4.1.2 Counting carbon – and little else

Very few suppliers (5/131) provided LCA data, and those that did could only provide carbon footprints. This lack of LCA data is likely to reflect the absence of legal requirements for companies to carry out product-level LCAs, resulting in low prioritisation (Ciroth et al., 2019). Furthermore, the sole availability of carbon footprints could be explained by the existing regulations and expectations for carbon, including the UK Emissions Trading Scheme (UK ETS) and voluntary ISO 14040/14044 gold standard for LCAs (ISO, 2006a; ISO, 2006b; Gov.UK, 2024). As carbon footprinting tools are already well-established, including the Greenhouse Gas Protocol, and Higher Education Supply Chain Emissions Tool (HESCET), this makes them more understandable and affordable, potentially facilitating greater uptake (WRI & WBCSD, 2004; BUFDG & HEPA, 2023).

4.1.3 Limitations and future directions

These results are problematic for organisations attempting to achieve Nature Positive goals, as whilst large-scale estimates using platforms such as "Trase" offer alternatives, they cannot replace actual organisational data for specific supply chains (Trase, n.d.). The fact that only two suppliers provided all requested product information highlights the limited progress made in supply chain traceability and transparency, and the need for more bottom-up assessments.

Procurement issues and low supplier knowledge have implications for future efforts. For example, if quantity and weight data were collected, and supplier relationships improved, this could result in greater availability of raw material and origin information. Subsequently, this could enhance biodiversity footprint precision for more raw materials (Figure 12, Step 2). Future efforts would also benefit from including procurement from Oxford colleges, which are likely to have substantial supply chain impacts.

Finally, waste, and recycled materials were not considered in this study, focusing instead on upstream supply chains for raw materials. Further work would benefit from considering "the circular economy"[6] for impact mitigation, as this would both reduce waste and prevent further resource extraction. This supports broader transformative change - necessary for a Nature Positive future (Ruokamo et al., 2023; Booth et al; 2024).

4.2 Coffee's Footprint

4.2.1 The importance of geography

Estimating the biodiversity footprint of Oxford's coffee revealed regional variation, not only in overall impact, but also in the environmental pressures combining to form the footprint. This reflects the literature, which highlights the significance of product origins when considering biodiversity impacts (Bromwich et al., 2025). In this way, more location-specific biodiversity footprint estimations could aid decisions on where mitigation should be focused, and what pressures should be targeted. For example, land use in East Africa made up a large proportion of the footprint, suggesting land restoration actions in this region could be prioritised to address Oxford's coffee supply chain. This also demonstrated how LCIA results (part 3.2), and the matrix of mitigation actions (Figure 11) could be used in tandem.

However, comparisons across LCIA models and CF geographical specificity for South America demonstrated that the relative contribution of environmental pressures varies with these choices (Figure 9; Huijbregts et al., 2016; Verones et al., 2020). Whilst this highlights that uncertainty must be acknowledged in footprinting, it also underlines the importance of location-specific CFs, and bespoke on-site LCAs for specific production systems in particular geographies, to better estimate key pressures associated with different products.

4.2.2 Limitations and future directions

Though I minimised assumptions and limitations to the greatest extent, they remain a key source of uncertainty when calculating biodiversity footprints (Bromwich et al., 2025; Appendix E). For example, Kenya midpoint CFs were used as a proxy for East Africa, due to data availability limitations. Whilst this allowed for region-specific impacts to be estimated, it introduced uncertainty through assuming similarities in ecology and agriculture across East Africa. Additionally, CFs were not species-specific, overlooking ecological and production differences between coffee varieties such as *C. arabica* and *C. canephora* (Bunn et al., 2014). Furthermore, country-level CFs lacked

[6] Sustainable economic model incorporating recycling, reduced waste, and design improvements (Ruokamo et al., 2023).

confidence bounds, making it difficult to assess the uncertainty of results, which would also be expected to increase when averaging for regional estimates. Therefore, to increase accuracy of LCIA tools and reliability of results to help inform decision making, it is important to improve both the location-specificity of data and uncertainty estimates for CFs.

Using Kenya as a proxy for East Africa could help explain the greater biodiversity footprint and land use pressure of East Africa's coffee, as Kenya has poor coffee yields, producing around 474 kg/ha compared to 1950kg/ha in Brazil (Wairegi et al., 2018; Bacsi et al., 2022). This lower productivity means Kenya requires more land than other sourcing countries to produce the same mass of coffee. One reason for this is climate change causing increased temperatures and associated pest damage, which could also help explain why eutrophication is the second most significant pressure in East Africa's footprint, followed by climate change (Jaramillo et al., 2011). On one hand, Kenya is a good representative for East Africa, as other countries in the region also have lower coffee yields on average than South and Central American countries (e.g. up to 1268kg/ha/year in Burundi; Kagisye et al., 2024). However, on the other hand, Kenya's productivity is particularly low, suggesting that if midpoint CFs were available for other East African countries, the contrast between regions may not have been so great. Finally, this difference in footprint could have been caused by sampling issues, with only four farms (or groups of farms) being used to develop midpoint CFs for Kenya, three being from the same study (Appendix F, Table A1). This means that if any Kenyan study sites were outliers in production method or ecology, it would skew the CFs (Maina et al., 2014; Poore & Nemecek, 2018). Nevertheless, using more location-specific midpoint CFs still provides a more accurate reflection of regional impacts than global average alternatives.

4.3 Mitigation Strategies

4.3.1 Offsets through local NGOs

Survey results revealed that generally, Oxford researchers in the conservation and biodiversity disciplines have strong collaborations, which could be harnessed to help mitigate supply chain impacts. A main type of institution listed in these collaborations were NGOs, which could serve as useful mechanisms to deliver offsets. For example, in Figure 11, within the "Cultivation" and "Offset" box, one potential action is to fund NGOs carrying out agroforestry[7] projects in areas Oxford source coffee. This idea was inspired by an Oxford collaboration with the conservation NGO "Pan Nature" in Vietnam, which worked directly with coffee farmers (Ngoc, 2023; Table 1). Although Vietnam was not identified as one of Oxford's coffee sourcing countries in this study, it provides a useful illustration of what could be achieved in relevant areas, highlighting that research connections – particularly those incorporating NGOs – could aid practical and locally-based interventions to approach supply chain impacts.

[7] Integrating crops with native trees, shown to improve both biodiversity and economic outcomes (Moreira et al., 2018)

4.3.2 Midpoints to help guide mitigation

When creating the matrix, I found that land use and freshwater eutrophication were the leading pressures at the cultivation stage of the coffee supply chain, whilst water use, freshwater eutrophication, and climate change dominated the processing stage (Figure 11; Pelupessy, 2003; Usva et al., 2020). This could further support use of midpoint pressures in prioritising mitigation (see 4.2.1), as it demonstrated that pressures are associated with supply chain stages as well as specific interventions. For example, the large land use component in East Africa (Figure 8) might suggest a focus on actions in the cultivation stage, whilst the greater climate change pressure in South America's footprint might suggest prioritisation of actions at the processing stage. This aligns with literature suggesting that whilst LCIA results should not be used alone in decision making, midpoints provide greater insight than endpoint measures (Bromwich et al., 2025; SBTN 2022).

4.3.3 Limitations and future directions

Future studies could expand the matrix to include downstream stages, supporting circular economy strategies and broader transformative change (Ruokamo et al., 2023; Booth et al., 2024). Costs of different interventions could also be estimated, allowing for ecological benefits to be weighed against economic feasibility, and further supporting decision-making on mitigation strategies (White et al., 2022). An example of this approach is the "Conservation Intervention Cost Data Portal" developed by Arizona State University (ASU), which provides resources to support cost-effective conservation action (Iacona, n.d.; Iacona et al., 2018). Finally, further work could actively encourage Oxford's biodiversity and conservation researchers to establish stronger links in areas with large residual supply chain impacts, to increase feasibility of mitigation action in these locations.

4.4 Conclusion

This study was the first to examine the biodiversity footprint of a single organisation's supply chains, from a bottom-up perspective. Using the University of Oxford as a case study, it not only demonstrated the importance of location-specific data when addressing supply chain impacts, but also explored mitigation options for a case study product, coffee, at each stage of its supply chain. This resulted in the development of a conceptual framework, which could be applied to other businesses and organisations to approach their own supply chains, and support movement towards their Nature Positive goals. Whilst work must be done to reduce uncertainties in LCIA modelling, and future efforts could build upon this framework to consider the circular economy and economic costs of interventions, this proof-of-concept project provides a foundation to address supply chain impacts - a vital step to achieving the Global Biodiversity Framework's mission, and movement towards a Nature Positive future.

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7 Management Report

Throughout my project, I met with my supervisors for 30 minutes, every two weeks. If one supervisor was unavailable, they ensured a separate check-in to support my progress. They also provided written input when needed.

Task	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25
Narrowing scope, creation of new research proposal and questions	■	■	■					
Access to, and analysis of EP&L data, including contacting suppliers (Q1)		■	■	■				
Survey and ethics submission (Q3)		■	■					
Drafting introduction			■	■				
Coffee footprint calculations (Q2)				■	■	■		
Supplier outreach analysis (Q1)				■	■			
Development and revisions of conceptual framework					■	■	■	
Survey analysis (Q3)						■		
Matrix of mitigation interventions (Q3)						■	■	
Write-up					■	■	■	■

Initial Planning and Project Direction (October-November)

At my first meeting in October, my supervisors suggested revising the project focus. Whilst this new direction differed significantly from my original proposal (which had received positive feedback), it represented an exciting opportunity that had emerged over the holidays. However, the initial framing was very broad, and I spent the first few weeks narrowing the scope and creating a new research proposal. Whilst my college tutor and I had some concerns about the projects change in direction and access to data, following productive discussions with my supervisors, I was able to clarify and shape the focus. A third supervisor also joined the team to offer expertise on Life Cycle Impact Assessment (LCIA) methods, and who had previously worked with the University's biodiversity manager on the datasets I would be using.

I gained access to the Environmental Profit & Loss (EP&L) data at the start of November and met with Oxford's biodiversity manager as frequently as possible before her departure at the end of November. We also met with a member of the Purchasing team to request more detailed product-level data. Whilst they made every effort to get this data to me promptly, it was only available on the 12th of December due to unavoidable constraints.

EP&L Analysis and Survey Development (December-January)

By December, I had established my three research questions, and spent the final few weeks of term writing my survey questions and analysing the EP&L data. By the final supervisor meeting on the 13th of December, I had submitted my survey for ethics approval, and selected coffee as the case study commodity. Over the Christmas break, I drafted my introduction, and contacted the 131 identified suppliers.

Coffee Footprint Analysis and Collecting Supplier Responses (January-February)

At the start of Hilary term, I focused on calculating the biodiversity footprint of Oxford's coffee. I spent the first few weeks experimenting with different LCIA models, and levels of geographic specificity, eventually deciding on using the LC-IMPACT model with regional-level characterisation factors. Simultaneously, I monitored and compiled supplier responses from the outreach I had conducted over the holidays. I had still not received a response from ethics into late January, resulting in both my lead supervisor and I sending follow-up emails. On the 31st of January, I gained ethics approval and sent out my survey.

Conceptual Framework and New Coffee Data (February-March)

In February, I continued analysing supplier responses for the first research question but shifted some focus to what had been acknowledged as the most challenging aspect: bridging the gap between LCIA results, and actionable biodiversity mitigation. To identify critical next steps to answer this, I prioritised the creation of the conceptual framework, producing the first version by early March.

Although the University's biodiversity manager had requested Compass purchasing data in November, I only received it on the 11th of March due to delays. Until then, I had used food sales data to estimate Oxford coffee's biodiversity footprint, assuming each cup contained 18 grams of ground coffee (the average double espresso). However, once I received the new data with mass of coffee beans purchased, I was able to recalculate the footprint.

Mitigation Matrix and Writing (March-May)

At my final supervisor meeting of Hilary term on the 25th of March, we considered different approaches I had developed for costing compensation. I had reviewed the literature on opportunity costs to develop potential methods for estimating the amount of money that could be argued as required for compensation action. However, following discussion, we agreed a cost-focused approach for this project was not the most appropriate direction. Informed by this, I shifted my focus to investigate potential mitigation interventions for the case study commodity, coffee, drawing on insights from the LCIA results, and survey responses. This also meant a slight reframing of the project, putting greater emphasis on consideration of the whole mitigation hierarchy, rather than compensation alone.

I spent the next couple of weeks of researching and creating a matrix outlining potential intervention options across the stages of the coffee supply chain and produced the result two weeks into the holidays. This allowed me to complete my final generalised conceptual framework. I then focused on completing my first draft of my thesis by the end of April/beginning of May, allowing my lead supervisor time to review it before taking leave. Overall, despite the revised project idea, and a few minor setbacks throughout, with the support of my supervisors, I was able to complete my thesis research and write-up effectively and on time. This experience has taught me a great deal about navigating the challenges of independent research.

8 Appendices

Appendix A. Glossary of Footnotes

1. **Nature:** Denotes the "abundance, diversity, integrity and resilience of species, ecosystems and natural processes" (Nature Positive Initiative, n.d.).

2. **Science Based Targets Network (SBTN):** A 2019 NGO-founded initiative, that develops targets for cities and companies to address their environmental impacts (SBTN, 2022).

3. **Taskforce for Nature-related Financial Disclosures (TNFD):** 2020 Initiative consisting of corporates, financial institutions, and market service providers. Provides recommendations to decision makers on nature-related issues (TNFD, 2023).

4. **Transformative Change:** A systemic and fundamental reconfiguration "across technological, economic and social factors", normalising sustainability (Díaz et al., 2019).

5. **Distributor:** Purchase products from other suppliers and sell them to buyers (Smith et al., 1997)

6. **Circular Economy:** A sustainable economic model incorporating recycling, reduced waste, and design improvements (Ruokamo et al., 2023).

7. **Agroforestry**: The integration of crops with native trees, shown to improve both biodiversity and economic outcomes (Moreira et al., 2018).

Appendix B. List of Purchasing Category Item Descriptions (PCIDs)

Construction:
1. Construction Services
2. Repairs, Alterations and Decorating Materials
3. Flooring
4. Repairs, Alterations and Decorating Services

Research:
1. Chemicals, Chemical Elements and Chemical Reagents
2. Handheld/Bench Top/ Capital Laboratory/ Scientific/ Medical/ Refrigeration Equipment
3. Laboratory Plasticware
4. Laboratory Furniture
5. Laboratory Glassware

Operations:
1. Desktop, Laptop and Tablet Computers
2. Computer Accessories and Peripherals
3. Office, Classroom, Library and Outdoor Furniture
4. Electronic Components (incl. Batteries)
5. Other Disposable Items inc. Paperware
6. Workshop & Machining Equipment
7. Animals (Not Used as Food in the UK)
8. Stationery & Office Supplies
9. Books
10. Purchase of Audio-Visual Equipment
11. Newspapers Magazines Journals and Periodicals (Hard Copy)
12. Protective Clothing & Safety Apparel (PPE)
13. Animal Feed
14. Office Equipment

15. Purchase of Mobile Phones
16. Metals
17. Mechanical Components
18. Purchase of Video Equipment
19. Telecoms Equipment (exc. Mobile Phones)
20. Photocopier Purchase (incl. Stand-Alone MFD)
21. Water Coolers
22. Plastics, Rubber, Glass & Ceramics
23. Animals (Can be Used as Food or Produce Food for Human Consumption in the UK)
24. Printer Purchase (incl. Networked MFD)
25. Mail Order Packaging
26. Wood
27. Sheet Music
28. Vending Machine purchase
29. Pre-Packaged Pet Food

Appendix C. Limitations and Gaps in Oxford's Supply Chain Data Collection

1. Some invoices were in the wrong Purchasing Category Item Description (PCID).
    a. E.g. Both the highest and third highest spend item in "Laboratory Plasticware" in the Research supply chain were not plastics.
    b. E.g. Some paper items were placed in the "Laboratory Furniture" PCID.
    c. E.g. Some items in "Computer Accessories and Peripherals", and "Office, Classroom, Library and Outdoor Furniture" should have been in "Desktop, Laptop & Tablet Computers".

2. Some invoices were replicated in more than one PCID.
    a. The top three spend items in "Repairs, Alterations and Decorating Services", and "Repairs, Alterations and Decorating Materials", were identical.

3. Two identified products were listed as supplied by the incorrect supplier.

4. As only spend data was available, some of the high-spend items I inquired about were not those purchased in the high volume.

Appendix D. Supplier Email Template

Dear Sir/Madam,

My name is ……., and I am a researcher at the University of Oxford working with the University's procurement team to investigate the biodiversity impacts of the products in our supply chains.

I am carrying out a project which includes tracing products that the University purchases down the supply chain, to get a more location-specific understanding of the biodiversity footprint and size of impact for these different commodities around the world.

You are receiving this email because you are one of the top 10 spend suppliers for our purchasing categories: ……… and we are seeking the following information about these three products:

1. *…..*
2. *…..*
3. *…..*

1. Could you provide a detailed ***breakdown*** *of the* ***primary materials*** *in these products, including their specific* ***quantities*** *or* ***percentage*** *composition?*

*2. Could you provide any available details on the **geographic origins** and **sourcing locations** for the materials in each product?*

3. Do you have any information on the environmental impacts of these products? e.g. Life Cycle Assessment (LCA) detailing, for example, carbon emissions, other emissions to air and water, land or water stress, and any quantified biodiversity effects?

I have also provided a table below if it makes it easier to fill in.

Product	Breakdown of Primary Materials	Geographic Origins/Sourcing Locations of Products	Environmental Impact of Products
1.			
2.			
3.			

Thank you so much for your help with this,

………

Appendix E. Assumptions for Estimating Oxford's Coffee Biodiversity Footprint

1. Compass Group plc only cater for 19 Cafeterias across Oxford, but Oxford has 28 in total. So, the Compass data was extrapolated to account for these nine other cafeterias.

2. I assumed that the total weight of purchased coffee by the University of Oxford could be equally divided between the three regions, as there was no evidence to suggest otherwise (See Appendix G for a sensitivity test of this assumption).

3. It was assumed that all University cafes get their coffee from Change Please Coffee. Whilst this is true for the Dorothy Crowfoot Hodgkin Building and University Club Cafe, it is not confirmed for all Compass-supplied cafes.

4. I assumed all coffee was either Arabica (*C. arabica*) or Robusta (*C. canephora*), as they are the two most cultivated species globally (Perrois et al., 2014).

5. I excluded instant coffee from the data, as it is not in raw form, and undergoes significant processing (which changes characteristics including the weight). I assumed it does not reflect the same impacts as raw coffee.

6. When calculating the midpoint and endpoint regional characterisation factors (CFs), the values for every country in each region were summed together, and then divided by the number of countries to get the average. If a country had an N/A value for a particular pressure, it was not included in the calculations for that CF. For example, acidification and freshwater eutrophication midpoint CFs were not available at the country-level for Colombia (See Tables A1 and A4 In Appendix F for the countries included in each region, used to calculate the midpoint and endpoint regional CFs).

7. Kenya midpoint CFs were used as a proxy to represent East Africa, as there were no other country-level midpoint CFs provided for countries from the East African region (these country-level CFs came from a requested dataset from J. Poore, an extension to the supplementary material in Poore & Nemecek, 2018; see Appendix F, Table A1).

8. There were no freshwater eutrophication or acidification midpoint CFs for Kenya, meaning there were no regional-level midpoint CFs for these environmental pressures to represent

East Africa. To complete regional calculations, global average midpoint CFs were used for these pressures.

9. An assumption was made that country-level midpoint and endpoint CFs could be averaged to provide regional CFs.

10. The LC-IMPACT LCIA methodology doesn't have multipliers to convert the different midpoint environmental pressures into units that are compatible with endpoint biodiversity footprint CFs, so that the absolute biodiversity footprint can be calculated. So, multipliers from the ReCiPe LCIA model were used for land use and acidification conversions (See Table A2 in Appendix F). These can also be found in Electronic Supplementary Material 2 (ESM2) in Huijbregts et al., (2016).

11. ReCiPe publishes three sets of CFs based on different perspectives (Individualist, Hierarchist, and Egalitarian). Bull et al., (2022) used the "Hierarchist" perspective, which represents a balanced viewpoint, reflecting scientific consensus. For methodological consistency, the same perspective has been used in this study both for the ReCiPe footprint calculations in Appendix H, Table A10 and A11, and for multipliers used in LC-IMPACT calculations (Appendix F, Table A2).

12. Where applicable, the 100 yr. time horizon was used (Verones et al., 2020). This is a standardised timeframe indicating that measurement of the environmental considers impacts over the next 100 years. This timeframe was chosen for methodological consistency with Bromwich et al., (2025), and as it also aligns with the "long-term" scenario for ReCiPe, improving comparability across frameworks.

13. Some environmental pathways could not be included in this analysis due to the midpoint CFs from Poore & Nemecek (2018) not being available. These included photochemical ozone formation, freshwater ecotoxicity, marine eutrophication, marine ecotoxicity and terrestrial ecotoxicity.

    a. For example, LC-IMPACT characterises freshwater and marine eutrophication separately, but the CML2 baseline method utilised by Poore & Nemecek (2018) only has a singular eutrophication potential, so only freshwater eutrophication has been included.

Appendix F. Characterisation Factors (CFs) and Multiplier Tables

TABLE A1: A table showing the country-level midpoint characterisation factors (CFs) for coffee, used to calculate the regional-level CFs. These values were requested as an extension to supplementary material from Poore & Nemecek (2018). N/A represents missing country-level CFs for a particular environmental pressure. Each entry represents results calculated from a different farm/set of farms, and the functional unit (FU) used in this dataset is 1kg. The final row shows the global mean for each environmental pressure (from Poore & Nemecek (2018), SM file: aaq0216_datas2.xls).

Country	Land Use Endpoint CF (m2.year/FU)	Climate Change Endpoint CF (kgCO2eq/FU)	Freshwater Eutrophication Endpoint CF (gPO43.eq/FU)	Acidification Endpoint CF (gSO2eq./FU)	Water Use Endpoint CF (L/FU)
Brazil	8.39569519	4.72722158	41.13430944	52.73316674	10.40501315
Brazil	11.87623247	7.3698298	45.55210249	69.96931497	34.54980462
Colombia	15.84131518	15.63563381	NA	NA	10.40501315
Colombia	20.44908626	9.85072741	NA	NA	10.40501315
Colombia	20.89266731	11.3914511	NA	NA	10.40501315

Costa Rica	23.00900939	7.11659588	NA	NA	10.40501315
Costa Rica	21.32728778	7.29992215	NA	NA	10.40501315
Costa Rica	16.2211336	7.59108807	NA	NA	10.40501315
Costa Rica	13.95546439	7.33278358	NA	NA	10.40501315
Costa Rica	22.06707807	6.10130497	192.3889276	33.35126396	10.40501315
Costa Rica	16.04878405	7.12681766	177.9621997	127.1124152	10.40501315
Costa Rica	15.13171068	8.62944494	143.1729068	58.54785267	10.40501315
Costa Rica	10.69918937	9.73230777	112.4849033	73.79432347	10.40501315
Indonesia	40.05450025	84.58619177	268.7959498	105.0489975	38.27971401
Kenya	230.0721565	29.29055477	NA	NA	11.76727592
Kenya	194.1387635	30.11083762	NA	NA	11.76727592
Kenya	177.8695361	30.96244083	NA	NA	11.76727592
Kenya	97.02136063	21.22649804	NA	NA	11.76727592
Nicaragua	22.53452003	37.92991574	22.74405092	46.39795269	10.40501315
Nicaragua	16.54878815	31.37697227	59.9117094	181.5647453	10.40501315
Nicaragua	19.25677166	34.38806271	15.57561612	37.76562138	10.40501315
Nicaragua	14.91721748	29.12798206	20.3335897	53.35392958	10.40501315
Nicaragua	34.96034477	64.06755347	NA	NA	10.40501315
El Salvador	28.71700192	20.4738381	NA	NA	10.40501315
Guatemala	15.42060672	19.09237024	NA	NA	10.40501315
Colombia	22.14926942	33.39807343	NA	NA	10.40501315
Colombia	11.45971836	28.487531	NA	NA	10.40501315
Vietnam	9.58405525	6.50923808	49.99559352	87.63819659	33.27852041
Global Mean	28.5	27.7	110.5	83.1	26.0

TABLE A2: A table showing the ReCiPe multipliers used to convert the midpoint pressures into units compatible with the endpoint characterisation factors. This is so that the endpoint biodiversity footprint (in either PDF.year or Species.year) can be calculated. These can be found in ESM2 in Huijbregts et al., (2016).

Pressure	Multiplier	Details
Land Use	0.775	This is the average annual crop equivalent between pasture (0.55 annual crop eq.) and annual crops (1 annual crop eq.). The land impact/use for food is a mix of half crop and half pasture, so the average between the two ((1+0.55)/2) has been calculated.
Freshwater Eutrophication	0.33	To convert kg PO_4^{3-} eq. to P eq. This is because it is estimated that a kilogram of PO_4^{3-} has a third of the eutrophication potential compared to a kg of P.
Water Use	0.00044	To convert from litres to m^3 and account for converting water withdrawals to consumption for agriculture (in agriculture some water returns to the source).

TABLE A3: A table showing the LC-IMPACT endpoint global and regional characterisation factors for different environmental pressures. The regional CFs are an average of the available country-level endpoint CFs (see Table A4 for the country-level CFs used to calculate the regional CFs).

Pressure	**Regionalised?**	**Global Endpoint Characterisation Factor**	**Regional Endpoint Characterisation Factor**	**Units**
Climate Change/GHG Emissions (Terrestrial)	No	1.76E-15	No region-specific values	PDF.year/kg Carbon Dioxide
Climate Change/GHG Emissions (Freshwater)	No	5.47E-16	No region-specific values	PDF.year/kg Carbon Dioxide
Acidification	Yes	6.559E-14	**South America:** 8.71E-13 **Central America:** 1.27E-13 **East Africa:** 1.4303E-15	PDF.year/kg Sulfur dioxide
Freshwater Eutrophication	Yes	1.812E-12	**South America:** 3.65E-12 **Central America:** 5.24E-12 **East Africa:** 4.52E-12	PDF.year/kg Phosphorus (water)
Land Use	Yes	2.105E-15	**South America:** 3.99E-15 **Central America:** 1.09E-14 **East Africa:** 7.13E-15	PDF.year/m^2 annual crop eq.
Water Use	Yes	1.652E-13	**South America:** 4.58E-14 **Central America:** 1.12E-14 **East Africa:** 1.50E-14	PDF.year/m^3 consumed

TABLE A4: A table showing the LC-IMPACT country-level endpoint characterisation factors used to calculate the regional-level endpoint CFs. Source: *LC-IMPACT Downloads, Characterisation Factors*.

Country	Land Use Endpoint CF (PDF·yr/m^2)	Freshwater Eutrophication Endpoint CF (PDF·yr/kg)	Terrestrial Acidification Endpoint CF (PDF·yr/kg)	Water Use Endpoint CF (PDF·yr/m^3)
Argentina	6.99E-16	5.61E-13	1.27253E-15	2.63E-15
Bolivia	1.58E-15	5.57E-12	3.98705E-12	1.36E-13
Brazil	2.49E-15	3.18E-12	5.53667E-15	2.85E-15
Chile	1.27E-15	1.78E-13	6.65577E-14	8.86E-14
Colombia	9.00E-15	6.02E-12	5.47912E-12	6.94E-14
Ecuador	1.56E-14	2.59E-12	6.65628E-14	1.83E-13
Guyana	2.97E-15	2.86E-12	1.12898E-17	1.30E-15
Paraguay	9.57E-16	2.78E-12	3.87681E-16	3.50E-15
Peru	5.68E-15	5.53E-12	8.3957E-13	5.76E-14
Suriname	2.81E-15	3.52E-12	7.18198E-16	9.48E-16
Uruguay	7.62E-16	1.35E-12	8.95216E-16	1.91E-15
Venezuela	4.04E-15	9.72E-12	3.26013E-15	2.33E-15
Belize	7.74E-15	4.24E-12	1.58686E-13	7.74E-15
Costa Rica	1.54E-14	6.56E-12	5.4232E-15	2.12E-14
El Salvador	1.00E-14	4.07E-12	4.48317E-13	8.92E-15
Guatemala	1.06E-14	4.82E-12	2.74967E-14	1.60E-14
Honduras	9.94E-15	2.78E-12	5.44723E-15	9.36E-15
Nicaragua	8.11E-15	1.59E-12	2.06502E-15	6.80E-15
Panama	1.47E-14	1.26E-11	2.38553E-13	8.56E-15
Burundi	2.47E-15	2.02E-12	1.081E-15	2.82E-14
Comoros	5.72E-14	N/A	N/A	N/A
Djibouti	5.41E-16	3.11E-13	2.135E-15	6.43E-15
Eritrea	8.85E-16	9.30E-13	6.68968E-16	5.86E-15
Ethiopia	1.72E-15	3.39E-12	1.19304E-15	6.63E-15
Kenya	1.22E-15	2.76E-12	1.25718E-16	5.75E-15
Madagascar	1.48E-14	2.25E-12	1.00005E-15	9.75E-14
Malawi	9.74E-16	1.80E-11	2.92765E-15	1.99E-15
Mauritius	3.06E-14	N/A	N/A	N/A
Mozambique	9.52E-16	8.45E-12	9.06135E-15	2.81E-15
Rwanda	4.44E-15	7.45E-13	4.20116E-16	3.07E-14
Seychelles	N/A	N/A	N/A	N/A
Somalia	9.21E-16	7.15E-13	2.80747E-17	3.21E-15
South Sudan	2.98E-16	N/A	2.65182E-16	N/A
Tanzania	1.37E-15	5.00E-12	6.03291E-16	4.66E-15
Uganda	1.49E-15	6.47E-13	1.68703E-15	1.13E-14
Zambia	6.30E-16	4.08E-12	1.40558E-16	2.94E-15
Zimbabwe	7.01E-16	1.40E-11	1.17678E-16	2.54E-15

TABLE A5: A table showing the global and regional ReCiPe endpoint characterisation factors for different environmental pressures. The regional CFs are an average of the available country-level endpoint CFs. (See Table A6 for the list of ReCiPe country-level endpoint CFs).

Pressure	**Regionalised?**	**Global Endpoint Characterisation Factor**	**Regional Endpoint Characterisation Factor**	**Units**
Climate Change/GHG Emissions (Terrestrial)	No	2.80E-09	No region-specific values	Species.year/kg Carbon Dioxide
Climate Change/GHG Emissions (Freshwater	No	7.65E-14	No region-specific values	Species.year/kg Carbon Dioxide
Acidification	Yes	2.12E-7	**South America:** 1.95E-07 **Central America:** 1.54E-07 **East Africa:** 4.86E-07	Species.year/kg Sulphur dioxide
Freshwater Eutrophication	Yes	6.71E-7	**South America:** 6.25E-07 **Central America:** 3.92E-07 **East Africa:** 1.30596E-07	Species.year/kg Phosphorus (water)
Land Use	No	8.88E-09	No region-specific values	Species.year/m^2 annual crop eq.
Water Use (Terrestrial)	Yes	1.45E-08	**South America:** 2.44E-09 **Central America:** 2.88E-09 **East Africa:** 2.65E-08	Species.year/m^3 consumed
Water Use (Freshwater)	Yes	6.04E-13	**South America:** 2.12E-12 **Central America:** 9.25E-14 **East Africa:** 4.57E-12	Species.year/m^3 consumed

TABLE A6: A table showing the ReCiPe **country-level endpoint characterisation factors** used to calculate the regional-level endpoint CFs. Source: ESM1 in Huijbregts et al., (2016).

Country	Freshwater Eutrophication Endpoint CF (Species·yr/kg)	Acidification Endpoint CF (Species·yr/kg)	Terrestrial Water Use Endpoint CF (Species-eq·yr/m^3)	Aquatic Water Use Endpoint CF (Species-eq·yr/m^3)
Argentina	1.96E-07	1.25E-07	9.73E-09	2.47E-12
Bolivia	5.25E-06	2.53E-07	1.52E-09	2.74E-12
Brazil	1.37E-06	8.36E-09	2.07E-09	2.39E-12
Chile	1.06E-07	5.08E-07	4.28E-09	N/A
Colombia	1.69E-07	3.80E-08	8.01E-10	1.48E-12
Ecuador	5.81E-08	4.01E-08	3.51E-09	2.55E-12
Guyana	2.19E-09	2.09E-07	7.37E-10	2.73E-12
Paraguay	1.85E-08	8.66E-08	2.27E-09	2.74E-12
Peru	2.59E-07	1.94E-07	2.17E-09	2.51E-12
Suriname	2.86E-08	6.28E-07	4.77E-10	5.89E-13
Uruguay	2.52E-08	2.37E-07	5.60E-10	1.46E-12
Venezuela	1.45E-08	1.15E-08	1.21E-09	1.62E-12
Belize	2.99E-08	6.35E-08	1.01E-09	N/A
Costa Rica	1.21E-08	9.01E-10	1.47E-09	N/A
El Salvador	3.88E-08	3.11E-07	3.97E-09	9.50E-14
Guatemala	3.32E-08	2.15E-08	8.54E-09	1.83E-13
Honduras	5.51E-09	2.31E-07	9.92E-10	5.80E-14
Nicaragua	1.52E-07	1.22E-07	1.00E-09	N/A
Panama	2.91E-09	3.26E-07	3.20E-09	3.40E-14
Burundi	1.86E-06	4.74E-07	1.97E-09	5.24E-12
Comoros	N/A	1.30E-06	N/A	N/A
Djibouti	1.15E-07	3.52E-07	5.86E-08	N/A
Eritrea	1.65E-08	2.90E-07	5.43E-08	6.64E-12
Ethiopia	2.23E-07	5.65E-07	1.28E-08	6.64E-12
Kenya	2.71E-07	5.93E-07	1.57E-08	2.36E-12
Madagascar	2.03E-08	3.71E-07	8.15E-09	N/A
Malawi	8.32E-07	1.88E-07	6.71E-09	2.89E-12
Mauritius	N/A	2.40E-07	1.16E-08	N/A
Mozambique	8.91E-08	1.75E-07	N/A	2.69E-12
Rwanda	5.88E-07	7.56E-07	1.13E-09	5.93E-12
Seychelles	N/A	3.89E-07	N/A	N/A
Somalia	1.87E-08	2.99E-08	1.61E-07	N/A
South Sudan	3.64E-08	4.13E-08	3.41E-08	6.60E-12
Tanzania	7.93E-07	5.25E-07	6.51E-09	3.36E-12
Uganda	9.24E-07	4.44E-08	9.15E-10	6.62E-12
Zambia	1.92E-07	1.89E-07	5.67E-09	3.06E-12
Zimbabwe	2.81E-08	1.69E-06	1.87E-08	2.76E-12

Appendix G. Testing Sensitivity to Differences in Coffee Weight Division

In this study, I assumed the weight of coffee purchased by the University of Oxford was equally divided between South America, Central America, and East Africa. To test this assumption, I developed two alternative scenarios for the balance across regions, recalculated the total endpoint biodiversity footprint (for all three regions added together), and then compared my results. This allowed me to understand whether the overall endpoint biodiversity footprint was sensitive to the assumption of dividing coffee equally between the three sourcing regions.

TABLE A7: A table showing the **three different scenarios for dividing coffee weight between regions**, and the total biodiversity footprint in Species.year.

Scenario	South America	Central America	East Africa	Total Endpoint Biodiversity Footprint (PDF.year)
1	33.3%	33.3%	33.3%	2.68E-09
2	50%	30%	20%	2.05E-09
3	30%	20%	50%	3.33E-09

Using these two alternative scenarios, the total endpoint biodiversity footprint for Oxford's purchased coffee had a variation of approximately -24% to +24%, compared to the equal split scenario. This indicated that the regional distribution of coffee weight had a moderate influence on the overall biodiversity footprint result.

Appendix H. Comparing LCIA Methods and CF Choices

To provide a quantitative estimate of the uncertainties within and between models, I estimated the midpoint and endpoint biodiversity footprint using both the LC-IMPACT methodology (the method used in this study) and ReCiPe (used in Bull et al., 2022). I also varied the use of global or regional endpoint CFs to explore whether using more location-specific data affected the biodiversity footprint estimates. However, it is important to note that this was not possible for every pressure (e.g. Land use in ReCiPe does not have regional endpoint CFs, and climate change does not have regional endpoint CFs in general). All methods used regional midpoint CFs.

Part I: Biodiversity footprint calculation tables

TABLE A8: Table showing how the total biodiversity footprint in PDF.year was calculated for each region that Oxford source coffee, using LC-IMPACT with regional endpoint characterisation factors (CFs). The orange rows represent the coffee weight multiplied by the midpoint CFs per functional unit (FU; 1kg; the rows in blue). All light green boxes represent the midpoint pressures converted to units that align with endpoint CFs. The dark green row shows the overall biodiversity footprint calculated for each region, and the last four yellow rows show the percentage breakdown of this total footprint into the pressure components.

Measurement	South America	Central America	East Africa
Coffee weight (kg)	1,515.73	1,515.73	1,515.73
Land Use (m2. year/FU)	15.86628346	19.38766054	174.7754542
Climate Change (kg CO2e/FU)	15.83720973	19.82579731	27.89758282

Freshwater Eutrophication (g PO43e/FU)	43.34320597	93.07173794	110.5
Acidification (g SO2e/FU)	61.3512409	76.486013	83.1
Water Use (L/FU)	13.85426907	10.40501315	11.76727592
2022/23 Land use (m^2/ year)	24049.00182	29386.45871	264912.3992
2022/23 Climate Change (kg CO2e)	24004.9339	30050.55576	42285.20321
2022/23 Freshwater Eutrophication (g PO4^3e)	65696.59758	141071.6253	167488.165
2022/23 Acidification (g SO2e)	92991.9163	115932.145	125957.163
Water Use (L)	20999.33126	15771.19058	17836.01313
Land Use (m^2·annual crop eq.)	18637.97641	22774.5055	205307.1094
Land Use Biodiversity footprint PDF.year/ (m2·annual crop eq.)	7.43655E-11	2.55074E-10	1.46384E-09
Climate Change Biodiversity Footprint for Terrestrial Ecosystems (PDF.year/kg CO2 eq.)	4.22E-11	5.2889E-11	7.4422E-11
Climate Change Biodiversity Footprint for Freshwater Ecosystems (PDF.year/kg CO2 eq.)	1.31307E-11	1.64377E-11	2.313E-11
Total Climate Change Biodiversity Footprint (PDF.year/kg CO2 eq.)	5.54E-11	6.93266E-11	9.7552E-11
Freshwater Eutrophication Impact (kg PO4^3eq)	65.69659758	141.0716253	167.488165
Freshwater Eutrophication Impact (kg Peq.)	21.6798772	46.55363636	55.27109445
Biodiversity Footprint for Freshwater Eutrophication (PDF.year/kg P)	7.91E-11	2.43941E-10	2.49825E-10
Acidification Impact (kg SO2e)	92.99191631	115.9321445	125.957163
Acidification Biodiversity Footprint (PDF.year/kg SO2 eq.)	8.0996E-11	1.47234E-11	1.80157E-13
Water Use for Agriculture (L)	9.24E+00	6.939323856	7.847845777
Water Use Biodiversity Footprint (PDF.yr/m3 consumed)	4.23E-13	7.77204E-14	1.17718E-13
Total Biodiversity footprint (PDF.year)	2.90E-10	5.83143E-10	1.81151E-09
Land use as percentage of total biodiversity footprint (%)	25.61717313	43.7413039	80.80748937
Climate change as a percentage of total biodiversity footprint (%)	19.07689367	11.88843942	5.385104211
Freshwater eutrophication as a percentage of total biodiversity footprint (%)	27.25895686	41.83209771	13.79096304
Acidification as a percentage of total biodiversity footprint (%)	27.9012013	2.524831133	0.009945076

Water use as a percentage of Total Biodiversity Footprint (%)	0.14577504	0.013327845	0.006498301

TABLE A9: Table showing how the total biodiversity footprint in PDF.year was calculated for each region that Oxford source coffee, using **LC-IMPACT** with **global** endpoint CFs. The FU is 1kg.

Measurement	South America	Central America	East Africa
Coffee weight (kg)	1,515.73	1,515.73	1,515.73
Land Use (m2. year/FU)	15.86628346	19.38766054	174.7754542
Climate Change/GHG Emissions (kg CO2e/FU)	15.83720973	19.82579731	27.89758282
Freshwater Eutrophication (g PO43e/FU)	43.34320597	93.07173794	110.5
Acidification (g SO2e/FU)	61.35124086	76.48601303	83.1
Water Use (L/FU)	13.85426907	10.40501315	11.76727592
2022/23 Land use (m^2/ year)	24049.00182	29386.45871	264912.3992
2022/23 Climate Change/GHG Emissions (kg CO2e)	24004.9339	30050.55576	42285.20321
2022/23 Freshwater Eutrophication (g PO4^3e)	65696.59758	141071.6253	167488.165
2022/23 Acidification (g SO2e)	92991.91631	115932.1445	125957.163
Water Use (L)	20999.33126	15771.19058	17836.01313
Land Use (m^2·annual crop eq.)	18637.97641	22774.5055	205307.1094
Land Use Biodiversity footprint PDF.year/ (m2·annual crop eq.)	3.92329E-11	4.79403E-11	4.32171E-10
Climate Change Biodiversity Footprint for Terrestrial Ecosystems (PDF.year/kg CO2 eq.)	4.22E-11	5.2889E-11	7.4422E-11
Climate Change Biodiversity Footprint for Freshwater Ecosystems (PDF.year/kg CO2 eq.)	1.31307E-11	1.64377E-11	2.313E-11
Total Climate Change Biodiversity Footprint (PDF.year/kg CO2 eq.)	5.54E-11	6.93266E-11	9.7552E-11
Freshwater Eutrophication Impact (kg PO4^3eq.)	65.69659758	141.0716253	167.488165
Freshwater Eutrophication Impact (kg Peq.)	21.6798772	46.55363636	55.27109445
Biodiversity Footprint for Freshwater Eutrophication (PDF.year/kg P)	3.93E-11	8.43552E-11	1.00151E-10
Acidification Impact (kg SO2e)	92.99191631	115.9321445	125.957163
Acidification Biodiversity Footprint (PDF.year/kg SO2 eq.)	6.09934E-12	7.60399E-12	8.26153E-12
Water Use for Agriculture(L)	9.24E+00	6.939323856	7.847845777

Water Use Biodiversity Footprint (PDF.year/m3 consumed)	1.53E-12	1.14638E-12	1.29646E-12
Total Biodiversity footprint (PDF.year)	1.42E-10	2.10373E-10	6.39433E-10
Land use as percentage of total biodiversity footprint (%)	27.72214954	22.78830612	67.58670636
Climate change as a percentage of total biodiversity footprint (%)	39.13128891	32.95422416	15.25601865
Freshwater eutrophication as a percentage of total biodiversity footprint (%)	27.75818432	40.09800743	15.66251327
Acidification as a percentage of total biodiversity footprint (%)	4.309817421	3.614535456	1.292009466
Water use as a percentage of total biodiversity footprint (%)	1.078559797	0.544926826	0.202752257

TABLE A10: Table showing how the total biodiversity footprint in Species.year was calculated for each region that Oxford source coffee, using **ReCiPe with regional** endpoint CFs. The FU is 1kg.

Measurement	South America	Central America	East Africa
Coffee weight (kg)	1,515.73	1,515.73	1,515.73
Land Use (m2. year/FU)	15.86628346	19.38766054	174.7754542
Climate Change/ GHG Emissions (kg CO2e/FU)	15.83720973	19.82579731	27.89758282
Freshwater Eutrophication (g PO43e/FU)	43.34320597	93.07173794	110.5
Acidification (g SO2e/FU)	61.35124086	76.48601303	83.1
Water Use (L/FU)	13.85426907	10.40501315	11.76727592
2022/23 Land use (m^2/ year)	24049.00182	29386.45871	264912.3992
2022/23 Climate Change/ GHG Emissions (kg CO2e)	24004.9339	30050.55576	42285.20321
2022/23 Freshwater Eutrophication (g PO4^3e)	65696.59758	141071.6253	167488.165
2022/23 Acidification (g SO2e)	92991.91631	115932.1445	125957.163
Water Use (L)	20999.33126	15771.19058	17836.01313
Land Use (m^2·annual crop eq.)	18637.97641	22774.5055	205307.1094
Land Use Biodiversity Footprint Species.year/ (m2·annual crop eq.)	0.000165505	0.000202238	0.001823127
Climate Change Biodiversity Footprint for Terrestrial Ecosystems (Species.year/kg CO2 eq.)	6.72E-05	8.41416E-05	0.000118399
Climate Change Biodiversity Footprint for Freshwater Ecosystems (Species.year/kg CO2 eq.)	1.83638E-09	2.29887E-09	3.23482E-09

Total Climate Change Biodiversity Footprint (Species.year/kg CO2 eq.)	6.72E-05	8.41439E-05	0.000118402
Freshwater Eutrophication Impact (kg PO4^3eq.)	65.69659758	141.0716253	167.488165
Freshwater Eutrophication Impact (kg Peq.)	21.6798772	46.55363636	55.27109445
Biodiversity Footprint for Freshwater Eutrophication (Species.year/kg P)	1.35E-05	1.8249E-05	2.21084E-05
Acidification Impact (kg SO2e)	92.99191631	115.9321445	125.957163
Acidification Biodiversity Footprint (Species.year/kg SO2 eq.)	1.81334E-05	1.78536E-05	6.12152E-05
Water Use for Terrestrial Ecosystems (L)	2.25E-08	1.99853E-08	2.07968E-07
Water Use for Freshwater Ecosystems (L)	1.95882E-11	6.41887E-13	3.58647E-11
Water Use Biodiversity Footprint (Species.year/m3 consumed)	2.26E-08	1.99859E-08	2.08004E-07
Total Biodiversity footprint (Species.year)	2.64E-04	3.22504E-4	2.025061E-3
Land use as percentage of total biodiversity footprint (%)	62.59018933	62.70855335	90.02827714
Climate change as a percentage of total biodiversity footprint (%)	25.41937997	26.09079216	5.846827807
Freshwater eutrophication as a percentage of total biodiversity footprint (%)	5.124262593	5.658541914	1.091742057
Acidification as a percentage of total biodiversity footprint (%)	6.857634757	5.535915477	3.022881512
Water use as a percentage of total biodiversity footprint (%)	0.008533352	0.006197099	0.010271484

TABLE A11: Table showing how the total biodiversity footprint in Species.year was calculated for each region that Oxford source coffee, using **ReCiPe** with **global** endpoint CFs. The FU is 1kg.

Measurement	South America	Central America	East Africa
Coffee weight (kg)	1,515.73	1,515.73	1,515.73
Land Use (m2. year/FU)	15.86628346	19.38766054	174.7754542
Climate Change/ GHG Emissions (kg CO2e/FU)	15.83720973	19.82579731	27.89758282
Freshwater Eutrophication (g PO43e/FU)	43.34320597	93.07173794	110.5
Acidification (g SO2e/FU)	61.35124086	76.48601303	83.1
Water Use (L/FU)	13.85426907	10.40501315	11.76727592
2022/23 Land use (m^2/ year)	24049.00182	29386.45871	264912.3992
2022/23 Climate Change/ GHG Emissions (kg CO2e)	24004.9339	30050.55576	42285.20321

2022/23 Freshwater Eutrophication (g PO4^3e)	65696.59758	141071.6253	167488.165
2022/23 Acidification (g SO2e)	92991.91631	115932.1445	125957.163
Water Use (L)	20999.33126	15771.19058	17836.01313
Land Use (m^2·annual crop eq.)	18637.97641	22774.5055	205307.1094
Land Use Biodiversity Footprint Species.year/ (m2·annual crop eq.)	0.000165505	0.000202238	0.001823127
Climate Change Biodiversity Footprint for Terrestrial Ecosystems (Species.year/kg CO2 eq.)	6.72138E-05	8.41416E-05	0.000118399
Climate Change Biodiversity Footprint for Freshwater Ecosystems (Species.year/kg CO2 eq.)	1.83638E-09	2.29887E-09	3.23482E-09
Total Climate Change Biodiversity Footprint (Species.year/kg CO2 eq.)	6.72157E-05	8.41439E-05	0.000118402
Freshwater Eutrophication Impact (kg PO4^3eq)	65.69659758	141.0716253	167.488165
Freshwater Eutrophication Impact (kg Peq)	21.6798772	46.55363636	55.27109445
Biodiversity Footprint for Freshwater Eutrophication (Species.year/kg P)	1.45472E-05	3.12375E-05	3.70869E-05
Acidification Impact (kg SO2e)	92.99191631	115.9321445	125.957163
Acidification Biodiversity Footprint (Species.year/kg SO2 eq.)	1.97143E-05	2.45776E-05	2.67029E-05
Water Use for Terrestrial Ecosystems (L)	1.25E-07	9.36809E-08	1.05946E-07
Water Use for Freshwater Ecosystems (L)	5.58078E-12	4.19135E-12	4.7401E-12
Water Use Biodiversity Footprint (Species.year/m3 consumed)	1.25E-07	9.36851E-08	1.05951E-07
Total Biodiversity footprint (Species.year)	2.67E-04	3.4229E-4	2.005425E-3
Land use as percentage of total biodiversity footprint (%)	61.96212156	59.08365978	90.90977704
Climate change as a percentage of total biodiversity footprint (%)	25.16430655	24.58260325	5.904076243
Freshwater eutrophication as a percentage of total biodiversity footprint (%)	5.446203865	9.126023799	1.849329183
Acidification as a percentage of total biodiversity footprint (%)	7.38066705	7.180343111	1.331534335
Water use as a percentage of total biodiversity footprint (%)	0.046700969	0.027370065	0.005283203

Part II: Comparing relative pressure proportions between methods and CF choices

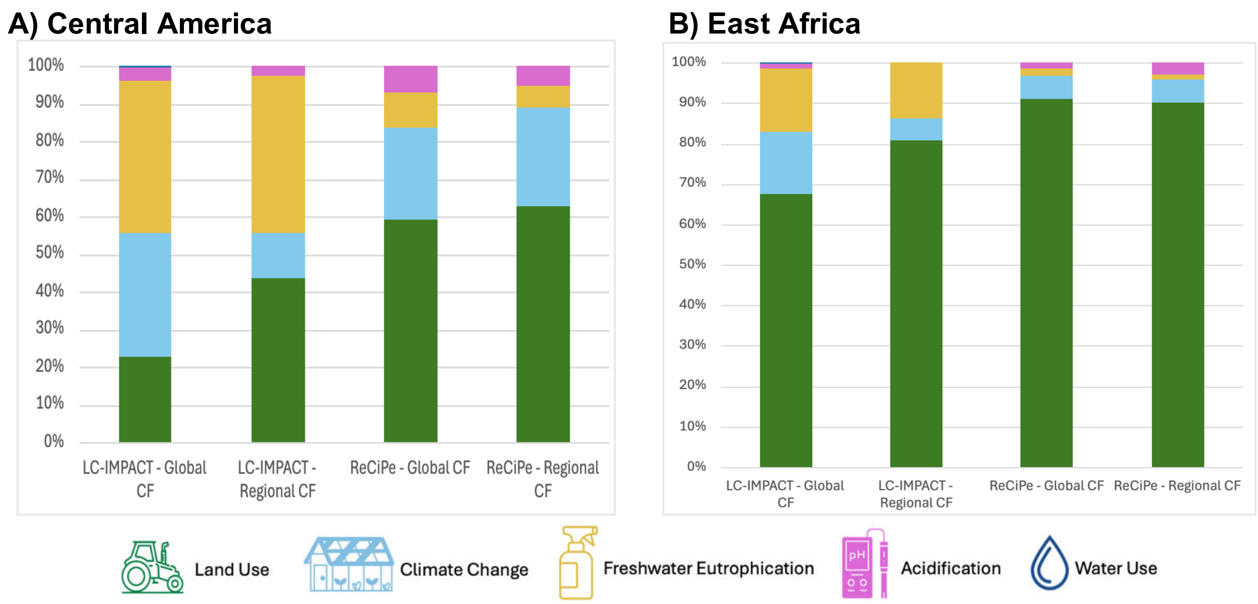

FIGURE A1: **Stacked bar graphs comparing the composition of the estimated biodiversity footprint of coffee sourced from (A) Central America and (B) East Africa,** using the two different models, and either global or regional endpoint CFs. The comparison for South America is included in the main text (Figure 9).

(A) ***Central America*** *model comparison:*

For coffee sourced from Central America, both ReCiPe models estimated land use to be the greatest pressure, followed by climate change (Figure A1, graph A). In contrast, when using LC-IMPACT- with regional CFs (the model used in this study), the greatest component was still land use, but this was followed by freshwater eutrophication. Furthermore, for LC-IMPACT using regional CFs there was only a 2% difference between these two greatest pressures, whilst for ReCiPe with regional CFs, there was a 37% difference. This highlights the decision-based uncertainty that comes with to model choice.

The composition of pressures using LC-IMPACT with global CFs had a markedly different pattern, demonstrating the effects of using more spatial-specific CFs. Here, the greatest component of the biodiversity footprint was freshwater eutrophication, followed by climate change. In fact, only 23% of the footprint was attributed to the land use pressure, being the third most impactful driver.

(B) ***East Africa*** *model comparison:*

For all four LCIA models applied to East Africa, land use emerged as the dominating environmental pressure, and water use had the smallest impact (Figure A1, graph B). In both ReCiPe models, climate change followed, comprising 6% of the total footprint. Contrastingly, for both LC-IMPACT models (regional and global), freshwater eutrophication was the second largest pressure (14% and 16% respectively).

Comparing ReCiPe model choices for East Africa, the impact of freshwater eutrophication when using global CFs was the third largest, greater than acidification, whilst when using regional CFs, acidification contributed a greater proportion. When I compared the two LC-IMPACT models, whilst the order of impacts was the same, notably, climate change accounted for a smaller proportion in the regional CF version (5%), compared to the global CF version (15%).

<u>Part III: Comparing total impact scores between regional and global endpoint CFs</u>

As well as comparing the contribution of environmental pressures to the total estimated biodiversity footprint, the quantitative final values can also be compared within the models (but not between, as they use different units; Figures A2 and A3).

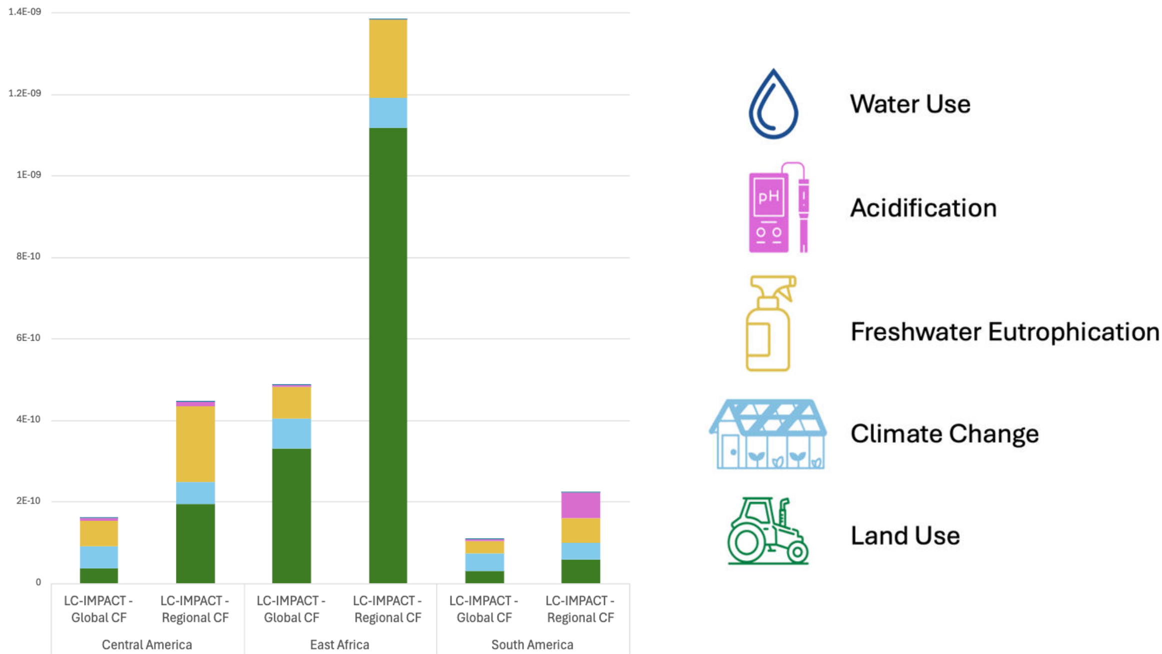

FIGURE A2: Graph comparing the biodiversity footprint of coffee sourced from each region in **PDF.year**, between the **LC-IMPACT** model using **regional** and **global** characterisation factors (CFs).

For all regions, using LC-IMPACT with regional CFs produced a larger overall biodiversity footprint (measured in PDF.year). This suggested that the choice of CFs affects the overall endpoint footprint, as well as affecting the relative contribution of each pressure. This difference is particularly pronounced in East Africa, where the biodiversity footprint using regional CFs is 2.8 times larger than when using global CFs (1.81 E-9 PDF.year compared to 6.39E-10 PDF.year using the global model).

Using the ReCiPe models, the endpoint biodiversity footprint estimations (in Species.year) are relatively similar between the regional and global CF versions. As previously mentioned, this may be due to the limited availability of regional CFs in ReCiPe compared to LC-IMPACT. However, there is some variation, and there is no overall trend for which model produces the largest footprint. For

Central America, the global CF version has a slightly higher overall footprint (3.42E-4 Species.year using global CFs compared to 3.23E-4 Species.year using regional), whilst for East Africa and South America, the regional CF model produces footprints slightly larger than the global CF model.

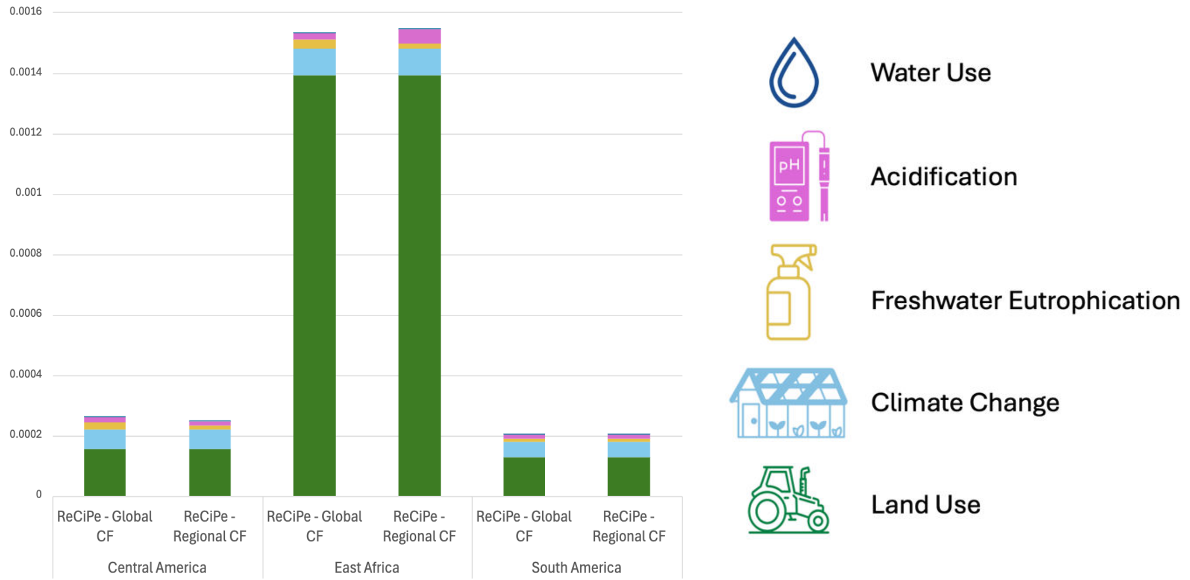

FIGURE A3: Graph comparing the biodiversity footprint of coffee sourced from each region in **Species.year**, between the **ReCiPe** model using **regional** and **global** characterisation factors (CFs).

Appendix I. Spearman's Rank

Spearman's Rank is a non-parametric test, where the correlation coefficient, ρ (rho), measures how strong the association is between two ranked variables, and the direction of this association. This allowed me to statistically test if the models and spatial scales agree when it comes to which environmental pressures contribute the most or least to the endpoint biodiversity footprint.

The table below shows the results of the Spearman's Rank which measured the monotonic relationship of the biodiversity footprints of South American coffee across the five environmental pathways. The model compared the relative rankings of these pressures across LCIA models (ReCiPe and LC-IMPACT), and spatial scales (global and regional).

TABLE A12: **Results from Spearman's Rank comparing models and spatial levels for the relative composition of pressures in the biodiversity footprint of South American coffee.** Columns (from left to right) include (1) the models and endpoint CF versions being compared, (2) Spearman's correlation coefficient, rho, (3) the p-value, and (4) the interpretation of these results.

Model Versions Compared	Spearman's Rho	p-value	Interpretation
LC-IMPACT Global vs ReCiPe Global	0.5	0.45	Rho of 0.5 would suggest a moderate positive correlation. However, the p-value > 0.05, so no evidence to suggest null hypothesis can be rejected. Cannot confidently say that there is correlation.
LC-IMPACT Global vs ReCiPe Regional	0.5	0.45	Rho of 0.5 would suggest a moderate positive correlation. However, the p-value > 0.05, so no evidence to suggest null hypothesis can be rejected. Cannot confidently say that there is correlation.
LC-IMPACT Regional vs ReCiPe Global	0.2	0.7833	Rho of 0.2 would suggest a weak positive correlation. However, the p-value > 0.05, so no evidence to suggest null hypothesis can be rejected. Cannot confidently say that there is correlation.
LC-IMPACT Regional vs ReCiPe Regional	0.2	0.7833	Rho of 0.2 would suggest a weak positive correlation. However, the p-value > 0.05, so no evidence to suggest null hypothesis can be rejected. Cannot confidently say that there is correlation.
ReCiPe Global vs ReCiPe Regional	1	0.01667	Rho of 1 suggests a strong positive correlation. The p-value < 0.05, so there is evidence to reject the null hypothesis.
LC-IMPACT Global vs LC-IMPACT Regional	0.1	0.95	Rho of 0.1 would suggest a very weak positive correlation. However, the p-value is very high, so no evidence to suggest null hypothesis can be rejected. Cannot confidently say there is a relationship.

Overall, when LC-IMPACT and ReCiPe were compared, Spearman's rho was low and the p values were not significant, suggesting that there was no meaningful relationship between rankings, with models ranking environmental pressures very differently.

In contrast, when the two ReCiPe versions were compared, there was a perfect positive correlation (rho=1), and it was statistically significant, suggesting that the choice of local or regional endpoint CFs when modelling with ReCiPe did not affect the relative proportions of the midpoint environmental pressures. As mentioned, this could have been because there were fewer regional CFs available for ReCiPe, and so many of the CFs used were the same in both global and regional versions (e.g. land use).

However, when comparing LC-IMPACT using regional and global CFs, the correlation was very weak (rho = 0.1) and a high p value, which suggested the ranking was very different between these two versions. This suggests spatial sensitivity in these outputs and that the choice of regional or global CFs when using LC-IMPACT will change the relative contributions of environmental pressures in the footprint. Whilst this result must be treated with caution as there are several assumptions and limitations when estimating biodiversity footprints (see Appendix E), it does indicate differences in ranking depending on CFs and model choice, which could affect mitigation strategies.

Appendix J. Survey Details and Questions

Part I: Participant information and consent

We appreciate your interest in participating in this online survey. You have been invited to participate as you are a researcher or member of staff in the University of Oxford, who is working with collaborators overseas on a topic related to biodiversity, ecology, or conservation. Please read through this information before agreeing to participate (if you wish to) by ticking the 'yes' box below.

You may ask any questions before deciding to take part by contacting the researcher (details below). This survey is being carried out by ……., who is a MBiol student in the Biology Department at the University of Oxford. This research is being completed under the supervision of ……….

Do I have to take part?
No. Please note that participation is voluntary. If you do decide to take part, you may withdraw at any point for any reason before submitting your answers by pressing the 'Exit' button/ closing the browser.

How will my data be used?
- It is optional to provide your name. This information is only collected to read the research published by this staff member.
- No specific responses will be published without permission, only aggregated and anonymised data.- The result of the study will include the following elements: The collaborating institution, partner country, and the nature of the collaboration.
- This information will be made available to the wider public (including being written up for an MBiol degree and potential publication).

Who will have access to my data?
The University of Oxford is the data controller with respect to your personal data and, as such, will determine how your personal data is used in the research. The University will process your personal data for the purpose of the research outlined above. Research is a task that we perform in the public interest. Further information about your rights with respect to your personal data is available from https://compliance.admin.ox.ac.uk/individual-rights.

Who has reviewed this research?

This research has been reviewed by, and received ethics clearance through, a subcommittee of the University of Oxford Central University Research Ethics Committee (MS IDREC) – 933634.

Who do I contact if I have a concern or I wish to complain?
If you have a concern about any aspect of this research, please contact ……… (email: ……) or …….... (email: ……….) and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the University of Oxford Research Governance, Ethics & Assurance (RGEA) team at rgea.complaints@admin.ox.ac.uk or on 01865 616480.

If you have read the information above and agree to participate with the understanding that the data you submit will be processed accordingly, please tick the box below to start.

Part II: Survey questions

In this section, we ask you to list up to five of your most important collaborations/links that you have with colleagues in other countries. This could include academic research, policy advice, project implementation, training, and capacity building. It could include work with universities, communities, NGOs, government, or businesses. We are looking for your most current and active links which have the potential to persist, not completed projects or short-term engagements. We are also asking you to rate the strength of each collaboration or link from 1 (less recent/distant/short-term) to 5 (current/active/close/long-term).

We realise that within a country or project, you might be collaborating with several institutions in one or more projects. In these cases, we ask that you provide more context and detail.

1. What is your position in Oxford University?
    - Professor
    - Associate Professor
    - Research Fellow
    - Post-Doctoral Researcher
    - Research Associate
    - PhD Student
    - Other

2. Where is the collaboration taking place?

3. Please name the main collaborating institution(s) in the country concerned.

4. What types of institution(s) are involved?
    - University
    - Research Institute
    - NGO
    - National Government
    - Local Government
    - Business
    - Other

5. What is the collaboration about?
    - Research
    - Policy Advice
    - On-the-ground Conservation
    - Technical Advice
    - Other

6. How large-scale is the project's footprint?
   - National
   - Provincial
   - Local
   - Global

7. Can you give up to five keywords to describe the activities you are carrying out in this collaboration, or the methods you are using?

8. What is the strength of this collaboration?
   - 1. Less recent, distant, and occasional collaboration
   - 2. Current, distant, and occasional collaboration
   - 3. Recent close and active collaboration that would require additional commitment and negotiation to be called into action
   - 4. Recent active and close collaboration that could be called into action quickly
   - 5. Current, active, and close collaboration in which you are actively working together to implement a project with joint decision-making

9. If possible, please provide more context and detail on this collaboration.

10. Do you think this is a collaboration that could form the basis for actions to mitigate the impacts of Oxford's operations, research, construction, or food supply chains?
    - Yes
    - Maybe
    - No
    - Don't Know

11. Can you say more about your answer?

12. One particular commodity I am investigating and using as a case study is coffee and would be particularly interested in responses from researchers on coffee. Do you work on coffee, or in areas where coffee is grown?
    - Yes
    - No

Appendix K. Detailed Findings from Examining Oxford's Supply Chains

Part I: Contacting suppliers

TABLE A13: A table showing the **number of suppliers contacted** in each of the supply chain categories **("Descriptions").**

Contacted? (Yes/No)	Construction	Operations	Research	Grand Total
No	23	18	2	43
Yes	8	32	48	88
Grand Total	**31**	**50**	**50**	**131**

TABLE A14: A table showing the **number of suppliers contacted** in each of the supply chain subcategories **("Purchasing Category Item descriptions"**; PCIDs).

Contacted? (Yes/No)	Chemicals, Chemical Elements and Chemical Reagents	Computer Accessories and Peripherals	Construction Services	Desktop, Laptop + Tablet Comput-ers	Electronic Components (incl. Batteries)	Flooring	Handheld/Bench Top/ Capital Laboratory/ Scientific/ Medical/ Refrigeration Equipment	Laboratory Furniture	Laboratory Glassware	Laboratory Plasticware	Office, Classroom, Library and Outdoor Furniture	Other Disposable Items inc. Paperware	Repairs, Alterations and Decorating Materials	Repairs, Alterations and Decorating Services	Grand Total
No	0	1	10	3	5	0	0	2	0	0	3	6	4	9	43
Yes	10	9	0	7	5	1	10	8	10	10	7	4	6	1	88
Grand Total	10	10	10	10	10	1	10	10	10	10	10	10	10	10	131

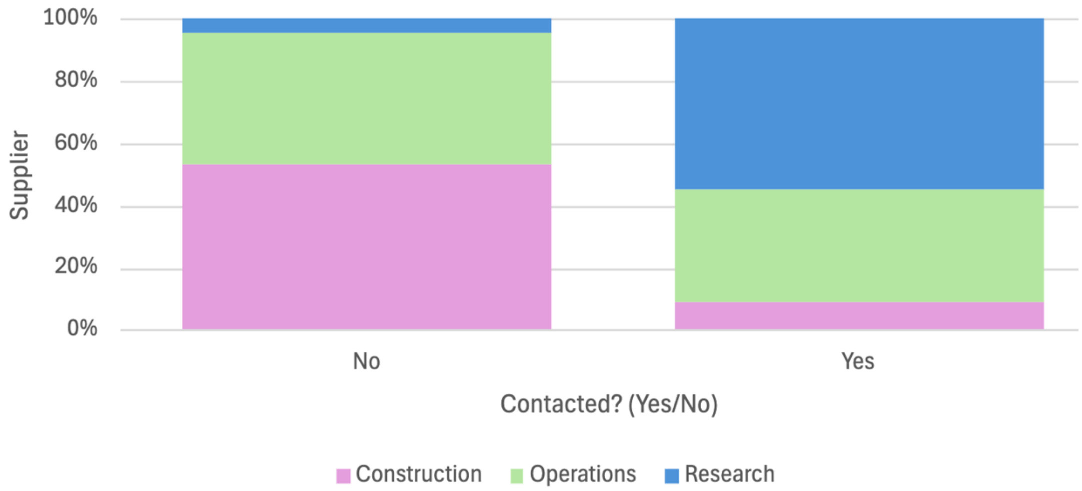

FIGURE A4: Stacked bar graph providing a visual representation of the **number of suppliers contacted** in each of the supply chain categories.

Part II: Recording replies from suppliers

TABLE A15: A table showing the **number of suppliers from each "Description" who replied**, and who did not reply when contacted. In total 88 were contacted.

Replied (Yes/No)	Construction	Operations	Research	Grand Total
No	1	10	12	23
Yes	7	22	36	65
Grand Total	8	32	48	88

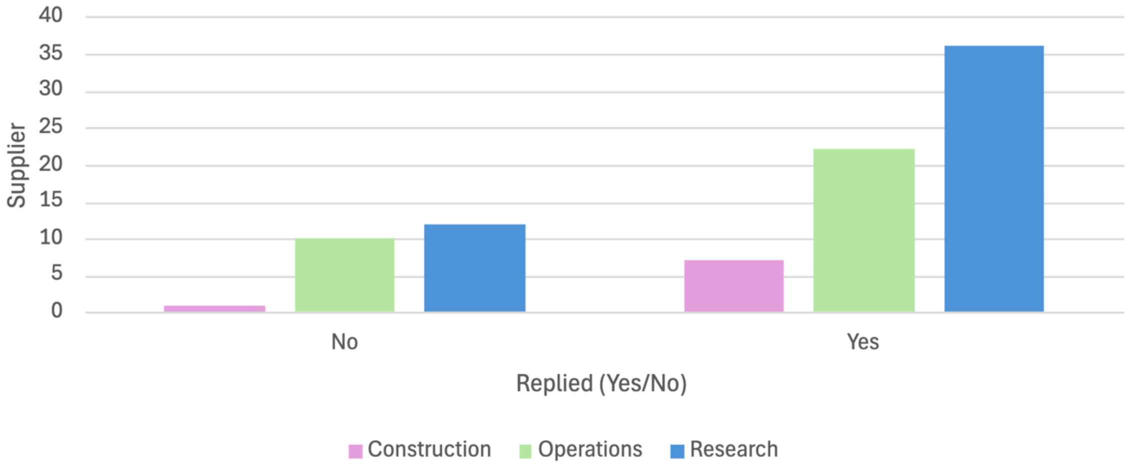

FIGURE A5: Bar graph providing a visual representation of the **number of suppliers who replied** in each of the supply chain categories.

Part III: Recording number of products queried

TABLE A16: **Table showing the number of invoices for physical consumables that were available for each supplier.** The aim was to find out information about the top three spend products for each supplier, but this was not always possible. "All" represents all three top spend products being identified and queried.

Top 3 Spend Invoices available? (None,1,2, All)	Count of Supplier
1	17
2	11
All	59
None	1
Grand Total	**88**

Part IV: Data provided by suppliers: Raw materials, origins, and product LCAs

TABLE A17: Table showing the number of suppliers able to provide information on the raw materials in their products, in each "Description". "Yes" represents that raw materials for all products inquired about could be provided. "Some" indicates that some raw material information could be provided, and "No" represents no raw material information being provided.

Raw Materials Available? (Yes/No/Some)	Construction	Operations	Research	Grand Total
No	4	13	21	38
Some	2	6	12	20
Yes	1	3	3	7
Grand Total	**7**	**22**	**36**	**65**

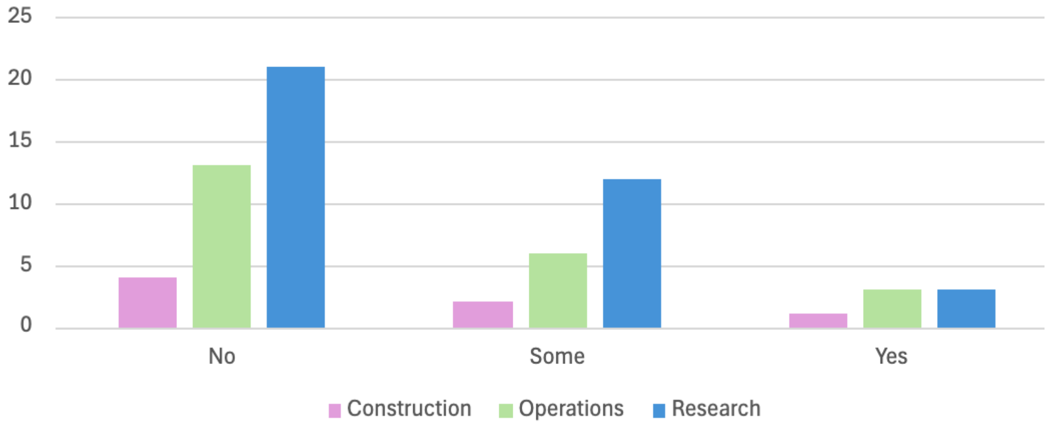

FIGURE A6: Bar graph providing a visual representation of the **number of suppliers** who were able to provide **raw material information**, in each of the supply chain categories.

TABLE A18: Table showing the **number of suppliers able to provide information on raw materials**, in each subcategory (**PCID**).

Raw Materials Available? (Yes/No/Some)	Chemicals, Chemical Elements and Chemical Reagents	Computer Accessories and Peripherals	Desktop, Laptop + Tablet Computers	Electronic Components (incl. Batteries)	Flooring	Hand held/Bench Top/ Capital Laboratory/ Scientific/ Medical/ Refrigeration Equipment	Laboratory Furniture	Laboratory Glassware	Laboratory Plasticware	Office, Classroom, Library and Outdoor Furniture	Other Disposable Items inc. Paperware	Repairs, Alterations and Decorating Materials	Repairs, Alterations and Decorating Services	Grand Total
No	3	6	4	1	1	4	6	3	5	2	0	3	0	38
Some	5	1	1	1	0	1	0	4	2	2	1	1	1	20
Yes	0	0	0	0	0	1	2	0	0	3	0	1	0	7
Grand Total	**8**	**7**	**5**	**2**	**1**	**6**	**8**	**7**	**7**	**7**	**1**	**5**	**1**	**65**

TABLE A19: **Table showing the number of suppliers able to provide information on the source location for the raw materials in their products, in each "Description".** "Yes" represents that locations for all products inquired about could be provided. "Some" indicates that some locations could be provided, and "No" represents that no location information for the raw materials in products could be given.

Location Available for product? (Yes/No/Some)	Construction	Operations	Research	Grand Total
No	6	18	16	40
Some	0	2	13	15
Yes	1	2	7	10
Grand Total	**7**	**22**	**36**	**65**

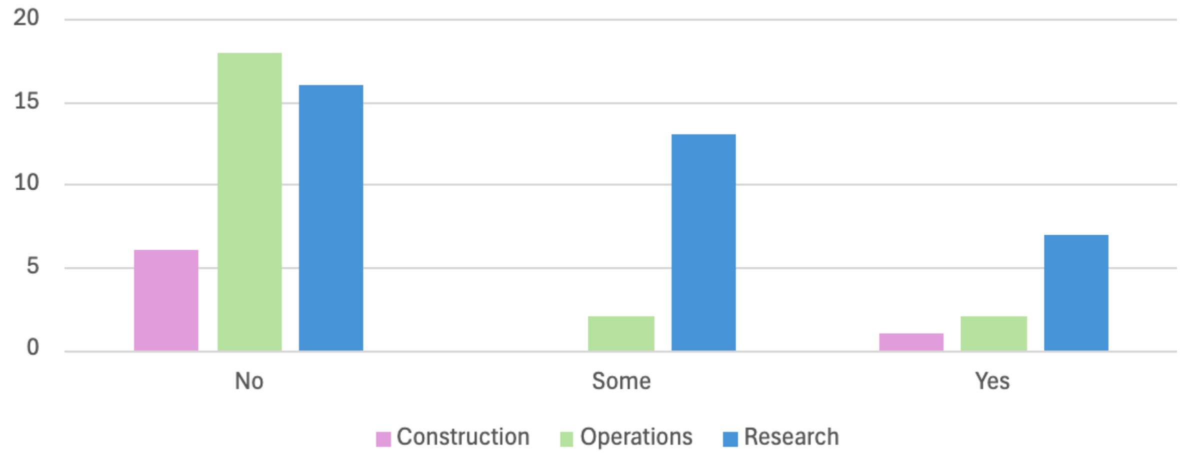

FIGURE A7: Bar graph providing a visual representation of the **number of suppliers** who were able to provide **source locations** for their product materials, in each of the supply chain categories.

TABLE A20: Table showing the **number of suppliers able to provide information on source location**, in each subcategory (**PCID**).

Location Available for product? (Yes/No/Some)	Chemicals, Chemical Elements and Chemical Reagents	Computer Accessories and Peripherals	Desktop, Laptop + Tablet Computers	Electronic Components (incl. Batteries)	Flooring	Hand held/Bench Top/ Capital Laboratory/ Scientific/ Medical/ Refrigeration Equipment	Laboratory Furniture	Laboratory Glassware	Laboratory Plasticware	Office, Classroom, Library and Outdoor Furniture	Other Disposable Items inc. Paperware	Repairs, Alterations and Decorating Materials	Repairs, Alterations and Decorating Services	Grand Total
No	2	7	5	2	1	4	4	3	3	3	1	4	1	40
Some	3	0	0	0	0	2	1	3	4	2	0	0	0	15
Yes	3	0	0	0	0	0	3	1	0	2	0	1	0	10
Grand Total	**8**	**7**	**5**	**2**	**1**	**6**	**8**	**7**	**7**	**7**	**1**	**5**	**1**	**65**

TABLE A21: Table showing the **number of suppliers able to provide any LCA information**, in each category ("Description").

LCA information for at least one Product?	Construction	Operations	Research	Grand Total
No	7	18	35	60
Yes	0	4	1	5
Grand Total	**7**	**22**	**36**	**65**

Table A22: Table showing each of the raw materials and source locations provided by 18 suppliers. The table also shows the supply chain category ("Description") and subcategory ("Purchasing Category Item Description") that these suppliers come from. The names of the suppliers have been omitted, due to confidentiality requirements set by the University's Purchasing Department. This was the data used to make the map in Figure 7.

Supply Chain Category (Description)	Supply Chain Sub-Category (PCID)	Raw Material	Source Location
Construction	Repairs, Alterations and Decorating Materials	Steel	China
Construction	Repairs, Alterations and Decorating Materials	Aluminium	China
Construction	Repairs, Alterations and Decorating Materials	Cast Iron	China

Construction	Repairs, Alterations and Decorating Materials	Plastic	China
Operations	Office, Classroom, Library and Outdoor Furniture	Plywood	Finland
Operations	Office, Classroom, Library and Outdoor Furniture	Metal	Taiwan
Operations	Office, Classroom, Library and Outdoor Furniture	Metal	China
Operations	Office, Classroom, Library and Outdoor Furniture	Metal	Italy
Operations	Office, Classroom, Library and Outdoor Furniture	Metal	Poland
Operations	Office, Classroom, Library and Outdoor Furniture	Metal	United States
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	Taiwan
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	China
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	Italy
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	Poland
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	United States
Operations	Office, Classroom, Library and Outdoor Furniture	Foam	High Wycombe, UK
Operations	Office, Classroom, Library and Outdoor Furniture	Foam	Hertfordshire, UK
Operations	Office, Classroom, Library and Outdoor Furniture	Fabric	UK
Operations	Office, Classroom, Library and Outdoor Furniture	Steel	Denmark
Operations	Office, Classroom, Library and Outdoor Furniture	Electrics	China
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	Wigan, UK
Operations	Office, Classroom, Library and Outdoor Furniture	Fabric	Yorkshire, UK
Operations	Office, Classroom, Library and Outdoor Furniture	Foam	Darwin, UK
Operations	Office, Classroom, Library and Outdoor Furniture	Plastic	Italy
Operations	Office, Classroom, Library and Outdoor Furniture	Steel	Italy
Operations	Office, Classroom, Library and Outdoor Furniture	Foam	UK
Operations	Office, Classroom, Library and Outdoor Furniture	Fabric	UK

Operations	Office, Classroom, Library and Outdoor Furniture	Aluminium	East Asia
Operations	Office, Classroom, Library and Outdoor Furniture	Plywood	Europe
Operations	Office, Classroom, Library and Outdoor Furniture	Steel	UK
Operations	Office, Classroom, Library and Outdoor Furniture	Polypropylene	Italy
Research	Chemicals, Chemical Elements and Chemical Reagents	Plastic	West Sussex, UK
Research	Laboratory Furniture	Paper	Finland
Research	Handheld/Bench Top/ Capital Laboratory/ Scientific/ Medical/ Refrigeration Equipment	Metal	Germany
Research	Handheld/Bench Top/ Capital Laboratory/ Scientific/ Medical/ Refrigeration Equipment	Copper	Germany
Research	Laboratory Plasticware	Polypropylene	Europe
Research	Laboratory Plasticware	Polyethylene	Europe
Research	Chemicals, Chemical Elements and Chemical Reagents	Foetal Bovine Serum	France
Research	Chemicals, Chemical Elements and Chemical Reagents	4-(2-Aminoethyl) benzenesulfonyl Fluoride Hydrochloride	United States
Research	Laboratory Plasticware	Polystyrene	United States
Research	Laboratory Plasticware	Polypropylene	United States
Research	Laboratory Plasticware	Polycarbonate	United States
Research	Laboratory Furniture	Steel	UK
Research	Laboratory Furniture	Glass	UK
Research	Laboratory Furniture	Aluminium	Switzerland
Research	Laboratory Glassware	Soda Lime Glass	China
Research	Chemicals, Chemical Elements and Chemical Reagents	Phosphate-buffered saline	San Diego, CA, USA
Research	Laboratory Glassware	Polypropylene	India
Research	Chemicals, Chemical Elements and Chemical Reagents	Anti-Met antibody	China

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