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Assessing the Contribution of Greenhouse Gas Emissions Towards Organisational Biodiversity Footprints

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ABSTRACT

Organisations play a key role in addressing climate change and biodiversity loss, which are closely connected. Biodiversity footprinting has initially suggested that greenhouse gas (GHG) emissions may contribute to a large proportion of many organisations' biodiversity impacts. If true, mitigating GHG emissions could help organisations to tackle their climate and biodiversity liabilities in tandem. Consequently, there is a need for greater understanding of (i) how much GHG emissions contribute to biodiversity footprints across economic sectors and (ii) how reliable current footprinting methods are at estimating the impact of GHG emissions. On average, our results estimate that GHG emissions contribute to 47% of an economic sector's total biodiversity footprint. This proportion is much higher than studies into observed biodiversity loss from climate change, which may be due to the methodological limitations of footprinting approaches. Overall, we find that biodiversity footprinting provides a useful but imperfect tool to interrogate the connections between climate change and biodiversity loss in organisations.

1 | Introduction

The climate and ecological crises, driven by anthropogenic activities, poses an increasingly large risk for humanity (IPCC 2023; Pörtner 2021) and require urgent and systemic action across all sectors of society (Díaz et al. 2019). The private sector has an essential role to play in reducing both biodiversity loss and greenhouse gas (GHG) emissions: For example, target 15 of the Global Biodiversity Framework explicitly mentions the role of businesses to achieve global goals (CBD 2022; Leclère et al. 2020; Mace et al. 2018). Climate and biodiversity commitments are therefore taking centre stage within organisational sustainability strategies, including the adoption of Net Zero and, more recently, Nature Positive goals (Hale et al. 2022; Zu Ermgassen et al. 2022).

Climate change and biodiversity loss are closely linked and should be addressed in tandem by organisations. Climate change is an increasingly substantial driver of biodiversity loss, driving population declines and extinctions through alteration of habitats, species range shifts and increasing extreme weather events. It is predicted to overtake land-use conversion as the largest driver of biodiversity loss by the middle of the century (Pigot et al. 2023; Trisos et al. 2020; Newbold et al. 2020; IPCC 2023; Urban et al. 2016). Mitigating GHG emissions is therefore essential to prevent both current and

Climate change and biodiversity loss are typically addressed separately in organisational sustainability strategies. Carbon and biodiversity footprinting methodologies are a leading approach for quantifying and monitoring progress towards both climate (e.g., Net Zero) and biodiversity (e.g., Nature Positive) goals. Here, we assess the contribution of climate change towards organisational biodiversity footprints. We comment on the implications of our findings for organisations extending their sustainability strategies to be inclusive of both Net Zero and Nature Positive goals.

future biodiversity loss. Similarly, actions to halt and reverse biodiversity loss often support climate change mitigation and adaptation efforts (Díaz et al. 2019; Shin et al. 2022). In recent years, there have been a number of calls to integrate climate and biodiversity action across science, policy and the private sector (Essl et al. 2018; Pettorelli et al. 2021; Pörtner 2021). The Global Biodiversity Framework explicitly includes a target to minimise the impacts of climate change on biodiversity (2030 Target 8) (CBD 2022).

Organisational strategies that address drivers of climate change and biodiversity loss concurrently may be more likely to achieve climate and biodiversity goals (Maddinson et al. 2025). Enacting joint climate and biodiversity strategies may also reduce the transition, regulatory and physical risks of inaction for organisations (e.g., the risk of ecosystem service disruption caused by climate change-driven weather extremes) (White et al. 2024). Despite this, climate and biodiversity goals have so far largely been considered separately by organisations, highlighted by calls to improve the knowledge-gap on this area (Anthesis 2025; UNEP 2024).

At an organisational level, biodiversity footprinting has increasingly been employed to identify the contribution of GHG emissions towards biodiversity loss. Biodiversity footprinting enables organisations to identify, monitor and communicate their largest sources of biodiversity impact across complex value chains and between different actors (Bromwich et al. 2026; Damiani et al. 2023; Marques et al. 2017). Footprinting methods quantify the contribution of several key drivers of biodiversity loss, such as climate change, land use change and pollution (IPBES 2019), towards an overall measure of biodiversity impact, termed 'footprint' (Hoekstra and Wiedmann 2014). Results often suggest a major contribution from climate change to biodiversity loss, with several studies identifying GHG emissions as one of the largest contributors to an organisation's biodiversity footprint (Bull et al. 2022; El Geneidy et al. 2026; Maddinson et al. 2025; Martínez-Ramón et al. 2025). If GHG emissions genuinely do drive a large proportion of organisational biodiversity impacts, then considerable potential exists for achieving climate and biodiversity goals in tandem (Maddinson et al. 2025). Where such cases are identified, sustainability strategies should prioritise mitigation of GHG emissions. Integrated climate and biodiversity assessment may further inform corporate performance measurement, climate and biodiversity risk assessment and sustainability reporting and disclosure frameworks. Doing so will facilitate more effective action for climate and biodiversity and follows the guidance of frameworks such as the Task Force for Nature-Related Financial Disclosures (Kedward et al. 2023; TNFD 2025).

Greater confidence is now needed in the degree to which GHG emissions do drive organisational biodiversity impacts in order to integrate climate and biodiversity strategies. However, concerns remain about the robustness of biodiversity footprinting methods in quantifying biodiversity loss and designing sustainability strategies. Biodiversity footprinting tools are increasingly used by organisations for strategy design, and it is imperative that uncertainties are acknowledged and addressed (Bromwich et al. 2026; Barahmand and Eikeland 2022; Martínez-Ramón et al. 2025). Further attention must therefore be given to how the biodiversity impacts of GHG emissions are estimated in biodiversity footprinting tools, particularly because uncertainties exist in assessing the effect of future climate change on biodiversity (Li et al. 2022; Iordan et al. 2023). Although climate change is often one of the largest drivers of biodiversity loss in footprinting studies (e.g., Bull et al. 2022; El Geneidy et al. 2026; Maddinson et al. 2025; Martínez-Ramón et al. 2025), this trend is not echoed in reviews of biodiversity loss, which highlight land (and sea) use change and direct exploitation of natural resources as the largest drivers (Jaureguiberry et al. 2022; Maxwell et al. 2016). The discrepancy between footprinting studies and other forms of biodiversity assessment warrants further attention to avoid ineffective strategy design or overemphasis of the impacts of climate change on biodiversity (Caro et al. 2022).

We evaluate the connection between GHG emissions and biodiversity footprints through two questions. First, we determine how much GHG emissions contribute to biodiversity footprints across economic sectors. We therefore comment on how widespread the opportunities are to mitigate climate and biodiversity impacts together. To do so, we quantify the estimated share of biodiversity footprints driven by GHG emissions across key industrial sectors in the global economy, across a range of footprinting approaches. Second, we explore the reliability of footprinting assessments to quantify the impact of GHG emissions, providing a conceptual development for the results generated from the first research question. We compare several footprinting approaches to illustrate how and why footprinting method choices drive different outcomes, as well as the key uncertainties and assumptions of the selected approaches. We further comment upon the discrepancies between footprinting results and other biodiversity studies, which may incentivise different sustainability actions.

2 | Methods

2.1 | Quantifying the Contribution of GHG Emissions to Total Biodiversity Footprints

We used Life Cycle Impact Assessment (LCIA) approaches to quantify our biodiversity footprints in this study. LCIA is a leading approach to quantify biodiversity loss caused by environmental impactful activities across complex value chains and different actors (Bromwich et al. 2026; Bull et al. 2022; Peura, El Geneidy, et al. 2023). LCIA tools build upon the classic life cycle assessment (LCA) methodology, combining LCA outputs for the major drivers of biodiversity loss with characterisation factors (biodiversity impact per unit of environmental driver). LCIA methods are highlighted as potential tools in key sustainability frameworks such as the Taskforce for Nature-relate Financial Disclosures (TNFD) and the EU Corporate Sustainability Reporting Directive (European Commission 2023; TFND 2023).

Methodological or data differences in the most commonly applied LCIA approaches may result in differing results for organisational biodiversity impacts and differing corporate strategies (Bromwich et al. 2026). Our analysis used four different LCIA approaches, namely LC-IMPACT, GLOBIO, IMPACT WORLD+ and ReCiPe (Bulle et al. 2019; Huijbregts et al. 2016; Verones 2021). In all four approaches, we used global average characterisation factors, which are used to quantify the relationship between GHG emissions and globally distributed biodiversity loss. Regional specific characterisation factors were further used for one approach (LC-IMPACT) based on previous footprinting assessments undertaken by (El Geneidy et al. 2026). In doing so, we assessed how the inclusion of spatially specific characterisation factors influences our footprinting results.

To estimate total biodiversity footprints for different sectors of the world economy, we first paired the chosen LCIA approaches with data from the environmentally extended multi regional input–output (EEMRIO) database EXIOBASE. EEMRIO databases are frequently used alongside LCA approaches to estimate biodiversity impacts at an economy level (Bjelle et al. 2021; Marques et al. 2019; Wilting et al. 2021). EXIOBASE provides estimates of the environmental impacts of different product and industry groups (e.g., land use and GHG emissions) per unit of consumption (€). We used values from EXIOBASE version 3.8.2 (Stadler et al. 2018, 2021), exported to Excel using the python tool pymrio. EXIOBASE values are reported for 200 products and 49 regions (44 countries and five rest of world regions), as well as 21 industrial sectors. To aggregate results according to major sectors, we harmonised EXIOBASE product categories with the NACE classification for European economic activities (Eurostat 2008). We have not considered the implications of EEMRIO choice (EXIOBASE) here, although other databases exist such as Eora and WIOD (Lenzen et al. 2012; Timmer et al. 2014). Previous studies have shown that discrepancies in EEMRIO data sources result in different carbon footprinting values; we would expect similar outcomes for biodiversity footprinting (Moran et al. 2014).

Next, we calculated the biodiversity footprint intensity (biodiversity footprint per million euros of financial spend) of each biodiversity loss driver, for each sector. We combined EXIOBASE consumption data and LCIA characterisation factors together. For example, the characterisation factor for water consumption (PDF.year/m^3) in LC-IMPACT was multiplied with the consumption value (m^3/Million €) for water consumption from EXIOBASE. Characterisation factors were sourced from the LCIA databases themselves when available, using average factors and a time horizon of 100 years (Verones et al. 2020; Bulle et al. 2019; Huijbregts et al. 2016). When databases were not readily available (as was the case for GLOBIO), we used values from previous approaches to collect and harmonise characterisation factors (Sanyé-Mengual et al. 2022). Absolute biodiversity impacts were calculated by multiplying biodiversity impact per million euros of financial spend with values of total financial output per sector. The proportion of impacts driven by GHG emissions was calculated as total impacts due to GHG emissions, divided by total biodiversity impacts summed across ecosystems and drivers. Here, we report biodiversity impacts summed across terrestrial, marine and freshwater ecosystems without the inclusion of species weights (correcting for different species numbers across ecosystems) (El Geneidy et al. 2026). Our reporting of ecosystem totals is based on common convention for biodiversity footprint results; future studies, however, are needed to see how the inclusion of species weighting results in differing footprinting outcomes.

Overall, we quantified the contribution of GHG emissions towards total biodiversity footprints of 21 industrial sectors of the global economy, with individual data points available per region and product as provided by EXIOBASE. The full range of data, per LCA approach, industrial sector, region, product and impact driver, is provided within Supporting Information S2. We applied statistical tests to investigate whether the proportion of biodiversity impacts driven by GHG emissions varies according to economic sector and LCIA method choice. We fitted separate multiple linear regression models using the R *stats* package, using proportion of impacts driven by GHG emissions as the dependent variable and economic sector and LCIA method choice respectively as categorical independent variables. Here, we report the extent to which each factor explains variation in the contribution of GHG emissions to biodiversity footprints, reported as R^2 values. Model assumptions of linearity, constant variance (homoscedasticity), normality and independence were verified through residual analysis. We further carried out Spearman's rank correlation tests and coefficients of variation (CV) for economic sector and LCIA method choice data.

2.2 | Evaluating the Robustness of GHG Emission Pathways in Biodiversity Footprinting Tools

To contextualise the results generated in part (2.2.), we explored the robustness of GHG emission pathways across different biodiversity footprinting tools. In doing so, we highlight the assumptions and uncertainties associated with the above results (2.2), as well as the limitations of biodiversity footprint assessments for integrating climate and nature goals. We evaluated the underlying calculation methodologies of a range of LCIA footprinting tools. Approaches were selected from a review by Damiani et al. (2023), as well as two follow-up papers produced by the same authors since the original publication (Damiani et al. 2023) (identified in December 2024). A total of eight approaches were identified: six out of 23 original approaches from Damiani et al. (2023) and two follow up papers (Iordan et al. 2023; de Visser et al. 2023) (see Supporting Information S1 for a complete list of approaches). Approaches were selected for analysis due to their widespread utility in organisational footprinting; the availability of open-source online documentation for the approaches, being LCA-based and not utilising the same methods as other LCIA approaches. Screening of approaches was undertaken based on guidance from expert LCIA practitioners; further detail on the selected approaches is available in Supporting Information S1. The most recent papers (Iordan et al. 2023; de Visser et al. 2023) are used in the new Global Guidance for LCIA Indicators and Methods approach (GLAM) (Askham et al. 2025). Selected approaches therefore reflect current and developing calculation approaches for the biodiversity impact of GHG emissions.

To explore the robustness of GHG emission pathways we evaluated the methodology behind each biodiversity footprinting approach. We produced a table outlining the key methodological steps for each approach, including the underlying papers used to determine values of biodiversity impact and assumptions made.

3 | Results

3.1 | How Much Do GHG Emissions Contribute to Biodiversity Footprints?

According to sector-level results, GHG emissions consistently contribute towards a large—but highly variable—proportion of overall biodiversity footprints, across economic sectors (Figure 1). On average, our selected footprinting methodologies estimated that GHG emissions contribute to 47% of an economic sector's total biodiversity footprint (SD = 28%). Our results suggest there are many opportunities to achieve climate and biodiversity goals simultaneously, as mitigating GHG emissions may significantly reducing biodiversity footprints. Though our results are somewhat consistent with previous LCIA analyses, they diverge from previous estimates of climate-change driven biodiversity loss obtained via other methodological routes, which place GHG emissions as a much smaller driver of biodiversity impact (compared with land use or direct exploitation, for instance) (e.g., Caro et al. 2022; Jaureguiberry et al. 2022; Maxwell et al. 2016). There is a concern, therefore, that our results represent an over-estimation of the role of GHG emissions in driving biodiversity loss. The discrepancy between our results and alternative biodiversity assessments is commented upon in depth in the Discussion.

Our results further indicate that economic sectors may have differing contributions of GHG emissions to biodiversity footprints, therefore driving different strategic priorities. Regression analysis showed that economic sector was a significant predictor for the proportion of biodiversity footprints driven by GHG emissions (Figure 1), explaining around 57% of total variance in impacts (multiple linear model $R^2 = 0.57$, $p = 5.8e{-}08$). Sectors including mining and quarrying (Sector B in Figure 1, mean = 64%, SD = 27%) and electricity, gas, steam and air conditioning supply (Sector D in Figure 1, mean = 64%, SD = 27%), for example, displayed a high proportion of their estimated biodiversity footprints being driven by GHG emissions. For these sectors, taking actions to reduce GHG emissions may go a long way towards reducing overall biodiversity footprints. Conversely, sectors such as agriculture, forestry and fishing (Sector A in Figure 1, mean = 22%, SD = 23%) and accommodation and food service activities (Sector I in Figure 1, mean = 24%, SD = 14%) displayed relatively low contributions of GHG emissions to the overall biodiversity footprint. Here, designing sustainability strategies which are inclusive of climate and biodiversity will

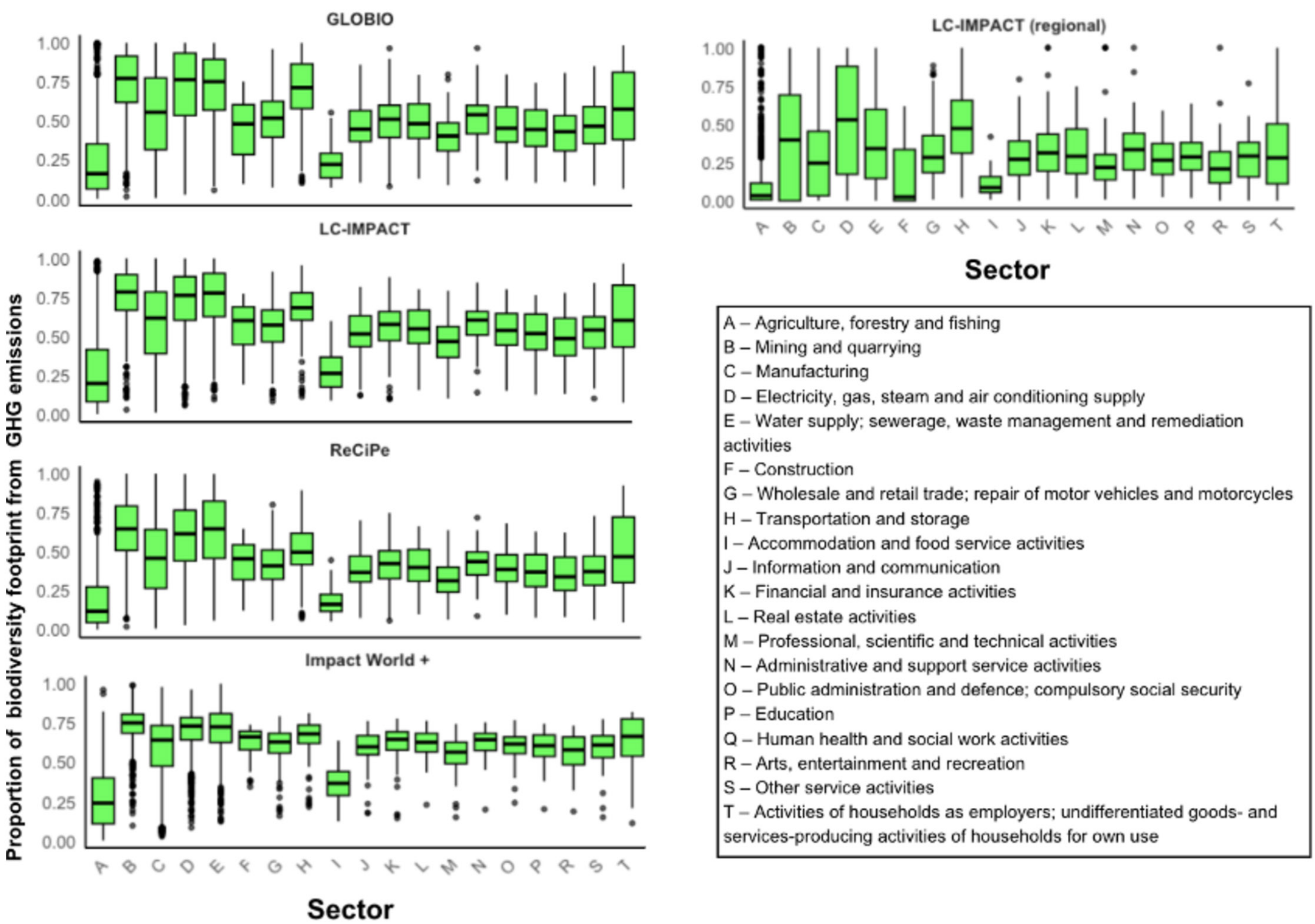

FIGURE 1 | Proportion of total biodiversity footprint driven by GHG emissions for major sectors of the global economy, based on LCIA footprinting methods GLOBIO, LC-IMPACT, ReCiPe and Impact World+. Results are based on global average characterisation factors for all LCIA approaches except LC-IMPACT ('regional'), which uses region-specific characterisation factors. Horizontal lines in the coloured boxes represent median values; coloured boxes denote interquartile ranges (IQR); whiskers represent range of values within 1.5× the IQR; dots represent outliers beyond 1.5× the IQR.

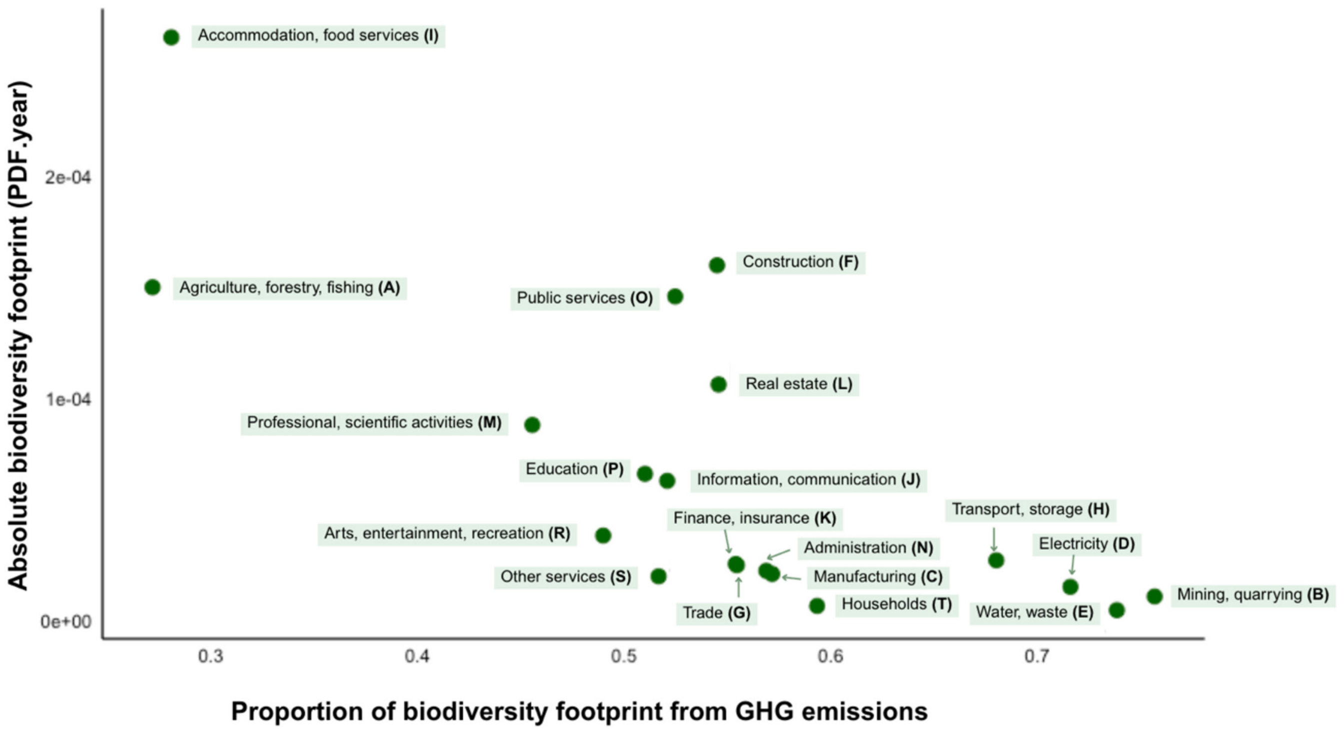

FIGURE 2 | Average absolute biodiversity footprint, compared with the proportion of biodiversity footprint driven by GHG emissions. Figures are reported for major sectors of the global economy using the LCIA framework LC-IMPACT. A full list of EXIOBASE names for each sector can be found in Figure 1.

likely require large investment in tackling alternative drivers of biodiversity loss (e.g., land use and water pollution). Such trends may be used to design sustainability strategies in the absence of extensive biodiversity footprinting data. However, as highlighted in Figure 1, variability within sector results is high (standard deviation [SD] = 28%, coefficient of variation [CV] = 56%, all footprinting approaches), indicating the need for more granular information (on-site biodiversity assessments, or product-level data, for instance).

Figure 2 highlights the difference in absolute biodiversity footprint for major sectors of the global economy, and their relation to GHG emissions. Results are reported using LC-IMPACT, with results from the remaining four approaches detailed in Supporting Information S3. In Figure 2, we can identify (a) the absolute size of a sector's biodiversity footprint (and therefore how high a priority impact mitigation is) and (b) the proportion of impacts driven by GHG emissions (with high proportions, mitigation of GHG emissions has the potential to significantly reduce absolute biodiversity footprints). Accommodation and food service activities (Sector I in Figure 2), for example, drive a large average absolute biodiversity footprint of 2.6×10^{-4} PDF.year (LC-IMPACT), of which only 28% is caused by GHG emissions. For such sectors, extensive biodiversity strategies outside of their climate neutrality approaches may be required. In comparison, activities with high relative impact of GHG emissions but low absolute biodiversity footprints may not warrant top priority within an organisation's biodiversity strategy. Water supply, sewerage, waste management and remediation activities (E in Figure 2), for example, drive average absolute biodiversity impacts of 4.8×10^{-6} PDF.year (LC-IMPACT), 74% of which is estimated to be caused by GHG emissions. Importantly, absolute biodiversity impacts are driven not only by biodiversity impact intensity (biodiversity impact per unit of financial spend) but also the total financial spend of a sector. As such, our results encompass a wide range of spending levels and drive some unexpected results. Public services, for example, have a high biodiversity footprint intensity due to the significant levels of public spending by government (Figure 2, Sector O); in comparison, Mining and Quarrying (Figure 2, Sector B) has an unexpectedly low absolute footprint. A higher level of granularity may be needed to design strategies for individual organisations.

The large contribution of GHG emissions to biodiversity footprints was seen consistently across LCIA approaches (47% average contribution). We carried out Spearman rank correlation analyses to compare the average proportion of biodiversity footprint driven by GHG emissions for all EXIOBASE sectors, across footprinting approaches. Our results displayed close alignment between all footprinting approaches (Spearman's $r > 0.77$) (Figure 3), indicating high levels of similarity between LCIA approaches. The generally high alignment between footprinting results was somewhat surprising, particularly given the diverse number of drivers considered in each LCIA approach (2–13 drivers). Regression analysis showed that the number of drivers in each LCIA approach was not a significant predictor for the proportion of biodiversity footprints driven by GHG emissions (linear model, $\beta = 0.0072$, $p = 0.12$, multiple $R^2 = 0.025$, $n = 96$). We would expect the proportion of biodiversity footprint driven by climate change to decrease as more drivers (e.g., land use change) are included in the calculations. Our results highlight the dominance of GHG emissions within LCIA-based biodiversity footprints, as well as high levels of agreement found between footprinting

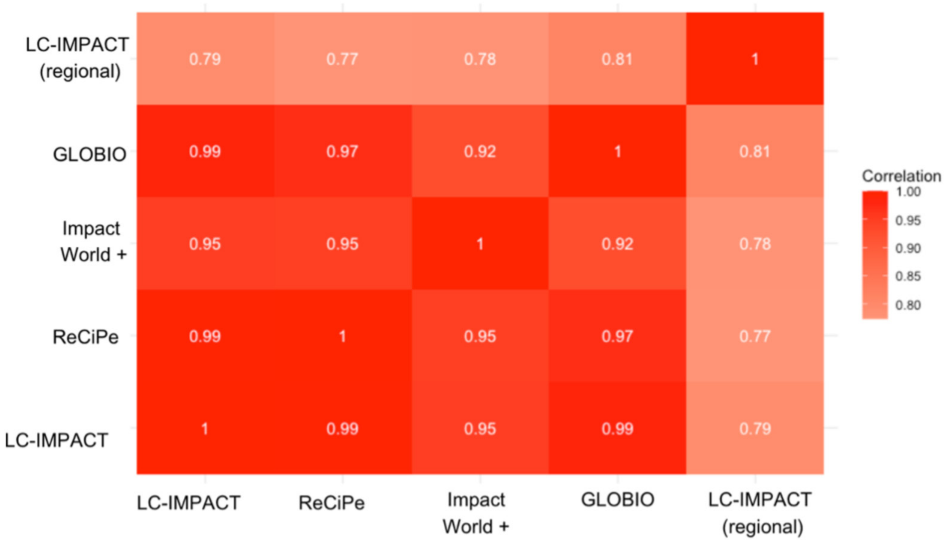

FIGURE 3 | Correlation heatmap, assessing the degree to which different LCIA methods agree on the contribution of GHG emissions towards biodiversity footprints. Results are reported at the sector-level, highlighting the correlation between the results shown in Figure 2.

results. We comment upon these findings in detail- including whether the high level of agreement reflects robustness or shared systemic biases- in the Discussion.

We did, however, see a difference between results when applying global characterisation factors versus region-specific factors. Results using region-specific LC-IMPACT characterisation factors displayed a lower average proportion of biodiversity footprint driven by GHG emissions than for the other methods (33%, compared with 60% average using LC-IMPACT global factors) and greater variance in results (CV = 63% using region-specific values versus 54% with global average) (Figure 3). Evidently, the decision to use global average or region-specific characterisation factors may drive differing overall results for the contribution of GHG emissions towards biodiversity footprints. Discrepancies in footprinting results in turn may alter corporate climate and biodiversity strategies, therefore warranting further attention (See Discussion for more detail) (Bromwich et al. 2026; Martínez-Ramón et al. 2025).

3.2 | Evaluating the Robustness of GHG Emission Pathways in Biodiversity Footprinting Approaches

We further evaluate the robustness of GHG emission pathways across different biodiversity footprinting tools. We focus on 6 LCIA approaches from a review (Damiani et al. 2023), as well as 2 additional approaches published by the same authors since the original review (Iordan et al. 2023; de Visser et al. 2023).

Across LCIA approaches, the basic framework to calculate the biodiversity impacts of GHG emissions remains the same. GHG emissions are translated into values of biodiversity impact through multiplication with 'characterisation factors' (Hellweg et al. 2023; Kuipers et al. 2025). Characterisation factors are calculated through several steps (Figure 4). First, increases in temperature driven by GHG emissions (°C/kg CO_2e) are quantified using global climate models (Figure 4a). IPCC projections are used to estimate global temperature increases across all of the approaches (IPCC 2014; Joos et al. 2013) (Table 1). Newer approaches also estimate ecosystem-specific temperature increases based on Representative Concentration Pathways (RCPs) (approaches 6–8, Figure 4a; Table 1). Next, predicted temperature increases are linked to biodiversity loss in terrestrial, freshwater, and marine ecosystems. Values of biodiversity loss caused by temperature increases are estimated using scientific literature (Figure 4b; Table 1). Approaches use highly similar literature to estimate the biodiversity impact of climate change: for example, approaches 1–5 all use meta-analyses of biome distribution changes driven by global temperature increases (Arets et al. 2014; Thomas et al. 2004; Urban 2015).

Our LCIA approaches report biodiversity loss at the species level, using differing numbers of drivers (Table 1). Many of the identified approaches report climate change-driven biodiversity footprints in terms of Potentially Disappeared Fraction of species (PDF, 4 approaches), or Mean Species Abundance (MSA, 2 approaches). PDF and MSA are commonly used indicators to quantify losses in local or global biodiversity integrity driven by environmentally impactful activities (Kuipers et al. 2025). Alternative approaches use species. Year (local species loss integrated over time) or PAF.year (Potentially Affected Fraction of species per year) metrics. Values of biodiversity loss driven by climate change are totalled with other drivers of biodiversity loss, for example, from land use change. The number of drivers considered by LCIA approaches ranged from 1 to 9 drivers (Table 1), although linear analysis showed that this is not a significant predictor for the proportion of biodiversity footprints driven by GHG emissions (Section 3.1). This likely reflects shared systemic biases due to the high levels of methodological similarity between approaches.

There remain methodological differences between LCIA approaches (Table 1), however, which may drive variation and hinder comparability between LCIA results. These differences are driven by varying empirical bases and modelling choices. LCIA approaches use a different combination of climate models

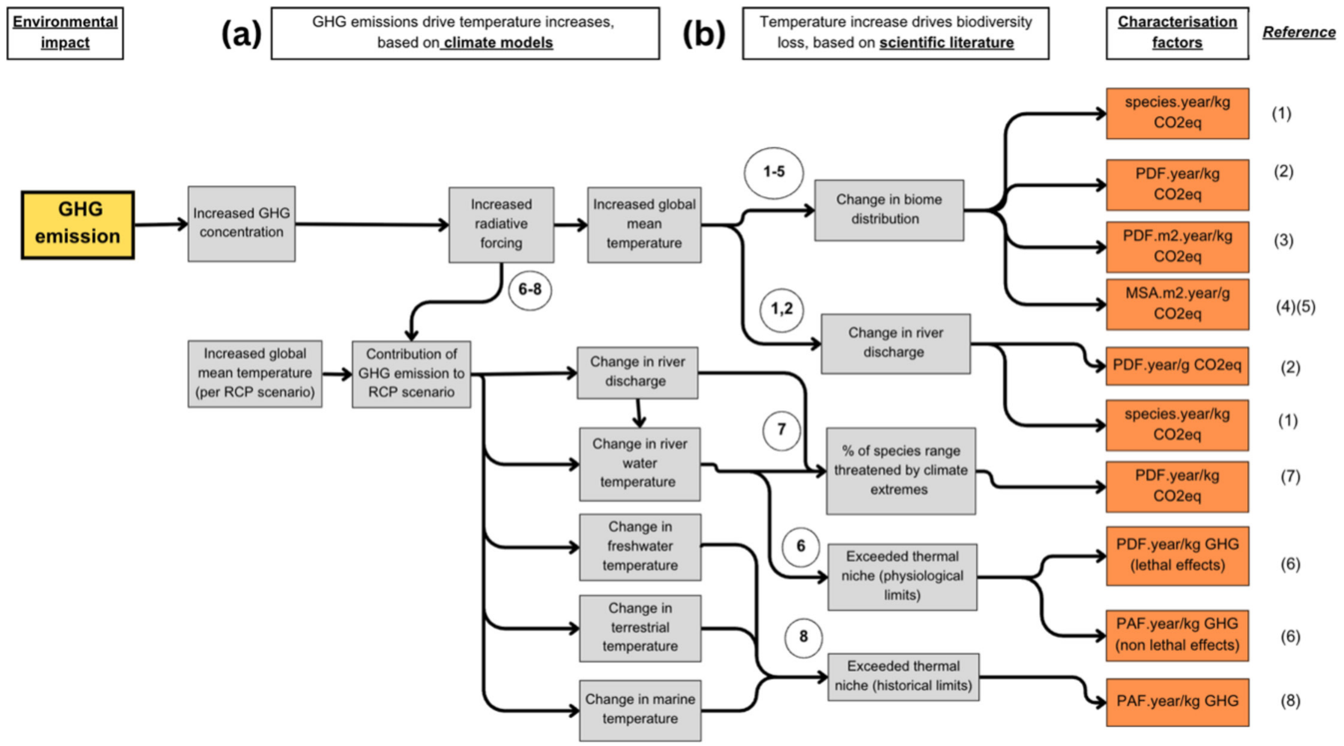

FIGURE 4 | Overview of pathways used to determine the biodiversity impact of GHG emissions. GHG emissions are translated into temperature increases (a) and biodiversity loss (b) using climate models and established scientific literature. Estimations for biodiversity loss per unit of emission are reported as characterisation factors (orange boxes). LCIA approaches are numbered according to Table 1 (Approaches 1–9). Circled numbers indicate the pathway used for each LCIA approach.

and scientific literature to determine characterisation factors (Table 1, 'Key References'). As such, different LCIA approaches include different ecological aspects, including ecosystem coverage, spatial resolution, time horizon and species specificity (see Table 1). Only one approach included terrestrial, freshwater and marine environments, for example, highlighting the lack of empirical marine biodiversity data in the remaining LCIA approaches. This is surprising given the vulnerability of marine organisms to the effects of climate warming (Bongaarts 2019). Similarly, most approaches calculated biodiversity impacts on a global scale due to a lack of location-specific data (Table 1, Spatial Resolution). We expect this to be an important source of variation, as shown when comparing LC-IMPACT regionalised and global values (Section 3.1).

Time horizons also differed between footprinting approaches, for example, with the impacts of climate change modelled between 20 and 1000 years. Here, we used a time horizon of 100 years in our analysis (Section 3.1.) Again, we would expect large changes in footprinting results based on the time horizon, as the effects of climate change are cumulative over time. The majority of footprinting approaches (Table 1, Approaches 1–5), furthermore, estimate climate change-driven biodiversity impacts as linear averages across species. More recent LCIA approaches—particularly the GLAM approach—have clearly identified that species and regions are not equally vulnerable to climate change (Table 1, Approaches 6–8) (Iordan et al. 2023). This represents an important methodological development and an improvement in data granularity and has been up taken by the novel LCIA approach GLAM (UNEP/GLAM 2023).

Evidently, selected LCIA approaches use a common conceptual framework to quantify the biodiversity impacts of GHG emissions. LCIA approaches do however use varying empirical bases and consider different ecological variables (e.g., species specificity), which limits their comparability and applicability. Perhaps most significant is the number of assumptions and high level of uncertainty within LCIA calculations, as evident in the results of Figures 3 and 4 and the lack of ecological variables in many of the approaches outlined in Table 1 (Bromwich et al. 2026). We comment upon the implications of this in Section 4.

4 | Discussion

Our results support the trend observed in previous biodiversity footprinting case studies, where climate change is a dominant driver of an organisation's total biodiversity footprint (Bull et al. 2022; Peura, El Geneidy, et al. 2023; Peura, Pokkinen, et al. 2023). We find that on average 47% of biodiversity footprints are driven by GHG emissions, with high levels of correlation across approaches (Spearman's $r > 0.77$) (Section 3.1).

There is a discrepancy, however, between modelled LCIA findings and other empirical biodiversity assessments; for example, analysed the primary threats facing 8688 species on the IUCN Red List. Overexploitation and agriculture were identified as having the greatest impact on biodiversity currently, threatening 72% and 62% of the IUCN Red List species respectively. Conversely, climate change is currently affecting 19% of species listed on the Red List. It is therefore likely that LCIA

TABLE 1 | Comparison of selected LCIA approaches. Adapted from Iordan et al. (2023). The unit of biodiversity loss ('unit'), number of drivers of biodiversity loss considered by each approach ('number of drivers', based on Sanyé-Mengual et al. 2022) and key models and meta-analyses used to quantify climate-change driven biodiversity loss ('key references') are provided. Climate change-driven biodiversity footprints may be calculated for one or more ecosystem ('ecosystems'), species ('species specificity') and GHGs ('GHG specificity'). The highest level of spatial resolution provided by each approach is highlighted ('spatial resolution'). Approaches with a global resolution, for example, provide global averages biodiversity impacts only. Results may be reported according to differing climate change scenarios ('sensitivity to future climate change') and time horizons ('time horizon'). Several approaches utilise Representative Concentration Pathways (RCPs), climate change scenarios to project future GHG concentrations, from RCP2.6 (very low future emissions) to RCP8.5 (very high emissions scenario).

	Approach	Unit	No. of drivers	Key references	Ecosystems covered	Species specificity	Spatial resolution	Time horizon
1	ReCiPe	species.year	9	Urban (2015), Hanafiah et al. (2011), IPCC (2014)	Terrestrial, freshwater	No	Global average	20, 100, 1000 years
2	LC-IMPACT (Verones et al. 2020)	PDF.year	7	Urban (2015), Hanafiah et al. (2011), Xenopoulos and Lodge (2006), IPCC (2014)	Terrestrial, freshwater	No	Global average	100, 1000 years
3	IMPACT WORLD (Bulle et al. 2019)	PDF.m^2.year	13	Thomas et al. (2004), IPCC (2023)	Terrestrial	No	Global average	100, 500 years
4	Global Biodiversity Score (Global Biodiversity Score: 2018 Technical Update|CDC Biodiversité, n.d.)	MSA.loss.m^2	2	Arets et al. (2014), Wilting et al. (2017), IPCC (2014)	Terrestrial, freshwater	No	Biome-specific	100 years
5	Biodiversity Footprint Method (Wilting et al. 2017)	MSA.ha.year	2	Arets et al. (2014), Wilting et al. (2017), IPCC (2014)	Terrestrial	No	Biome-specific	100 years
6	Water temperature and Freshwater Fish (Dan Li et al. 2022)	PDF.year	1	Comte and Olden (2017), Barbarossa et al. (2021), IPCC (2014)	Freshwater	Yes	Region-specific	RCP dependent
7	Climate Change & Freshwater Fish (de Visser et al. 2023)	PDF.year	1	Barbarossa et al. (2021), IPCC (2014)	Freshwater	Yes	Region-specific	RCP dependent
8	CFs for GHG impacts on biodiversity (Iordan et al. 2023)	PAF	1	Trisos et al. (2020), IPCC (2014)	Terrestrial, freshwater and marine	Yes	Region-specific	RCP dependent; reported for 2050 and 2100

results overestimate the current real-world contribution of GHG emissions towards total biodiversity loss. However, a growing body of evidence indicates that climate change is a major and increasing driver of biodiversity loss (Newbold 2018; Trisos et al. 2020; Urban 2015), meaning that this discrepancy may change over time.

Methodological choices within LCIA models drive the discrepancy between biodiversity footprinting results and observed data, as well as similarities in model outputs (Section 3.2). LCIA approaches use limited and often overlapping empirical datasets to determine biodiversity impacts, resulting in inherent biases in LCIA characterisation factors. As outlined in Table 1, there are a number of limitations in spatial specificity, temporal scales, species specific responses to climate change and ecosystems covered by LCIA approaches, driving large amounts of uncertainty and systemic biases in results (Bromwich et al. 2026). Furthermore, changes in species interactions are ignored by all approaches despite being a key factor in community-level responses to climate change (Åkesson et al. 2021). Limitations in representing the drivers of biodiversity loss may drive further uncertainty in LCIA approaches. Invasive species and direct exploitation are not considered in any of the approaches, for example, despite being key drivers of observed biodiversity loss (IPBES 2019). Finally, LCIA approaches rely on models projecting future outcomes of climate change (e.g., species responses to altered biome distribution or temperature extremes) (Figure 2b). There is a large amount of uncertainty regarding the effects of future climate change, which is inevitably reflected in LCIA models (Iordan et al. 2023; Payne et al. 2016; Rangwala et al. 2021).

Therefore, we should be careful about the ability of current LCIA approaches to estimate the biodiversity impact of GHG emissions, a sentiment echoed by similar studies (Bromwich et al. 2026; Martínez-Ramón et al. 2025). Uncertainties in footprinting approaches may present a major roadblock for their use in informing climate and biodiversity strategies. Overestimation of climate impacts relative to other drivers of biodiversity loss, for example, could result in biodiversity threats being viewed through the single myopic lens of climate change (Caro et al. 2022). Incomplete characterisation of other drivers of biodiversity loss may also impede a comprehensive assessment of biodiversity footprints and reduce the effectiveness of sustainability strategies (Damiani et al. 2023; Iordan et al. 2023; Maier et al. 2019).

LCIA approaches are already developing to address some of the systemic biases highlighted in our study. Newer LCIA methodologies such as Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM) are more spatially explicit and include greater species specificity (UNEP/GLAM 2023). Work is ongoing to include additional drivers of biodiversity loss in LCIA assessment methods (e.g., plastic pollution and invasive species), which may help to reduce the overrepresentation of climate change in footprinting results (Corella-Puertas et al. 2023; Gjedde et al. 2024). Organisations also play a role in improving biodiversity footprinting methodologies, including through research collaborations with LCIA developers. Footprinting assessments should be undertaken in an iterative way, enabling new results to be calculated as methods develop. Following existing guidance on uncertainties will also be of use here, for example, Bromwich et al. (2026).

Despite the uncertainties, LCIA approaches remain one of the best available means to estimate biodiversity loss across value chains and to support predictive strategical decision-making in businesses. LCIA approaches are particularly important to communicate the effects of climate change on biodiversity loss. Direct measurement approaches (site level biodiversity assessments, for instance) alone are insufficient for quantifying impacts, as they may not capture the impact of climate change, which occurs over a relatively long timeframe.

Currently, the relationship between GHG emissions and biodiversity loss is not always made clear within organisations. Integrated climate and biodiversity footprints may help to progress this knowledge gap, informing strategies that tackle climate and biodiversity loss together. Our results suggest that efforts to reduce the impacts of climate change may go some way in reducing organisational biodiversity impacts. Indeed, this has been shown when assessing the biodiversity impacts of an organisation's climate strategy (Maddinson et al. 2025). Organisations can leverage these findings, including through scenario analysis and decision-support systems (Bull et al. 2022; Nature Positive Initiative 2024). Sectors (and associated products) identified here as having a high proportion of impacts driven by climate change (both relative and absolute) should double down on their efforts to reduce GHG emissions in a biodiversity-respectful way. Conversely, organisations can identify when reducing an organisation's climate impacts has a negligible effect on absolute biodiversity impacts. Here, additional biodiversity-specific strategies (e.g., focusing on land-use change or pollution) must be prioritised in order to achieve biodiversity goals. Cross-sectoral benchmarking presents another interesting application of our approach, and has been highlighted in the recent IBPES Business and Biodiversity report (IPBES 2026).

Integrated climate and biodiversity impact assessment may further inform organisations to meet the needs of the current and emerging sustainability reporting frameworks, such as TNFD and CSRD. For one, footprinting enables organisations to better identify their 'material' issues, as actions that produce a large amount of GHG emissions inevitably contribute heavily to biodiversity loss. Indeed, the results provided in this paper could inform organisations, for example, in their double materiality assessments as part of the EU CSRD regulation (EFRAG 2025). If organisations have assessed that climate change is a material topic to them, biodiversity should be identified as a material topic as well, and vice versa. Overall, footprinting helps organisations to clearly assess and communicate their climate and biodiversity impacts, enabling more effective performance measurement systems, supply chain management and risk assessment (Kedward et al. 2023; TNFD 2025).

5 | Conclusion

Organisations are increasingly interrogating their role as drivers of both climate change and biodiversity loss. Here, we highlight the role of footprinting approaches in quantifying the connections between, and charting progress towards, integrated climate and biodiversity strategies. Our results indicate that climate change is a major contributor to biodiversity footprints, presenting an opportunity to address climate and biodiversity impacts concurrently in organisational strategies.

However, modelling of future climate–biodiversity interactions within biodiversity footprinting remains highly uncertain. Footprinting studies are constrained by a number of methodological limitations, including a narrow representation of biodiversity loss drivers and ecosystems, as well as large assumptions regarding time horizons, spatial specificity and species-specific responses to climate change. Methodological limitations reduce the effectiveness of biodiversity footprinting in informing organisational sustainability strategies, reporting and decision-making. Biodiversity footprinting results that overestimate the impacts of climate change, for example, may hinder organisations from addressing alternative drivers of biodiversity loss—such as land use—in their sustainability strategies.

Future research should therefore further develop biodiversity footprinting methodologies for organisations, including through greater use of spatially explicit and species-specific characterisation factors, better integration of nonclimate biodiversity drivers and stronger validation of LCIA-based footprinting estimates against empirical biodiversity data.

Author Contributions

C.M., S.E.G., J.B. and J.K. devised the project and the main conceptual ideas. C.M. collected and analysed the data, drafted the manuscript and designed the figures. All authors reviewed and approved the final manuscript.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Supplementary Material. **Data S2:** Supplementary Material.